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Research Article

Product Form Evolutionary Design Integrated with TRIZ Contradiction Matrix

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This paper aims to construct a product form evolution design method integrating the TRIZ contradiction matrix, which is used to eliminate the contradiction between users' psychological expectations and product engineering requirements, thus simplifying the product form evolution process. We first obtain the psychological needs of users during the whole process of using the product through behavior analysis and then perform an ergonomic simulation of the product to obtain the engineering properties of the product. On this basis, we construct the TRIZ contradiction matrix and solve the contradiction matrix according to the TRIZ theory method. In this way, the ergonomic engineering design attributes of products and the psychological needs of users can be relatively independent, so that the conflict between the ergonomic functional attributes and the psychological needs of users in the design matrix can be effectively transformed into a general TRIZ problem to provide intuitive guidance for product form design. In addition, a detailed design case is provided, which shows that this method can simplify the difficulty and complexity of product form design, and users are more inclined to use the optimized product.

1. Introduction

Ergonomic analysis can effectively improve the comfort and safety of users in the process of using products, enhance user experience, and reduce the probability of accidents, which provides a scientific reference for product form design [1]. The stickiness of products needs to consider the emotional factors of users, to maximize the use efficiency of products [2]. In the context of human-centered product design, consumers tend to consider their personal preferences rather than the rationality of products [3]. It is a prerequisite for product form design to fully consider the ergonomic attributes of the product and the emotional factors of the user. Ergonomics theory mainly focuses on the engineering properties of products, which can guide the form design of products from the scientific aspects of human body structure parameters [4, 5], biomechanics [6, 7], ergonomics simulation [8, 9], and so on, so that users can use products more conveniently. Users' psychological expectations are highly subjective, and they may not like products that meet ergonomic attributes. However, if the designer considers the user's psychological expectation in the process of designing the product, it is necessary to reconduct feasibility simulation analysis on the designed product. Moreover, designers also need to design product forms that meet users' psychological expectations through continuous testing and adjustment, which greatly increases the difficulty and complexity of product form design.

To balance ergonomic attributes and users' psychological expectations in product form design, the main method adopted at present is to model users' cognitive needs and then integrate them into the framework of product functional requirements and then solve the design [10]. This is a simple and effective way, but it lacks the consideration of the whole process of users using the product. With the development of new technologies, an interdisciplinary method was constructed in [11, 12], which uses both subjective and objective parameters to guide product design utilizing monitoring and simulation, to improve user satisfaction and safety and shorten the time to market. By constructing the digital twin of the user and the device and comparing the actual operation of the user and the virtual operation of the digital twin at the same time, the product attributes can be dynamically adjusted in real time, which also provides a new solution to solve the contradiction between the psychological expectation of users and the product engineering attributes [13]. However, such a processing method requires the development of a mature software and hardware system to complete the corresponding test, which requires high technical cost and low universality. For ordinary designers, product form design needs a more universal theoretical method to map the engineering properties of products and the psychological needs of users to product form, to shorten the product development cycle and enhance product stickiness.

TRIZ theory is a knowledge-based and human-oriented approach to inventing problem-solving [14]; TRIZ provides design engineers with a series of innovative tools to help solve problems in the design process, reducing the number of trial and error, and has been used in many industries across the country. Integrating TRIZ theory into the product form design process can decompose functional requirements and user requirements, decouple coupling design, and eliminate potential conflicts [15]. Combining the user requirements acquisition method with TRIZ contradiction analysis can lead to specific solutions for product design and improve product flexibility [16]. In addition, the TRIZ contradiction matrix can also provide an effective solution for product ergonomic product innovation [17]. Therefore, this study integrates the TRIZ contradiction matrix into a product form evolutionary design. Firstly, the conflict between ergonomic scientific attributes and user psychological attributes is transformed into TRIZ contradiction through 39 engineering parameters of TRIZ theory. Then, by analyzing the causes and specific processes of contradictions, we can determine the types of contradictions between the two factors in the process of product form design, so that the ergonomic engineering attributes of products and the psychological expectations of users are relatively independent. Finally, the 40 invention principles of TRIZ theory are used to solve the contradiction and generate an alternative scheme for ergonomic product innovation design, which provides strong support for the design of product forms that meet users' psychological expectations and ergonomic engineering attributes, shortens the design cycle, and simplifies the design process.

2. Methodology

Firstly, we analyze the specific tasks of users by observing the whole process of using the target product and then carry out an ergonomic simulation on the specific tasks involving more users' ergonomic contacts to obtain the key components of unreasonable product form design and the ergonomic engineering attributes of the product. According to the observation record of user behavior, the significance table of user behavior is established to analyze the psychological expectation hidden behind the user behavior. Then, the contradiction matrix between ergonomic attributes and user expectations is constructed, and the matrix is solved by using TRIZ theory to obtain the actual product form design attributes to guide the product design practice (see Figure 1).

2.1. Analyze Users' Psychological Expectations. User behavior analysis is a key means to obtain users' psychological needs [18]. The meaning behind user behaviors can be obtained through observation of user behaviors combined with the subjective inquiry. Meaning extraction is the process of explaining user behavior. By observing the whole process of users using the product, the interaction between users and the product is described in detail from the perspectives of sociology, psychology, and life experience, to obtain the mapping relationship between user behavior and meaning. The user meaning table is constructed from three dimensions of experience, construction, and semantics, which can map user needs to the product form. From the perspective of product form, users' demands for products can generally be divided into basic functional demands and psychological demands. Product demands directly obtained are ambiguous and irregular. Therefore, we need to screen demands to obtain accurate user expectations. The method of extracting meaningful keywords was adopted to deal with user needs, which were arranged in the order of similarity and relevance.

(1) The importance of keywords in meaning is represented by weights, which are calculated according to the TF-IDF formula:

$$w_{ik} = \frac{\lg(f_{ik} + 1) \times \lg(N/N_k + 0.01)}{\sqrt{\sum_{j=1}^{M} \left[\lg\left(f_{ij} + 1\right) \times \lg(N/N_k + 0.01)\right]^2}}. \quad (1)$$

In the above formula, w_{ik} is the weight of the meaning word t_k in the meaning text vector D_i, f_{ik} is the word frequency of word t_k in the meaning text vector D_i, N is the total number of texts in the meaning text vector space, and N_k is the proportion of the meaning word t_k to the total text vector space N, that appears in the text vector space number of texts; $w_{ik} \in [0, 1]$.

(2) If the weight of correlation in user behavioral meaning is $w_{rk} \in [0, 1]$, the correlation between user behavioral meaning and user psychological expectation is

$$\mathrm{sim}(D_i, R_0) = \sum_{T_k} w_{ik} w_{rk}, \quad (2)$$

where R_0 is the meaning word and T_k is the meaning word object set.

2.2. Ergonomic Simulation. From the perspective of ergonomics, product form design should achieve the optimal match between users and products and then achieve the

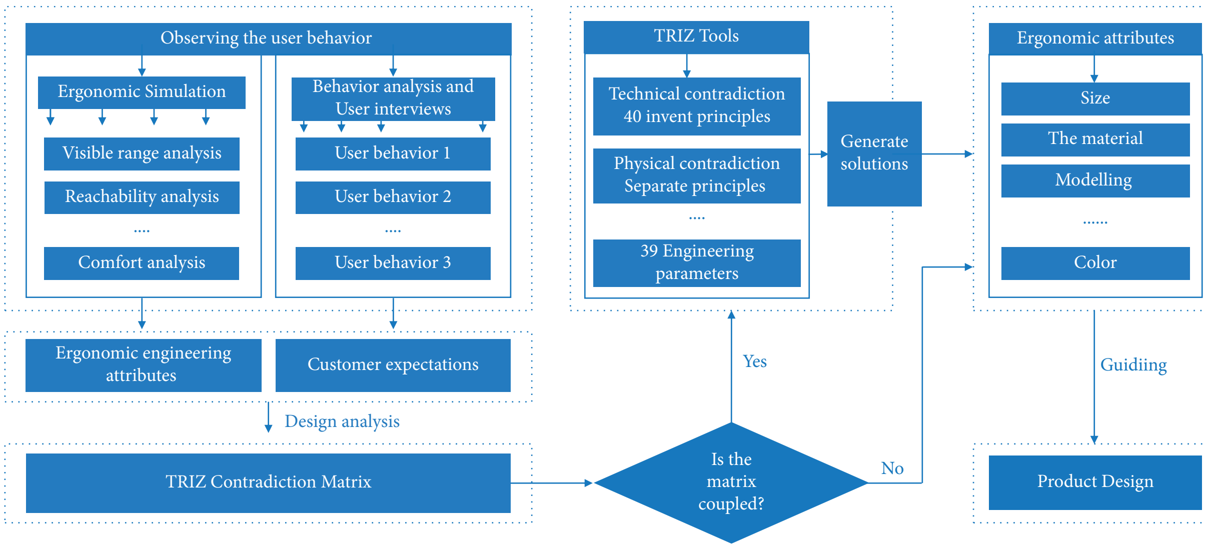

Figure 1: Research process and methods.

coordination effect between products and human physiological function and psychological function to meet the user experience of products. According to the process of using the product, ergonomic simulation of the product can effectively obtain the engineering basis of product design. With the development of computer technology, the research content of modern ergonomics is gradually expanding. Digital human modelling technology has become the focus of many researchers. The simulation analysis of JACK software can help researchers design safer and more ergonomic products and also greatly reduce the analysis cost. According to the whole process of users using the product, ergonomic simulation of the product will obtain a series of or repeated product form design requirements, which need to calculate the attribute weights of each indicator of product form evolution design. We refer to the information entropy calculation formula:

$$Q^{\varphi} = -k \sum_{i=1}^{m} P_i^{\varphi} \ln P_i^{\varphi}, \tag{3}$$

where Q^{φ} is the entropy value of the φ-th ergonomic engineering attribute, P_i^{φ} represents the proportion of the φ-th parameter appearing in the i-th dimension in the ergonomic simulation parameters in the overall parameters, $0 < P_i^{\varphi} < 1$, and k is a constant.

Equation (4) is used to obtain the proportion of ergonomic engineering parameters in the overall parameters:

$$P_i^{\varphi} = \frac{v_{ib}^{\varphi}}{\sum_{i=1}^{m} v_{ib}^{\varphi}}, \tag{4}$$

and substitution into formula (3) is used to obtain the weight of the entropy value of the φ-th ergonomic engineering attribute in the whole:

$$W^{\varphi} = \frac{1 - Q^{\varphi}}{\sum_{\varphi=1}^{n} 1 - Q^{\varphi}}. \tag{5}$$

2.3. Constructing Contradiction Matrix and Solving. The TRIZ contradiction matrix first constructs the attributes of user psychological needs, as well as ergonomic engineering needs into attribute sets, $M = [m_1, m_2, m_3 \ldots m_m]$, and $N = [n_1, n_2, n_3 \ldots n_n]$. The VIKOR method focuses on sorting the correlations according to various potentially conflicting schemes. The VIKOR method is used to calculate the correlation between engineering attributes and user psychological attributes, and the specific value of $L_{p,i}$ correlation can be obtained.

$$L_{p,i} = \left\{ \sum_{j=1}^{n} \left[\frac{w_j \left(f_j^* - f_j^- \right)}{\left(f_j^* - f_j^- \right)} \right]^p \right\}^{1/p}, \tag{6}$$

where $1 \le p \le \infty$ and $i = 1, 2 \ldots m$.

The variables with strong correlation with each other are associated with X, and the variables with no correlation or weak correlation are represented by 0, and then the matrix in (7) is established:

$$[A] = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & X & X \end{bmatrix}, \tag{7}$$

and determine whether matrix $[A]$ is a coupling matrix, and if it is a coupling matrix, it needs to be decoupled. According to the relationship between the matrix variables, we mainly get the negative relationship. When solving the contradiction matrix, if there are multiple pairs of contradictions, firstly find the corresponding invention principle of each pair of contradictions from the contradiction matrix, and then find the invention principle with a relatively high frequency. The success rate and efficiency of solving using these inventive principles will be relatively high. At the same time, the design scheme obtained by solving may weaken some necessary functions, so functional inspection is also required, and only schemes that meet the basic functional requirements can be included in the alternative schemes. If it cannot be satisfied, it needs to be solved again, and the basic functional engineering parameters are used as the premise of solving until a satisfactory solution is obtained.

3. Practice of Product Form Design and Evaluation

3.1. User Behavior Observation Records. This paper introduces a practical case of a handheld head massager. Thirty subjects with sedentary work, 15 male and 15 female users aged between 22 and 40 years, were chosen for this study. Among them, 12 had previous experience in using head massagers and the remaining 18 subjects had the device. Lengths of the upper arm, forearm, and palm of the users were recorded. Usage postures and behavior of head massager users are collected under the condition that subjects freely use the device, and the movement space and upper limb posture of the handheld head massager are determined through a nonparticipatory observation method. The research team summarized and compared the behavior of the interviewed users and divided the entire activity into six subprocesses on the basis of the statistical analysis of the observation results (see Figure 2).

Observation of the entire massage process showed that the six processes can be further divided into 24 actions (see Figure 3). Users were then interviewed on their psychological feelings during the entire process and other functions they would like to achieve. Table 1 shows the user's psychological and functional requirements for the handheld head massager throughout the process.

3.2. Analysis of Ergonomic Simulation. The main human-machine contact in the entire usage process of the handheld head massager happens during massaging. The simulation of the massage process can effectively analyze the rationality of the product's ergonomic design. According to the task analysis of user behavior during the massage process, five consecutive actions of holding the massager handle, adjusting the massager gear position, moving the massager on the head, switching hands, and adjusting the massager gear position are performed. Jack virtual simulation software is used in this work to simulate how the subjects utilize the handheld head massager. The massage process is virtually simulated and ergonomic analysis is carried out from aspects of visible range, force, reachability, and comfort..

(1) Visible range analysis: The user maintains a normal sitting posture in the standard work scenario. According to the simulation results of Jack, all parts of the massager are within the user's visual range and the display lights and button logos can correctly serve as a guide for operation before the massage process begins. The handheld head massager is completely out of the user's visible range and the user requires voice reminders because the operating state of the massager cannot be assessed by vision in the actual massage process (see Figure 4).

(2) Reachability analysis: Reachability analysis during the massage process is divided into the following aspects: (a) According to the simulation result of Jack, the finger reachability is poor because the gear adjustment switch is outside the finger movement area of the user. The complexity of using the product increases because the user can only adjust the gear with the other hand. (b) According to the Jack simulation result, the user will complete the head massage with one hand, which is insufficient to cover all massage points of the entire head, in a posture that appears abnormal when the shoulder is lifted and rotated to the left and right extreme positions during the massage process (see Figure 5).

(3) Comfort analysis: The comfort analysis mainly focuses on the user's wrist, elbow, and shoulder in the normal sitting position during the massage process. The RULA function analysis in Jack (see Figure 6) is applied on the basis of body posture, muscle use, weight, load, and task duration and frequency to evaluate the risk of upper limb movement. The simulation results showed that other parts of the human body can be distributed in the normal state, but the heaviest is 2 kg and can be used for up to 2 minutes in this position.

Through the above product virtual simulation analysis, we can obtain the engineering attributes of each design component of the product and provide scientific reference for the subsequent product form design by constructing the spatial structure model (Figure 7), which is a six-degree-of-freedom spatial structure model of the arm and is hand constructed by simulation analysis results, mainly to analyze the comfort degree of the upper limb during the use of the product. Joint (A) is the origin of spatial coordinates, (AB) is the upper arm, (BC) is forearm, and (CD) is palm. In the figure, $\partial 1$ is the forward and backward swing angle, $\partial 2$ is the abduction angle, $\partial 3$ is the internal and external rotation angle, $\partial 4$ is the buckling angle, $\partial 5$ is the extension and flexion angle, and $\partial 6$ is the flexion and ulna flexion angle.

3.3. Constructing TRIZ Contradiction Matrix. Through formulas (3)–(5), the engineering attribute of product ergonomics is focused on obtaining the engineering attribute of the product. Meanwhile, the psychological expectation of user behavior analysis is summarized in formulas (1) and (2). The analysis results were transformed into design demand attributes (see Table 2) from ergonomic simulation analysis of scientific attributes and user psychological demand attributes and based on the experimental handheld head massager, combined with the principle of product ergonomics; the existing product demand attributes were designed and analyzed (see Table 3).

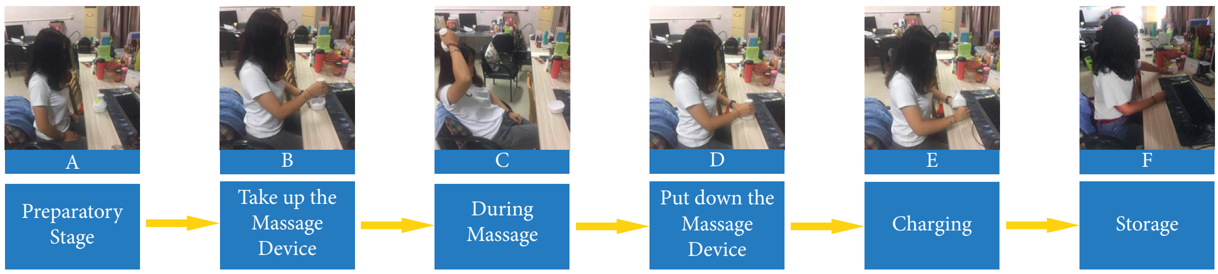

Figure 2: Image of the user usage process.

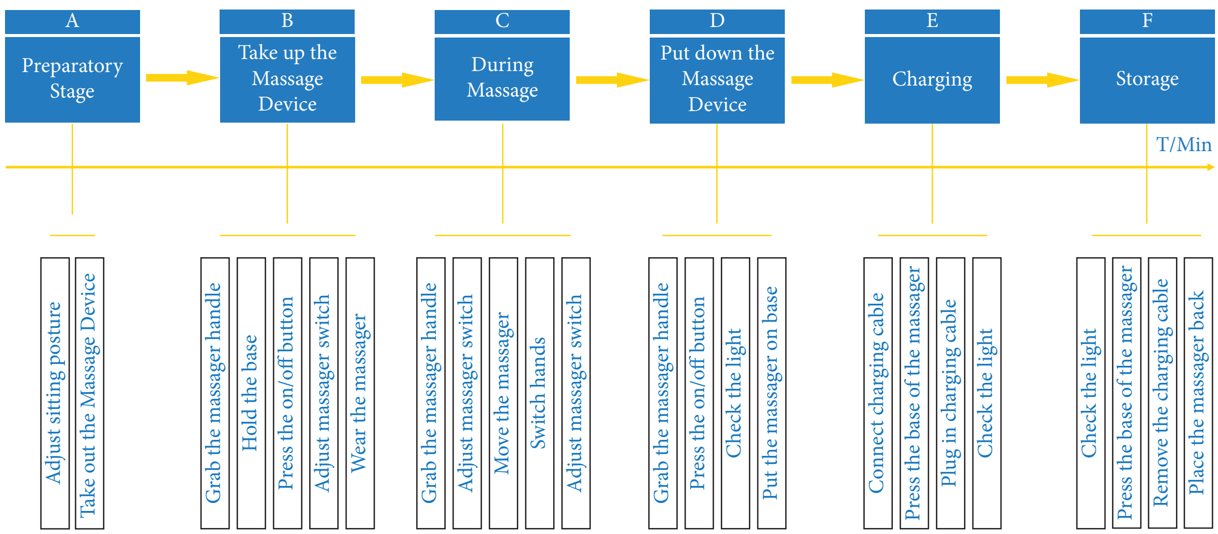

Figure 3: User action analysis.

Table 1: User psychological demands behind user actions.

User actions	User psychological demands
A1 Adjust sitting posture	Chair backrest angle is reasonable and the body is relaxed
A2 Take out the massager	Easy accessibility and continuity of operation
B1 Grab the massager handle	Grip strength, massager grip size and diameter, grip fit of hand and massager, touch, and antislip effect
B2 Hold the massager base	Massager is easily taken out with a single hand and available force area of the massager base is sufficient
B3 Press the on/off button	Satisfactory controllability, smooth process, easy-to-understand operation, and timely feedback
B4 Adjust the massager switch	Timely control, satisfactory controllability, smooth operation, and easy operation
B5 Wear the massager	Accurate and controllable massage position and large arm curvature
C3 Move the massager	Motion range of wrist, shoulder and elbow joint, support strength, head comfort, and force on head
C4 Switch hands	Length of the massager grip matches with the hand, vibration amplitude is controlled, and shoulder and elbow are comfortable
D3 Check the display light	Display light corresponds to the state of the massager (i.e., whether the controller stops)
D4 Place the massager on its base	Massager can be easily placed on the base
E1 Connect the charging cable	Tidiness of the table, compatibility of the charging port, and handleability
E2 Press the base of the massager	Steadiness of the massager
E3 Plug in charging cable	Easy to operate, charging port is easily seen, and accessible
E4 Check the display light	Recognition, logical clarity, and timeliness of information
F4 Replace the massager	Charging cable is easy to organize and store

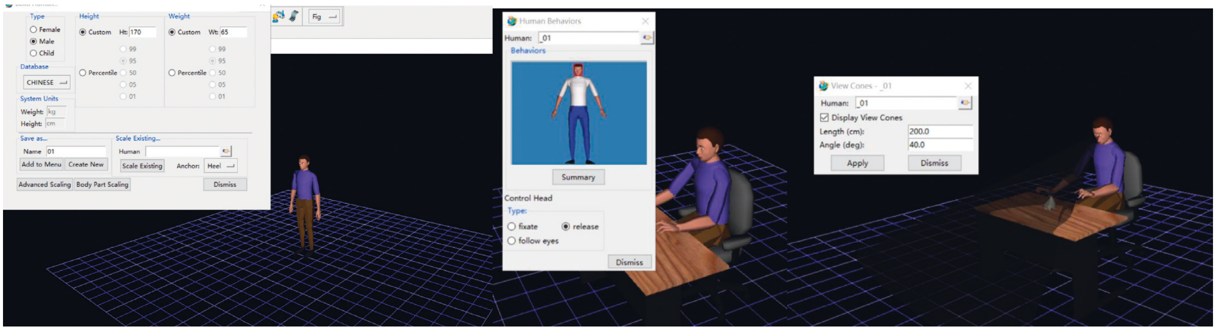

Figure 4: Ergonomic simulation system construction and visible range analysis.

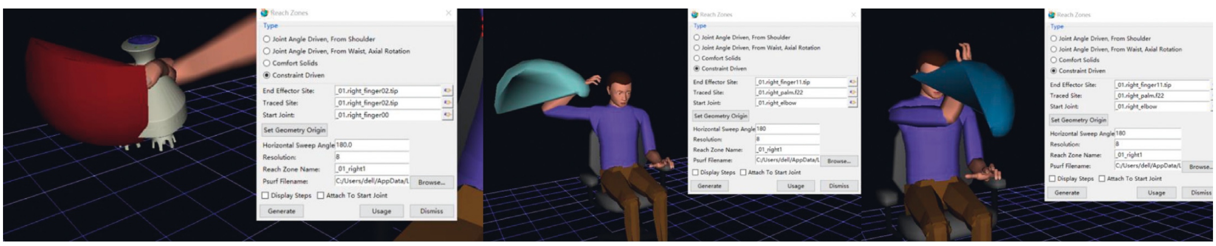

Figure 5: Reachability analysis.

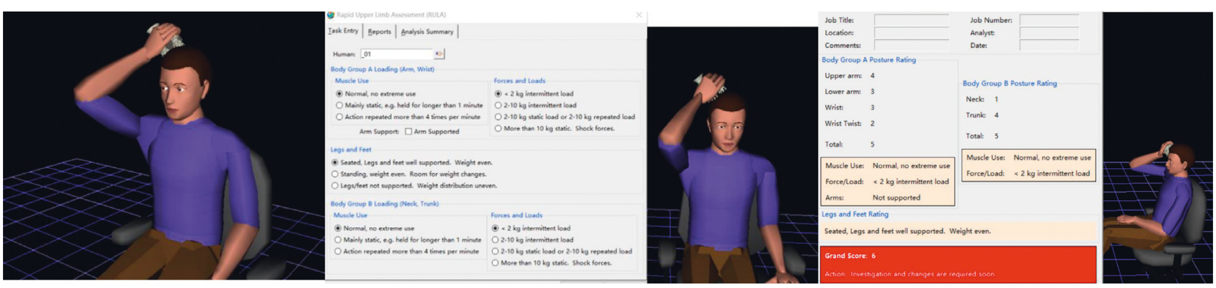

Figure 6: Comfort analysis.

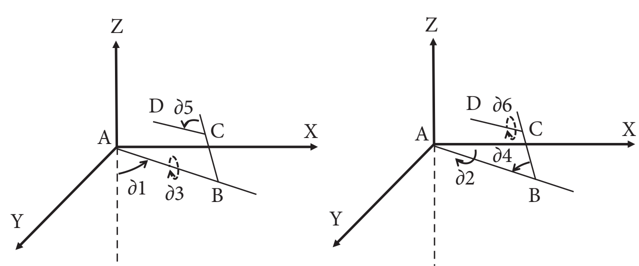

Figure 7: Model of spatial structure of arms and hands.

Table 2: Designing demand attributes on different levels.

Demand attribute type	Design requirement attribute	Design attribute description
Rational attribute of ergonomic simulation	Massager state display (M1)	Massager is outside the visible range and cannot be reflected visually
	Adjustment switch position (M2)	Adjustment switch is reachable by a finger
	Massage method (M3)	Hand switch while holding the massager
	Massage duration (M4)	Maximum of 2 minutes
	Massager weight (M5)	Maximum of 2 kg

Table 2: Continued.

Demand attribute type	Design requirement attribute	Design attribute description
User psychological demand attributes	Accuracy (M6)	Users can accurately receive feedback on the running state during massage
	Recognition degree (M7)	During charging, users can easily identify how long the product needs to be charged.
	Controllability (M8)	Massage tasks can be done with a single hand
	Comfort of the handle grip (M9)	Pressure on the palm is distributed evenly and easy to grab with a single hand
	Stability of the handle grip (M10)	Satisfactory balance, steady grip, and reasonable pressure
	Force feedback (M11)	Intensity of the massager can be precisely adjusted in real time during the massage
	Comfort (M12)	Comfortable even with high messaging intensity; the scalp massage must last for 15 minutes
	Convenience (M13)	Convenient and simple control of massage speed and intensity
	Safety (M14)	Massager nodes are safe and will not entangle with the hair
	Intelligence (M15)	Real-time self-regulating massage intensity and automatic stop after massage

Table 3: Design analysis of the experimental handheld head massager.

Design requirement attribute	Design analysis
Massager running state display (M1)	Voice reminder device (N1)
Intensity switch position (M2)	Intensity switch position (N2)
Massage method (M3)	Handle shape and size (N3)
Massage duration (M4)	Massager control logics (N4)
Massager weight (M5)	Handle material and size (N5)
Accuracy (M6)	Voice reminder device (N6)
Recognition degree (M7)	Logic control of display light (N7)
Controllability (M8)	Handle shape and size (N8)
Comfort of handle grip (M9)	Handle shape and material (N9)
Stability of handle grip (M10)	Handle structure and size (N10)
Force feedback (M11)	Massager nodes and logic control (N11)
Comfort (M12)	Massager motor intensity, node material, and control logics (N12)
Convenience (M13)	On/off intensity switch (N13)
Safety (M14)	Massager node material (N14)
Intelligence (M15)	Massager control logics (N15)

A matrix of design demand attributes of the handheld head massager can be constructed using the design analysis of existing product demand attributes. The mapping relationship between variable parameters of design demand attributes and the design analysis can be used to obtain the following:

$$\left\{\begin{array}{c}\text{M1 : Status display of massager}\\ \text{M2 : Adjustment switch position}\\ \text{M3 : Massage mode}\\ \text{M4 : Massage duration}\\ \text{M5 : Massage weight}\\ \text{M6 : Accuracy}\\ \text{M7 : Recognition}\\ \text{M8 : Controllability}\\ \text{M9 : Handle grip comfort}\\ \text{M10 : Handle grip steadiness}\\ \text{M11 : Force feedback}\\ \text{M12 : Comfort}\\ \text{M13 : Convenience}\\ \text{M14 : Safety}\\ \text{M15 : Intelligence}\end{array}\right\} = [A]\left\{\begin{array}{c}\text{N1 : Voice remainder device}\\ \text{N2 : Adjustment switch position}\\ \text{N3 : Handle size and shape}\\ \text{N4 : Massager control logics}\\ \text{N5 : Massager material and size}\\ \text{N6 : Voice remainder device}\\ \text{N7 : Display light logic control}\\ \text{N8 : Handle shape size}\\ \text{N9 : Handle shape and material}\\ \text{N10 : Massager structure and size}\\ \text{N11 : Massager nodes and control logics}\\ \text{N12 : Massager node material and control logics}\\ \text{N13 : On/Offadjustment switch}\\ \text{N14 : Massager node material}\\ \text{N15 : Massager control logics}\end{array}\right\}. \quad (8)$$

According to the correlation principle between variables, variables with strong relations are associated with X, whereas unrelated or weakly related variables are represented by 0. The design matrix $[A]$ can be obtained as follows:

$$[\mathrm{A}] = \begin{bmatrix} X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 & 0 & 0 & X & 0 & 0 & 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & X & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & X & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & X & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & X & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & X & 0 & X & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & X \end{bmatrix}. \tag{9}$$

The coupling matrix $[A]$ requires decoupling. According to the relationship between matrix variables, we obtain the following pairs of negative relationships: (1) The user desires to complete the entire massage process with one-handed manipulation M8 when using the massager, but completing the entire head massage with one hand fails to conform to the ergonomic design N3. (2) If the user wants to adjust the intensity switch position of the massager M13 during the massage process, then the adjustment switch must be set within reach of the fingers; however, setting the switch within the reach of the fingers may lead to the misoperation of N2. (3) A head massage should be at least 15 minutes M12 according to a medical suggestion. However, holding the massager for more than 2 minutes will cause user discomfort N4.

3.4. Solution under TRIZ. TRIZ is introduced to solve design conflicts in the product ergonomic optimization. The three conflicts in Section 2 can be transformed into general TRIZ problems using 39 engineering parameters (see Table 4). Engineering parameter analysis and conflict matrix solution are then performed to obtain general and engineering-specific solutions of the invention principle.

The first group of general TRIZ problems is a physical conflict wherein the moving object should be sufficiently large to cover the user's head completely and the shape should be suitable for comfortable hand grip; however, the area of the moving object should also be sufficiently small to ensure that the reachable range is the maximum. The proposed principles of invention are numbered as follows: principles of 1. division, 14. spherical shape, 15. dynamics, and 17. transition to another dimension. No. 1 division principle is first used in practical problems to divide massager nodes in the massager body and ensure that these nodes are connected by an independent mechanism. No. 14 spherical principle is then used to increase the motion coverage of the object without increasing the product shape area by changing the linear motion of nodes to the rotational motion (see Figure 8). Hence, the first conflict is eliminated.

The second set of conflicts is a technical problem. If users want to adjust the massager intensity during the massage process, then the gear adjustment device must be set within finger reach. However, misoperations that can occur may seriously affect the user experience. The proposed principles of invention are numbered as follows: principles of 17. division, 19. spherical shape, 21. dynamics, and 28. transition to another dimension. No. 17 principle is used in the actual product design to tilt or side the adjustment device and then change the gear control mode to a long press or double click according to the No. 19 periodic action principle. Hence, the probability of misoperation is minimized.

The third conflict is also a technical problem and must be resolved within the massage duration. The medically suggested duration is clearly larger than the time range of comfortable usage of the handheld head massager. Proposed principles of invention are as follows: principles of 18. mechanical vibration, 22. turning harm into benefit, and 24. intermediary. No. 18 mechanical vibration principle is first used in the practical application of the handheld head massager to increase the motor power and vibration frequency while performing additional massage work within the normal force intensity. No. 22 principle of turning harm to benefit is then applied to seek the advice of professional physicians while maintaining the normal massage process, modify the handle to ensure that the arm position allows the shoulder and neck to be in the stretched state and intensify the user's shoulder and neck movement in the office environment effectively, and transform the feeling of comfort into rehabilitation training for the shoulders and neck.

4. Product Design Practice and Evaluation

4.1. Practice of Product Form Design. Design demand attributes of the handheld head massager are systematically analyzed and TRIZ is used to eliminate the conflict between the user's psychological demand and rational ergonomic attributes and avoid their dependency in this study. Product ergonomic optimization can independently start from a certain demand without considering the mutual interference between various demands and then use ergonomic principles to complete the product design and create product prototypes efficiently (see Figure 9). Unreasonable parts of the product are corrected and the final product design specifications are obtained via real-time comparison, testing, and simulation of the prototype (see Table 5).

4.2. Evaluation of the Optimized Design. The design of handheld head massagers aims to meet the user's physical and psychological needs and thus enhance the user

Table 4: Conflict transformation based on TRIZ.

Specific conflict	Corresponding 39 engineering parameters	General TRIZ problem
Solve one-handed operation M8 and normal single-hand reachable range N3	Single-hand operation-5. Coverage of moving objects; 12. Shape Object reachable range-5. Coverage of moving object	Solve problems in 5 and 12
Solve adjustment switch for intensity M13 and misoperation in finger reachable range N2	Adjustment switch position-33. Handle ability Finger reachable range-33. Handle ability	Solve problems in 33
Necessary massage duration M12 and massage duration should not be excessively long N4	Massage duration-15. Action duration of moving object Massage duration-19. Moving object application	Solve problems in 15 and 19

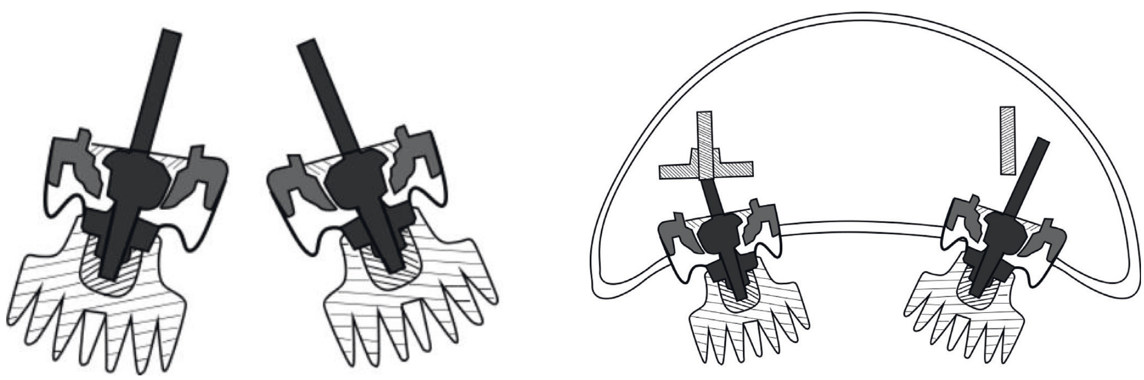

Figure 8: Feasibility structure chart of the product solution.

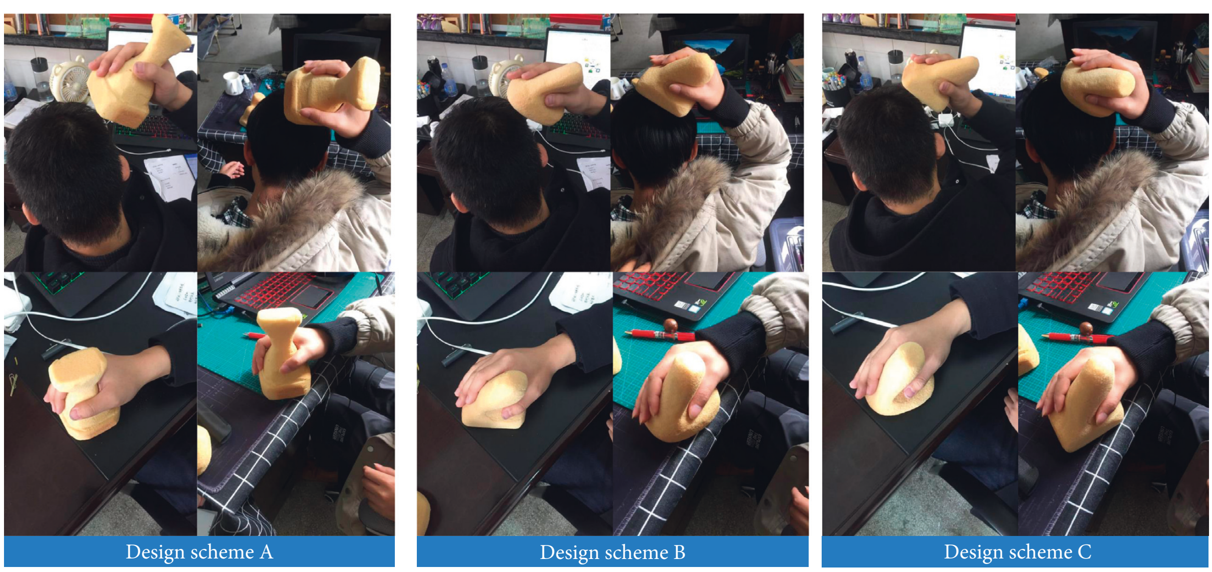

Figure 9: Product prototype testing.

experience. Design evaluation criteria should be established on the basis of the user's demand attributes. Health aid products are consumer-oriented items with multiple attributes but vague information on their evaluation indicators. Fuzzy information axiom is a method of fuzzy mathematics that mainly evaluates multistandard problems on the basis of potential uncertainty languages. The handheld head massager in this study is evaluated using fuzzy information axioms to assess the user's psychological attributes. Ten psychological demand attributes are divided into five levels, namely, excellent, good, fair, flawed, and bad, with a corresponding basic description for each level (see Table 6). The subjects completed the evaluation table and obtained the results for future data support after they used the two massagers. The researchers explain and supplement the unachieved function while testing the new massager because

Table 5: Product ergonomic dimensions.

Part name	Size type	Size
Handheld head massager	Height	145 mm
	Length	100 mm
	Width	100 mm
Massager handle	Height	83 mm
	Cross-sectional thickness (at the handle)	20 mm
	Maximum fillet (handle section)	28°
	Width	40 mm
Adjustment switch for intensity	Length	18 mm
	Width	13 mm
Display light	Length	10 mm
	Width	4 mm
On/off button	Operational resistance	5 N
	Button depth	3 mm

Table 6: Evaluation table of user demand attributes.

Requirement attribute	Excellent	Good	Fair	Flawed	Bad
M6	Very accurate	Easy to handle	Generally accurate	Inaccurate	Very inaccurate
M7	Very easy to recognize	Easy to recognize	Can recognize	Difficult to recognize	Fails to recognize
M8	Very good user experience without problems encountered	Convenient to use	Can operate normally	Strenuous to use	Fails to operate normally
M9	Very comfortable without pain	Comfortable	Generally comfortable	Strenuous to use	Fails to operate normally
M10	Satisfactory balance and steady grip	Fairly good balance and steady	Generally steady	Unbalanced and feels strange	Fails to operate normally
M11	Sensible, sensitive feedback, and sufficient strength	Fairly good sensitive feedback and appropriate strength	Normal feedback with minimal difference	Unsatisfied feedback with unreasonable strength	Absence of feedback
M12	Very comfortable without pain	Comfortable	Generally comfortable	Minimal comfort	Very uncomfortable
M13	Very convenient	Fairly convenient	Fairly good	Difficult to adjust	Very inconvenient
M14	Excellent safety and relaxed and comfortable use	Fairly safe and equipped with a reminder device	Unsure of its safety	Time may be excessively long and unsafe	Seems very unsafe
M15	Very smart	Fairly smart	Neutral	Not smart	Not smart at all

the product is still in the prototype stage. Evaluation indicator values of new and old schemes can be obtained according to the evaluation results (see Table 7). M8, M9, M10, M11, M12, and M13 have many designs, while those of M14, M6, M7, and M15 are limited according to the weight analysis.

The fuzzy information axiom is used to calculate the information content of intangible attributes. The qualitative indicator is nearly linear because it adopts the trapezoidal fuzzy membership function. The indicator described by these qualitative languages is quantified by the fuzzy comprehensive evaluation method. The membership function curve is illustrated in Figure 10. Taking controllability as an example, the information amount I ((10) and (11)) is obtained, and finally the total amount of information (see Table 8) for each attribute is obtained.

$$\begin{aligned} I_{\text{New}} &= \log_2\left(\frac{\text{Fuzzy design range}}{\text{Fuzzy common range}}\right) \\ &= \log_2\left(\frac{(5+4)\times 0.5}{(5-4)\times 0.5\times 0.5}\right) = 4.169, \end{aligned} \tag{10}$$

$$\begin{aligned} I_{\text{Original}} &= \log_2\left(\frac{\text{Fuzzy design range}}{\text{Fuzzy common range}}\right) \\ &= \log_2\left(\frac{(5+4)\times 0.5}{(4+2)\times 0.5}\right) = 0.585. \end{aligned} \tag{11}$$

The formula presents that the final information volume of all design attribute evaluation indicators is $I_{\text{New}} < I_{\text{Original}}$. The fuzzy information axiom demonstrates that the optimized scheme is better.

Table 7: Evaluation index of design scheme.

Design scheme	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15
Optimized design	Excellent	Good	Excellent	Excellent	Good	Good	Excellent	Good	Good	Fairly good
Experimental design	Flawed	Fairly good	Fairly good	Fairly good	Fairly good	Good	Flawed	Fairly good	Flawed	Fairly good

Table 8: Total amount of information.

Evaluation indicator M	New design I_{New}	Original design $I_{Original}$
Accuracy (M6)	0.321	4.700
Recognition degree (M7)	1.115	1.700
Controllability (M8)	0.585	4.169
Comfort of the handle grip (M9)	0.585	4.169
Stability of the handle grip (M10)	1.169	4.169
Force feedback (M11)	1.169	1.169
Comfort (M12)	0.585	5.231
Convenience (M13)	1.169	4.169
Safety (M14)	1.169	5.231
Intelligence (M15)	1.700	1.700
Total amount of information I	9.567	36.407

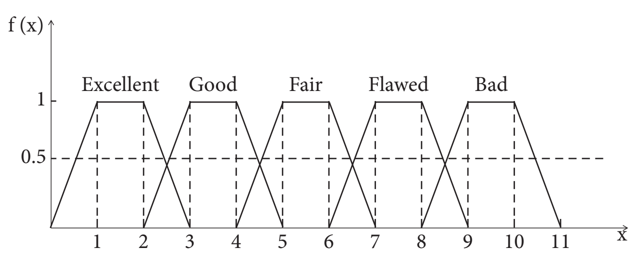

Figure 10: Membership function curve.

5. Discussion

Products express users' expectations in specific product forms. In the actual product development process, combining product engineering attributes and users' psychological needs to drive product form design can more effectively improve user experience and maximize product use [19]. Compared with [20, 21], which only consider the emotional factors of users, this paper supplements the engineering attributes of products through ergonomic analysis and gives full consideration to the physiological functions of users, thus increasing the convenience and safety of products. Reference [22] analyzed the design of product form from the perspective of user cognition but failed to consider that users' more hidden needs are generated in the process of using the product, which also leads to the further evolution of product form after users use it. Ergonomic simulation can obtain the corresponding scientific design attributes according to the characteristics of users and can guide the design of products in line with ergonomic theory [23]. This mode has been applied to many engineering cases but factors related to emotional design were rarely considered.

The product form that conforms to the product ergonomics theory is not necessarily the product that the user likes, and the product form that the user likes is not necessarily the product that conforms to the ergonomics theory. This kind of fuzzy boundary is the contradiction that designers often encounter in the process of form design. Just because of this contradiction, [11–13] constructed an interdisciplinary method to solve this contradiction in the production and design process, thus saving designers' development time and greatly improving the efficiency of product form design. However, different from the above research, our research takes more consideration from the development cost. The development of complex sensor equipment and a delicate digital twin will require more integration of disciplinary knowledge, which is still very difficult for product designers. Therefore, the TRIZ theory is integrated into the process of product form evolution design in this study, and the main contradictions are solved by solving the TRIZ contradiction matrix. Based on the basic theory, this method is more conducive for more product designers to master and is quickly applied to the development practice of product form evolution.

6. Conclusion

In this study, a new model of product form evolution design integrated with the TRIZ contradiction matrix was constructed to solve the contradiction between users' psychological expectations and product engineering attributes. Through this mode, the designer can independently add the interrelated variables to the TRIZ contradiction matrix and then meet the users' expectations one by one in a linear way. The user's psychological strength and product engineering attributes are integrated into the product form at one time, greatly simplifying the product form evolution design process. Finally, the fuzzy comprehensive evaluation method is used to evaluate the new and old products. The results show that the optimized handheld head massager can more meet the physiological and psychological needs of users, improve the user experience, enhance the efficiency of the product, and verify the feasibility of the design mode. However, there are still several parts of this study which need to be further studied. First, the number of observers should be increased, because a small number of observations will only make it easier for designers to obtain the commonalities, while the consideration of differences is not enough. Second, we need to further improve the test prototype, so that users can experience the whole process of using the product thoroughly, so as to make the product evaluation more real and accurate. Finally, more cases are needed to verify the feasibility of this design model. In the subsequent research process, we will add more design practices for different product categories to ascertain the feasibility of this design model through more practical cases. Through this design mode, the current product form will be the optimal solution at the present stage before the further development of the times and technology.

Data Availability

The data supporting the findings of this study are available within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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