Research Article

Design and Evaluation of the Interface of Recreational Intelligent Escort Products

Xu Han,[1] Lulu Jiao,[1] Baohua Tan ⓘ,[2] Fang Tian ⓘ,[3] Wenbin Zhao, and Hua Yu

[1]*School of Industrial Design, Hubei University of Technology, Wuhan 430068, China*
[2]*School of Science, Hubei University of Technology, Wuhan, China*
[3]*College of Informatics, Huazhong Agricultural University, Wuhan, China*

Correspondence should be addressed to Baohua Tan; tan_bh@126.com and Fang Tian; fangzhihai_2003@mail.hzau.edu.cn

In the context of the Internet of Things (IoT), the user interface has become the main means of interaction between the user and the network system, and the increasing variety of ways of interacting with the user interface has created many "digital problems" for the elderly. In order to explore the preferences of elderly people in using smart products and to help designers to objectively and rationally select interface design solutions, to enhance the experience of elderly people in using smart products and the naturalness of the interaction process, and to motivate them to actively participate in Internet life, this study proposes a new approach to interface design solution selection, which reduces the subjectivity of solution selection in the design process. Firstly, the interface was decomposed into 7 components, and the orthogonal experimental design was used to calculate the evaluation indexes and the correlation degree between the objects of 18 typical solutions, and finally the preferred solution was obtained. Secondly, conjoint analysis was used to obtain the importance that older users attached to the seven interface components and their preferences for the types of elements. The research takes the interface design of an elderly companion robot as an example. The method enables the optimization of the target problem of how to match the interface design elements and the final solution preference in IoT systems, enabling designers to use mathematical and rational thinking to study contradictory problems, enhancing the objectivity and scientificity of interface design and solution selection, providing a more natural and comfortable interaction experience for elderly users, and promoting healthy ageing.

1. Introduction

With the development of the Internet of Things (IoT) [1], more and more smart devices are connected to the Internet and used in smart homes, smart healthcare, and other fields. Huang et al. [2]. define a smart ageing platform as a technological platform that provides intelligent and personalized services to the elderly by accurately identifying and processing key environmental and human data through technologies, such as the Internet of Things and artificial intelligence. The advantages of IOT applications in the field of smart ageing continue to emerge, with some scholars arguing that intelligent systems based on the Internet of Things (IoT) can help prevent cognitive decline in older people [3]. IoT-based systems for elderly companionship products are constantly being used in smart ageing, where

elderly people can control the system through a human-machine interface such as a touch screen to achieve personalized services. Human-machine interface in the traditional sense is divided into human-machine interface (HMI) generated by human-machine interaction and human-computer interface (HCI) generated by human-computer interaction. Human-robot interface (HRI) is a general term for the physical and information interfaces formed during the interaction between aging people and service robots. Compared to traditional human-machine interfaces, HRIs focus more on the safety and efficiency of human-machine interaction and the friendliness of the interface experience [4]. Intelligent companion products for the elderly are gradually flooding into the market, and with the rise of voice, gestures, and other emerging interaction methods, the research on the interface design of intelligent

companion products for the elderly should not be limited to the study of HCI. In order to improve the acceptance and satisfaction of intelligent escort products among the elderly population, HCI and HMI should be studied comprehensively, combined with the different ways of interaction between the elderly and the interface as well as the feedback, to jointly explore the influencing factors of the interface design of intelligent products for elderly escorts.

Numerous scholars have explored HRIs from different perspectives. Yi et al. [5] verified the role played by different interface designs and users' educational backgrounds on task performance and subjective evaluations of mobile terminal customization systems. Reddy et al. [6] investigated whether, for older adults, redundancy in the interface is advantageous over text or symbol-based interfaces during early or intermittent device use. Based on the model of working memory, Xu et al. [7] explored the key points of product interface design elements that affect the memory depth of the elderly in each memory stage from the perspective of caring for the elderly rehabilitation population. Jiang et al. [8] derived three principles for the design of information product interfaces for the elderly based on an experiential perspective through an experiential study of three aspects, including sensory recognition, functional cognition, and behavioral associations. Most of the studies in the above literature explore product interface design and grade evaluation from the point of view of elderly users themselves, ignoring the interaction behavior and interaction mode between users and the interface. Many scholars have since incorporated human-computer interaction behaviors and modalities into their research. For example, Karpov and Yusupov [9] conducted an analytical review of the state-of-the-art and future intelligent interfaces for human-computer interaction, detailing the organizing principles, main features, and types of multimodal user interfaces. Oulasvirta et al.'s [10] layout design problem for graphical user interfaces is defined as an integer programming task that allows to identify the type of problem, analyze its complexity, and utilize known algorithmic solutions. Wang et al. [11] proposed an interactive device with a tangible interface that combines human-computer interaction technology and older adults' life experiences to provide three functions: nostalgia, leisure, and entertainment, in order to help older adults achieve active aging. Wang et al. [12] explored how interface design features affect the gaze behavior and behavioral performance of older users in mobile news applications. In comprehension of the above literature, many researchers have explored the design of human-machine interface by combining the physiological and psychological characteristics of elderly users and the interaction mode between users and the interface but ignored the evaluation of the preferential link in the design process. While designers propose multiple interface design solutions, they need to make decisions on the optimal solution with a scientific and objective approach. At the same time, the interface components are connected and influenced by each other, and the researcher fails to evaluate the superiority of the object precisely by considering the user and the interface as a whole. Such a problem will lead to the final design solution not meeting the cognitive characteristics of elderly users, reducing the user's experience of using smart products and the naturalness of the interaction process.

The combination of different types of each interface component of a recreational intelligent product will result in multiple design solutions, and the evaluation and selection of the solutions requires a more comprehensive evaluation system. Many scholars have been experimenting and summarizing according to the actual practice, while drawing on the knowledge of other disciplines such as operations research, management science, and mathematics to study the evaluation methods, mainly hierarchical analysis [13, 14], entropy power method [15, 16], the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method [17–19], and comprehensive evaluation method [20–22]. When these methods are applied, expert interviews and questionnaires are often used to establish evaluation indicators and evaluation systems, and the indicators are often derived based on direct generalization by the researcher, without being able to classify the evaluation indicators of the interface based on scientific logic. The superiority rating of different design solutions is determined only by a single weight, which is more subjective, without theoretical support and more one-sided. Extenics regards the world as a primitive world, a collection of objects or a system of objects, and the interface of recreational intelligent products can be treated as an object, and the comprehensive index of the evaluation interface reflects the overall situation of the interface as its properties. Extenics was introduced to establish a topologic evaluation system to find the evaluation index more accurately by using the topologic performance of the object elements and to establish the degree of association between factors based on the correlation function to evaluate the superiority of the object more accurately, instead of relying on the weights alone to determine the superiority and inferiority levels of different design solutions [23]. Liu et al. [24] proposed a method for configuring complex machine product modules based on extenics-based case reasoning. Liu et al. [25] developed an extenics-based model to formulate a dependence function for measuring the correlation between bus and system performance. Gu et al. [26] used extenics principles to address the choice between color differences (affecting sensitivity and the number of matching colors) and performance timeouts (affecting the degree of fatigue) in the design of human-machine interfaces for nuclear power plants. Yang et al. [27] conducted a comprehensive evaluation of landslide hazards based on extenics principles combined with fuzzy hierarchical analysis. Zhang et al. [28] proposed a method to evaluate the degree of impact on seven damaged mountains in Jinan based on the material element model derived from the extenics theory.

Synthesizing the above literature, there are few studies on the application of extenics to product interface design, and the method can optimize the target problem of how to match the interface design elements and the final solution preference. At the same time, the topologically superior evaluation method is a practical method for comprehensive evaluation, which can combine multiple evaluation indexes to determine the degree of superiority or inferiority of a

solution [29]. Therefore, the research is based on topologic theory to establish the object-metarelationship of the interface design of recreational smart products in order to obtain the optimal solution and the preference of elderly users for the interface design elements and to provide a theoretical reference for designers to design the interface of recreational smart products.

The key contributions of this study include the following.

(1) We analyze the extenics evaluation system, the interface of smart devices and its components and discuss the interface design evaluation process based on extenics in detail

(2) Next, we construct an evaluation hierarchy; four evaluation features were expanded and divided into interrelated levels to make them organized

(3) Then, we use the Analytic Hierarchy Process (AHP) that combines qualitative and quantitative analyses, construct the fuzzy mutual inverse judgment matrix, and perform a joint analysis of users' preferences for interface elements

(4) Finally, 18 sets of elderly companion robot interfaces are designed using the optimized combinations derived from the orthogonal design, and prototypes are made for the research population to operate in the experiments

2. Extenics Evaluation System Establishment

2.1. Decomposition of Interface Components. By observing and analyzing the interface design of most smart devices on the market (especially for elderly companion robots), then consulting professional evaluation websites, consulting interface design experts, and also interviewing elderly users, the collected information and the records of interviews with elderly people and experts were compiled, and the seven constituent elements and the types of each element that need attention in the interface design of recreational smart products were determined as shown in Table 1.

2.2. Orthogonal Experimental Design. Orthogonal experimental design is a design method to conduct experiments with multiple factors and multiple levels according to an orthogonal table for three or more experimental factors, which is characterized by using the results of partial experiments to analyze the situation of the full experiment, with the aim of finding the optimal combination of levels.

According to the numbering of each element type in Table 1 to arrange the combination, if a full-scale experiment is conducted, there are 1458 possible scenarios, but doing so is not only a large amount of work, and there is duplication, and the optimal-level combination needs to be found. Therefore, the orthogonal design module in SPSS 26.0 was used to conduct orthogonal experiments on the constituent elements, and 18 typical combination schemes could be obtained, as shown in Table 2.

2.3. Evaluation Process Construction. Extenics [30–32] is a discipline founded in 1983 by Chinese scholars led by researcher Wen Cai from Guangdong University of

TABLE 1: Interface components and types.

Elements	Type	Number
A: Interface layout mode	Android	A1
	Windows phone	A2
B: Wake-up method	Gestures	B1
	Touch	B2
	Voice	B3
C: Icon design	Pattern	C1
	Text	C2
	Graphic	C3
D: Color settings	Cold tones	D1
	Mid-tone	D2
	Warm tones	D3
E: Touch area (px)	8×8	E1
	10×10	E2
	12×12	E3
F: Information input method	Handwriting input	F1
	Pinyin input	F2
	Voice input	F3
G: Feedback method	Images	G1
	Sound	G2
	Vibrations	G3

Technology, and is also known as the method of physical meta-analysis. The primitive theory is one of its three pillars, which suggests that the basic elements of things include the thing element, the matter element, and the relationship element. After establishing the evaluation indexes, the final correlation degree of each solution is determined through the calculation of the weight and the correlation function, and then the solution is preferred. The interface design evaluation process based on extenics is shown in Figure 1.

2.4. Establishment of Topo Evaluation Indicators

2.4.1. Determine the Object Element. The expression of the object element theory is an ordered triple: $R = (N, c, v)$, where N stands for the name of the thing, c stands for its characteristic value, and v stands for the quantity of c. If R is a multidimensional object element, then there are multiple features and the corresponding quantity values, and then R can be represented by the matrix column:

$$R = (N, c, v) = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} = \begin{bmatrix} & c_1 & v_1 \\ & c_2 & v_2 \\ N & \vdots & \vdots \\ & c_n & v_n \end{bmatrix}. \quad (1)$$

Let U be a theoretical domain, and if x is any element in U, then the extension set A in U is

$$A = \{(x, y), x \in U, y = k(x) \in (-\infty, +\infty)\}, \quad (2)$$

where $y = k(x)$ is the correlation function of A and $k(x)$ is the correlation degree.

According to the research question, the name of the target product, that is, the thing to be evaluated, is determined to be the interface design, and a comprehensive

TABLE 2: 18 typical schemes after orthogonal design.

| Serial number	Interface layout mode	Wake-up method	Icon design	Color settings	Touch area (px)	Information input method	Feedback method
1	Android	Voice	Pattern	Cold tones	10×10	Pinyin input	Sound
2	Android	Gestures	Pattern	Cold tones	12×12	Handwriting input	Images
3	Android	Touch	Pattern	Warm tones	12×12	Handwriting input	Vibrations
4	Windows	Gestures	Pattern	Mid-tone	8×8	Pinyin input	Vibrations
5	Android	Gestures	Text	Mid-tone	8×8	Handwriting input	Sound
6	Android	Voice	Text	Mid-tone	12×12	Pinyin input	Images
7	Windows	Voice	Pattern	Warm tones	8×8	Voice input	Images
8	Android	Touch	Text	Cold tones	8×8	Voice input	Images
9	Android	Gestures	Text	Warm tones	10×10	Voice input	Vibrations
10	Android	Touch	Graphic	Cold tones	8×8	Pinyin input	Vibrations
11	Android	Voice	Graphic	Mid-tone	12×12	Voice input	Vibrations
12	Android	Gestures	Graphic	Cold tones	8×8	Handwriting input	Sound
13	Windows	Voice	Graphic	Warm tones	12×12	Voice input	Sound
14	Android	Gestures	Graphic	Warm tones	10×10	Pinyin input	Images
15	Windows	Touch	Graphic	Mid-tone	10×10	Handwriting input	Images
16	Android	Touch	Pattern	Mid-tone	10×10	Voice input	Sound
17	Windows	Touch	Text	Warm tones	12×12	Pinyin input	Sound
18	Windows	Gestures	Text	Cold tones	10×10	Handwriting input	Vibrations
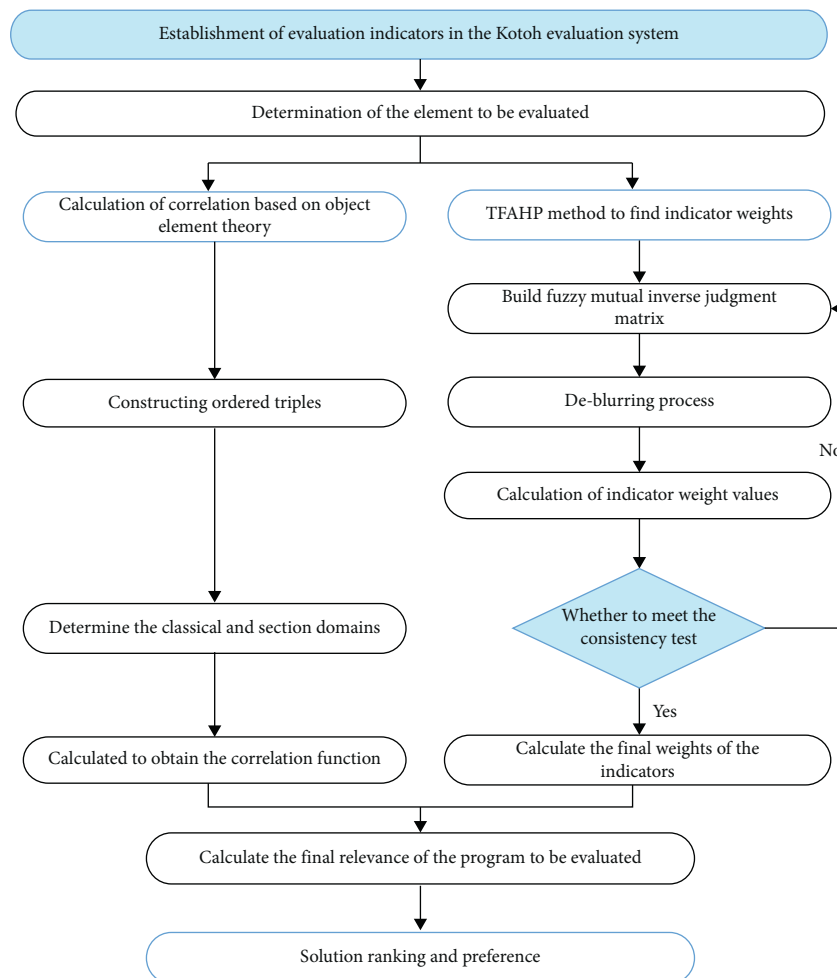
FIGURE 1: Interface design evaluation process.

analysis is conducted from functional, user, and experience aspects using the primitive method. The three design experts collate the information to obtain the interface design evaluation datum and then establish the interface evaluation target primitives according to the formal description in the theory of expandable innovation as follows:

$$R = \begin{bmatrix} & \text{Interaction method} & v_1 \\ & \text{Interface quality} & v_2 \\ \text{Interface Design} & \text{Cognitive Support} & v_3 \\ & \text{User Experience} & v_4 \end{bmatrix}. \quad (3)$$

2.4.2. Evaluation Hierarchy Construction.

The interface evaluation target primitives have been constructed, but the evaluation indexes of the interface design of recreational and intelligent products involve multilevel and multicriteria, and in deciding the criterion layer and subcriteria layer, the factors affect or constrain each other, and at the same time, the elderly should be considered as a special group of people to reduce their cognitive difficulty, and the evaluation criteria should be selected to ensure their comprehensiveness and representativeness. Therefore, the four evaluation feature values were expanded by combining the topologic topology and the hierarchical clarity of hierarchical analysis and divided into interrelated and ordered levels to make them organized.

(1) Target layer: The only and definitive one, that is, the wellness smart product interface design.

(2) Guideline layer: To ensure the comprehensiveness of the scope of the evaluation criteria design, the interface needs to be evaluated in a multifaceted manner. The four first-level criteria are interaction mode M_1, interface quality M_2, cognitive support M_3, and user experience M_4, then the set of first-level criteria $Q = \{M_1, M_2, M_3, M_4\}$. Through the questionnaire method of the literature [33, 34] and by integrating the opinions of experts and designers, and using the expanded method of the topologic theory, the scientific, comprehensiveness, and objectivity of the evaluation index establishment are ensured. The finalized 14 evaluation indexes for the interface design of recreational and intelligent products are shown in Table 3. From this, the set of secondary subcriteria is constructed:

$$\begin{aligned} M_1 &= \{N_1, N_2, N_3, N_4\}, \\ M_2 &= \{N_5, N_6, N_7, N_8\}, \\ M_3 &= \{N_9, N_{10}, N_{11}\}, \\ M_4 &= \{N_{12}, N_{13}, N_{14}\}. \end{aligned} \quad (4)$$

(3) Program level: 18 typical combination programs.

(4) The construction of the evaluation hierarchy for the interface design of recreational and intelligent products is shown in Figure 2.

$$k(x) = \frac{p(x, X_0)}{D(x, X_0, X)}, \quad (5)$$

2.5. Correlation Function Determination.

The association function is calculated using the following method: let $X_0 = a, b, X = a_p, b_p, X_0 \in X$, the primary association function can be obtained as follows.where X_0 is the classical domain, X is the nodal domain, $p(x, X_0)$ denotes the value of the association function of an element under the classical domain, and $D(x, X_0, X)$ denotes the value of the association function of an element under the nodal domain; then, the functional relationship equation is

$$p(x, X_0) = \left| x - \frac{a+b}{2} \right| - \frac{b-a}{2}. \quad (6)$$

$$D(x, X_0, X) = \begin{cases} p(x, X) - p(x, X_0), & x \notin X_0 \\ -1, & x \in X_0 \end{cases} \quad (7)$$

To select the optimal solution among multiple solutions, the set $F = \{F_1, F_2, \ldots, F_m\}$ can be chosen by the device, and the object element model matrix is

$$R = (F_i, C, V_I) = F_i \begin{bmatrix} C_1 & V_{i1} \\ C_2 & V_{i2} \\ \vdots & \vdots \\ C_n & V_{in} \end{bmatrix} (i = 1, 2, \ldots m), \quad (8)$$

where F_i represents multiple scenarios, $C_j (i = 1, 2, \ldots, n)$ represents the impact characteristics of multiple scenarios, and V_{ij} represents the quantity value of the ith scenario corresponding to C_j, that is, the specific data collected from the experts.

In the evaluation process, we also need to give the object element model of the ideal solution as a basis to judge whether the evaluated solution meets the requirements, and the expression is

$$R^* = (F, C, V) = F^* \begin{bmatrix} C_1 & V_1 \\ C_2 & V_2 \\ \vdots & \vdots \\ C_n & V_n \end{bmatrix}, \quad (9)$$

where F^* represents the ideal solution, C_j represents the impact characteristics of the evaluated solution, V_j represents the domain of the ideal solution corresponding to the quantity of C_j, that is, $V_j = a_j, b_j$, is the range given about the characteristics $(C_1, C_2, \ldots, C_n)^T$, that is, classical domain, which is determined by the decision maker according to the real life situation.

In multiple evaluated solutions, $(C_1, C_2, \ldots, C_n)^T$ represents the feature indicators, $(V_1, V_2, \ldots, V_n)^T$ represents the score given to each indicator by the decision maker, and note that $V_{pj} = a_{pj}, b_{pj}$ is the range allowed by the feature set $(C_1, C_2, \ldots, C_n)^T$, that is, the nodal domain, determined by

TABLE 3: Establishment of first-level guidelines and second-level subcriteria.

| Level 1 guidelines	Secondary subcriteria		Number
Interaction method	Multichannel interaction	Multisensory interaction	N_1
	Naturalness	Easy and convenient to wake up the terminal	N_2
	Validity	Output messages are accepted and executed correctly	N_3
	Immediacy	Feedback can be quickly made clear to older adults	N_4
Interface quality	Simplicity	The picture is simple, no extra decoration	N_5
	Reasonable color scheme	Color affinity, but not too beautiful	N_6
	Reasonable layout	Proper arrangement of user interface elements	N_7
	Visual design	Reasonable overall aesthetics and neatness	N_8
Cognitive support	Ease of learning	Simple operation steps, easy to learn	N_9
	Consistency	Element semantics in line with user perception	N_{10}
	Easy to understand	Icon function semantics are easy to understand	N_{11}
User experience	Efficiency	Complete tasks simply and efficiently	N_{12}
	Fault tolerance	Low error rate	N_{13}
	Caring and friendly	Humanistic care for the elderly	N_{14}
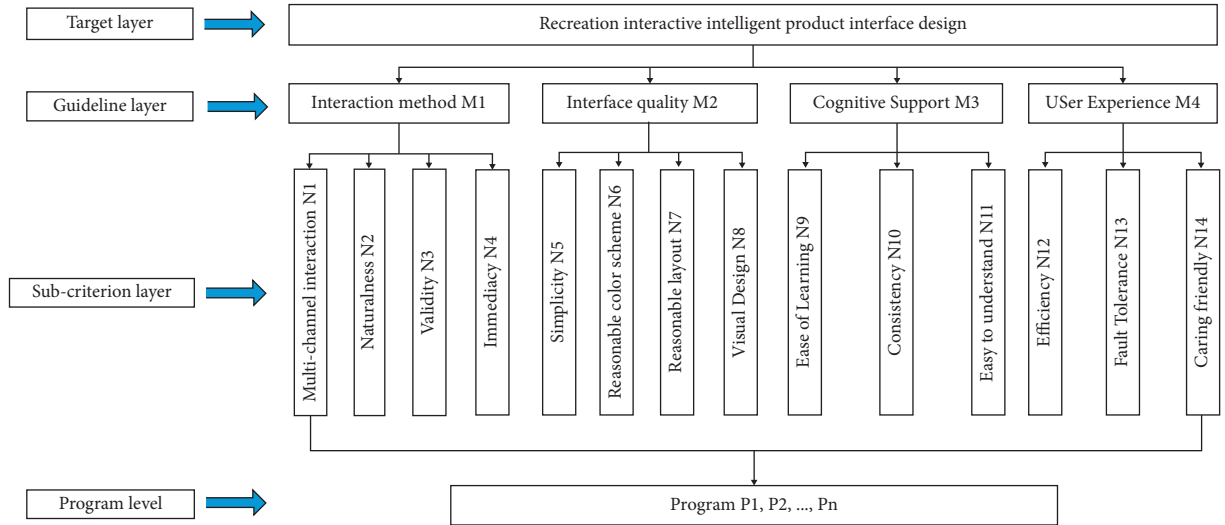
FIGURE 2: Evaluation hierarchy of the interface design of recreational and intelligent products.

the maximum range of quantitative values scored by the decision maker for each feature value.

The expression of the association function of the evaluated scheme, obtained from the primary association calculation, is

$$k_{ij}(v_{ij}) = \begin{cases} -p(v_{ij}, V_j), & v_{ij} \in V_j \\ \dfrac{p(v_{ij}, V_j)}{p(v_{ij}, V_{pj}) - p(v_{ij}, V_j)}, & v_{ij} \notin V_j \end{cases}, \quad (10)$$

where $V_j = a_j, b_j$, $V_{pj} = a_{pj}, b_{pj}$.

2.6. Calculation of Indicator Weights. Analytic Hierarchy Process (AHP) combines qualitative and quantitative analysis but is more subjective and susceptible to the influence of extreme values in the judging process. Triangular fuzzy analytic hierarchy process (TFAHP) is a study of mathematical problems with vagueness using triangular fuzzy numbers, which can combine multiple elements and

attributes to solve vagueness and subjectivity [35–37], and its main calculation steps are as follows.

2.6.1. Construction of Fuzzy Mutual Inverse Judgment Matrix for Two-by-Two Comparison of Criterion Layers. First, the first-level evaluation criterion is scored in two comparisons for the target layer to construct a first-level fuzzy mutual inverse judgment matrix. Secondly, the subcriteria are scored in two comparisons for the first-level criterion to construct a fuzzy mutual inverse judgment matrix for the second-level subcriteria. Judges are required to use a scale of 1 to 9 for judging decisions, and the quantification and meaning of the defined terms are shown in Table 4.

Take the target layer element Q and its corresponding first-level criterion $M_1, M_2, \ldots, M_n$ of the criterion layer as an example, and construct the fuzzy mutual inverse judgment matrix A:

$$A = r_{ij\,n \times n}, \quad (11)$$

where the fuzzy set of r_{ij} is (l_{ij}, m_{ij}, u_{ij}), and the nth-term criterion is compared for judgment; then, we get

TABLE 4: 1–9 quantification and meaning of linguistic terms of proportional scales.

Scale	Judgment	The relative importance between elements i and j	Fuzzy number	Countdown
1	Equally important	Comparison of two indicators is equally important	1, 1, 1	1, 1, 1
2			1, 2, 3	1/3, 1/2, 1
3	Slightly more important	One metric is slightly more important than the other	2, 3, 4	1/4, 1/3, 1/2
4			3, 4, 5	1/5, 1/4, 1/3
5	Obviously important	One metric is significantly more important than the other	4, 5, 6	1/6, 1/5, 1/4
6			5, 6, 7	1/7, 1/6, 1/5
7	Very important	One metric is very important over another	6, 7, 8	1/8, 1/7, 1/6
8			7, 8, 9	1/9, 1/8, 1/7
9	Extremely important	The extreme importance of one metric over another	8, 9, 10	1/10, 1/9, 1/8

Note: 2, 4, 6, and 8 are the compromise values, $r_{ij} = r_{ij}^{-1}$. One indicator is less important than the other, using the reciprocal representation.

$$A = \begin{bmatrix} r_{11} & r_{12} & r_{13} & \cdots & r_{1n} \\ r_{21} & r_{22} & r_{23} & \cdots & r_{2n} \\ r_{31} & r_{32} & r_{33} & \cdots & r_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & r_{n3} & \cdots & r_{nn} \end{bmatrix}. \quad (12)$$

The criteria of each level of each scheme are scored by z experts, and the fuzzy comprehensive mutual inverse judgment matrices of $Q - M$ level and $M - N$ level are established, respectively. Assuming that similar scorers have similar levels of knowledge as well as judgment, an arithmetic average is used to combine the scoring information. Thus, the integrated fuzzy mutual inverse judgment matrix of the $A - R$ layer can be obtained as follows:

$$A = \left(\frac{\sum_{t=1}^{z} l_{ij}^{t}}{z}, \frac{\sum_{t=1}^{z} m_{ij}^{t}}{z}, \frac{\sum_{t=1}^{z} u_{ij}^{t}}{z} \right)_{n \times n} \quad (13)$$
$$= \left(L_{ij}, M_{ij}, U_{ij}, \right)_{n \times n},$$

where r_{ij} denotes the importance between element i and element j, and $r_{ij} = r_{ij}^{-1}$.

The data were pooled and processed using the Delphi method [38] to build all fuzzy mutual inverse judgment matrices for the $Q - M$ and $M - N$ layers. Then, we have the following: the first-level fuzzy mutual inverse judgment matrix $Q = (m_{ij})_{4 \times 4}$ ($i, j = 1, 2, 3, 4$) comes from the scoring of the company's decision makers. The two-level fuzzy mutual inverse judgment matrix ($A_1 = (n_{ij})_{4 \times 4}$ ($i, j = 1, 2, 3, 4$), $A_2 = (n_{ij})_{4 \times 4}$ ($i, j = 5, 6, 7, 8$), $A_3 = (n_{ij})_{3 \times 3}$ ($i, j = 9, 10, 11$), and $A_4 = (n_{ij})_{3 \times 3}$ ($i, j = 12, 13, 14$)) is derived from the scores of experts, designers, and older users.

2.6.2. Calculation of Weight Values

(1) *Defuzzification of the Matrix.* Firstly, the fuzzy judgment matrix needs to be transformed into the judgment matrix of exact figures, and the mean area method is generally used, as shown in equation (4), followed by the consistency test.

$$A = \left(\frac{L_{ij} + 2M_{ij} + U_{ij}}{4} \right)_{n \times n} = \left(r_{ij} \right)_{n \times n}. \quad (14)$$

(2) *Weight Value Calculation.* After the defuzzification process, the calculation of the weight vectors of each

matrix begins, and the usual methods are least squares, arithmetic averaging, and geometric averaging. In this paper, the geometric mean method is used, and the specific steps are as follows [39].

Step 1. Calculate the product of each row of the judgment matrix

$$A_i = \prod_{i=1}^{n} r_{ij}, i = 1, 2, \ldots, n, \quad (15)$$

where r_{ij} denotes the element of the ith row and jth column of the matrix and n is the number of elements.

Step 2. Find the geometric mean of M_i

$$w_i = \sqrt[n]{A_i}. \quad (16)$$

Step 3. Normalization process

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}. \quad (17)$$

2.6.3. Consistency Check.
Due to the ambiguity and limitations of human thinking and the complexity of judging things, there may be inconsistencies in the judgments given by decision makers in the judging process, so the consistency of the matrix needs to be checked. If the tested judgment matrix possesses consistency, then it can be assumed that the original triangular fuzzy matrix can also pass the consistency test [40].

First, the matrix is input into MATLAB software to find the maximum eigenvalue $\lambda_{\max}$, and then the consistency of the matrix is tested by combining the consistency criterion CI and the random consistency criterion RI. The selection of the mean random consistency criterion RI is shown in Table 5. The CI as well as the consistency ratio CR is calculated as follows:

(1) Calculate the degree of inconsistency CI:

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \quad (18)$$

where $\lambda_{\max}$ is the maximum eigenvalue of the matrix and n is the matrix order.

Table 5: Average random consistency criterion.

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

(2) Calculate the consistency ratio CR:

$$CR = \frac{CI}{RI}. \tag{19}$$

When $CR < 0.1$, the judgment matrix is considered to have good consistency; otherwise, the matrix needs to be adjusted until good consistency is achieved.

2.6.4. Calculation of the Final Weights of Each Evaluation Index at the Criterion Level. After completing the consistency test, the total hierarchical ranking needs to be obtained as a reference for the final program evaluation. In this paper, there are two levels of criterion level and subcriteria level, and the weights of the subcriteria need to be multiplied with the weights of the corresponding criterion when calculating the final weights of the indicators. For example, to calculate the final weight of indicator N_1, the weight of N_1 is multiplied by the weight of the corresponding criterion M_1.

2.7. Final Correlation Calculation and Solution Preference. In the evaluated scenario, each feature has a different degree of influence on the scenario; therefore, the weights of the features need to be combined; then, the correlation between the evaluated scenario and the ideal scenario is

$$\lambda_i = \sum_{j=1}^{n} \omega_j K_{ij} \, (i = 1, 2, \ldots, m). \tag{20}$$

A larger λ_i means that the evaluated solution is closer to the ideal solution and also closer to the decision maker's expectation, and the correlation value is used as a reference to rank and prefer the solution.

2.8. Joint Analysis of Older Users' Preference for Interface Design Elements. Based on the topology primitive theory, a topology evaluation system can be constructed for 18 typical solutions, and the best combination can be selected. To obtain the preference of elderly users for each type of interface components, the utility value and importance of each element should be calculated by joint analysis. Positive and negative validity values can reflect whether the research population holds a preference for the type of element, and the magnitude of the value can reflect the degree of preference or dislike. Importance reflects the degree to which the element is valued in the overall interface design. Not only can we get the preferences of elderly users, but also can help designers to grasp the design focus and at the same time can support the correctness of the above solution preferences. The

preferences of elderly users for the interface design of recreational smart products were obtained from the analysis of both the combination of overall design elements and the calculation of the importance of single design elements.

2.8.1. Collection of Scoring Data. A random sampling method was used to select z elderly users with experience in using wellness smart products as the research population, covering different occupations, genders (differences between men and women are not discussed in the text), and ages, and 18 typical combination scenarios were scored using a 7-point Likert scale, and reliability was calculated after the questionnaires were collected.

2.8.2. Overall Utility Value and Importance Calculation. Once the questionnaire had qualified reliability, the collated data were imported into SPSS 26.0 and the conjoint analysis module was used to calculate statistics such as individual and overall utility values as well as importance values. The utility and importance values provide statistics on the overall intention of the research population, that is, the user's preferences.

2.8.3. T-Test. In addition, u elderly users were selected to evaluate the survey of the same judging scheme, and their results were used as actual values; the results of the survey of z elderly users in the previous period were used as predicted values, and the confidence level of the experiment or model was captured by calculating the correlation between the two values.

3. Design Application: Example of Interface Design for Elderly Escort Robots

Using the typical optimized combinations derived from the orthogonal design described above, 18 sets of elderly companion robot interfaces were designed and high-fidelity prototypes were made for the research population to operate in the experiments. The prototype is defined as a master controller as a client and connects to the server side via the ESP8266 Wi-Fi module, which is in station mode. The server side uses PHP to provide socket support and uses the unofficial PHP extension Swoole to build the socket communication server. The high-fidelity interface is shown in Figures 3(a)–3(r).

3.1. Object Element and Classical Domain, Node Domain Determination

3.1.1. Object-Ordered Triad Construction. N is the interface design, c is the 14 secondary subcriteria evaluation indexes identified in Table 3, and v represents the quantity value of c. Then, a matrix column of ordered triads is obtained as follows:

FIGURE 3: Interface design of 18 elderly companion robots.

$$R = (N, c, v) = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} = \begin{bmatrix} \text{Interface design} & \begin{array}{cc} \text{Multichannel interaction} & v_1 \\ \text{Naturalness} & v_2 \\ \vdots & \vdots \\ \text{Caring and friendly} & v_{14} \end{array} \end{bmatrix}. \tag{21}$$

3.1.2. Classical Domain and Section Domain Determination.
The evaluation indexes for the interface design of the elderly companion robot were distributed to three experts, who were asked to score the 18 options to be selected as shown in Figure 3 according to the four primary and 14 secondary evaluation indexes identified in Table 3 on a percentage scale. The final scores of the indicators were obtained by taking the arithmetic average of the scores of the three experts, and the results are shown in Table 6.

Evaluation scoring is conducted on a percentage system, and the evaluation results can be divided into four levels: excellent (75–100), good (50–74), moderate (25–49), and poor (0–24). After consulting with the evaluation experts, it is known that the expected range of the evaluation indicators of the evaluated program metamodel, that is, the classical domain, should be within 75–100 is a good and reasonable level, and the maximum range of all evaluation indicators, that is, the nodal domain, can be taken as 0–100; then the classical domain and the nodal domain are as follows.

Classical domain:

$$V_1 = 75, 100,$$
$$V_2 = 75, 100,$$
$$V_3 = 75, 100,$$
$$V_4 = 75, 100,$$
$$V_5 = 75, 100,$$
$$V_6 = 75, 100,$$
$$V_7 = 75, 100,$$
$$V_8 = 75, 100,$$
$$V_9 = 75, 100,$$
$$V_{10} = 75, 100,$$
$$V_{11} = 75, 100,$$
$$V_{12} = 75, 100,$$
$$V_{13} = 75, 100,$$
$$V_{14} = 75, 100. \tag{22}$$

Section domain:

$$V_{1P} = 0, 100,$$
$$V_{2P} = 0, 100,$$
$$V_{3P} = 0, 100,$$
$$V_{4P} = 0, 100,$$
$$V_{5P} = 0, 100,$$
$$V_{6P} = 0, 100,$$
$$V_{7P} = 0, 100,$$

TABLE 6: Quantitative scoring table for the 18 options to be selected.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
N_1	78	88	73	83	85	75	76	74	90	76	75	89	76	73	74	81	77	76
N_2	76	84	75	86	92	76	73	70	76	71	75	73	75	72	74	73	74	73
N_3	84	84	83	84	80	82	80	78	85	77	82	87	88	94	80	77	90	82
N_4	84	80	77	85	76	77	76	85	82	80	85	82	90	85	75	82	80	82
N_5	95	80	75	85	85	90	82	77	84	77	87	90	85	80	82	87	85	93
N_6	77	78	82	82	86	90	92	87	92	84	80	92	87	84	90	90	87	90
N_7	85	75	75	76	74	85	70	78	85	82	90	85	90	82	75	85	82	96
N_8	75	82	85	76	85	82	82	92	82	80	84	86	85	84	84	74	78	80
N_9	85	78	87	90	85	80	82	88	88	90	90	80	78	87	83	88	82	83
N_{10}	76	77	76	85	82	80	76	77	74	72	75	82	85	76	73	75	80	76
N_{11}	76	75	76	74	85	70	76	82	85	76	85	82	82	76	88	83	90	85
N_{12}	75	78	87	77	75	82	96	82	75	84	85	72	90	76	75	90	73	75
N_{13}	90	92	87	92	84	90	82	82	74	84	83	92	88	82	80	92	90	80
N_{14}	82	92	74	78	72	75	85	90	82	83	75	82	76	80	74	82	82	75

$$V_{8p} = 0, 100,$$

$$V_{9p} = 0, 100,$$

$$V_{10p} = 0, 100,$$

$$V_{11p} = 0, 100,$$

$$V_{12p} = 0, 100,$$

$$V_{13p} = 0, 100,$$

$$V_{14p} = 0, 100.$$

(23)

3.2. Calculation of Evaluation Index Weights. To determine the weights of each evaluation index, three company decision makers were selected to evaluate the $Q - M$ layer uniformly, and three experts, designers, and elderly users each were selected to evaluate the $M - N$ layer uniformly. In the secondary subcriteria, M_1, M_3 are evaluated by experts, M_2 has designers for evaluation, and M_4 is evaluated by the elderly user population. According to equations (9)-(11), all evaluators' ratings are summarized and organized to obtain all integrated fuzzy mutual inverse judgment matrices:

$$Q = \left\{ \begin{array}{cccc} 1, 1, 1 & 5, 6, 7 & 0.51, 0.58, 0.78 & 6.33, 7.33, 8.33 \\ 0.14, 0.17, 0.21 & 1, 1, 1 & 0.20, 0.25, 0.34 & 1.67, 2.33, 3 \\ 1, 1.67, 2.33 & 3.33, 4.33, 5.33 & 1, 1, 1 & 4, 5, 6 \\ 1, 1, 1 & 1, 1, 1 & 1, 1, 1 & 1, 1, 1 \end{array} \right\},$$

$$A_1 = \left\{ \begin{array}{cccc} 1, 1, 1 & 0.17, 0.21, 0.26 & 0.17, 0.21, 0.11 & 0.51, 0.58, 0.78 \\ 1.33, 2.33, 3.33 & 1, 1, 1 & 0.26, 0.36, 0.61 & 2.67, 3.67, 4.67 \\ 4, 5, 6 & 2.33, 3, 4 & 1, 1, 1 & 6, 7, 8 \\ 1.67, 2.33, 3 & 0.23, 0.32, 0.53 & 0.13, 0.15, 0.18 & 1, 1, 1 \end{array} \right\},$$

$$A_2 = \left\{ \begin{array}{cccc} 1,1,1 & 1.67,2.33,3 & 0.56,0.67,1 & 6,7,8 \\ 0.51,0.58,0.78 & 1,1,1 & 0.56,0.67,1 & 6.33,7.33,8.33 \\ 1,1.67,2.33 & 1,1.67,2.33 & 1,1,1 & 3.33,4.33,5.33 \\ 0.13,0.45,0.54 & 0.12,0.14,0.16 & 0.20,0.25,0.34 & 1,1,1 \end{array} \right\},$$

$$A_3 = \left\{ \begin{array}{ccc} 1,1,1 & 0.26,0.36,0.61 & 0.31,0.44,0.83 \\ 2.33,3,4 & 1,1,1 & 2.33,3,4 \\ (1.33,2.33,3.33) & 0.26,0.36,0.61 & 1,1,1 \end{array} \right\},$$

$$A_4 = \left\{ \begin{array}{ccc} 1,1,1 & 4,5,6 & 0.51,0.58,0.78 \\ 0.17,0.21,0.26 & 1,1,1 & 0.17,0.21,0.26 \\ (1.67,2.33,3) & 4,5,6 & 1,1,1 \end{array} \right\}.$$

$$(24)$$

According to equations (12)-(15), defuzzification is performed and the weight values of each evaluation index at the criterion level are calculated; the matrix is input into MATLAB software to calculate the maximum eigenvalue of the matrix, and then equations (16)-(17) are used to test the consistency of each judgment matrix to obtain the final evaluation index weights and the consistency ratio of each judgment matrix; see Tables 7–11.

3.3. Final Correlation Calculation. The correlation degree and optimal order of each evaluated solution were calculated according to equations (3)-(8) and (20), and the results are shown in Table 12.

3.4. Calculating Utility Values and T-tests. According to the steps of utility value calculation in Section 3.4, 60 elderly users with experience in using recreational smart products were selected as the research population for scoring. The alpha coefficient of the questionnaire was 0.827 and the Kaiser–Meyer–Olkin (KMO) was 0.776, indicating that the questionnaire has good reliability and can be used as a basis for the next analysis. The research data were imported into SPSS 26.0 software, and the overall utility and importance values could be obtained by using the conjoint analysis module, and the results are shown in Table 13.

In addition, 15 elderly users were selected to rate the same evaluated program, and their results were used as the actual values, and the data from 60 users in the previous period were used as the predicted values, and the correlation between the two values was calculated by paired-sample t-test, and their analytical data are shown in Table 14.

As can be seen from Table 14, the p value is 0.588, which is greater than 0.01, and there is no significant difference between the two samples. It indicates that the predictive ability of this joint analysis is better and can truly reflect the degree of users' preferences.

4. Discussion

The orthogonal design was used to obtain 18 typical solutions for the optimal combination of the constituent elements of the interface design of the recreational intelligent products, after which the correlation degree of each solution was calculated based on the primitive theory, and the different importance of the elderly users to the constituent elements of the interface and the preference of each element type were obtained by the joint analysis method. The following conclusions can be drawn from the data in Tables 12 and 13.

(1) Of the 18 optimized typical combinations, the 13th package was the most preferred by elderly users. Due to ageing, the physiological and psychological functions of the elderly are gradually fading. In the home recreation environment, intelligent products should not only help the elderly to complete their tasks, but also establish emotional care and help and guide the elderly to use modern intelligent products more conveniently from the design level. The 13th solution helps seniors to wake up the operation interface or companion robot more conveniently through voice so as to complete the user's commands. The Windows-style interface layout and the icon style with graphics and text can reduce the cognitive load of elderly users and enhance the care for them.

(2) According to the importance data in Table 13, it can be seen that among the seven components of the interface design of recreational smart products, elderly users attach the most importance to the information input method, followed by the feedback method; then the interface layout method, touch area and wake up method, and the overall design of icons and color settings are relatively less important,

TABLE 7: Consistency ratios of the first-level criterion judgment matrix and their weights.

A	M_1	M_2	M_3	M_4	W_1	
M_1	1.000 0	6.000 0	0.612 5	7.330 0	0.403 9	λ_{max} = 4.237 1
M_2	0.172 5	1.000 0	0.260 0	2.332 5	0.100 8	
M_3	1.667 5	4.330 0	1.000 0	5.000 0	0.434 6	CR = 0.087 8
M_4	0.140 0	0.462 6	0.212 5	1.000 0	0.060 7	

TABLE 8: Interaction mode criterion judgment matrix consistency ratio and its weights.

A_1	N_1	N_2	N_3	N_4	W_2	
N_1	1.000 0	0.505 0	0.175 0	0.462 5	0.008 4	λ_{max} = 4.193 6
N_2	2.330 0	1.000 0	0.397 5	3.670 0	0.024 3	
N_3	5.000 0	3.082 5	1.000 0	7.000 0	0.057 6	CR = 0.071 7
N_4	2.332 5	0.350 0	0.152 5	1.000 0	0.010 6	

TABLE 9: Interface quality criteria judgment matrix consistency ratio and its weights.

A_2	N_5	N_6	N_7	N_8	W_3	
N_5	1.000 0	2.332 5	0.725 0	7.000 0	0.035 2	λ_{max} = 4.223 3
N_6	0.462 5	1.000 0	0.725 0	7.330 0	0.023 8	
N_7	1.667 5	1.667 5	1.000 0	4.330 0	0.035 4	CR = 0.082 7
N_8	0.372 5	0.140 0	0.260 0	1.000 0	0.006 5	

TABLE 10: Interface quality criteria judgment matrix consistency ratio and its weights.

A_3	N_9	N_{10}	N_{11}	W_4	
N_9	1.000 0	0.397 5	0.505 0	0.069 2	λ_{max} = 3.152 3
N_{10}	3.082 5	1.000 0	3.082 5	0.250 2	
N_{11}	2.330 0	0.397 5	1.000 0	0.115 2	CR = 0.084 6

TABLE 11: Consistency ratio of user experience criteria judgment matrix and its weights.

A_4	N_{12}	N_{13}	N_{14}	W_4	
N_{12}	1.000 0	5.000 0	0.462 5	0.145 6	λ_{max} = 3.142 4
N_{13}	0.212 5	1.000 0	0.212 5	0.039 2	
N_{14}	2.332 5	5.000 0	1.000 0	0.249 7	CR = 0.079 1

TABLE 12: Relevance and ranking of 18 typical programs.

Program serial number	Correlation degree λ value	Sort
1	4.680 0	12
2	4.639 4	13
3	4.115 7	15
4	6.062 0	6
5	5.481 1	7
6	4.429 5	14
7	4.986 0	11
8	6.716 3	3
9	5.382 5	8
10	5.181 1	9
11	5.075 5	10
12	6.773 8	2
13	7.553 3	1
14	4.008 4	16
15	2.932 8	18
16	6.521 2	5
17	6.565 7	4
18	3.293 1	17

TABLE 13: Overall utility values and importance values.

Elements	Type	Effectiveness value	Importance
A: Interface layout mode	Android	−0.261	13.683
	Windows phone	0.261	
B: Wake-up method	Gestures	−0.282	12.664
	Touch	0.081	
	Voice	0.201	
C: Icon design	Pattern	−0.138	6.186
	Text	0.040	
	Graphic	0.098	
D: Color settings	Cold tones	−0.069	5.531
	Mid-tone	−0.071	
	Warm tones	0.140	
E: Touch area (px)	8 × 8	−0.319	14.920
	10 × 10	0.068	
	12 × 12	0.251	
F: Information input method	Handwriting input	−0.135	26.638
	Pinyin input	−0.441	
	Voice input	0.576	
G: Feedback method	Images	0.226	20.378
	Sound	0.276	
	Vibrations	−0.502	

TABLE 14: t-test analysis data.

		Pairing difference							
				Difference 95% confidence interval					
		Average value	Standard deviation	Standard error mean	Lower limit	Upper limit	t-value	Degree offreedom	Sig. (bobtail)
Pairing 1	Predicted value-actual value	0.051 9	0.398 1	0.093 8	−0.146 1	0.249 8	0.553	17	0.588

indicating that elderly users favor the convenience of operation, the accuracy of information feedback, and the visibility of information.

(3) In the interface layout mode element, older users prefer Windows phone type. The interface is visually the most unified and simple, and the icons are large enough to be easily operated and recognized. The voice method is undoubtedly the most popular among the wake-up elements. The voice method can wake up the smart products faster and more conveniently so that they can receive information or instructions quickly. The icon design with graphics and text is preferred by users more than pure pattern or pure text design, which has much to do with the cognitive ability of elderly users, as pure text or pattern is not enough for elderly users to understand the functions represented by the icons. In the color setting, older users prefer warm colors; the reason is that cold colors give users a cold, unfeeling feeling, and older people need more emotional care, so cold colors have the lowest utility value. For the touch area is undoubtedly the larger the better, because the elderly physiological function and normal people have obvious differences in the operation process is

likely to point or click unresponsive, moderate increase in touch area can be more convenient for elderly users to operate. In terms of information input and information feedback, elderly users prefer voice input and voice feedback because the elderly group is unfamiliar with smart devices and visual fading, so voice input is faster and more direct, and auditory feedback is also more effective than visual feedback, but visual and haptic feedback should also be incorporated in the design process to create a multisensory, multichannel interaction mode so as to enhance user experience.

5. Conclusion

Under the IoT system, the elderly face many "digital divide" problems in the use of smart products, especially in the design of the interface of recreational smart products ignore the impact of the interaction between the elderly user and the interface, interaction mode. The method used for the selection of multiple design solutions is also subjective and one-sided, and designers do not have a comprehensive evaluation system as a reference in the process of solution evaluation and selection and fail to evaluate the user and the

interface as a whole to accurately evaluate the merit of the object. Based on this, the study uses topology as the theoretical basis, divides the seven constituent elements of the interface and the types of each element according to the needs and characteristics of elderly users, calculates the final correlation degree of 18 typical solutions based on the correlation function in primitive theory to obtain the final correlation degree, and realizes the ranking and preference of solutions. Finally, the joint analysis was applied to obtain the preference degree of elderly users for the interface design of recreational smart products, which broadened the research ideas of interactive interface design and optimized the target problem of how to match the interface design elements and the final solution preference. The use of mathematical and rational thinking to study contradictory problems enables the objectivity and scientific nature of interface design and solution selection to be improved, indirectly enhancing the naturalness and comfort of the interaction experience of elderly users and promoting the development of the Internet of Things in the cause of smart ageing. There are also limitations in the study: the evaluation process is more subjective and the sample size is limited, so the follow-up study will consider using eye-tracking technology to obtain rigorous experimental data and combine subjective and objective evaluation statistical methods for further in-depth exploration.

Data Availability

The data used to support the findings of this study are included within the article.

Consent

Informed consent was obtained from all subjects involved in the study

Conflicts of Interest

The authors declare that they have no competing interests regarding the publication of this paper.

Authors' Contributions

Lulu Jiao, Baohua Tan, and Fang Tian contributed equally to this work. Xu Han contributed the central idea, analysed most of the data, and wrote the initial draft of the paper. The remaining authors contributed to refining the ideas, carrying out additional analyses and finalizing this paper. Lulu Jiao designed research, performed research, analyzed data, and wrote the paper. Baohua Tan is responsible for drafting and modifying the contents of important research knowledge. Fang Tian makes substantial contributions to the conception or design of the research, to the collection, analysis, and interpretation of research data; Wenbin Zhao analysed the data and were involved in writing the manuscript. Hua Yu developed the idea for the study, did the analyses, and involved in writing the manuscript.

References

[1] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): a vision, architectural elements, and future directions," *Future Generation Computer Systems*, vol. 29, no. 7, pp. 1645–1660, 2013.

[2] H. Huang, K. Zhou, S. Cao et al., "Establishment and application of a smart elderly care platform based on hybrid perception model[J]," *Chinese Journal of Nursing*, vol. 56, no. 3, pp. 421–426, 2021, (in Chinese).

[3] W. C. Mann, *Smart Technology for Aging, Disability and Independence: The State of the Science [M*, Wiley-Interscience, Hoboken, New Jersey, 2005.

[4] Q. Wang, Y. Zhang, and L. Liu, "Research progress of human-machine interface design for aging service robots[J]," *Machine Design*, vol. 35, no. 09, pp. 105–113, 2018, (in Chinese).

[5] M. Yi, Y. Wang, X. Tian, and H. Xia, "User experience of the mobile terminal customization system: the influence of interface design and educational background on personalized customization," *Sensors*, vol. 21, no. 7, p. 2428, 2021.

[6] G. R. Reddy, A. Blackler, V. Popovic, M. H. Thompson, and D. Mahar, "The effects of redundancy in user-interface design on older users," *International Journal of Human-Computer Studies*, vol. 137, Article ID 102385, 2020.

[7] X. Xu, X. Zhao, Xi Fu et al., "Exploring the elements of interface design for elderly intelligent rehabilitation products under working memory model and method[J]," *Packaging Engineering*, vol. 41, no. 16, pp. 83–90, 2020, (in Chinese).

[8] Y. Jiang and B. Feng, "Research on the interface interaction design of information products for the elderly from the perspective of experience[J]," *Packaging Engineering*, vol. 36, no. 02, pp. 67–71, 2015, (in Chinese).

[9] A. A. Karpov and R. M. Yusupov, "Multimodal interfaces of human-computer interaction," *Herald of the Russian Academy of Sciences*, vol. 88, no. 1, pp. 67–74, 2018.

[10] A. Oulasvirta, N. R. Dayama, M. Shiripour, M. John, and A. Karrenbauer, "Combinatorial optimization of graphical user interface designs," *Proceedings of the IEEE*, vol. 108, no. 3, pp. 434–464, 2020.

[11] C.-M. Wang, S.-M. Tseng, and C.-S. Huang, "Design of an interactive nostalgic amusement device with user-friendly tangible interfaces for improving the health of older adults," *Healthcare*, vol. 8, no. 2, p. 179, 2020.

[12] X.-s. Wang, F. Guo, M.-m. Li, and X.-h. Tian, "Effects of mobile news interface design features on users' gaze behaviours and behavioural performance: evidence from China," *Behaviour & Information Technology*, vol. 40, no. 16, pp. 1741–1754, 2020.

[13] Z. Song, H. Gao, W. Liu, L. Li, W. Zhang, and D. Wang, "Systematic assessment of dredged sludge dewaterability

improvement with different organic polymers based on analytic hierarchy process," *Journal of Environmental Sciences*, vol. 103, pp. 311–321, 2021.

[14] A. Gouareh, B. Settou, and N. Settou, "A new geographical information system approach based on best worst method and analytic hierarchy process for site suitability and technical potential evaluation for large-scale CSP on-grid plant: an application for Algeria territory," *Energy Conversion and Management*, vol. 235, p. 113963, 2021.

[15] Z. Wang, P. Yang, H. Peng et al., "Comprehensive evaluation of 47 tea [Camellia sinensis (L.) O. Kuntze] germplasm based on entropy weight method and grey relational degree[J]," *Genetic Resources and Crop Evolution*, vol. 68, pp. 1–14, 2021.

[16] S. Zhang, P. Su, and S. Liu, "Fusion of cognitive information: evaluation and evolution method of product image form[J]," *Computational Intelligence and Neuroscience*, vol. 2021, Article ID 5524093, 19 pages, 2021.

[17] P. Chen, "Effects of the entropy weight on TOPSIS," *Expert Systems with Applications*, vol. 168, Article ID 114186, 2021.

[18] S. Ahmed and A. Alhumam, "Unified computational modelling for healthcare device security assessment," *Computer Systems Science and Engineering*, vol. 37, no. 1, pp. 1–18, 2021.

[19] S. R. Mohandes and X. Zhang, "Developing a Holistic Occupational Health and Safety risk assessment model: an application to a case of sustainable construction project," *Journal of Cleaner Production*, vol. 291, Article ID 125934, 2021.

[20] H. Zhang, M. Lu, X. Ke et al., "Evaluation model of black-start schemes based on optimal combination weights and improved VIKOR method," *International Journal of Electrical Power & Energy Systems*, vol. 129, Article ID 106762, 2021.

[21] S. G. Xu, Y. X. Cui, C. X. Yang et al., "The fuzzy comprehensive evaluation (FCE) and the principal component analysis (PCA) model simulation and its applications in water quality assessment of Nansi Lake Basin, China[J]," *Environmental Engineering Research*, vol. 26, no. 2, Article ID 200022, 2021.

[22] Y. Wu, H. Li, S. Zou, G. Wang, H. Jiang, and F. Huang, "The application portfolio empowerment method and ELECTRE-I for optimising the control of ammonia release during the aerobic fermentation process," *Bioprocess and Biosystems Engineering*, vol. 44, no. 4, pp. 673–682, 2021.

[23] W. Li, *Research on User-Centered Topable Interaction Design for Smartphones [D]*, Nanjing University of Aeronautics and Astronautics, Nanjing, China, (in Chinese), 2009.

[24] Z. Liu, J. Liu, J. Lyu, H. Zhao, and Y. Xu, "Configuration of product plan based on case reasoning of extenics," *Alexandria Engineering Journal*, vol. 60, no. 2, pp. 2607–2618, 2021.

[25] Y. Liu, S. Chien, D. Hu, N. Wang, and R. Zhang, "Developing an extenics-based model for evaluating bus transit system[J]," *Journal of Advaced Transportation*, vol. 2020, Article ID 8879664, 2020.

[26] P.-f. Gu, W. Xi, W.-p. Ye, J. Shi, and J. Zhao, "Extenics matter-element analysis on dilemma problem in HMI design of nuclear power plant," *Nuclear Engineering and Design*, vol. 350, pp. 176–181, 2019.

[27] W. Yang, Z. Zheng, X. Zhang, B. Tan, and L. Li, "Analysis of landslide risk based on fuzzy extension analytic hierarchy process," *Journal of Intelligent and Fuzzy Systems*, vol. 33, no. 4, pp. 2523–2531, 2017.

[28] Y. Zhang, S. Li, and F. Meng, "Application of extenics theory for evaluating effect degree of damaged mountains based on analytic hierarchy process," *Environmental Earth Sciences*, vol. 71, no. 10, pp. 4463–4471, 2014.

[29] F. Hu, K. Zhou, and Y. Mai, "Research on topologizable evaluation method of user experience for product service system[J]," *Machine Design*, vol. 35, no. 02, pp. 109–114, 2018, .(in Chinese).

[30] W. Cai, C. Yang, S. Florentin, and L. Vladareanu, *Extenics and Innovation Methods[M]*, CRC Press, Boca Raton, Florida, 2019.

[31] W. Chen, J. Fu, and F. Xiong, "Grey clustering evaluation model for construction safety of fabricated building project [J]," *China Safety Science Journal*, vol. 26, no. 11, pp. 70–75, 2016.

[32] O. I. Şandru, L. Vlădăreanu, P. Şchiopu, and V. Vladareanu, "Multidimensional extenics theory[J]," *UPB Sci. Bull., Series A*, vol. 75, no. 1, pp. 3–12, 2013.

[33] M. Zhou and Y. J. Li, "Research on interactive aging-appropriate design of products for elderly services with Chinese characteristics[J]," *Art 100*, vol. 33, no. 01, pp. 233-234, 2017.

[34] Z. Liu and B. Ge, "QFD-based design of elderly home escort robot[J]," *Journal of Graphology*, vol. 39, no. 04, pp. 695–699, 2018.

[35] X. Li, S. Yu, and J. Chu, "Optimal selection of manufacturing services in cloud manufacturing: a novel hybrid MCDM approach based on rough ANP and rough TOPSIS," *Journal of Intelligent and Fuzzy Systems*, vol. 34, no. 6, pp. 4041–4056, 2018.

[36] I. Vinogradova-Zinkevič, V. Podvezko, and E. K. Zavadskas, "Comparative assessment of the stability of AHP and FAHP methods[J]," *Symmetry*, vol. 13, no. 3, p. 479, 2021.

[37] S. Kubler, J. Robert, W. Derigent, A. Voisin, and Y. Le Traon, "A state-of the-art survey & testbed of fuzzy AHP (FAHP) applications," *Expert Systems with Applications*, vol. 65, pp. 398–422, 2016.

[38] X. G. Zhang, Q. Lin, X. M. Zhang et al., "Constructing a health status evaluation scale for the elderly based on Delphi method [J]," *Chinese Journal of Gerontology*, vol. 39, no. 22, pp. 5623–5627, 2019, .(in Chinese).

[39] M. Yang, Y. Cong, and X. Li, "A comprehensive evaluation and preference method of aging-friendly products integrating FAHP and TOPSIS--a case study of elderly smart bracelets [J]," *Journal of Graphology*, vol. 41, no. 03, pp. 469–479, 2020, (in Chinese).

[40] M. Chen and L.-X. Guo, "A comprehensive evaluation method of electric vehicle dynamics economy based on AHP-entropy power-TOPSIS [J]," *Machine Design*, vol. 30, no. 04, pp. 15–19, 2013, (in Chinese).