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Research on the Design Method of *Camellia oleifera* Fruit Picking Machine

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Abstract: *Camellia oleifera* fruit pickers are essential for improving picking efficiency and promoting the *Camellia oleifera* industry. However, it is challenging to develop pickers that meet user needs. Current design tools and methods have limitations, such as a single model, poor synergy between integrated models, and subjective bias when analysing user requirements and translating them into product attributes. To solve these problems, this study proposes a new design decision model based on the Fuzzy Analytic Hierarchy Process (FAHP), Function Analysis System Technique (FAST), Theory of Inventive Problem Solving (TRIZ Theory), and extension transformation theory. The model was developed and applied to design an *Camellia oleifera* fruit picker. In this paper, an empirical investigation of an *Camellia oleifera* base in Wuhan was carried out, and multi-level demand analysis was used to identify the design demands in the behavioural process; FAHP was used to calculate the demand weights to clarify the design focus; expert knowledge was used to convert the demands into specific product functional features, and FAST was used to decompose these features to find the contradictory conflicts; TRIZ theory was used to determine the principles of resolving the contradictions, and the extension transformation theory were used to generate the creative design solutions for the products. By integrating FAHP, FAST, TRIZ theory and the extension transformation theory, the subjective bias in product design is eliminated, the design decision-making process is improved, and new methods and ideas are provided for the design of oleaginous tea fruit pickers and similar products. Finally, the conceptual design of an *Camellia oleifera* fruit picking machine was produced. However, the conceptual design has yet to be subjected to exhaustive simulation experiments and prototype testing. Future research will focus on conducting the necessary simulations, prototypes, and field tests to fully assess the feasibility and effectiveness of the design and make the required iterative improvements accordingly to commercialize the product eventually.

Keywords: *Camellia oleifera* fruit pickers; fuzzy analytic hierarchy process (FAHP); function analysis system technique (FAST); theory of inventive problem solving (TRIZ theory); extension transformation theory

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1. Introduction

The development of intelligent agricultural picking is promising and full of opportunities. With the continuous progress of technology and the expansion of application scenarios, picking robots will play an increasingly important role in modern agriculture. However, compared to the rapid development of the picking industry, the development and design of *Camellia oleifera* fruit picking machines have lagged behind. In recent years, China's scientific research teams have conducted extensive and in-depth research on *Camellia oleifera* fruit picking machines, focusing mainly on vibratory, comb and brush, and extrusion machines [1]. The vibratory type has high picking efficiency and a low bud damage rate. Still, due to the difficulty of achieving precise control of the vibration frequency and amplitude, etc., associated with this picking method, it may cause damage to the roots and buds of the *Camellia oleifera* tree and even the death of the fruit tree [2]. The advantages of comb-brush picking equipment are simple structure and rapid picking, but due to its large size; working in a mountainous area becomes energy-intensive, slow, and prone to dangerous accidents. In addition, it is difficult to pick the fruits inside the *Camellia oleifera* tree, and the leakage rate is high [3]. The advantages of extrusion picking equipment are small size, less energy consumption during picking, ability to pick flexibly in complex situations, minor damage to branches and buds, and preservation of the *Camellia oleifera* yield for the following year. However, the disadvantages include difficulty in picking the fruits inside the *Camellia oleifera* tree, high leakage rate, requirement of many passes over the same tree, and low picking efficiency [4]. In summary, the existing *Camellia oleifera* fruit picker has a relatively low degree of intelligence, pays less attention to the comprehensive needs of the user and the environment, and has a variety of shortcomings and deficiencies, so the functional and morphological design of the *Camellia oleifera* fruit picker remains to be optimized [1]. Users need more efficient, reliable and intelligent harvesters to meet their complex needs of terrain differentiation, so developing a suitable harvester has become a key factor. Rigorous scientific design and development methodologies are essential to ensure the design and development of more suitable, reliable and efficient harvesting machines. Various tools and methods such as Behavioural Analysis, KANO model, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy Analytic Hierarchy Process (FAHP), Multi-criteria Compromise Solution Ranking (VIKOR), Quality Function Deployment (QFD), and Theory of Inventive Problem Solving (TRIZ Theory) are applied in the product design process [5]. FAHP, FAST, TRIZ theory, and the extension transformation theory are essential for accurate user orientation and requirements, clear design focus, innovativeness, and solution concretization. Yongchuan Li et al. [6] conducted a research on sustainable user experience optimization design of elderly smart home products based on QFD. Yin Zhao et al. [7] explored for modular children's wooden storage cabinets. An evaluation model consisting of the Kano model, hierarchical analysis, and grey relational analysis is proposed. Yauwseph Tandiono et al. [8] proposed an enhanced model using the Kano model, Quality Function Deployment for Environment (QFDE), and the theory of inventive problem solving (TRIZ), with a component-based approach for systematically designing sustainable and innovative products. Deng Zhao et al. [9] combined the KANO-QFD model with the TRIZ innovative invention principle to optimize helmets and improve their safety. However, previous multidisciplinary research on integrating methods with product innovation and design lacks paradigmatic models integrating user needs analysis, product design decisions, and creative solution generation.

Therefore, this study proposes an integrated approach to analysis, decision-making, and problem-solving in product design and development to bridge this gap. Focusing on user requirements, the requirements are transformed into concrete and feasible design solutions or product structures through a scientific decision-making process and the support of innovative thinking [10]. Its unique advantages lie in the precision of user orientation, the scientific and focused clarity of decision-making, the ability to transform needs for functional realization, the stimulation of innovativeness, and the concreteness of solutions. The design method ensures the integrity and scientificity of the design process. These advantages work together in the whole process of product design, which helps improve the product's market competitiveness and user satisfaction. A case study of an *Camellia oleifera* fruit picker proves the effectiveness of this approach. The paper is structured as follows: Section 2 provides a more detailed literature review, introducing the definitions and research basis of FAHP, FAST, TRIZ theory and extension transformation theory, which are used to guide this research and prove the legitimacy of this research. Section 3 describes the framework and process of the design method theoretically, which provides guidance for the subsequent design practice. Section 4 applies the design method to the actual operation process of the design of camellia fruit picker, resulting in a specific conceptual design scheme. Finally, the paper concludes with discussion and summary.

2. Relevant Theory

2.1. FAHP

The fuzzy analytic hierarchy process combines fuzzy mathematics and the analytic hierarchy process to deal with fuzzy and uncertain decision-making factors. It improves the problems of traditional analytic hierarchy processes, improves decision-making reliability, and transforms qualitative problems into quantitative ones [11]. The fuzzy analytic hierarchy process is based on expert judgment and assessment by constructing a hierarchical structure, setting criteria and sub-criteria, and using fuzzy language to describe each criterion's relative importance and priority. The analysis steps are (1) constructing a recursive hierarchy; (2) constructing a fuzzy complementary judgment matrix; (3) calculating the weights from the fuzzy agreement matrix; (4) ranking the total weights of the hierarchy [12].

Based on sustainable analysis and creative template method, Zhou Junyu et al. [13] combined KANO mode, function behavior structure (FBS) model and fuzzy analytic hierarchy process (FAHP). Iterative conceptual design of modular products is carried out. Yuanjian Du et al. [14] propose an evaluation model based on Kansei engineering that uses FAHP to efficiently acquire, filter, and rank perceptual words. Dominika Siwie et al. [15] combined FAHP and TOPSIS to support qualitative environment decisions in the development of any product.

2.2. FAST

The FAST method is a systematic, top-down approach to creating a functional analysis. The FAST method demonstrates the connection between internal and external functions by gradually decomposing the main function layer by layer into several sub-functions, revealing the logical relationship and clarifying the relationship between product functions [16].

Hui Wang et al. [17] proposed the B/AHP/FAST method, which is an integrated design method to find requirements and match them to functions from the perspective of user behaviour. Jun Wang et al. [18] used the FAST method to transform user requirements into product functions, established a FAST function tree, and obtained the design parameters involved in children's scooters. Cuiyu Li et al. [19] proposed FAST–FBS integrated innovative design method to achieve accurate mapping from functional decomposition to structural transformation.

2.3. TRIZ Theory

The modern TRIZ theory system includes 39 engineering parameters, 40 invention principles and other theoretical tools. Its core lies in using the invention principle tools to solve the conflict in the contradiction matrix to achieve the final ideal solution. The problem-solving process involves generally defining the problem first, then analysing the situation, and finally selecting the optimal solution by examining the solution [20].

Jing Xiao et al. [21] combined TRIZ and AD theory to carry out innovative design of giant shaft boring machine (SBM) cutter head. Qizhi Xie et al. [20] applied creative problem solving theory (TRIZ) to identify and resolve physical and technical conflicts during the creative design process of peristaltic pipe robots. S. Vinodh et al. [22] used ECQFD to identify design options and associated with TRIZ to identify innovative design options.

2.4. Extension Transformation Theory

Extension transformation entails changing one object into another or decomposing it into several objects based on the topology of primitives. In topology, the primary tool for solving paradoxical problems is the extension transformation. The objects here include various objects, things, and relations and the object, thing, and relation elements used to describe them and their primitives. The fundamental topological transformations include the following forms: substitution transformations, addition and deletion transformations, expansion and contraction transformations, decomposition transformations and copying transformations [23].

Jinfeng Li et al. [24] used the innovative design methods of axiomatic design (AD) and extension to analyse the innovative design of the powertrain architecture of distributed hybrid electric tractor (DHET). Shilin Wu [25] considers the advantages of extension and D-S theory in dealing with uncertain and incompatible decision problems, and proposes a special children's toy design scheme based on extension analysis and D-S theory. Wenjuan Li [23] introduces a method to improve the design procedure of axiomatic design theory (AD) with extenics.

3. Design Methodology

This study combines FAHP, FAST, TRIZ theory and topological transformation theory, and proposes a FAHP–FAST–TRIZ–E design decision model based on the complementary strengths of user requirement weights, requirement-function transformation and creative problem-solving theory. The model analyses product user requirements, identifies potential demand points, calculates FAHP demand weights, ranks design requirements to clarify design priorities and converts them into functional priorities, decomposes functional conflicts by FAST, resolves conflicts by using TRIZ theory, and generates specific design solutions by using topological transformations.

This study proposes a new product design decision-making method in combination with the FAHP–FAST–TRIZ–E model from the perspective of user requirements weighting and resolving functional conflicts. The novelty of the model lies in the following aspects:

(1) Each design requirement is clarified through multi-level requirement analysis, and FAHP calculates the requirement weights to describe the design focus, thus improving the accuracy of the design.
(2) FAST is analysed in depth at the functional level to provide a more comprehensive and detailed perspective for decision-making.
(3) TRIZ and Extension transformation theory are applied to generate appropriate innovation principles for the product design process to guide problem-solving and reduce design subjectivity.

The model consists of the following four steps, the design flow chart is shown in Figure 1.

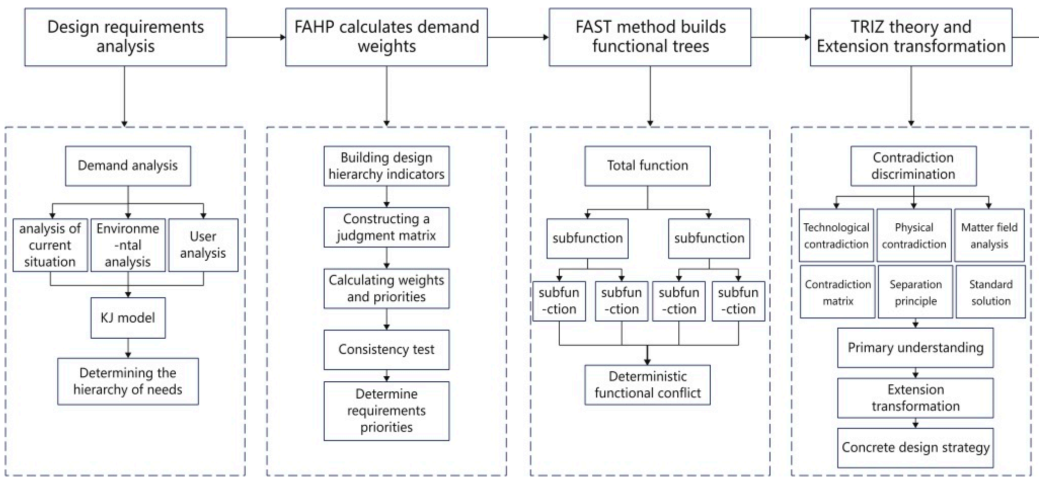

Figure 1. Methodology adopted in this study.

Step 1: Gather multi-level needs for the product through user interviews, status quo analysis, and environment analysis; classify and transform the results using the KJ model and expert knowledge to provide three-level requirements.

Step 2: Build the hierarchical demand model and determine the priorities and weights of the demands [26];

(1) The fuzzy complementary judgment matrix is constructed. The quantitative expression of "the relative importance of the two factors to the upper level of the index (criterion)" is adopted through the two-by-two comparison judgment between the factors. The fuzzy complementary judgment matrix $R = (r_{ij})_{n*n}(i, j = 1, 2, \ldots, n)$ is obtained if the quantitative scale is carried out by the 0.1–0.9 scale method shown in Table 1. Where, r_{ii} = 0.5 means that factor r_i is equally important compared with itself; if $r_{ij} \in [0.1, 0.5)$, it means that factor r_j is more important than factor r_i; if $r_{ij} \in (0.5, 0.9]$, it means that factor r_i is more important than factor r_j.

Table 1. 0.1–0.9 scale method and its meaning.

Scale	Define	Clarification
0.5	Equally important	Two factors are compared and are equally important.
0.6	Slightly important	When comparing the two factors, one is slightly more important than the other.
0.7	Significantly important	Comparing the two factors, one factor is significantly more important than the other factor.
0.8	Much more important	When comparing the two factors, one factor is much more important than the other.
0.9	Extremely important	When comparing two factors, one factor is extremely important compared to the other factor.
0.1, 0.2, 0.3, 0.4	Inverse Comparison	If factor r_i is compared with factor r_j to obtain the judgment r_{ij}, then factor r_j is compared with factor r_i to obtain the judgment $r_{ij} = 1 - r_{ij}$.

(2) Compute the weight vector W.

$$W_i = \frac{\sum_{j=1}^{n} r_{ij} + \frac{n}{2} - 1}{n(n-1)} i = 1,\ 2,\ 3,\ \ldots,\ n \tag{1}$$

where $\sum_{j=1}^{n} r_{ij}$ is the sum of the elements in row i.

(3) Calculate the feature matrix W^*.
Let W = $(W_1, W_2, \ldots, W_n)$ be the weight vector of fuzzy judgment matrix R, where $\sum_{i=1}^{n} W_i = 1, W_i \geq 0(i = 1, 2, 3, \ldots, n)$, so that:

$$W_{ij} = W_i / (W_i + W_j)(i,\ j = 1,\ 2,\ 3,\ \ldots,\ n) \tag{2}$$

For example W_{01}, its result is equal to $W_0/(W_0 + W_1)$, after the data in each position of the $n * n$ matrix are computed using the values in the weight vector W, we get the n-order matrix.

$$W^* = (W_{ij})_{n*n} \tag{3}$$

W^* is called the identity matrix of the judgment matrix A.

(4) Calculate the compatibility index I.
Let matrix $A = (a_{ij})_{n \times n}$ and $B = (b_{ij})_{n \times n}$ are both fuzzy judgment matrices, say.

$$I(A, B) = \frac{1}{n^2} \sum_{i-1}^{n} \sum_{j=1}^{n} |a_{ij} + b_{ij} - 1| \tag{4}$$

(5) Consistency test.

The fuzzy judgment matrix R and its feature matrix W* to calculate the compatibility index I (R,W*), if I (R,W*) ≤ a, the consistency test is considered to be passed. A smaller α suggests that the decision-maker expects the fuzzy judgment matrix to be more consistent., generally can be taken as a = 0.1.

Step 3: Construct the product function tree.

Step 4: The contradictions between functions are analysed through TRIZ theory to find innovative solutions, and the specific design of the picking machine is obtained by using the extension transformation.

4. Design Practice

This study proposes the FHAP–FAST–TRIZ–E design decision model, which integrates FAHP, FAST, TRIZ theory and extension transformation theory to provide structured guidance for conceptual design. It is used to guide the conceptual design of the *Camellia oleifera* fruit picker, which includes four phases: (1) requirement analysis; (2) calculating the requirement weights and clarifying the design focus; (3) transforming the requirement functions and judging the function conflicts; and (4) generating the specific and innovative design solutions.

4.1. Product Multi-Level Needs Analysis

4.1.1. Environmental Analysis

Camellia oleifera forests are widely distributed and scattered, with significant differences in planting patterns worldwide, and have yet to achieve a unified standardized, short and dense planting standard. This status quo directly leads to a massive challenge for mechanized harvesting. In hilly and mountainous areas and other complex operating environments, the problem is particularly prominent. These areas are not only rugged and variable terrain but also accompanied by a high degree of environmental complexity; the picking machinery puts forward stringent requirements [1].

4.1.2. User Analysis

In response to the user needs for mechanized picking of *Camellia oleifera* fruit, we conducted in-depth and detailed user interviews, covering three key groups of people: *Camellia oleifera* base managers, individual farmers and picking employees. The research aims to comprehensively understand and analyse users' difficult point, expectations and specific needs in the picking process to provide a solid theoretical foundation and practical guidance for designing intelligent *Camellia oleifera* fruit picking machines, as shown in Table 2.

Table 2. Summary of user interview records.

Questions	Answers
What do you think are the current difficulties when picking	*Camellia oleifera* tree is planted on hilly mountain slopes, and the tree is too high to make it easier to pick *Camellia oleifera* fruits, increasing the picker's risk factor; manual picking efficiency is low. The *Camellia oleifera* orchard area is large, the fruit is dense, and the manual labour load is large. The labour demand is large, and the labour cost is high.
Safety Requirements for *Camellia oleifera* Fruit Picking Machines	We hope the machine can adjust to environmental needs and will not topple over while turning and moving because *Camellia oleifera* is cultivated on hilly slopes.
Economic Requirements for *Camellia oleifera* Fruit Picking Machines	Reasonable cost, recyclable, reusable
Functional expectations for *Camellia oleifera* Fruit Picking Machines	Easy to operate, flexible to adapt, efficient and accurate, low damage
Things to look out for when harvesting with a machine	Buds indicate the yield for the following year, so do not injure them.

The KJ Method, also known as the Affinity Diagram Method, was introduced by Prof. Jiro Kawakita in 1964 as a method of obtaining functional requirements, organizing them into functional cards, and ultimately obtaining a list of requirements. The KJ method is now widely used in design and other disciplines [27]. Ma Xuehan et al. [28] analysed the functional requirements of a fruit app using the KJ method. Hu Haowei et al. [29] used the KJ model to analyse the design requirements of aging-friendly home gardening products. Therefore, this paper utilizes the KJ method to extract and classify the environment and user requirements for pickers, as shown in Figure 2.

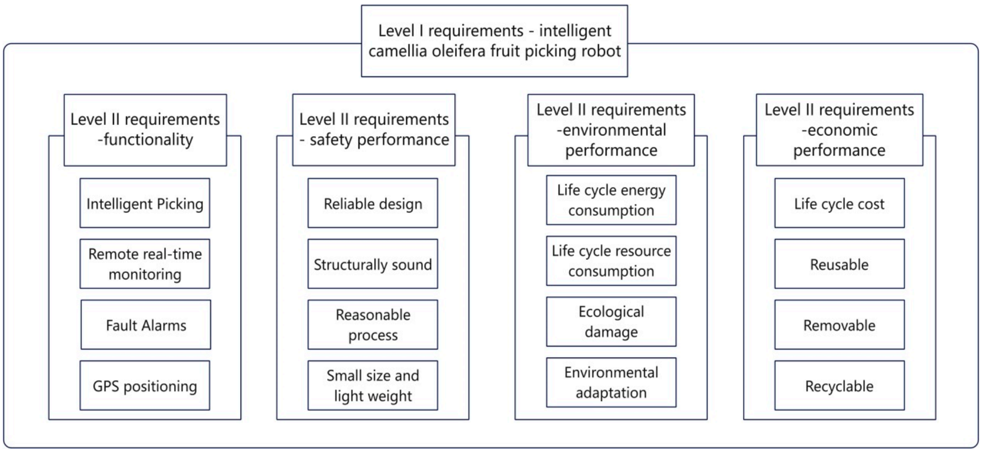

Figure 2. Design requirement.

4.2. Constructing a Hierarchical Requirements Model and Calculating Requirements Weights and Priorities

4.2.1. Constructing the Hierarchical Analysis Model

Based on the hierarchical analysis model, we systematically and meticulously categorized the design requirements for the *Camellia oleifera* fruit picker. This categorization relies on the KJ model constructed by the previous multilevel requirements. Under the FAHP framework, we mapped the first-, second-, and third-level requirement cards in the KJ model to the goal, criterion, and indicator layers of FAHP, respectively, as shown in Figure 3 [7].

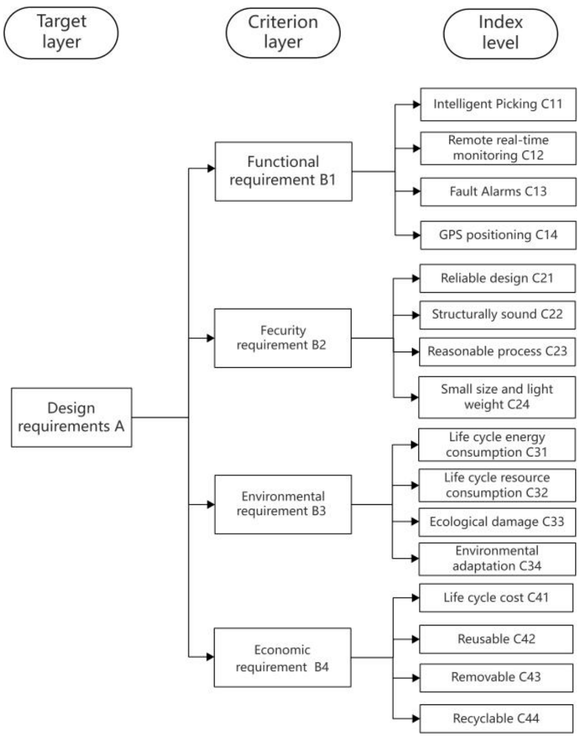

Figure 3. Hierarchical index model of *Camellia oleifera* fruit picker design.

4.2.2. Construct Judgment Matrix and Calculate Weights

The fuzzy analytic hierarchy process effectively evaluates the matrix and weight coefficient information between the elements. Equation (1) calculates the weights of demand indicators, and Table 3 displays the judgment matrix and weight data for each indication.

Table 3. Judgment matrix.

Complementary Judgment Matrix of Picker Design Requirements					
A	B_1	B_2	B_3	B_4	W_A weight
B_1	0.5	0.6	0.7	0.7	0.2971
B_2	0.4	0.5	0.6	0.7	0.2667
B_3	0.3	0.4	0.5	0.6	0.2333
B_4	0.3	0.3	0.4	0.5	0.2083
Functional Requirements Complementary Judgment Matrix					
B_1	C_{11}	C_{12}	C_{13}	C_{14}	W_{B1} weight
C_{11}	0.5	0.7	0.7	0.6	0.2917
C_{12}	0.3	0.5	0.6	0.4	0.2333
C_{13}	0.3	0.4	0.5	0.4	0.2167
C_{14}	0.4	0.6	0.6	0.5	0.2583
Complementary Judgment Matrix for Security Requirements					
B_2	C_{21}	C_{22}	C_{23}	C_{24}	W_{B2} weight
C_{21}	0.5	0.4	0.6	0.4	0.2417
C_{22}	0.6	0.5	0.6	0.4	0.2583
C_{23}	0.4	0.4	0.5	0.3	0.2167
C_{24}	0.6	0.6	0.7	0.5	0.2833
Complementary Judgment Matrix for Environmental Requirements					
B_3	C_{31}	C_{32}	C_{33}	C_{34}	W_{B3} weight
C_{31}	0.5	0.4	0.6	0.4	0.2333
C_{32}	0.6	0.5	0.6	0.4	0.2167
C_{33}	0.4	0.4	0.5	0.3	0.2583
C_{34}	0.6	0.6	0.7	0.5	0.2917
Complementary Economic Requirements Judgment Matrix					
B_4	C_{41}	C_{42}	C_{43}	C_{44}	W_{B4} weight
C_{41}	0.5	0.6	0.6	0.7	0.2833
C_{42}	0.4	0.5	0.4	0.6	0.2417
C_{43}	0.4	0.6	0.5	0.6	0.2583
C_{44}	0.3	0.4	0.4	0.5	0.2167

According to Equation (2), the compatibility between the judgment matrix and the feature matrix is 0.0769, 0.0690, 0.0604, 0.0691 and 0.0604, respectively, all of which are less than 0.1. Therefore, it can be concluded that the weight vector W_A, W_{B1}, W_{B2}, W_{B3}, W_{B4} is reliable as the weight of the demand indicator. Following the consistency test, the weight values of the indicator and guideline layers are multiplied to provide the integrated weight values, which are then ordered as indicated in Table 4 [30].

Detailed ranking of every indicator layer: C_{11} Intelligent and precise picking > C_{14} GPS location > C_{24} Lightweight > C_{12} Remote real-time monitoring > C_{22} Reasonable structure > C_{34} Environmental adaptability > C_{21} Reliable design > C_{13} Fault Alarm > C_{33} Ecological damage > C_{41} Life-cycle costs > C_{23} Rationalized process > C_{31} Life-cycle energy consumption > C_{43} Detachable > C_{32} Life cycle resource consumption > C_{42} Reuse > C_{44} Recyclable. The thorough and independent ranking of each criterion index leads to the conclusion that users focus more on the functionality of the *Camellia oleifera* fruit-picking machine, specifically on whether features like GPS positioning, intelligent and precise picking, remote real-time monitoring, and other features meet their needs. They also pay close attention to whether the picking machine is lightweight, sturdy, and built to last, among other things. As a result, these indicators serve as both the main focus of design considerations and a crucial yardstick for assessing how well the picking machine's design worked [13].

Table 4. *Camellia oleifera* fruit picker weight value.

Index		Hierarchical Weight		Absolute Weight	Overall Ranking
First-Level Indicators	**Second-Level Indicators**	**First-Level Weight**	**Second-Level Weight**		
B_1 Functionality Performance	C_{11} Intelligent and precise picking	0.2971	0.2971	0.0883	1
	C_{12} Remote real-time monitoring		0.2333	0.0693	4
	C_{13} Fault Alarm		0.2167	0.0644	8
	C_{14} GPS location		0.2583	0.0767	2
B_2 Safety Performance	C_{21} Reliable design	0.2667	0.2417	0.0645	7
	C_{22} Reasonable structure		0.2583	0.0689	5
	C_{23} Reasonable process		0.2167	0.0578	11
	C_{24} Lightweight		0.2833	0.0756	3
B_3 Environmental Performance	C_{31} Life cycle energy consumption	0.2333	0.2333	0.0544	12
	C_{32} Life cycle resource consumption		0.2167	0.0506	14
	C_{33} Ecological damage		0.2583	0.0603	9
	C_{34} Environmental adaptability		0.2917	0.0681	6
B_4 Economic performance	C_{41} Life cycle cost	0.2083	0.2833	0.0590	10
	C_{42} Reuse		0.2417	0.0503	15
	C_{43} Detachable		0.2583	0.0538	13
	C_{44} Recyclable		0.2167	0.0451	16

4.3. Building a Function Tree

When designing the *Camellia oleifera* fruit picking machine, it is necessary to comprehensively consider the user and environmental needs as well as the picking process. Then, applying FAST method to transform the complex design requirements into product functions, assisting in finding the best match between the functional requirements and the design expression, is necessary. As per the weighting analysis results and design focuses, the picker's functional requirements (i.e., intelligent and precise picking, GPS positioning, remote real-time monitoring) are prioritized. At the same time, the product's light weight, reasonable structure, reliable design and environmental adaptability should also be considered. Building the function tree, as shown in Figure 4.

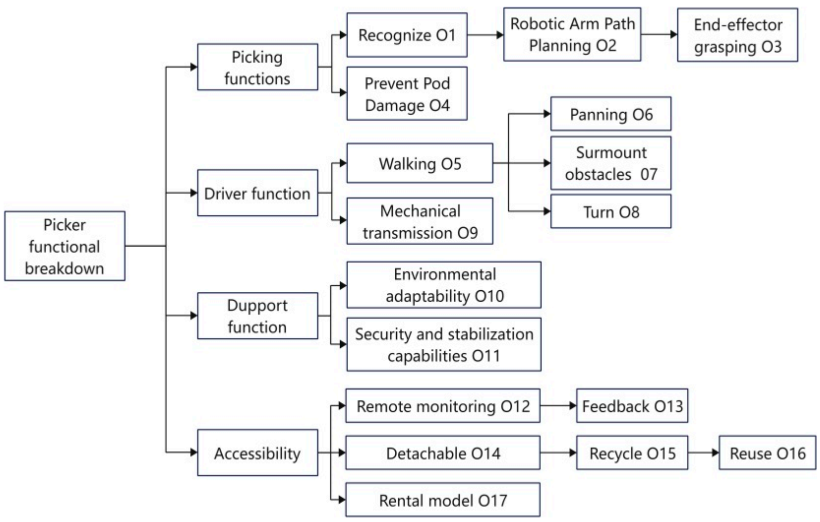

Figure 4. Functional breakdown.

Two functional conflicts were identified in the design system: (1) O_5 Walking (O_6 Translation, O_7 Obstacle Crossing, O_8 Turning) and O_{10} Environmental Adaptability, O_{11}Safety and Stability; and (2) O_3 End-effector Gripping and O_4 Prevention of Pod Damage Conflict. These findings were obtained through correlation analysis between functional design elements.

Conflict 1: O_5 walking (O_6 translation, O_7 obstacle crossing, O_8 turning) and O_{10} environmental adaptability, O_{11} safety and stability. The study state mentioned above indicates that the mechanized picking machine drive mode is primarily tracked, resulting in a complex structure and large machine size. Analysis of environmental requirements showed that *Camellia oleifera* trees grow in hilly areas, and large machines have safety hazards, such as rollover and difficulty in crossing obstacles.

Conflict 2: O_3 end-effector picking and O_4 prevent bud damage. The biological features of *Camellia oleifera* fruit trees allow them to bear flowers and fruits simultaneously. The flower buds represent the yield for the following year, and damage to the buds and branches during harvesting might impact the yield for the following year. Based on current studies, most picker designs have increased picking efficiency, yet throughout the harvesting process, there is harm to the buds.

4.4. TRIZ Conflict Solving and Extension Transformation

These two pairs of specifically technological conflicts that are negatively correlated are analytically abstracted into 39 generic engineering parameters. Conflict 1 corresponds to NO.7 Volume of Moving Objects and NO.35 Adaptability, producing two creative principles; Conflict 2 corresponds to NO.21 Power and NO.31 Harmful Factors Produced by Objects, producing three creative principles, as shown in Tables 5 and 6 [31].

Table 5. TRIZ solutions corresponding to conflicts.

Conflict	Improving Factors	Exacerbating Factors	TRIZ Solution (Principles of Invention)
1	NO.7 Volume of Moving Objects	NO.35 Adaptability	NO.15 Dynamic principle NO.29 Principles of pneumatic and hydraulic structures
2	NO.21 Power	NO.31 Harmful Factors Produced by Objects	NO.2 Principle of Extraction NO.35 Principle of Parameter Variation NO.18 Principle of Mechanical Vibration

There are a lot of abstract principles and revelatory writings in the TRIZ method, and it might be difficult to translate these ideas into practical, workable solutions. Specific design solutions or product structures are generated by extracting the extension transformations and establishing primitive expression models, utilizing substitution, decomposition, addition, deletion, expansion and contraction, and composite transformations of physical and matter elements. This process converts the high-level TRIZ principles into workable, practical solutions for better problem-solving and innovative design [32].

According to the preliminary comparative analysis, NO.15 dynamic principle A "the object is divided into parts, and the relative positions of the parts can be changed," is chosen as a reference to solve the conflict 1. The above-study status indicates that most tracked machines are found in mountainous places. These machines are used as an example to develop the mobile mechanism of the initial object element model for iterative innovation design.

Table 6. Corresponding inventive principles.

Serial Number	Name	Description of Invention Principle
15	Dynamic principle	A. The object is divided into parts, and the relative positions of the parts can be changed. B. To change a stationary object into a movable object, or to make the object adaptive.
29	Principles of pneumatic and hydraulic structures	A. Replace solid parts with gaseous or liquid parts. These parts can be expanded by air or water, or by an air cushion or water cushion.
2	Principle of Extraction	A. Extract disturbing parts or attributes from an object, or extract necessary parts (or attributes) from an object separately.
35	Principle of Parameter Variation	A. Changing the physical state of an object (e.g., becoming A gas, liquid or solid). B. Change the concentration or viscosity. C. Change the flexibility. D. Change the temperature.
18	Principle of Mechanical Vibration	A. Cause the object to oscillate or vibrate. B. Increase its frequency (even to ultrasonic). C. Use resonant frequencies. D. Replace mechanical vibration with piezoelectric vibration. E. Combine ultrasonic vibrations and electromagnetic fields.

$$M_1 = \begin{bmatrix} \text{Mobile Organizations} & \text{Functions} & \text{Support, walk} \\ & \text{Structure} & \text{Crawler type} \\ & \text{Volume} & \text{Large} \\ & \text{Environmental adaptability} & \text{Poor} \end{bmatrix}$$

Decomposition transformation of the initial object element M_1: $T_1M_1 = M_{11} + M_{12}$

$$M_{11} = \begin{bmatrix} \text{Wheel set} & \text{Function} & \text{Support, walk} \\ & \text{Structure} & \text{Drive wheel, Guide wheel, Planetary wheel} \\ & \text{Volume} & \text{Smaller} \\ & \text{Environmental adaptability} & \text{Poor} \end{bmatrix}$$

$$M_{12} = \begin{bmatrix} \text{Crawler} & \text{Function} & \text{Support, walk} \\ & \text{Structure} & \text{Crawler} \\ & \text{Volume} & \text{Large} \\ & \text{Environmental adaptability} & \text{Poor} \end{bmatrix}$$

According to the hint of NO.15 dynamic principle, the direction of the problem-solving is obtained by dividing the object into several parts and changing the relative positions between the parts. Therefore, it is considered that the parts of the picking mechanism and the moving mechanism can be designed to move relative to each other to enhance adaptability. The final replacement of M_{12} is carried out: $T_2M_{12} = M'_{12}$

$$M'_{12} = \begin{bmatrix} \text{Tracks} & \text{Function} & \text{Provides a sliding chamber for the wheelset} \\ & \text{Structure} & \text{Transverse and longitudinal tracks are nested, Slot} \\ & \text{Volume} & \text{Small} \\ & \text{Environmental adaptability} & \text{Good} \end{bmatrix}$$

To make the relative movement of the picking mechanism and the mobile mechanism, a track is set up over the *Camellia oleifera* tree as the mobile mechanism, and a picking machine is placed on the track so that the picking mechanism is connected to the mobile mechanism, forming a new scheme of the mobile mechanism: $T_3M'_1 = M_{11} + M'_{12}$, as shown in Figure 5.

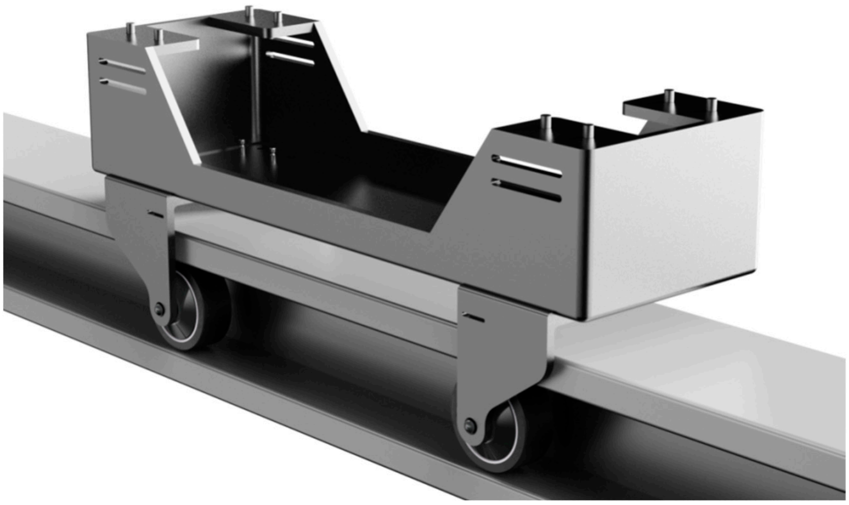

Figure 5. Track moving mechanism.

To resolve the competing issues of O_3 end-effector picking and O_4 preventing bud damage, NO.35 Parameter Change Principle C, "Change the flexibility", was chosen as a guide based on the preliminary comparison analysis. According to the analysis of the picking parameters, the best picking effect is the vibration type picking machine, with high picking efficiency and clean picking rate. Take the suspension vibration type picking machine as an example. Construct the initial object element model of the picking mechanism for the iterative innovation design.

$$M_2 = \begin{bmatrix} \text{Picking Mechanism} & \text{Function} & \text{Picking} \\ & \text{Structure} & \text{Mechanical arm, gripping claw} \\ & \text{Picking efficiency} & \text{High} \\ & \text{Degree of bud damage} & \text{High} \end{bmatrix}$$

Decomposition transformation of the initial object element M_2: $T_4M_2 = M_{21} + M_{22}$

$$M_{21} = \begin{bmatrix} \text{Mechanical arm} & \text{Function} & \text{Connecting clamping jaws and power mechanism} \\ & \text{Structure} & \text{Connecting rod} \\ & \text{Picking efficiency} & \text{High} \\ & \text{Degree of bud damage} & \text{High} \end{bmatrix}$$

$$M_{22} = \begin{bmatrix} \text{Gripping Jaws} & \text{Function} & \text{Gripping the trunk} \\ & \text{Structure} & \text{Gripper} \\ & \text{Picking efficiency} & \text{High} \\ & \text{Degree of bud damage} & \text{High} \end{bmatrix}$$

The structural elements were changed and integrated based on the suspension vibration picker, according to the suggestions of NO.35 Parameter Change Principle C, "Change of Flexibility," to produce a new design solution to settle Conflict 2. M_{21} and M_{22} were eventually swapped out: $T_5M_{21} = M'_{21}$. $T_6M_{22} = M'_{22}$

$$M'21 = \begin{bmatrix} \text{Flexible mechanical arm} & \text{Function} & \text{Change the picking direction, drive the picking claw movement} \\ & \text{Structure} & \text{Pneumatic bellows structure, internal joints} \\ & \text{Volume} & \text{Small} \\ & \text{Picking efficiency} & \text{Higher} \\ & \text{Degree of bud damage} & \text{Low} \end{bmatrix}$$

$$M'22 = \begin{bmatrix} \text{Picking Jaws} & \text{Function} & \text{Grabbing fruits} \\ & \text{Structure} & \text{Picking Jaws} \\ & \text{Volume} & \text{Small} \\ & \text{Picking efficiency} & \text{Higher} \\ & \text{Degree of buddamage} & \text{Low} \end{bmatrix}$$

$$M3 = \begin{bmatrix} \text{Binocular Recognition Camera} & \text{Function} & \text{Recognition} \\ & \text{Structure} & \text{Binocular camera, connecting structure} \\ & \text{Degree of bud damage} & \text{Low} \end{bmatrix}$$

According to the principle of NO.35 parameter change, the direction of problem-solving is obtained by changing the flexibility, so the robotic arm and gripping claw design is considered flexible picking. Flexible picking can be realized by improving the robotic arm into a flexible robotic arm and the trunk gripping claw into a fruit-picking claw. However, to reduce bud damage and successfully pick the fruits, we must add computer vision recognition technology to realize accurate picking, the new scheme: $T_7M'_2 = M'_{21} + M'_{22} + M_3$. Flexible mechanical arm can effectively reduce bud damage by precise picking.

4.5. Specific Design Strategies

Based on the above innovative design concepts, the design scheme of the *Camellia oleifera* fruit picker is as follows: a horizontal track and a longitudinal track are nested to realize an omnidirectional coverage of a picking machine on a hillside, and the whole is divided into two modules, the track movement system and the picking system, as shown in Figure 6. The transversal track is mounted on the top of the tree, and it is laid in the horizontal direction along the field to provide the machine with the moving path in the horizontal direction, and the longitudinal track is laid vertically across the track to give the machine with the moving path in the vertical direction. The longitudinal track is laid vertically and crosswise with the transverse track to offer a longitudinal movement path for the machine; the track is designed with embedded slots for easy disassembly and maintenance, which ensures the system's flexibility and ease of operation. The general view of the manipulator is shown in Figure 7. The work flow of the picker is shown in Figure 8.

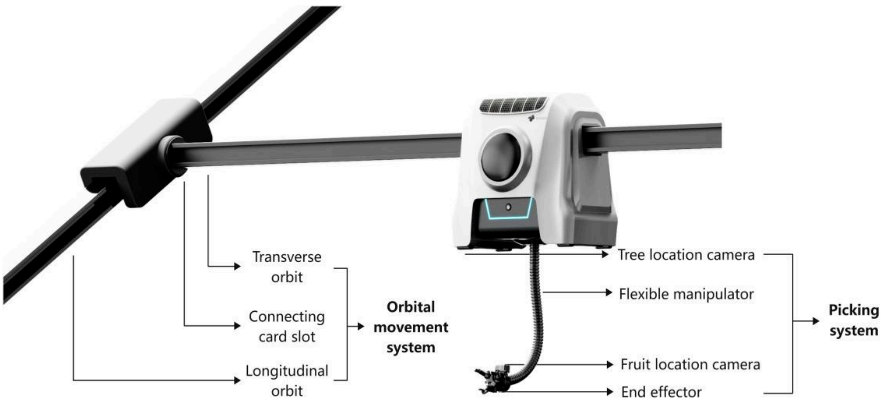

Figure 6. Picker structure display.

Figure 7. Analog to Figure 6 general view of the manipulator.

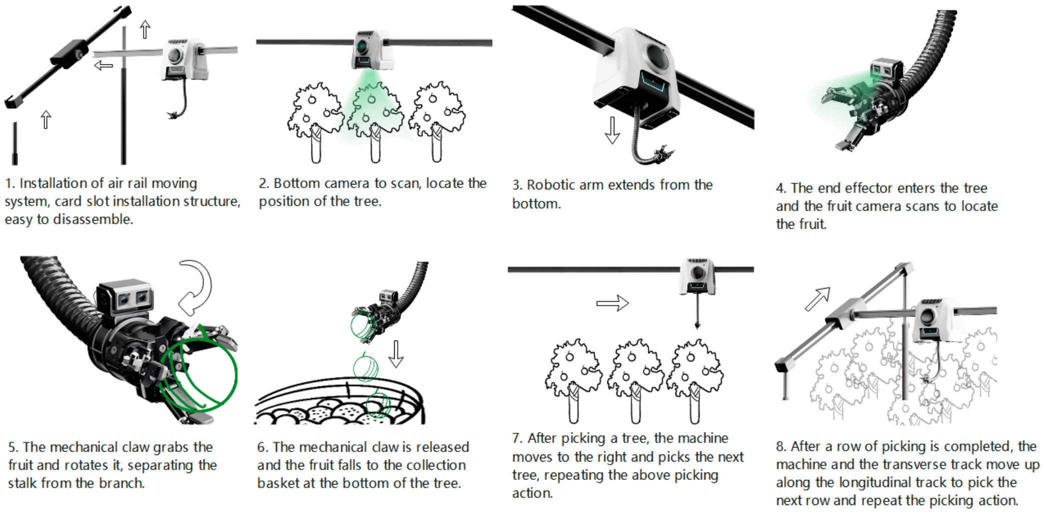

Figure 8. Picker Workflow.

Based on the above innovative design concepts, the rigid robotic arm in the traditional design strategy is finally replaced by a flexible robotic arm. At the same time, soft containers are placed underneath the fruit trees to receive the *Camellia oleifera* fruits picked by the flexible robotic arm to reduce the collection workload. Flexible robotic arm technology has been widely used and validated in several fields. In the medical field, flexible robotic arms have been used in surgical robots to realize high-precision, low-trauma surgical operations [33]; in the manufacturing field, flexible robotic arms have been used in tasks such as precision assembly and testing to improve productivity and product quality. The advantages of applying the robotic arm to the *Camellia oleifera* fruit picker are [34]:

(1) Flexibility: The flexible robotic arm is designed with flexible materials and joints, which can quickly realize complex three-dimensional movement trajectories, avoiding the traditional rigid robotic arm's difficulty in recognizing specific movements due to kinematic constraints. The flexible robotic arm can reach deep between the branches and leaves of the *Camellia oleifera* tree, accurately identify and locate the picking target, and realize efficient and accurate picking operations.

(2) Environmental adaptability: Its flexibility and elasticity allow it to quickly adapt to spatial changes and irregularly shaped objects to accomplish operational tasks in various unstructured environments. The robotic arm can flexibly cope with different shapes and sizes of *Camellia oleifera* fruits and complex growth environments to improve picking efficiency and quality.

(3) Cost and Maintenance: Compared to traditional rigid robotic arms, flexible robotic arms utilize flexible and lightweight materials, reducing the need for high-strength and high-precision components and thus lowering manufacturing costs. Flexible robotic arms' simple structure and durability minimize the need for repairs and replacement parts, reducing maintenance costs.

Based on the above innovative design concept, visual recognition technology also plays a crucial role in realizing the *Camellia oleifera* fruit picking machine's intelligent and accurate picking process. Visual recognition technology can recognize the *Camellia oleifera* fruit's precise positioning and recognition and provide accurate picking target information for the robotic arm. Visual recognition technology has been widely used in many fields, such as face recognition, behaviour analysis, intelligent transportation, intelligent manufacturing and other fields, and has achieved remarkable results. Gai, RL et al. proposed a blueberry recognition algorithm TL-YOLOv8 based on the YOLOv8 algorithm to improve the detection accuracy [35]. Li, TX et al. built an artificial peach dataset and introduced PeachYOLO, an efficient and lightweight peach target detection model in complex orchard environments [36]. These application cases verify the effectiveness of visual recognition technology and provide valuable experience and reference for its application in *Camellia oleifera* fruit picking machines.

5. Discussion

This study proposes an innovative FAHP–FAST–TRIZ–E product design integration methodology based on the science, versatility, innovation and efficiency of product design decisions. The methodology aims to help designers develop innovative products from new perspectives. The applicability and effectiveness of the method are verified through design practice studies. Compared with other conventional design decision-making methods, the technique shows apparent advantages.

The unique advantages of the proposed FAHP–FAST–TRIZ–E methodology lie in the accuracy of user orientation, scientific and focused clarity of decision-making, the ability to transform requirements for functional realization, the stimulation of innovativeness, and the concretization of solutions. Unlike traditional methods that rely only on the experience of designers or the guidance of a single theory, the methodology of this study integrates Fuzzy Hierarchical Analysis, Functional Analysis Systematic Technique Method, TRIZ Theory, and Topologically Transformable Theory, which can accurately transform user needs into specific design improvement points. This interdisciplinary integration not only deepens the understanding of user requirements but also improves the reliability of the design, ultimately leading to innovative solutions.

In addition, this study demonstrates a new approach to bridge the shortcomings of a single theory and produce a universal design theory. The proposed FAHP–FAST–TRIZ–E methodology, by integrating different design theories, especially applying TRIZ theory and Extension transformation theory in solving design problems, provides designers with an efficient tool that helps them quickly generate solutions when faced with complex design challenges. The FAHP–FAST–TRIZ–E approach provides a new perspective to overcome the challenge of translating the principle guidance of TRIZ theory into concrete product conceptual solutions in previous design research. Topological transformation theory reduces the difficulty of translating the original TRIZ understanding. It provides new ideas for innovative design by formally investigating the solution of contradictory problems to generate specific design solutions.

The conceptual design of this picker offers unique advantages over previous research pickers, and bears the potential to solve specific problems and meet market needs.

(1) Adaptability comparison. Compared with the traditional ground picker, the aerial rail-type *Camellia oleifera* fruit picker is more adaptable to complex terrain. It can work flexibly in steep slopes and narrow passages in *Camellia oleifera* forests, overcoming the difficulty of access for ground pickers.
(2) Picking efficiency comparison. Through the application of automation and intelligent technology, the picking efficiency of the aerial rail picker is much higher than that of the traditional manual picking and ground picker. This not only improves the harvesting speed of *Camellia oleifera* fruit but also reduces the labour intensity of fruit farmers.
(3) Cost-benefit comparison. Although the initial investment is significant, the overall cost-effectiveness of the picker is superior to that of the traditional picking method, considering the long-term use of the picker and the cost-reduction effect (e.g., reduction of labour costs, reduction of fruit damage rate, etc.).

In summary, the FAHP–FAST–TRIZ–E product design integration method embodies the innovation of product design decision-making methods and proves its effectiveness through empirical research. This approach provides designers with a new tool to better understand user needs, translate requirements, analyse functionality, reduce the difficulty of translating the original TRIZ understanding and generate specific design solutions, which ultimately promotes the development of the product service design field.

6. Conclusions

This study develops an integrated product innovation design model FAHP–FAST–TRIZ–E that combines multilevel requirements analysis, FAHP, FAST, TRIZ theory and topological transformation theory. Combining these methods provides multifaceted support and optimization for improving product design and manufacturing processes. Multilevel requirements of the status quo, environment and users are analysed, and FHAP is used to prioritize design requirements and clarify design priorities. Transform design requirements into functions through expert knowledge, decompose functions using FAST, and identify function conflict problems. TRIZ theory provides creative principles to provide innovative solutions to conflicting issues. The original TRIZ understanding is transformed into a concrete design solution by decomposing and substituting topological transformations.

The feasibility of the FAHP–FAST–TRIZ–E methodology was verified through a case study of *Camellia oleifera* fruit picker product design. Based on these analyses, this study designed an aerial rail-type intelligent *Camellia oleifera* fruit picker, considering the product's structure, function and appearance. The FAHP–FAST–TRIZ–E model has a guiding significance for the design of the picking machine, which can be used as a reference for future research.

Although this study has successfully proposed an innovative product concept design based on in-depth market research, user needs analysis, and technical feasibility assessment and has demonstrated its potential for solving a specific problem or meeting a market need, there are still some limitations to this study. Specifically, due to constraints such as time and resources, no exhaustive simulation experiments and prototype tests have been conducted on this product's conceptual design. Future research will focus on conducting necessary simulations, developing prototypes, and conducting field tests to thoroughly assess the feasibility and effectiveness of the design, making the required iterative improvements as needed to eventually commercialize the product.

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References

1. Qian, Q.; He, M.; Wang, J.; Chen, Q.; Zhou, H.; Jiang, X. Research Progress of Domestic *Camellia oleifera* Fruit Picking Equipment. *World For. Res.* **2023**, *36*, 101–106.
2. Gao, Z.C.; Zhao, K.J.; Li, L.J.; Pang, G.Y.; Wang, X.C. Design and experiment of suspended vibratory actuator for picking Camellia Olerfera fruits. *Trans. Chin. Soc. Agric. Eng.* **2019**, *35*, 9–17.
3. Luo, S.; Rao, H.; Zhang, L.; Yu, J.; Xu, X.; Li, T.; Liu, M. Test and Analysis of Best Parameter of Transverse Multi-Cylinder Device. *J. Agric. Mech. Res.* **2017**, *39*, 84–88+157.
4. Wang, Y.U.; Rao, H.; Wang, B.; Li, Q.; Liu, M. Manufacture of Portable Electro-hydraulic Camellia Fruit Harvester. *J. Agric. Mech. Res.* **2022**, *44*, 106–111.
5. Song, D.; Liu, L.; Zhu, T.; Zhang, S.; Huang, Y. B-FMEA-TRIZ Model for Scheme Decision in Conceptual Product Design: A Study on Upper-Limb Hemiplegia Rehabilitation Exoskeleton. *Heliyon* **2024**, *10*, e30684. [CrossRef] [PubMed]
6. Li, Y.; Ghazilla, R.A.R.; Abdul-Rashid, S.H. QFD-Based Research on Sustainable User Experience Optimization Design of Smart Home Products for the Elderly: A Case Study of Smart Refrigerators. *Int. J. Environ. Res. Public Health* **2022**, *19*, 13742. [CrossRef]
7. Zhao, Y.; Xu, Y. Evaluation Model for Modular Children's Wooden Storage Cabinet Design. *BioResources* **2023**, *18*, 7818–7838. [CrossRef]
8. Tandiono, Y.; Rau, H. An Enhanced Model Using the Kano Model, QFDE, and TRIZ with a Component-Based Approach for Sustainable and Innovative Product Design. *Sustainability* **2022**, *15*, 527. [CrossRef]

9. Zhao, D.; Chen, W. Design and Research of Smart Neck Helmets Based on the KANO-QFD Model and TRIZ Theory. *Secur. Commun. Netw.* **2021**, *2021*, 4693719. [CrossRef]
10. Hu, S.; Zhang, L.; Guo, W.; Zhang, D.; Jia, Q.; Yang, Z.; Guo, M. Research on the Design of Smart Sleep Aid Interactive Products. *Int. J. Ind. Syst. Eng.* **2024**, *46*, 151–168. [CrossRef]
11. Wang, L.; Xiong, J.; Ruan, C. Research on Product Design of FAHP Bone Marrow Aspiration Needle. *Heliyon* **2024**, *10*, e27389. [CrossRef] [PubMed]
12. Liu, M.; Zhu, X.; Chen, Y.; Kong, Q. Evaluation and Design of Dining Room Chair Based on Analytic Hierarchy Process (AHP) and Fuzzy AHP. *BioRes* **2023**, *18*, 2574–2588. [CrossRef]
13. Zhou, J.; Yu, M.; Zhao, W.; Zhang, K.; Chen, J.; Guo, X. An Iterative Conceptual Design Process for Modular Product Based on Sustainable Analysis and Creative Template Method. *Processes* **2022**, *10*, 1095. [CrossRef]
14. Du, Y.; Zhang, M.; Cai, M.; Park, K. Construction of Product Appearance Kansei Evaluation Model Based on Online Reviews and FAHP: A Case Study of Household Portable Air Conditioners. *Sustainability* **2024**, *16*, 3132. [CrossRef]
15. Siwiec, D.; Pacana, A. Model Supporting Development Decisions by Considering Qualitative–Environmental Aspects. *Sustainability* **2021**, *13*, 9067. [CrossRef]
16. Viola, N.; Corpino, S.; Fioriti, M.; Stesina, F. Functional Analysis in Systems Engineering: Methodology and Applications. In *Systems Engineering-Practice and Theory*; InTech: London, UK, 2012; pp. 71–96.
17. Wang, H.; Zhang, S.; Zou, J.; He, C. Research on Innovative Design Method of B/AHP/FAST Based on Animal Behavior Theory. *Packag. Eng.* **2022**, *43*, 144–152.
18. Wang, J.; Liu, T.; Fan, Y.; Li, J.; Liu, K. Innovative design method of children stroller based on A-Kano and FAST. *J. Mach. Des.* **2023**, *40*, 142–148.
19. Li, C.; Ma, X. Design of Glass Curtain Wall Cleaning Machine Based on FAST-FBS Integrated Innovative Design Method. *Mach. Des. Res.* **2023**, *39*, 191–195+201.
20. Xie, Q.; Liu, Q. Application of TRIZ Innovation Method to In-Pipe Robot Design. *Machines* **2023**, *11*, 912. [CrossRef]
21. Xiao, J.; Liu, F.; Yang, M.; Ke, W.; Liu, D.; Lin, L. An Innovative Design of Mega Shaft Boring Machine (SBM) Cutterhead Based on TRIZ and AD Theory. *Adv. Mech. Eng.* **2023**, *15*, 168781322311533. [CrossRef]
22. Vinodh, S.; Kamala, V.; Jayakrishna, K. Integration of ECQFD, TRIZ, and AHP for Innovative and Sustainable Product Development. *Appl. Math. Model.* **2014**, *38*, 2758–2770. [CrossRef]
23. Li, W.; Suh, C.S.; Xu, X.; Song, Z. Extenics Enhanced Axiomatic Design Procedure for AI Applications. *AI EDAM* **2022**, *36*, e23. [CrossRef]
24. Li, J.; Wu, X.; Zhang, X.; Song, Z.; Li, W. Design of Distributed Hybrid Electric Tractor Based on Axiomatic Design and Extenics. *Adv. Eng. Inform.* **2022**, *54*, 101765. [CrossRef]
25. Wu, S. Research on Toy Design for Special Children Based on Sensory Integration Training, D-S Theory, and Extenics: Taking Physical Toys for ADHD Children as an Example. *Sci. Program.* **2022**, *2022*, 1395265. [CrossRef]
26. Lai, R.; Lin, G.; Wu, R. Redesign Priority ldentification of Product Family Modules for Green Performance Optimization. *China Mech. Eng.* **2019**, *30*, 1329–1335.
27. Zhang, Z.; Yu, N. Furniture sharing design for pets based on KJ-KANO model. *Design* **2024**, *9*, 860. [CrossRef]
28. Ma, X.; Liu, W. Design of a "One-stop" Fruit APP Based on the KJ-KANO Model. *Packag. Eng.* **2024**, 1–17. Available online: https://link.cnki.net/urlid/50.1094.TB.20240422.1205.002 (accessed on 1 September 2024).
29. Hu, H.; Hu, J. Research on the design of age-appropriate household planting products based on KJ-AHP model. *Packag. Eng.* **2024**, *45*, 264–270.
30. Olabanji, O.M.; Mpofu, K. Fusing Multi-Attribute Decision Models for Decision Making to Achieve Optimal Product Design. *Found. Comput. Decis. Sci.* **2020**, *45*, 305–337. [CrossRef]
31. Hameed, A.Z.; Kandasamy, J.; Raj, S.A.; Baghdadi, M.A.; Shahzad, M.A. Sustainable Product Development Using FMEA ECQFD TRIZ and Fuzzy TOPSIS. *Sustainability* **2022**, *14*, 14345. [CrossRef]
32. Li, W.; Song, Z.; Mao, E.; Suh, S. Using Extenics to Describe Coupled Solutions in Axiomatic Design. *J. Eng. Des.* **2019**, *30*, 1–31. [CrossRef]
33. Wang, Z.; Bao, S.; Zi, B.; Jia, Z.; Yu, X. Development of a Novel 4-DOF Flexible Endoscopic Robot Using Cable-Driven Multisegment Continuum Mechanisms. *J. Mech. Robot.* **2024**, *16*, 031011. [CrossRef]
34. Xue, W.; Sun, Z.; Ye, H.; Liu, Q.; Jian, B.; Wang, Y.; Fang, H.; Ge, Q. Rigid-Flexible Coupled Origami Robots via Multimaterial 3D Printing. *Smart Mater. Struct.* **2024**, *33*, 035004. [CrossRef]
35. Gai, R.; Liu, Y.; Xu, G. TL-YOLOv8: A Blueberry Fruit Detection Algorithm Based on Improved YOLOv8 and Transfer Learning. *IEEE Access* **2024**, *12*, 86378–86390. [CrossRef]
36. Li, T.; Chen, Q.; Zhang, X.; Ding, S.; Wang, X.; Mu, J. PeachYOLO: A Lightweight Algorithm for Peach Detection in Complex Orchard Environments. *IEEE Access* **2024**, *12*, 96220–96230. [CrossRef]