Research Article

Research on Innovative Design and Evaluation of Agricultural Machinery Products

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In order to meet the user's increasing demands for integrated quality of agricultural machinery products, a new KE-TRIZ approach based on Kansei engineering (KE) and theory of inventive problem solving (TRIZ) was proposed. Designers used semantic difference (SD) method and principal component analysis (PCA) method to quantify and reduce the dimensions of the extracted perceptual vocabulary, which aimed to select the comprehensive variables that represented the user's needs. TRIZ theory was used in the product emotional intention to elaborate the invention principle of products' appearance structure and functional technology, and improvement explanation was put forward based on further contradiction analysis. Then, the industrial design theory was combined with the innovation design of agricultural machinery products. In order to explain the reliability of innovative design, the analytic hierarchy process (AHP) was used in objective assessment. Finally, a walking rotary cultivator design was used as a case to check the above methods. The research can effectively adjust the contradiction between rationality and sensibility in products and apply it to the product equipment with function as the main part to design the products of comprehensive quality that conform to the trend of social aesthetics so as to form the brand effect of high added value. The results showed that these methods were effective and feasible for the innovative design of agricultural machinery products.

1. Introduction

With the continuous integration and diversification of the global market and the growing demand for personalized consumption, industrial design is no longer limited to the traditional category with functions, colors, and shapes as the core, but develops to mass customization production. It is particularly important to quickly integrate the user's demand for agricultural machinery product design [1]. At present, functional and technical indicators are important indicators of agricultural machinery product design. However, with the increasing diversification of user demand for agricultural machinery products, its comprehensive quality is more and more important in the market competition. Therefore, designers are faced with two problems in designing agricultural machinery products, one is how to obtain and understand the needs of users and the other is how to better match the appearance of agricultural machinery products with the functional technology.

KE is a research method to explore the relationship between users and products [2]. It is an engineering technology that makes users feel satisfied by quantifying the perceptual needs of users and transforming them into a form factor considered by designers when designing products [3]. User preferences in design process of branded products are addressed through several layers of mediation link with consumers, products, and engineering designers or product designers. Designers cannot make their own assumptions about consumer needs and preferences. In order to quickly respond to the customer's demand of product modeling style, the key geometrical features of product modeling are extracted by the eye movement test, and the mapping relation and design progress between customers and product are established [5]. With the continuous development of personalized production, the design of mechanical equipment based on functional technology also needs to consider the user's demand for high-quality products. Designers need to introduce the

theory of sensible engineering to design mechanical products that are satisfactory to users.

The theory of inventive problem solving (TRIZ) was developed in the Soviet Union in 1946 by Genrich Altshuller. TRIZ is a method of innovative design which has been widely applied in engineering design and gradually expanded to other fields [6]. In order to solve the contradiction between products and service components, Kim and Yoon [7] proposed a new concept of product-service system (PSS), which was used to develop the quality functions of key features of products and services and was applied to automotive shared services. Tan et al. [8] combined TRIZ with analogy theory, put forward the related conceptual design process model, and improved the designer's innovative design ability. Liu et al. [9] combined morphology and TRIZ, broadened the application dimension of morphology matrix, and improved the innovation ability of solving product problems. Based on the analyses of 140 biological systems that were derived from biomimetic sources by a TRIZ-based method, Cohen et al. [10] provided a list and examples of structure-function patterns that repeat in biomimetic applications. However, the research of TRIZ mostly stays in the angle of product function and engineering technology and seldom pays attention to the subjective aesthetics of customers. In order to meet the user's perceptual preference for agricultural machinery products, it is necessary to fully consider the perceptual needs of users.

The above two methods have advantages in product innovation design. The KE method focuses more on product perception, and TRIZ is based on the functions and technologies of engineering design. Basing on KE and TRIZ, Sun and Kong [11] carried out innovative design and evaluation of automobile seats from the aspects of subjective aesthetics and structural functions. However, in the face of product structure and complex function, this method lacks reliability and effectiveness about the objective evaluation of innovative design. Therefore, it is imperative to develop interdisciplinary design approaches to solve "interface" issues among different domains, such as engineering design, market demand, usage context, social behavior, environmental impact assessments, and other factors [12].

The most straightforward explanation for perceptual engineering is the technology that translates the consumer's perceptuality into product design elements. The aim is to provide designers and manufacturers with a way to grasp the emotional and spiritual needs of users and translate these needs into product design elements in order to enhance the competitive advantage of products in the market. In industrial design, perceptual engineering regards the user's psychological feelings, imagery, and psychological expectations, such as practicability, aesthetics, high grade, exquisiteness, and so on. From the perspective of the design process, perceptual engineering uses engineering technology as a means to quantify people's feelings, finds the high-order function relationship between these sensible quantities and various physical quantities, and uses quantitative data as the basis of engineering analysis and research.

TRIZ conducts in-depth research on problems by asking questions, analyzing problems, performing component and

interaction analysis, constructing functional model diagrams, and using technical conflicts, physical conflicts, standard solutions, and scientific effects in the TRIZ toolbox so as to find the most simple, efficient, and economical solution. Among them, TRIZ proposes 39 engineering parameters describing the technical conflicts and 40 invention principles. In order to establish the corresponding relationship between the two, a contradiction conflict matrix is proposed. When solving the actual problem, as long as the conflict parameters in the design are determined, the corresponding invention principle can be selected in the conflict matrix, and the relevant solution is found according to the promptness of the invention principle.

With the promulgation of the Made in China 2025 policy, people's demand for comprehensive quality of mechanical equipment is increasing, but the design of mechanical equipment based on functional technology is limited by factors such as materials, structure, and process. Therefore, the contradictory solution, idealized solution, and evolutionary prediction technology in TRIZ are applied to the perceptual design. Through the mining and mapping of the contradiction between the mechanical product design elements and the perceptual design elements, the design conforms to the mechanical product design requirements. The idealized model and the innovative design model provide the basis for seeking the optimal solution of functional technology and art form in product design.

In this work, by constructing the innovative design model of KE-TRIZ and applying the AHP to verify the conceptual scheme of agricultural machinery products, an innovative design method to guarantee the high quality of agricultural machinery products was proposed. Taking the hand-held rotary tiller as an example, the conceptual design scheme matching appearance and function was obtained through the KE-TRIZ model. Then, the conceptual scheme and the typical samples of the product were analyzed by the AHP, and the weights of the relative innovative scheme for the hand-held rotary tiller was calculated, which indicated whether the conceptual design method was innovative or not. The results suggest that this design process was more convenient and efficient and also provide an important reference for the development of related agricultural machinery products and the design of other engineering products.

2. Innovative Design and Evaluation

Innovation design and evaluation model consists of there main steps (as shown in Figure 1): user requirement analysis (URA); innovative design based on KE and TRIZ; and design evaluation. These steps are explained as follows.

2.1. Step 1: User Requirement Analysis (URA)

- (1) Product perceptual image collection: the design object was analyzed; in this work, the design object was the agricultural machinery products based on function. Firstly, a large number of perceptual vocabularies were obtained by consulting relevant

FIGURE 1: Innovative design model for agricultural machinery products.

literature and consulting relevant design experts. In order to meet the requirements of different levels of users on the cognitive characteristics of the design objects, image adjectives describing the design objects were strictly selected as experimental variables by means of SD [13].

(2) Analysis of the elements of modeling design: a large number of samples were collected excluding the influence of material and brand. After discussing with experts and engineers with relevant experience, the samples were classified according to the shape and structure of the product, and then the

representative samples were selected according to the typical characteristic combination of the product.

- (3) Screening and dimension reduction of perceptual paired words: according to the degree of affiliation of the perceptual vocabulary which was analyzed and summed up, perceptual word pairs of the typical samples in reclaimed questionnaire data were scored by a 7-point Likert scale method and analyzed by Cronbach's alpha method and reliability analysis. The K Langbach coefficient method can test the reliability and consistency of the survey results. PCA [14] can be used to extract a small number of perceptual vocabularies which can represent most of the perceptual vocabulary variables. The PCA method was used to select the main perceptual vocabulary by the contribution rate of each index, and 4–6 pairs of perceptual vocabulary were screened out ultimately:

$$\alpha = \frac{k}{k-1} \left[1 - \frac{\sum_{i=1}^k S_i^2}{S_x^2} \right], \quad (1)$$

where α is the statistical factor in the K Langbach coefficient method; k is the number of items; S_i^2 is the variance of the item i ; and S_x^2 is the overall solution variance for all items.

When α is larger than 0.8, the questionnaire data are reliable.

2.2. Step 2: Innovative Design Based on KE-TRIZ

- (1) Creating conceptual design models: the above 4–6 pairs of perceptual words were classified into two groups based on KE. One group is about the appearance structure model, and the other is about the functional technology model. Based on the existing agricultural machinery product situation [15], a conceptual agricultural machinery design model was constructed in each group preliminarily.
- (2) Detailed design: by analyzing the perceptual image of the agricultural machinery product, finding out the engineering parameters of agricultural machinery products which need to be improve, and then carrying out the contradiction total matrix analysis is which based on TRIZ, a series of inventive principles were obtained and analyzed so as to put forward the detailed design principles of the agricultural machinery product. The contradiction between the appearance structure model and function technology model was analyzed. If there was a contradiction, the designer used TRIZ toolbox to analyze the design model in detail, which makes the design model more perfect.
- (3) Computer-aided design: according to the above steps, agricultural machinery products were designed by computer-aided industrial design software.

2.3. Step 3: Design Evaluation. In order to objectively evaluate the conceptual design of agricultural machinery products, the AHP was used to evaluate the innovative

design scheme and the previous selection of typical agricultural machinery samples [16]. The AHP was used for this work because it has good objectivity and practicability [17]. The basic steps of the AHP are shown as follows:

- (1) In determining the high-quality agricultural machinery product scheme, the hierarchical structure of the system should be established: target layer, criterion layer, and scheme layer.
- (2) Compare the indicators of criterion layer with the indicators of scheme layer to determine the weight coefficient of each layer. As shown in Table 1, a judgment matrix A (B) was constructed:

$$A(B) = (a_{ij})_{n \times n}. \quad (2)$$

A series of pairwise comparisons was made between A and B at the same level using the nine-point scale, which included all the odd numbers ranged from one to nine and their reciprocal values. In this step, pairwise comparative matrices are formulated for all evaluation criteria [18].

- (3) Calculate the relative importance of elements under a single criterion. The feature vector $W^{(2/3)}$ and the maximum eigenvalue $\lambda_{\max}$ of the judgment matrix A (B) are calculated. Eigenvalues are the weight vectors among the indexes, and the maximum eigenvalues are used to test the consistency of the judgment matrices:

$$\begin{aligned} CR &= \frac{CI}{RI}, \\ CI &= \frac{\lambda_{\max} - n}{n - 1}, \\ \lambda_{\max} &= \frac{1}{n} \sum_{i=1}^n \frac{\sum_{j=1}^n (n/j - 1) a_{ij} \omega_j}{\omega_i}, \end{aligned} \quad (3)$$

where CI is the consistency index; RI is the average random consistency index (as shown in Table 2); and λ is the eigenvalue of the matrix.

When $CR < 0.1$, it means that the judgment matrix is acceptable [19].

- (4) Calculate the weight of the scheme layer to the target layer P . The equation is presented as follows:

$$P = (\omega_1^{(3)} \ \omega_2^{(3)} \ \omega_3^{(3)}) \omega^{(2)}. \quad (4)$$

3. Innovative Design and Evaluation for Hand-Held Rotary Tiller

3.1. User Requirement Analysis (URA) for Hand-Held Rotary Tiller. The steps of KE are as follows: (1) target product samples and emotional image vocabulary collection; (2) preliminary clustering of perceptual vocabulary through questionnaires; and (3) use PCA to reduce the dimension of perceptual vocabulary and extract perceptual vocabulary that best represents users.

TABLE 1: The pairwise comparison judgment.

Intensity of importance	Explanation
1	Demand a_i has equal importance to demand a_j
3	Demand a_i has weak importance than demand a_j
5	Demand a_i has essential importance than demand a_j
7	Demand a_i is less important than demand a_j
1/3	Demand a_i is slightly less important than demand a_j
1/5	Demand a_i is obviously less important than demand a_j
1/7	Demand a_i is extremely unimportant than demand a_j

TABLE 2: Average random consistency index.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.94	1.12	1.24	1.32	1.41	1.45

This work took the innovative design of the hand-held rotary tiller as an example to illustrate the method. Firstly, 100 perceptual vocabularies related to hand-held rotary tillers were extracted from the objective natural language of users. Through Taobao, physical stores, and official websites, designers collected a large number of samples and conducted a large number of analysis and screening. Then, the designer analyzed the characteristics of the hand-held rotary tiller and selected four typical samples according to the modeling characteristics of the rotary tiller. The experiment finally selected 4 kinds of hand-held rotary tillers as typical samples, and they are shown in Table 3. Then, 10 senior designers and 20 rival rotary tillers drivers were selected as respondents. Among them, 4 designers majored in agricultural machinery, 6 designers were graduate students in industrial design, 5 drivers had no operation experience, and 15 drivers had driving experience. In the questionnaire, there were 12 pairs of adjectives and their antonyms, which were extracted as reference words for the style description of the hand-held rotary tiller, as shown in Table 4. However, some adjectives were overlaps in semantics. They were given marks according to the Likert 7-point scale method for four representative hand-held rotary samples. And 6 pairs among them were selected by PCA, and they were thought as representative semantic adjectives for the hand-held rotary tillers [20].

30 Likert 7-point scale questionnaires were designed according to the above theory. In order to analyze the reliability of the questionnaire data, the reliability of the questionnaire data was tested by reliability analysis by using SPSS 5.0. The reliability statistics is 0.885, which is greater than 0.8. To conclude, the 12 pairs of adjectives and their antonyms in these questionnaires are reliable.

A group of new variables was obtained by PCA. The contribution of variance of these new variables is not the same. The extraction of common factors is essentially to determine some factors from which the information of the original variables can be explained the most. All the factors with selectable eigenvalue greater than a certain critical value are used as common factors, and all the factors with selectable eigenvalue greater than 1 were extracted as common factors.

The data in Table 5 show the eigenvalues, variance contribution, and cumulative variance contribution of the factors after the extraction of common factors and after rotation [21].

12 groups of adjectives and antonyms were analyzed in SPSS, and the results are shown in Table 6. There were six pairs of adjectives and antonyms related to the principal component: the first group included dynamic-static and harmonious-disharmonious; the second group consisted of comfortable-uncomfortable and practical-gaudy; the third group included safe-dangerous; and the fourth group consisted of individual-common.

These four principal components contribute to 81.872% of the modeling style semantic feature information, that is to say, these four style semantic feature principal components can well describe the modeling style features of the test sample cases.

3.2. Innovative Design Based on KE and TRIZ for Hand-Held Rotary Tiller. Quality function deployment (QFD) translates customer or market requirements into design requirements, process requirements, and production requirements. In order to initially construct an idealized model, the house of quality is built by means of the selected perceptual vocabulary and relevant TRIZ invention principles, and the relationship between customer requirements and the performance of the corresponding products is determined by means of QFD theoretical knowledge, which lays a foundation for the application of TRIZ later. Building a House of Quality (HOQ) mainly includes the following steps: (1) calculating user needs and their weights; (2) 9, 3, and 1 represent values of the strong, medium, and weak relation, respectively, and the relation matrix is established according to the values; (3) the designer establishes the floor of the HOQ by determining the target value of the quality characteristics; (4) competitive analysis: collect the products of the rotary tiller and establish the competitive ability evaluation matrix (the competitive ability is expressed by 1~5, 1 is the worst, 5 is the best); (5) technical capability evaluation: according to the evaluation of professionals and their own experience, the technical capability of the current products is compared with that of the competitive products in the important characteristics, and the technical capability matrix is established; and (6) evaluation of the relationship between quality characteristics. The results are shown in Figure 2.

Based on the mapping of representative perceptual vocabulary with the engineering parameters of TRIZ and the current situation of the hand-held rotary tiller, the idealized model of hand-held rotary tiller design is preliminarily constructed from two aspects of exterior structure and function technology, as shown in Table 6 [22]. Designers can refer to the weight of stationary objects in TRIZ and create the dynamic sensibility of products through the overall volume of products. Designers can also embody the harmony of the whole product through the shape of the product. In order to personalize the product, the designer designs the product by feeding back different information to the consumers. Improving the reliability of products can improve the safety of users using products.

TABLE 3: Modeling features of the hand-held rotary tiller.

Sample	Modeling feature	Characteristic analysis	Typical sample
Sample 1		Rotary tiller knife and other tools can be replaced
Sample 2		Wheels and rotary tillage knife position put to the front
Sample 3		Traditional modeling.
Sample 4		Hand-held rotary tiller was adjustable

TABLE 4: 12 pairs of adjectives and their antonyms.

Num	Adjective pairs
1	Comfortable-uncomfortable
4	Dynamic-static
7	Steady-light
10	Easy-laborious
2	Hard-weak
5	Safe-dangerous
8	Advanced-outdated
11	Holistic-partial
3	Practical-gaudy
6	Individual-common
9	Gorgeous-simple
12	Harmonious-disharmonious

TABLE 5: PCA of semantic features of style.

Components	Initial eigenvalue			Extracting the sum of squares		
	Total	Variance contribution (%)	Cumulative contribution (%)	Total	Variance contribution (%)	Cumulative contribution (%)
1	5.876	48.965	48.965	5.876	48.965	48.965
2	1.617	13.477	62.442	1.617	13.477	62.442
3	1.322	11.019	73.460	1.322	11.019	73.460
4	1.009	8.412	81.872	1.009	8.412	81.872
...	...	...	...	...	...	...
12	0.010	0.086	100.000			

TABLE 6: Perceptual design of the hand-held rotary tiller idealized model.

	Emotional words	TRIZ engineering parameters	Current situation	Idealized model
Exterior structure	Dynamic	Weight of stationary object, shape, and loss of information.	Monotonous, old-fashioned color matching, poor, systematic design, and lack of corporate identity information.	Harmonious color design, refined geometrical shape, and full of corporate identity information.
	Harmonious Individual			
Functional technology	Safety	Reliability, harmful factors produced by objects, and adaptability and versatility.	Knife will hurt the operator and lacking ergonomic design.	Safety, high efficiency, comfortable ergonomic design, and reinforced structural structures.
	Comfortable Practical			

All TRIZ engineering parameters in Table 6 come from the 39 engineering parameters in TRIZ.

In order to improve the practicability of products, designers can adopt the principle of adaptability and versatility in TRIZ theory. Since the change in appearance structure affects the shape parameters, the invention is applied to the statistical principle of the shape parameters used in the contradiction matrix, as shown in Table 7. The invention principle with higher usage rate is selected so that the original understanding of the appearance structure design of the hand-held rotary tiller is provided, and the improvement description of the inductive design of the hand-held rotary tiller is proposed, as shown in Table 8. There are 17 principles of invention for design (C10: Prior action; C1: Segmentation; C14: Spheroidality; C15: Dynamicity; C32: Changing the color; C34: Rejecting and regenerating parts; C35: Transformation of physical and chemical states of an object; C2: Extraction; C4: Asymmetry; C29: Use a pneumatic or hydraulic construction; C40: Composite materials; C13: Inversion; C22: Convert harm into benefit; C26: Copying; C5: Combining; C17: Moving to a new dimension; C28: Replacement of a mechanical system).

According to the interpretation of the invention, the shape of the hand-held rotary tiller was initially drawn by hand. Designers can propose the direction of design through the inspiration of the principle of invention. In order to embody the dynamics and coordination of the scheme, the designer can use streamlined body language to form a concise and harmonious overall form of the handrail connecting rod and the head of the hand-held rotary tiller and match the reasonable color matching proportion to reduce the volume of the machine in the visual sense. In order to reflect the comfort of the scheme, the designer can divide the main view and the top view of the rotary tiller reasonably so as to stimulate the user's sense of stability of the machine (see Figure 3).

System component function analysis is a process of modeling system function. The model should include system components, hypersystem components, objects, and so on. On this basis, the functional model diagram of the hand-held rotary tiller was constructed, as shown in Figure 4. Functional model diagrams can help designers understand the system, identify the problems in the system, identify the types of problems, get inspiration to solve related problems, and then find appropriate solutions for each type of problems in a precise way. The designer first establishes the component hierarchy model by component analysis, then

analyses the relationship between system components, establishes the system component relationship model, and establishes the functional model. System component function analysis of the hand-held rotary tiller: the operator is safe when both hands leave the handle of the hand-held rotary tiller. System components: switch, hand-held connecting rods, chassis, motor, rotary tillage knife, wheels, and transmission; hypersystem components: vegetation and soil. Objects: handles and rotary blade.

As shown in Table 9, through the analysis of the relevant engineering parameters in the TRIZ conflict matrix, the designer has obtained the functional requirements of the hand-held rotary tiller, as well as the principles of the invention to solve the corresponding problems. In Table 9, (12) denotes the engineering parameter serial number and 1 denotes the serial number of the inventive principle.

In Table 10, “✓” indicates that the principle is the optimal solution; “?” indicates that the principle needs to be considered; and “X” means that the principle was constrained by the current system and structure or cannot work [23]. For instance, in consideration of safety, the physical/chemical parameters of the existing hand-held rotary tiller had been basically determined, and it was not necessary to increase the cost to change them. Cushion in advance was less innovative, but it is worthy of consideration. Segmentation, rushing through, and partial or overdone action were not useful for safety. Replacement of a mechanical system was a new idea that should be taken into consideration.

Several principles with “✓” and “?” in Table 11 are illustrated in Table 12 for technical improvement of the hand-held rotary tiller.

As shown in Table 11, the technical improvements (replacement of mechanical systems, porous materials, composites, and dynamics) made by the designer on the hand-held rotary tiller do not conflict with the appearance improvements in Table 9 (dynamic, harmonious, and individual). This indicated that the conceptual design can be continued. According to the interpretation of the invention principles, the functional technology of the hand-held rotary tiller was preliminarily conceived (see Figure 5).

According to the improvement of product appearance and function technology explained by the invention principles, three-dimensional modeling and rendering of the product were carried out by computer-aided technology. Designers should meet the physiological and psychological

TABLE 7: Number of times inventive principles are used by improving shape parameters.

Principle of invention	Num	Principle of invention	Num	Principle of invention	Num	Principle of invention	Num
1. Segmentation	9	11. Cushion in advance	0	21. Rushing through	0	31. Use of Porous material	0
2. Extraction	5	12. Equipotentiality	0	22. Convert harm into benefit	4	32. Changing the color	7
3. Local conditions	2	13. Inversion	4	23. Feedback	0	33. Homogeneity	1
4. Asymmetry	5	14. Spheroidality	9	24. Mediator	0	34. Rejecting and regenerating parts	7
5. Combining	3	15. Dynamicity	9	25. Self-service	1	35. Transformation of physical and chemical states of an object	6
6. Universality	2	16. Partial or overdone action	2	26. Copying	4	36. Phase transition	1
7. Nesting	2	17. Moving to a new dimension	3	27. An inexpensive short-life object instead of an expensive durable one	0	37. Thermal expansion	1
8. Counterweight	1	18. Mechanical vibration	2	28. Replacement of a mechanical system	3	38. Using strong oxidizers	0
9. Prior counter	1	19. Periodic action	1	29. Use a pneumatic or hydraulic construction	5	39. Inert environment	1
10. Prior action	10	20. Continuity of useful action	0	30. Flexible film or hydraulic construction	2	40. Composite materials	5

TABLE 8: Description of appearance improvements of hand-held rotary tiller.

Appearance	Original understanding	Description of improvement
Dynamic	Segmentation; curved surface; dynamic characteristics; physical/chemical change; combination	Curved surface design, geometric scale, bright and refreshing feeling
Harmonious	Preaction; discard or regenerate; extraction; pneumatic and hydraulic structures; spatial dimension change; mechanical system substitution	Parametric design, concise and harmonious, match colors for design, the sense of volume in geometric form
Individual	Change the color; composite; asymmetry; spatial dimension change	Reasonable division of the layout, systematic design, change harmful factors to favourable factors

All the original understandings come from TRIZ theory.

FIGURE 3: Hand drawing of the hand-held rotary tiller.

FIGURE 4: System component function analysis of the hand-held rotary tiller.

TABLE 9: Analysis on engineering parameters of hand-held rotary tillers.

Emotional words	Function	Improvement factors	Deteriorating factors	TRIZ solution
Safety	Safety	(27) Reliability	(9) Speed (12) Shape	1. Segmentation; 11. Cushion in advance; 21. Rushing through; 16. Partial or overdone action; 28. Replacement of a mechanical system; 35. Transformation of physical and chemical states of an object.
	Antivibration	(31) Harmful factors side effects	(36) Complexity of device	1. Segmentation; 19. Periodic action; 31. Use of porous materials.
Comfortable	Antiskid	(27) Reliability	(30) Harmful factors acting on object	2. Extraction; 27. An inexpensive short-life object instead of an expensive durable one; 35. Transformation of physical and chemical states of an object; 40. Composite materials.
Practical	Practical	(35) Adaptability	(36) Complexity of equipment	15. Dynamicity; 28. Replacement of a mechanical system; 29. Use a pneumatic or hydraulic construction; 37. Thermal expansion.

All Arabic numerals in Table 9 are the serial numbers in the TRIZ conflict matrix.

bull head has been reinterpreted into the modern image of bull head, as shown in Figure 6. It expressed the traditional cultivation culture. Finally, we used computer-aided industrial design software to model the hand-held rotary tiller with this image and obtained an innovative conceptual design scheme, as shown in Figures 7 and 8.

3.3. Design Evaluation for Hand-Held Rotary Tiller. In order to verify the reliability and innovation of conceptual design, a conceptual scheme evaluation map was made with four

typical samples, as shown in Figure 9. The weight of five schemes were calculated by the AHP and construction of judgment matrix, and the evaluation results of conceptual design scheme and other typical sample schemes were obtained [24].

Three aspects of the 5 schemes, modeling, function, and color matching, were evaluated to find out an innovative hand-held rotary tiller design scheme (see Figure 10). In this work, the evaluation weight was confirmed by several experts, including two industrial design experts and two agricultural machinery design experts. The results were more

TABLE 10: Functional principles of the hand-held rotary tiller.

Function	Principle	Principle elaboration
Safety	Replacement of a mechanical system ✓	Replacement of a mechanical system was currently a relatively new idea that can be tracked further.
	Cushion in advance ✓	Cushion in advance was less innovative, but it needed studying.
	Segmentation ✗	Segmentation, rushing through, and partial or overdone action were not useful for safety.
	Rushing through ✗	It was not necessary to increase the cost for transformation of physical and chemical states of an object.
	Partial or overdone action ✗	
Antivibration	Transformation of physical and chemical states of an object ✗	
	Use of porous materials ✓	Use of porous materials was useful for buffer vibrations. Periodic action may cause resonance.
	Periodic action ?	Segmentation was not appropriate for Antivibration.
Antiskid	Segmentation ✗	
	Composite materials ✓	Composite materials can be considered emphatically. The inventive principle of cheap alternatives was needed further analysis. The principle that transformation of physical and chemical states of a hand-held rotary tiller may increase costs was not taken into account.
	An inexpensive short-life object instead of an expensive durable one?	
	Transformation of physical and chemical states of an object ✗	Extraction was not very suitable for the product.
	Extraction ✗	
Practical	Dynamicity ✓	Dynamicity deserves to be considered and used.
	Replacement of a mechanical system?	The inventive principle of replacing mechanical systems using pneumatic or hydraulic structures can continue to be tracked. Thermal expansion can be excluded.
	Use a pneumatic or hydraulic construction?	
	Thermal expansion ✗	

All the principles come from the 40 original principles of TRIZ.

TABLE 11: Description of technical improvements of the hand-held rotary tiller.

Principle name	Description of improvement
Replacement of a mechanical system	The pressure sensor in the handle of the hand-held rotary tiller can detect the pressure of the operator's hands on the handle. When an accident occurs, the single chip microcomputer built in the hand-held rotary tiller will cut off the motor and stop the work.
Use of porous materials	Porous materials can be used for sound insulation, but also can reduce the quality and vibration of hand-held rotary tiller.
Composite materials	The composite material can be used to improve the strength and rigidity of the machine and reduce the quality of the hand-held rotary tiller.
Dynamicity	Hand-held connecting rod was adjustable. Rotary tiller blade can be replaced.

TABLE 12: Calculation results of scheme layer of hand-held rotary tillers.

	$A_{11}-B$	$A_{21}-B$	$A_{31}-B$	$A_{41}-B$	
$\omega_{s1}^{(2)}$	0.0608	0.0470	0.0460	0.0524	
	0.0348	0.0278	0.0460	0.0290	
	0.3419	0.4242	0.3953	0.4139	
	0.1597	0.1275	0.0985	0.1330	
	0.3419	0.3233	0.3569	0.3155	
$\lambda_{\max}$	0.0608	0.0502	0.0573	0.0561	
CI	6.5433	6.5882	6.5313	6.5504	
CR	0.1087	0.1176	0.1063	0.1101	
	0.0876	0.0949	0.0857	0.0888	Accept

objective because both of them were very familiar with the hand-held rotary tiller [25]. And several judgment matrices were constructed according to the data of questionnaires. Through the evaluation matrix, the designer determines the requirement weighting coefficients of the criterion layer and the scheme layer.

3.3.1. Construction of Judgment Matrix

- (1) Constructing judgment matrix A_{s1} of the criterion layer ($s = 1, 2, 3$, and 4, where s stands for expert; $t = 1, 2, 3, 4, 5$, and 6, where t stands for scheme):

$$A_{11} = \begin{pmatrix} 1 & 3 & \frac{1}{5} & \frac{1}{3} & \frac{1}{5} & 1 \\ \frac{1}{3} & 1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{5} & \frac{1}{3} \\ 5 & 3 & 1 & 3 & 1 & 5 \\ 3 & 3 & \frac{1}{3} & 1 & \frac{1}{3} & 5 \\ 5 & 5 & 1 & 3 & 1 & 3 \\ 1 & 3 & \frac{1}{5} & \frac{1}{5} & \frac{1}{3} & 1 \end{pmatrix}$$

FIGURE 5: Functional system diagram of the hand-held rotary tiller.

FIGURE 6: Iterative design of front face pattern of the rotary tiller.

FIGURE 7: Conceptual design scheme of the hand-held rotary tiller.

FIGURE 8: Color series of the hand-held rotary tiller.

FIGURE 9: Typical sample schemes and conceptual design scheme. (a) Scheme 1. (b) Scheme 2. (c) Scheme 3. (d) Scheme 4. (e) Scheme 5.

FIGURE 10: Hierarchical model of the hand-held rotary tiller.

(2) Constructing judgment matrix B_{st} of the scheme layer:

$$A_{21} = \begin{pmatrix} 1 & 3 & \frac{1}{7} & \frac{1}{3} & \frac{1}{7} & 1 \\ \frac{1}{3} & 1 & \frac{1}{5} & \frac{1}{3} & \frac{1}{5} & \frac{1}{3} \\ 7 & 5 & 1 & 5 & 1 & 7 \\ 3 & 3 & \frac{1}{5} & 1 & \frac{1}{3} & 5 \\ 7 & 5 & 1 & 3 & 1 & 3 \\ 1 & 3 & \frac{1}{7} & \frac{1}{5} & \frac{1}{3} & 1 \end{pmatrix},$$

$$A_{31} = \begin{pmatrix} 1 & 1 & \frac{1}{5} & \frac{1}{3} & \frac{1}{5} & 1 \\ 1 & 1 & \frac{1}{5} & 1 & \frac{1}{5} & \frac{1}{3} \\ 5 & 5 & 1 & 5 & 1 & 5 \\ 3 & 1 & \frac{1}{5} & 1 & \frac{1}{5} & 5 \\ 5 & 5 & 1 & 5 & 1 & 3 \\ 1 & 3 & \frac{1}{5} & \frac{1}{5} & \frac{1}{3} & 1 \end{pmatrix},$$

$$A_{41} = \begin{pmatrix} 1 & 3 & \frac{1}{7} & \frac{1}{3} & \frac{1}{5} & 1 \\ \frac{1}{3} & 1 & \frac{1}{5} & \frac{1}{3} & \frac{1}{5} & \frac{1}{3} \\ 7 & 5 & 1 & 5 & 1 & 5 \\ 3 & 3 & \frac{1}{5} & 1 & \frac{1}{3} & 5 \\ 5 & 5 & 1 & 3 & 1 & 3 \\ 1 & 3 & \frac{1}{5} & \frac{1}{5} & \frac{1}{3} & 1 \end{pmatrix}.$$

$$B_{11} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 5 & 3 & 1 \\ \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{7} & \frac{1}{7} \\ 5 & \frac{1}{5} & 7 & 1 & 1 \\ 5 & 1 & 7 & 1 & 1 \end{pmatrix},$$

$$B_{21} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 5 & 1 & \frac{1}{3} \\ \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{3} & \frac{1}{3} \\ 5 & 1 & 7 & 1 & 1 \\ 5 & 3 & 3 & 1 & 1 \end{pmatrix},$$

$$B_{31} = \begin{pmatrix} 1 & \frac{1}{3} & 5 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 3 & 1 & 1/3 \\ \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{5} & \frac{1}{7} \\ 5 & 1 & 5 & 1 & \frac{1}{3} \\ 5 & 3 & 7 & 3 & 1 \end{pmatrix},$$

(5)

$$B_{41} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{3} \\ 3 & 1 & 5 & \frac{1}{5} & \frac{1}{3} \\ \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{5} & \frac{1}{5} \\ 5 & 5 & 5 & 1 & 3 \\ 3 & 3 & 5 & \frac{1}{3} & 1 \end{pmatrix},$$

$$B_{12} = \begin{pmatrix} 1 & \frac{1}{3} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 3 & 5 & 1 \\ \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{5} & \frac{1}{7} \\ 5 & \frac{1}{5} & 5 & 1 & 1 \\ 5 & 1 & 7 & 1 & 1 \end{pmatrix},$$

$$B_{22} = \begin{pmatrix} 1 & \frac{1}{3} & 5 & \frac{1}{3} & \frac{1}{3} \\ 3 & 1 & 3 & 1 & 1 \\ \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 5 & 1 & \frac{1}{3} \\ 3 & 1 & 5 & 3 & 1 \end{pmatrix},$$

$$B_{32} = \begin{pmatrix} 1 & \frac{1}{3} & 5 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 3 & \frac{1}{3} & \frac{1}{3} \\ \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{7} & \frac{1}{7} \\ 5 & 3 & 7 & 1 & \frac{1}{3} \\ 5 & 3 & 7 & 3 & 1 \end{pmatrix},$$

$$B_{42} = \begin{pmatrix} 1 & \frac{1}{3} & 5 & \frac{1}{5} & \frac{1}{7} \\ 3 & 1 & 3 & \frac{1}{3} & \frac{1}{3} \\ \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{5} & \frac{1}{5} \\ 5 & 3 & 5 & 1 & 1 \\ 7 & 3 & 5 & 1 & 1 \end{pmatrix},$$

$$B_{13} = \begin{pmatrix} 1 & \frac{1}{5} & \frac{1}{3} & \frac{1}{7} & \frac{1}{5} \\ 5 & 1 & 3 & 1 & \frac{1}{3} \\ 3 & \frac{1}{3} & 1 & \frac{1}{3} & \frac{1}{7} \\ 7 & 1 & 3 & 1 & \frac{1}{3} \\ 5 & 3 & 7 & 3 & 1 \end{pmatrix},$$

$$B_{23} = \begin{pmatrix} 1 & \frac{1}{3} & 1 & \frac{1}{3} & \frac{1}{5} \\ 3 & 1 & 3 & \frac{1}{3} & \frac{1}{3} \\ 1 & \frac{1}{3} & 1 & \frac{1}{5} & \frac{1}{7} \\ 3 & 3 & 5 & 1 & \frac{1}{3} \\ 5 & 3 & 5 & 3 & 1 \end{pmatrix},$$

$$B_{33} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{7} \\ 3 & 1 & 3 & \frac{1}{3} & \frac{1}{5} \\ \frac{1}{3} & \frac{1}{3} & 1 & \frac{1}{7} & \frac{1}{7} \\ 5 & 5 & 3 & 1 & \frac{1}{3} \\ 7 & 5 & 7 & 3 & 1 \end{pmatrix},$$

$$B_{43} = \begin{pmatrix} 1 & \frac{1}{3} & 1 & \frac{1}{3} & \frac{1}{5} \\ 3 & 1 & 3 & \frac{1}{5} & \frac{1}{5} \\ 1 & \frac{1}{3} & 1 & \frac{1}{5} & \frac{1}{5} \\ 3 & \frac{1}{5} & 5 & 1 & 1 \\ 5 & 5 & 5 & 1 & 1 \end{pmatrix},$$

$$B_{14} = \begin{pmatrix} 1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 1 & \frac{1}{3} & \frac{1}{5} \\ 1 & 1 & 1 & \frac{1}{3} & \frac{1}{7} \\ 5 & 3 & 3 & 1 & \frac{1}{3} \\ 5 & 5 & 7 & 3 & 1 \end{pmatrix},$$

$$B_{24} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 3 & \frac{1}{3} & \frac{1}{3} \\ \frac{1}{3} & \frac{1}{3} & 1 & \frac{1}{7} & \frac{1}{7} \\ 5 & 3 & 7 & 1 & 1 \\ 5 & 3 & 7 & \frac{1}{3} & 1 \end{pmatrix},$$

$$B_{35} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{3} & \frac{1}{5} \\ 3 & 1 & 1 & \frac{1}{3} & \frac{1}{5} \\ 1 & 1 & 1 & \frac{1}{7} & \frac{1}{7} \\ 3 & 3 & 7 & 1 & 1 \\ 5 & 5 & 7 & 1 & 1 \end{pmatrix},$$

$$B_{34} = \begin{pmatrix} 1 & \frac{1}{3} & 5 & \frac{1}{7} & \frac{1}{5} \\ 3 & 1 & 5 & \frac{1}{5} & \frac{1}{3} \\ \frac{1}{5} & \frac{1}{5} & 1 & \frac{1}{7} & \frac{1}{5} \\ 7 & 5 & 7 & 1 & 1 \\ 5 & 3 & 3 & 1 & 1 \end{pmatrix},$$

$$B_{45} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{7} \\ 3 & 1 & 1 & \frac{1}{3} & \frac{1}{5} \\ \frac{1}{3} & \frac{1}{3} & 1 & \frac{1}{7} & \frac{1}{7} \\ 5 & 3 & 7 & 1 & \frac{1}{3} \\ 7 & 5 & 7 & 3 & 1 \end{pmatrix},$$

$$B_{44} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 3 & \frac{1}{3} & \frac{1}{3} \\ \frac{1}{3} & \frac{1}{3} & 1 & \frac{1}{7} & \frac{1}{7} \\ 5 & 3 & 7 & 1 & 1 \\ 5 & 3 & 7 & 1 & 1 \end{pmatrix},$$

$$B_{16} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 5 & 1 & \frac{1}{3} \\ \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{7} & \frac{1}{5} \\ 5 & 1 & 7 & 1 & 1 \\ 5 & 3 & 5 & 1 & 1 \end{pmatrix},$$

$$B_{15} = \begin{pmatrix} 1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{7} & \frac{1}{7} \\ 3 & 1 & 1 & \frac{1}{5} & \frac{1}{3} \\ 3 & 1 & 1 & \frac{1}{3} & \frac{1}{5} \\ 7 & 5 & 3 & 1 & 1 \\ 7 & 3 & 5 & 1 & 1 \end{pmatrix},$$

$$B_{26} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{3} & \frac{1}{5} \\ 3 & 1 & 7 & \frac{1}{3} & \frac{1}{3} \\ \frac{1}{5} & \frac{1}{7} & 1 & \frac{1}{5} & \frac{1}{7} \\ 3 & 3 & 5 & 1 & \frac{1}{3} \\ 5 & 3 & 7 & 3 & 1 \end{pmatrix},$$

$$B_{25} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{7} \\ 3 & 1 & 3 & \frac{1}{3} & \frac{1}{5} \\ 5 & \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{7} & \frac{1}{7} \\ 5 & 3 & 7 & 1 & \frac{1}{3} \\ 7 & 3 & 7 & 3 & 1 \end{pmatrix},$$

$$B_{36} = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 5 & \frac{1}{3} & \frac{1}{5} \\ \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{3} & \frac{1}{7} \\ 5 & 3 & 3 & 1 & \frac{1}{3} \\ 5 & 5 & 7 & 3 & 1 \end{pmatrix},$$

TABLE 13: Calculation results of scheme layer of hand-held rotary tiller.

$\omega_{1t}^{(3)}$	$B_{11}-C$	$B_{12}-C$	$B_{13}-C$	$B_{14}-C$	$B_{15}-C$	$B_{16}-C$	Expert 1
	0.0815	0.0497	0.0417	0.0496	0.0434	0.0796	
	0.3322	0.3482	0.2016	0.1062	0.1063	0.2091	
	0.0414	0.0465	0.0795	0.0797	0.1063	0.0433	
	0.2290	0.2244	0.2156	0.2518	0.3720	0.3086	
	0.3159	0.3312	0.4616	0.5127	0.3720	0.3594	
$\lambda_{\max}$	5.2876	5.3691	5.2469	5.0252	5.0939	5.2194	Accept
CI	0.0719	0.0923	0.0617	0.0063	0.0235	0.0548	
CR	0.0642	0.0824	0.0551	0.0056	0.0210	0.0490	
$\omega_{2t}^{(3)}$	$B_{21}-C$	$B_{22}-C$	$B_{23}-C$	$B_{24}-C$	$B_{25}-C$	$B_{26}-C$	Expert 2
	0.0856	0.1172	0.0712	0.0749	0.0658	0.0927	
	0.2247	0.2547	0.1524	0.1425	0.1209	0.1705	
	0.0611	0.0502	0.0643	0.0422	0.0396	0.0347	
	0.2799	0.2265	0.2619	0.4503	0.2726	0.2473	
	0.3487	0.3515	0.4502	0.2902	0.5012	0.4547	
$\lambda_{\max}$	5.4208	5.3773	5.2144	5.2785	5.2742	5.4268	Accept
CI	0.1052	0.0943	0.0536	0.0696	0.0685	0.1067	
CR	0.0939	0.0842	0.0479	0.0622	0.0612	0.0935	
$\omega_{3t}^{(3)}$	$B_{31}-C$	$B_{32}-C$	$B_{33}-C$	$B_{34}-C$	$B_{35}-C$	$B_{36}-C$	Expert 3
	0.0855	0.0826	0.0669	0.0758	0.0692	0.0744	
	0.1832	0.1419	0.1231	0.1393	0.1074	0.1416	
	0.0420	0.0379	0.0403	0.0359	0.0680	0.0448	
	0.2247	0.2890	0.2595	0.4186	0.3393	0.2434	
	0.4646	0.4485	0.5102	0.3304	0.4162	0.4957	
$\lambda_{\max}$	5.3965	5.4257	5.3429	5.4404	5.2374	5.4451	Accept
CI	0.0991	0.1064	0.0857	0.1101	0.0594	0.1113	
CR	0.0885	0.0950	0.0765	0.0983	0.0530	0.0994	
$\omega_{4t}^{(3)}$	$B_{41}-C$	$B_{42}-C$	$B_{43}-C$	$B_{44}-C$	$B_{45}-C$	$B_{46}-C$	Expert 4
	0.0846	0.0805	0.0697	0.0762	0.0658	0.0758	
	0.1454	0.1480	0.1216	0.1450	0.1209	0.1393	
	0.0444	0.0452	0.0629	0.0429	0.0396	0.0359	
	0.4757	0.3509	0.3538	0.3679	0.2726	0.3304	
	0.2499	0.3754	0.3919	0.3679	0.5012	0.4186	
$\lambda_{\max}$	5.4118	5.4301	5.2748	5.1295	5.2742	5.4404	Accept
CI	0.1029	0.1075	0.0687	0.0324	0.0684	0.1101	
CR	0.0919	0.0960	0.0613	0.0289	0.0612	0.0983	

$$B_{46} = \begin{pmatrix} 1 & \frac{1}{3} & 5 & \frac{1}{5} & \frac{1}{7} \\ 3 & 1 & 5 & \frac{1}{3} & \frac{1}{5} \\ \frac{1}{5} & \frac{1}{5} & 1 & \frac{1}{5} & \frac{1}{7} \\ 5 & 3 & 5 & 1 & 1 \\ 7 & 5 & 7 & 1 & 1 \end{pmatrix}. \quad (6)$$

3.3.2. Hierarchical Sequencing and Consistency Verification.

The maximum eigenvalue $\lambda_{\max} = 6.5433$ of the judgment matrix A_{11} was obtained by calculation, and it was normalized to $\omega_{11}^{(2)} = (0.0608, 0.0348, 0.3419, 0.1597, 0.3419, 0.0608)$. The six elements of the criterion layer are harmony, dynamics, safety, comfort, practicality, and individuality. Consistency test is to test the coordination of the importance of each element. CI value of less than 1 indicates that consistency of the judgment matrix is passed, and the results are listed in Table 12.

The element b_{ij}^{st} in the judgment matrix B_{st} is the comparison measure of the superiority of P_t to C in the scheme layer (hand-held rotary tiller). The weight $\omega_{1t}^{(3)}$, the maximum eigenvalue $\lambda_{\max}$, and the consistency index CI_{1t} were calculated from the comparison judgment matrix B_{1t} of the third layer, and the results are listed in Table 13. The average of the total ranking of the scheme layers is shown in Table 14.

After calculation, the weight coefficient P of the 4 sample schemes and a new conceptual design scheme of the target layer was obtained. $P_1(C1) = 0.07$, $P_2(C2) = 0.14$, $P_3(C3) = 0.06$, $P_4(C4) = 0.30$, and $P_5(C5) = 0.43$, where $P_t(C1)$ is the weight coefficient of sample 1 and so on. Therefore, the innovative conceptual design scheme was selected from the five schemes because the weight coefficient of the conceptual design scheme, $P_5(C5)$, was the largest one: 0.43. This method is effective and feasible for the innovative design of agricultural machinery.

4. Discussion

In order to improve the comprehensive quality of functional products and meet the needs of users for product

TABLE 14: Overall ranking result and average value of the third layer.

Scheme	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5
Expert 1	0.048558458	0.167268103	0.083016534	0.281635216	0.419521689
Expert 2	0.072929489	0.148099162	0.051450184	0.288521951	0.438999215
Expert 3	0.070614603	0.123757406	0.050002922	0.302460164	0.453164905
Expert 4	0.070748371	0.127513198	0.049909632	0.335077088	0.41675171
Average value	0.06571273	0.141659467	0.058594818	0.301923605	0.43210938

personalization, this paper puts forward the improvement explanation of appearance and function and obtains the innovative design scheme by introducing KE and TRIZ. The AHP was used to evaluate the innovative design scheme. Combining with the design of hand-held rotary tiller, the corresponding innovative design scheme was obtained, and the design process was attempted to be extended to other products. The main content of the literature study [8, 25, 26] focused on the user requirements mining or conceptual design stage, and the researchers have not studied the application of detailed design stage and the subsequent evaluation of innovative design. This paper establishes an innovative design model from user needs mining, conceptual design, detailed design, computer-aided design, and scheme evaluation, which is convenient for designers to design and develop products and also has a good reference for innovative design of other products.

However, because the main research content of this paper focuses on innovative design process, the research on the evaluation system of the scheme is insufficient. In the following work, designers can introduce other design theories and methods to combine with existing research in order to improve the process of innovative design.

5. Conclusions

In order to improve the comprehensive quality of agricultural machinery products based on functional technology and meet the needs of users, the innovation design model of agricultural machinery products based on KE-TRIZ was constructed.

Firstly, the designer used SD method and PCA method to quantify and reduce the dimension of affective intention words, aiming to select comprehensive variables representing the needs of users. Secondly, by constructing a KE-TRIZ innovative design model, the product appearance and function were innovatively designed, and the contradiction between product appearance and function was analyzed to make it well matched. Then, taking the innovative design of the hand-held rotary tiller as an example, the application flow was described, and the typical samples and design scheme were evaluated by the AHP, which shows that the method has obvious improvement in function and appearance. The KE-TRIZ method enables designers to design products more in line with the actual needs of users, which is effective and feasible for the innovative design of agricultural machinery.

The follow-up work is to further explore the integration of technology, cost, and other multi-objective-driven innovative designs of agricultural machinery products in order to improve the applicability and integrity of the method.

Data Availability

All data generated and analyzed during this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Jian-wei Wang conceived and designed the study. Jian-min Zhang completed the design evaluation. Jian-wei Wang completed product modeling. Jian-min Zhang revised and polished the manuscript. All authors have read and approved the final manuscript. All authors contributed equally to this work.

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