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Optimized Design and Decision Model Construction of Smart Home Interface for Elderly Users: Integrating Kano-QFD-HCI Methods

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ABSTRACT

Under the background of the deep integration of aging society and intelligent technology, the aging-adapted interface design of smart home products has become a key path to improve the quality of life of the elderly. In the interface design and development of smart home appliances, problems such as complex interaction and imprecise transformation of elderly users' needs often occur. This study proposes a framework that integrates quality function development (QFD) and human-computer interaction (HCI) theory to assist design decisions. The Kano model is used to classify the needs of elderly users in a refined way (basic, aspirational, and excited), and a "user needs-design parameters" quality house model is constructed to realize the quantification of demand priorities and the accurate mapping of design parameters; a multi-dimensional comprehensive evaluation of multiple solutions is carried out by combining the TOPSIS method, and the optimal design is screened out to take into account ease of use, safety, and emotional experience, combined with the TOPSIS method, we conducted a comprehensive evaluation of multiple solutions to select the optimal design solution that takes into account ease of use, safety and emotional experience. The results show that the core needs of elderly users are focused on simplified operation (e.g., one-button start), immediate feedback (e.g., voice prompts), and interface adaptation (e.g., large font, high contrast); the QFD-HCI fusion method can significantly improve the efficiency of requirements transformation and the practicality of design solutions. This study provides theoretical support and practical paradigm for the aging-friendly development and design of smart home products by taking the aging-friendly interface development of smart rice cooker as an example, focusing on exploring the inclusiveness of the elderly group to smart technology and promoting the concept of "technology for the elderly" from concept to realization.

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1. Introduction

1.1 Background of aging society and smart home technology

The trend of global population aging is increasing, and according to the United Nations, the proportion of the global population over 60 years old will exceed 20% by 2050. In this context, the quality of life and social well-being of the elderly has become an important issue for social development. The rapid progress of technology, especially the rise of smart home technology, provides new opportunities to improve the ability of the elderly to live independently [1, 2]. As the core carrier of home life, smart home appliances, the age-appropriate design of their operating interfaces is directly related to the acceptance of technology and the convenience of life for the elderly. However, smart home appliances in the current market are generally cantered on young users, with complex interface interactions and redundant functions, ignoring the special needs of elderly users due to physiological decline (e.g., declining eyesight, slow reaction) and psychological needs (e.g., sense of security in operation, emotional companionship). Taking smart rice cookers as an example, despite their increasingly rich functionality (e.g. remote control, multi-mode cooking), the complex touch interface and multi-layer menu design have led to the “technology exclusion” dilemma faced by elderly users, which has seriously constrained the universal value of smart technology.

1.2 Theoretical and Practical Progress of Smart Home Aging-Ready Design

In recent years, the research on smart home ageing-friendly design has shown a trend of multidisciplinary cross-fertilization, and scholars have carried out systematic exploration from the dimensions of technology integration, user psychology, interface optimization, etc., which has provided important theoretical support and practical references for the technical inclusiveness of the elderly user group.

The rapid development of smart home technology has injected new momentum into age-friendly design. In the field of sensors and health monitoring, Udupa and Yellampalli [3] proposed to build a real-time health monitoring system for the elderly through the integration of pressure sensors, temperature sensors, and network technology, which provides a technical guarantee for home safety; Tapia et al. [4] further verified the potential of miniaturized sensors in enhancing the convenience of life of the elderly. Tapia et al. [4] further verified the potential of miniaturized sensors in enhancing the convenience of life for the elderly. At the level of interaction mode optimization, Portet et al. [5] developed a voice control system that lowers the interaction threshold through remote command operation; Epelde et al. [6] combined ambient intelligence with TV services to design a multimodal interaction interface, which significantly improves the elderly's experience. In addition, Raghu et al. [7] proposed a multi-layered cloud-edge architecture for elderly care homes that leverages edge-based neural networks for real-time anomaly detection and risk prediction, demonstrating reduced latency and improved system responsiveness compared to traditional cloud-based solutions.

Technology acceptance behaviour of older users is influenced by both psychological and physiological factors. At the level of cognitive and emotional needs, Vujović et al. [8] pointed out that interface ease of use (e.g., icon recognizability, feedback immediacy) is the core demand of older users based on the Health Index model, while Courtney et al. [9] and Tural et al. [10] found that technology anxiety and self-efficacy significantly affect older users' acceptance of smart products. significantly affect older adults' willingness to accept smart products. Jiao [11] analysed the perceptual psychology of the elderly and refined design guidelines such as simplification of appliance processes and visual enhancement; Jing [12] optimized the interface of rice cooker from the dimensions of interaction design and sensory experience based on the theory of affectivity, which enhanced the sense of belonging of elderly users. It is worth noting that the comparison of the two investigators is in the experimental table show that touch screen design can alleviate older people's operating anxiety better than traditional buttons, and that the optimization of touch location (e.g., the layout of the central area of the screen) can further enhance the interaction efficiency.

The academic community has accumulated some practical results on product-specific design for aging. In the field of rice cookers, Zallio et al. [13]used fuzzy logic and graphical user interface (GUI) technology to realize intelligent fault detection and adaptive solution for the cooking process; Gang et al. [14] optimized the heat transfer efficiency and automation level of rice cookers through structural innovations (e.g., the integration of rotary motors and MCUs); In terms of interaction assessment methods, Mattheiss et al. [15] compared the advantages and disadvantages of contextual interviews, user observation, and online surveys, pointing out that the behavioural observation method can capture the real pain points of elderly users in a more comprehensive way, while Pérez-Espinoza et al. [16] proposed a quantitative assessment framework for voice interaction quality through audio paralinguistic analysis techniques.

Despite the fruitful existing results, the following key issues still exist: disconnected demand transformation, most studies rely on subjective questionnaire data, and lack of tools to systematically map user demands to design parameters (e.g., the integrated application of QFD and Kano model); a single evaluation dimension, existing evaluations mostly focus on functional utility, neglecting the comprehensive balance of affective experience, technological feasibility, and cost-effectiveness; and insufficient product relevance. There is a scarcity of research on interface design for specific products such as smart rice cookers, and the theoretical results can hardly directly guide engineering practice.

1.3 Research Positioning and Innovative Contribution of this Paper

Aiming at the above problems, this study proposes an interdisciplinary design framework integrating QFD and HCI theory with the smart rice cooker as the target. The Kano model is used to classify the needs of elderly users (basic, expectation, and excitement), and a “user needs-design parameters” quality house model is constructed to quantify and accurately map the priority of the needs; a multi-dimensional comprehensive evaluation of the design solutions is carried out by combining the TOPSIS method, and the optimal solution that takes into account the ease of use, safety, and emotional experience is filtered. The optimal solution that takes into account the ease of use, safety and emotional experience is selected.

The innovation of this paper is reflected in:

Methodological innovation - the first deep integration of QFD and HCI theories, forming a complete tool chain for demand capture, transformation and evaluation;

Practical value: the proposed aging guidelines for the interface design of smart rice cookers (e.g., one-button start logic, voice feedback thresholds), which provide the industry with implementable solutions;

2. Research Methodology

2.1QFD

QFD (Quality Function Deployment), as a systematic management tool, aims to transform customer needs into specific goals for product design, production and quality assurance, and to ensure that products are highly suitable for user needs through qualitative and quantitative analysis. In the field of smart home product design, the application of QFD is particularly critical, which not only promotes the accurate capture and transformation of user needs, but also strengthens the competitiveness of products in the market and user satisfaction [17].

QFD, as a core part of the product development process, realizes the direct mapping from customer requirements to design parameters through the House of Quality model (Figure 1). In this process, QFD not only optimizes the direction of product design, but also promotes the efficient allocation of resources and the refinement of time management.

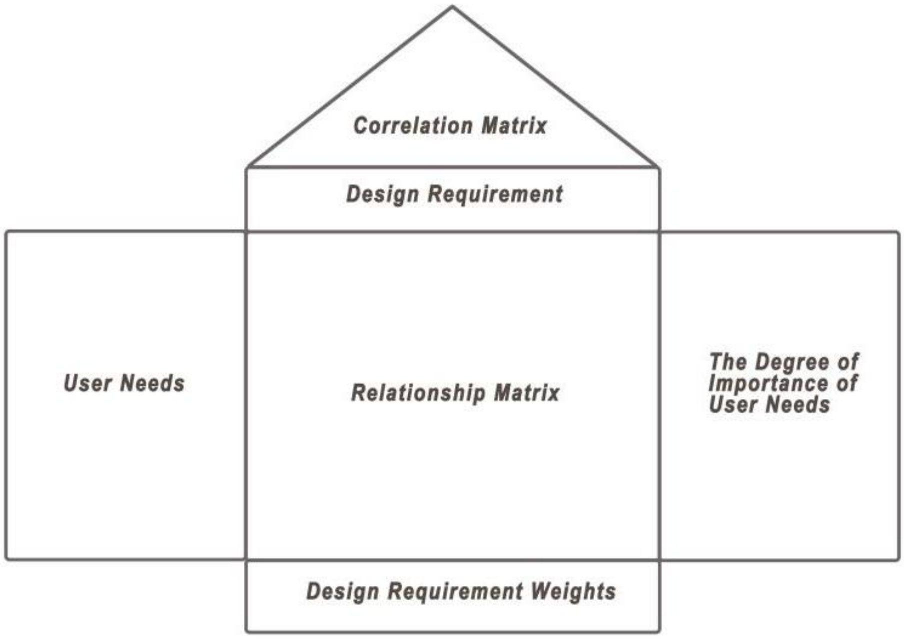

Fig. 1. QFD method diagram

QFD has been applied across multiple domains, including manufacturing, information technology, and service business model design. In the manufacturing industry, Ali et al. [18] used QFD to optimize the layout design of craft facilities and improve productivity; In the field of e-government, Rao [19] used QFD to segment and sort the quality characteristics of online services to promote the optimization and upgrading of government services. In addition, Sousa-Zomer and Miguel [20] applied QFD in the design of complex product-service systems (PSS) to transform customer requirements into engineering metrics and improve the accuracy of design evaluation.

In the field of smart home product design, QFD also shows strong advantages. Through QFD analysis, design teams are able to gain insight into user needs, reduce development blindness, and improve product market adaptability and user satisfaction. For example, in the smart home lighting system, QFD transforms the user's demand for light brightness, colour temperature, control mode, etc. into specific design parameters, realizing the personalized customization and intelligent control of products.

In recent years, several studies have demonstrated the effectiveness of the specific application of QFD in smart home product design. The study showed that the optimization of the user experience of smart home products through the QFD method, especially in the elderly group, achieved a sustainable user experience optimization strategy [16]. In addition, the Fuzzy-QFD model combined with grey correlation analysis effectively analyses the association between the needs of the elderly and the technical characteristics, which provides a strong support for the design of the senior care service platform [17]. The study in 2024 further combines the hierarchical analysis method (AHP) with QFD and applies it to the design of the smart blood glucose meter, which satisfies the physiological and psychological needs of the elderly users and improves the product's overall performance and user experience [18].

Although QFD has achieved remarkable results in smart home product design, there are still some challenges. Firstly, understanding customer needs accurately is one of the major difficulties in QFD analysis, and it is necessary to combine a variety of research tools to improve the accuracy of demand capture. Second, when facing a large amount of user data, the processing efficiency of QFD may be limited, and it is necessary to combine with other efficient data analysis tools to improve the speed and accuracy of analysis.

2.2 Kano Model

Kano model, proposed by Japanese scholar Noriaki Kano, is an advanced methodological tool based on user needs classification and prioritization. The model reveals users' deep-seated needs and potential expectations for product features through fine preference classification techniques, providing a scientific theoretical basis for product design and service optimization [21-23].

Since the Kano model was proposed, many scholars have conducted in-depth research and applied it in different fields. For example, the study of Sireli et al. [24] shows that the combination of Kano model and QFD method can optimize the design scheme and improve the customer satisfaction and priority ranking of design features. Tontini [25] further integrated the Kano model with QFD in depth to provide a scientific basis for the priority setting of product features in enterprises, while Chen et al. [26] combined the Kano model with Taguchi's experimental design to explore the optimal combination of product parameters.

In the field of smart home product design, the application of Kano model has also achieved remarkable results. For example, Tian et al. [27] introduced the Kano model into bicycle modelling design and successfully delineated the three major perceptual demand domains of basic, expectation and excitement, while Chang et al. [28] applied the Kano model to the field of drone modelling, which provided solid data support and strategic guidance for drone design. Through Kano model analysis, design teams can clearly identify users' basic, aspirational and excitement needs for a product and develop differentiated product design strategies accordingly. Luor et al. [29] study delves into the key quality attributes and models of smart home products, emphasizing the importance of Kano model in identifying user needs and guiding product design. Cheng et al. [30] used the Kano model to classify the functional requirements of major devices for home automation, which provided empirical support for the functional planning and design optimization of smart home products. Liu et al. [31] constructed a smart home system for future seniors by taking connectivity as the core element and demonstrated the effectiveness of the Kano model in enhancing product user experience and happiness, and demonstrated the effectiveness of the application of the Kano model in enhancing product user experience and happiness.

However, the Kano model also has certain limitations in practical application. For example, the categorization of needs in the model may vary depending on the user groups, requiring the design team to conduct in-depth user research and data analysis to ensure the accuracy of the categorization. In addition, the Kano model may not be flexible and detailed enough to handle complex user requirements, and needs to be combined with other tools and methods to improve the comprehensiveness and accuracy of the analysis.

2.3 HCI Theory

HCI design is a design field that focuses on enhancing the interactive experience between people and products. It emphasizes the design process to fully consider the user's comprehensive background, experience and feelings during operation, aiming to create interactive products that meet the user's needs and promote the convenience of life. HCI design is not only limited to software interfaces, but is also widely used in all kinds of physical products, especially with the rise of the smart home, the HCI theory is playing a vital role in improving the product's intellectualization, ease of use and user satisfaction. crucial role in enhancing product intelligence, ease of use and user satisfaction.

The United States, as a leader in human-computer modelling technology research, has also clearly listed HCI interface as an important element of software technology development in its national defence key technology plan. U.S. technology giants such as Microsoft and Apple have continuously invested resources to develop more user-friendly, natural and smooth operating system interfaces [32] such as Windows 7 and Leopard, and these efforts reflect the concept of user-centred design. Japan's FPIEND21 program aims to develop advanced computer interface systems for the 21st century information age, emphasizing the naturalness and efficiency of HCI. Germany has a number of institutions of higher learning and research institutes with profound research strength in the field of HCI, such as the Technical University of Munich and the Technical University of Berlin. These institutions are not only committed to basic theoretical research, but also actively promote the practical application of HCI technology. In the German industry, especially in the automotive industry, German automakers are actively adopting advanced HCI technology to improve driving experience and safety. HCI technology plays an important role in the “Industry 4.0” strategy proposed by Germany. Through the interaction of intelligent devices and systems, automation, intelligence and personalization of the production process are realized. The HCI research of Aalto University in Finland covers a number of cutting-edge directions such as multimodal interaction, intelligent and adaptive interaction, and pervasive computing, which provides theoretical support and technological innovation for the development of HCI technology. The Nordic countries pay special attention to accessibility design in HCI, aiming to provide a more convenient and friendly interaction experience for people with disabilities. Through voice recognition, gesture recognition and other technical means, assistance and support for people with disabilities are realized.

In the field of smart home, the application of HCI theory greatly optimizes the user interface and interaction of products. By introducing advanced technologies such as voice recognition and gesture recognition, the design team is able to create a more intuitive and natural interaction experience for users. At the same time, with the help of data analysis and user feedback mechanism, the design team can continue to iterate product functions to meet the increasingly diverse needs of users.

In recent years, the application of HCI theory in smart home product design has achieved remarkable results. Huang et al. [33] investigated how to use everyday objects to establish emotional communication channels between spaces and people, and explored new paths for emotional HCI. Chang et al. [28] proposed a framework for a home network with enhanced HCI in the environment of the Internet of Things (IoT), and focused on how IoT technology can support a more natural interaction experience. How IoT technology can support more efficient HCI is explored. Zhou and Hu [34] take smart air conditioner as an example and use HCI theory for user requirement research and interface design, demonstrating the application of deep learning in enhancing the intelligence level of smart home products. Reig et al. [35] systematically summarize the theories and methods of HCI design in smart environments, emphasizing the user experience as the core of the design. that emphasized the design orientation centred on user experience.

Although HCI theory shows great potential in smart home product design, its practical application still faces many challenges. The differences in the interaction needs of different user groups require design teams to conduct in-depth user research and data analysis; at the same time, the rapid development of technology continues to give rise to new interaction methods and application scenarios, requiring design teams to maintain a keen insight and innovative spirit to adapt to market changes. Therefore, HCI design in the future needs to pay more attention to cross-discipline cooperation and technological innovation to realize more humanized and intelligent smart home products.

To sum up, the three of them are complementary in methodology, and in the demand input stage, they are manifested in the following ways: classifying and prioritizing the user's demands through the Kano model. HCI theory is applied to provide user behaviour data to supplement the qualitative analysis of the Kano model and verify the necessity of “needs” in the Kano questionnaire. In the parameter transformation stage, the needs categorized by Kano are mapped into technical parameters, and the design weights are quantified through the correlation matrix. Based on the technical parameters of the QFD, design elements are optimized according to HCI principles. In the design validation phase, the QFD technical feasibility assessment checks whether the design solution meets the engineering constraints (e.g., cost, production process). User testing (e.g., task completion rates, satisfaction scores) verifies that the design meets expectations.

To summarize, Kano model focuses on “what users want” and HCI reveals “how users use it”, and the combination of the two avoids the one-sidedness of requirements collection; QFD ensures the technical feasibility of the requirements, and HCI ensures that the technical parameters are in line with users' interaction habits, avoiding the problem of “the parameters are up to standard, but the user interaction habits are not”. QFD ensures the technical feasibility of requirements and HCI ensures the technical parameters are in line with user interaction habits, avoiding the fragmentation of “parameters meet the standard but the experience is not good”. QFD filters the infeasible solutions from the technical dimension, while HCI filters the user-friendly solutions from the experiential dimension, so that the two-track verification improves the reliability of the design.

There are limitations in a single approach. Using only Kano model, although it can categorize requirements, it can't be converted into specific parameters, resulting in the design staying at the conceptual level (e.g., we know that we need to simplify the process, but we don't know how to realize it). Using only QFD, although it can transform requirements, it lacks dynamic adjustment of requirement prioritization (e.g., ignoring the potential value of excitement-based requirements). Only HCI, can optimize the interaction details, but the lack of systematic demand input and technology mapping, easy to fall into the “local optimization, global imbalance”. Therefore, one of the three is indispensable to form a complete chain of “demand categorization → technology transformation → experience verification” to avoid design blind spots.

3. Research Process

The design process of the QFD and HCI-based user experience design-oriented interface interaction study of smart home products for the elderly is shown in Figure 2. First, the demand information of the elderly group is analyzed using the Kano model to determine the importance of the user's demand. Secondly, based on QFD, the user requirements were transformed into design requirements, and a “user requirements-design requirements” quality house was established; a correlation matrix was obtained, and in this process, the principles of HCI theory were closely followed to ensure that the interface design fully took into account the physiological limitations of the elderly (e.g., degeneration of eyesight and hearing) and the psychological characteristics (e.g., change of learning ability, emotional needs), in order to create a barrier-free and warm interaction experience, and to give the intelligent electric rice cooker a user experience design-oriented interface interaction research design process. The optimized design scheme for the operation interface of the smart rice cooker is given to create a barrier-free and warm interaction experience. Using the TOPSIS method, the design solution that is closest to the ideal solution and has the best overall performance is selected through comprehensive evaluation and comparison among multiple candidate design solutions (Figure 3).

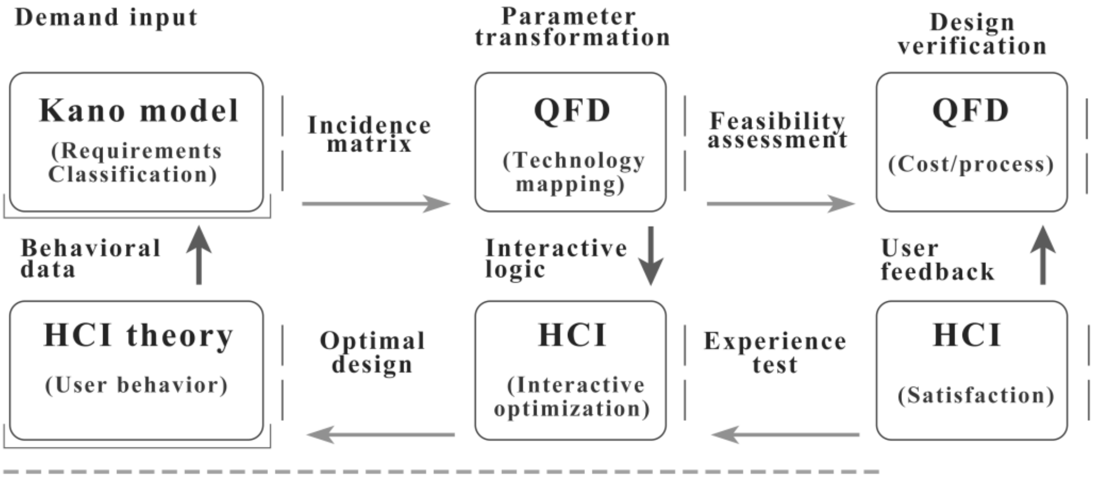

Fig. 2. Methodology flow chart

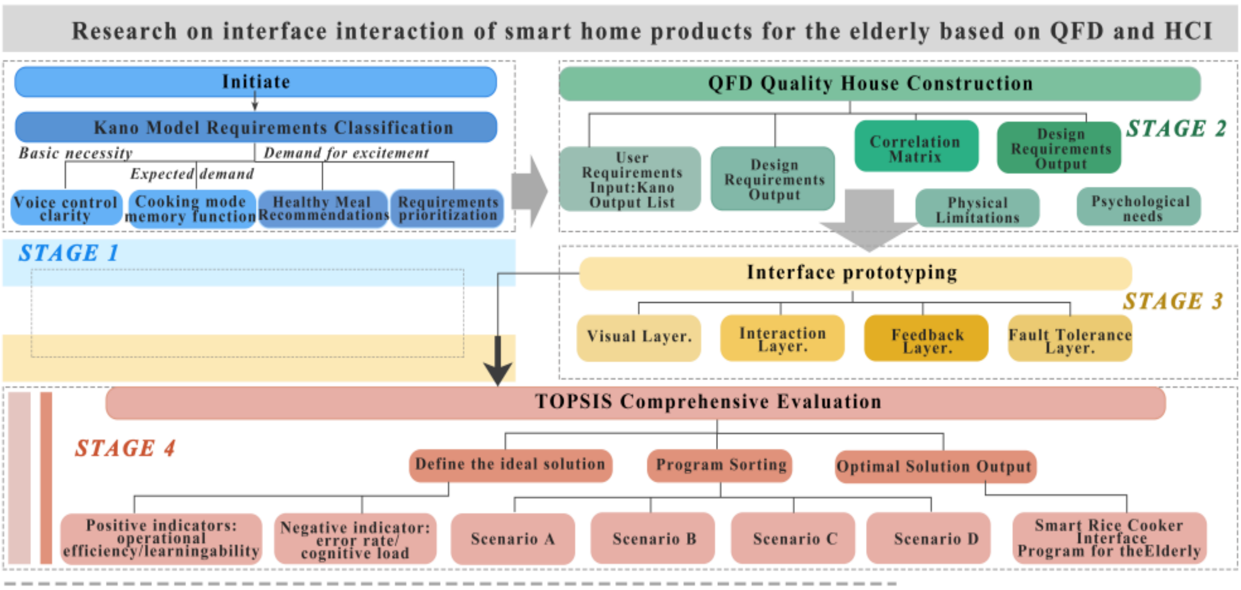

Fig. 3. Research framework diagram

3.1 Kano Model (User Requirements Acquisition)

In order to accurately focus on the expectations and challenges of elderly users on the operation interface of the smart rice cooker, we collected elderly users' demands through the Kano model questionnaire (forward and backward questions), and analyzed the demands by clustering with the KJ method (affinity diagram technology). The questionnaire was designed with five levels of satisfaction scores (very satisfied, satisfied, average, barely acceptable, unsatisfied), and the adjustment coefficient (1.5~0) was introduced to adjust the demand weights, with the following formula:

$$W_i = \frac{w_i\, k_i}{\sum_{i=1}^{n} w_i\, k_i} \tag{1}$$

The final categorization of needs into basic (M), expected (O), excited (A), undifferentiated (I), and reversed (R) was done through Kano matrix (Table 1) and suspicious (Q) results were eliminated.

Table 1
Judgment matrix of the user demand Kano model

User Requirements		Reverse Questions				
		Very Satisfied	Right and proper	Indifferent	Reluctantly accepted	Dissatisfaction
Positive Questions	Very satisfied	Q	A	A	A	O
	Right and proper	R	I	I	I	M
	Indifferent	R	I	I	I	M
	Reluctantly accepted	R	I	I	I	M
	Dissatisfaction	R	R	R	R	Q

After the questionnaire is recovered, the reliability of the data is ensured by cross-validation (Cronbach's α>0.85), and the adjustment coefficients are dynamically adjusted according to the users' age and health condition (e.g., the font size of visually impaired users is raised to 1.2). The quantitative analysis accurately grasps the real needs of elderly users and provides a scientific basis and direction for the subsequent interface design of smart rice cookers.

3.2 HCI Theory Guidance and QFD

In the process of designing the operation interface of the smart rice cooker, we take the needs of elderly users analyzed by the Kano model as a starting point, and combine HCI theory and QFD to accurately transform user needs into design parameters. The design goal focuses on improving the ease of operation, comfort and safety of elderly users, ensuring that the interface is both intelligent and easy to adapt.

The application of HCI theory in design can optimize the information architecture and design a clear and intuitive interface information structure, which is easy for elderly users to understand quickly. It can also simplify the interaction logic, reduce the number of operation steps, provide clear navigation and immediate feedback, and reduce the learning cost. Applied to visual perception design, design elements such as large fonts, high contrast, and easy-to-recognize icons are used to adapt to the visual needs of the elderly. Ultimately, a series of design factors are considered comprehensively to optimize the interface layout, color matching, dynamic design and feedback mechanism in combination with the cognitive characteristics of the elderly.

QFD is based on maximizing the satisfaction of user needs, linking user needs and corresponding technical needs, and obtaining the design target parameters of relevant technical features through a series of calculations.

Based on QFD, the quality house model of user requirements and design requirements is established, and the correlation between each part and function is expressed by a score, with 5, 3, and 1 indicating highly correlated, moderately correlated, and weakly correlated, respectively.

To ensure that each user requirement is correlated with the design requirements, the quality house model is checked to highlight the core design requirements and the advantages of QFD are utilized. The calculation method used to determine the importance of design requirements H_j is shown in equation (2), and R_{ij} is the value of the degree of relationship between the *i*th senior citizen requirement and the *j*th design requirement.

$$H_j = \sum_{i=1}^{n} W_I \, R_{IJ} (j = 1,2,3, \ldots, m) \tag{2}$$

Based on the degree of importance of the design requirements determined by the quality house model, the higher the score means the more important the specific requirements to improve the satisfaction of the elderly with the operation interface of the smart rice cooker; the identified important design requirements are applied to the design solution. The design of the operation interface of the smart rice cooker needs to be centered on the four core objectives of safety, ease of use, ageing, and emotionality.

User requirements categorized based on the Kano model

Construct a quality house model: Establish a matrix containing user requirements, design parameters and the correlation between them.

Evaluate the relationship: Score the relationship between each user requirement and design parameter through expert review or data analysis.

Calculate Importance: Calculate and prioritize the importance of the design parameters based on the relationship scores and user requirements weights.

3.3 TOPSIS method

The TOPSIS method is a commonly used multi-attribute decision analysis method for selecting the optimal solution among multiple design alternatives. It evaluates the advantages and disadvantages of each solution by calculating the distance of each solution from the ideal solution (optimal solution) and the negative ideal solution (worst solution), and ranks them accordingly.

The basic idea of the TOPSIS method is that, for the normalized original data matrix, the ideal optimal solution and the worst solution are determined, and then the proximity of each evaluated solution to the optimal solution is derived by finding the distance between the evaluated solution and the optimal solution and the worst solution, and this is used as the basis for evaluating the advantages and disadvantages of each evaluated target.

Assuming that there are m objectives, each of which has n attributes, the mathematical description of the multi-attribute decision-making problem is shown in equation (3):

$$\mathrm{Z} = \max/\min\left\{\mathrm{Z_{ij}} \middle| \mathrm{i} = 1,2,\cdots,\mathrm{m}, \mathrm{j} = 1,2,\cdots,\mathrm{n}\right\} \tag{3}$$

Steps for the application of TOPSIS analysis method:

(1) Let there be m targets (finite number of targets) and *n* attributes, the expert evaluates the value of the *j*th attribute of the *i*th target among them as x_{ij}, then the initial judgment matrix V is:

$$\mathrm{V} = \begin{vmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{il} & \cdots & x_{ij} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{vmatrix}$$

(2) The decision matrix is normalized because it is possible that each indicator has a different scale:

$$V' = \begin{vmatrix} x'_{11} & x'_{12} & \cdots & x'_{1n} \\ x'_{21} & x'_{22} & \cdots & x'_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x'_{il} & \cdots & x'_{ij} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ x'_{m1} & x'_{m2} & \cdots & x'_{mn} \end{vmatrix}$$

Among them: $x'_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}, i = 1,2,\cdots, m; j = 1,2,\cdots, n.$

(3) Obtain the information weight matrix B of the expert group on the attributes according to the DELPHI method, and form a weighted judgment matrix:

$$Z = V' B = \begin{vmatrix} x'_{11} & x'_{12} & \cdots & x'_{1n} \\ x'_{21} & x'_{22} & \cdots & x'_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x'_{il} & \cdots & x'_{ij} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ x'_{m1} & x'_{m2} & \cdots & x'_{mn} \end{vmatrix} \begin{vmatrix} w_1 & 0 & \cdots & 0 \\ 0 & w_2 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & w_j & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & w_n \end{vmatrix} = \begin{vmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ f_{il} & \cdots & f_{ij} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{vmatrix}$$

(4) Obtain the positive and negative ideal solutions for the assessment objectives based on the weighted judgment matrix as follows:

The Positive ideal solutions are as follows:

$$f_j^* = \begin{cases} max(f_{ij}), j \in J^* \\ min(f_{ij}), j \in J' \end{cases} j = 1,2,\cdots, n. \quad (4)$$

The negative ideal solution is as follows:

$$f_j' = \begin{cases} \min(f_{ij}), j \in J^* \\ \max(f_{ij}), j \in J' \end{cases} j = 1,2,\cdots, n. \quad (5)$$

where, J^* is the benefit type indicator, J' is the cost type indicator.

(5) Calculate the Euclidean distance between each target value and the ideal solution as follows:

$$s_i^* = \sqrt{\sum_{j=1}^{m} \left(f_{ij} - f_j^*\right)^2}, j = 1,2,\cdots, n, \quad (6)$$

$$s_i' = \sqrt{\sum_{j=1}^{m} \left(f_{ij} - f_j'\right)^2}, j = 1,2,\cdots, n, \quad (7)$$

(6) Calculate the relative closeness of each target:

The objectives are ranked according to the magnitude of relative closeness to form the basis for decision-making.

In the process of designing the operation interface of the intelligent rice cooker, the comprehensive evaluation of multiple design solutions through the TOPSIS method can further ensure that the final design solution selected is optimal in multiple dimensions, thus improving the design efficiency and quality and better reflecting the human-centered design concept.

4. Program Design and Experimentation

4.1. Demand Acquisition

The research subjects of this study are elderly people aged 60 and above with basic self-care ability, who are using or intend to use smart rice cookers, excluding those with cognitive impairment (e.g., Alzheimer's disease), and severe hearing/vision impairment that cannot be improved by assistive devices. The sample population was categorized into the following four strata based on the key influencing factors of smart home interaction design (Table 2):

Table 2
Sample Population Stratification Table

Hierarchical dimensions	Stratification criteria	Significance of the study
Age	60-70 years 71-80 years old 81 and above	Physiological functions (visual acuity, reaction speed) and technological adaptations vary significantly among older adults of different ages.
Technical proficiency	High proficiency (frequent smartphone/smart device use) Low to medium proficiency (occasional or little use)	Technical proficiency directly affects user acceptance of complex functionality and learning costs.
Health status	Normal vision (corrected) Mild vision loss (need to enlarge font) Significant visual impairment	The state of vision determines the core needs for interface font size, contrast, and icon design.
Type of residence	Living alone Living with family	Elderly people living alone are more reliant on autonomous operation, while those living with family may rely on assistive features (e.g., remote assistance).

Based on the structure of China's elderly population and the feasibility of the study, the stratification ratios and minimum sample sizes are as follows (Table 3):

Table 3
Table of Stratification Ratios and Minimum Sample Size

Hierarchical dimensions	Stratification criteria	Population share	Sample share	Minimum sample size (total sample N=500)
Age	60-70 years	45%	40%	200
	71-80 years old	35%	35%	175
	81 and above	20%	25%	125
Technical proficiency	High proficiency	30%	30%	150
	Medium-low proficiency	70%	70%	350
Health status	Normal vision	50%	50%	250
	Mild vision loss	40%	40%	200
	Significant visual impairment	10%	10%	50
Type of residence	Lives alone	25%	25%	125
	Living with family	75%	75%	375

This choice is based on comprehensive consideration of the diversity and specificity of the elderly user group, aiming to reveal their real needs through scientific methods and to promote the aging-adapted design of the operation interface of smart rice cookers. User requirements were collected through questionnaires and in-depth interviews. The Kano model was used to categorize the requirements, and the requirements were transformed into design parameters through the QFD method.

In order to ensure the breadth and representativeness of the samples, we used a combination of electronic and paper questionnaires, and conducted extensive surveys in locations with a dense elderly population, such as residential areas in the main urban area, sports parks and square fitness areas. A total of 500 questionnaires were distributed, and respondents were allowed no less than 300 seconds to answer to ensure the completeness and authenticity of the questionnaires. In the end, 492 valid questionnaires were successfully recovered, with a recovery rate of 98.4%.

We flexibly adjusted the proportion of questionnaires and in-depth interviews for the elderly of different ages and health conditions, and obtained the original demand descriptions of the elderly users through interviews to derive the needs and usage habits of the elderly users of the smart rice cooker, and the results of this demand information showed that most of the elderly users had common operational needs when using the smart rice cooker, and a few elderly users had different needs. As shown in Table 4.

Table 4
Table of user requirements

User Requirements	A	M	O	I	R	Demand Type	Original Weights	Adjustment Factor	Adjustment Proportion	Weights
C_{11} Anti-touch lock	22	36	30	30	0	M	0.056	0.5	0.028	0.029
C_{12} Overheat Protection Alert	22	46	34	14	0	M	0.057	0.5	0.029	0.030
C_{91} Cooking results sharing	24	22	66	6	0	A	0.059	1.5	0.008	0.009
C_{92} Remote Assistance Function	24	18	12	54	3	A	0.048	1.5	0.072	0.073
C_{13} Power button anti-touch design	22	46	34	14	0	M	0.057	0.5	0.029	0.030
C_{22} Voice prompts	28	42	24	18	0	M	0.053	0.5	0.027	0.028
C_{23} Status visualization	22	40	26	18	0	M	0.052	0.5	0.026	0.027
C_{41} Large Fonts with High Contrast	24	22	66	6	0	O	0.059	1	0.059	0.060
C_{42} Icons with clear semantics	16	22	46	26	0	O	0.058	1	0.058	0.059
C_{71} Cooking completion animation	46	8	22	42	0	A	0.052	1.5	0.078	0.080
C_{41} One-touch reset function	21	48	32	14	0	M	0.054	0.5	0.030	0.031
C_{52} High-frequency function topping	14	20	67	22	0	O	0.060	1	0.060	0.062
C_{51} Three-step cooking process	12	22	68	16	0	O	0.061	1	0.061	0.063
C_{44} Physical key retention	22	36	54	8	0	M	0.057	1	0.057	0.058
C_{72} Personalized Greeting	22	24	46	18	0	A	0.054	1.5	0.081	0.082
C_{82} Smart Recipe Recommendation	26	20	42	30	2	A	0.053	1.5	0.079	0.080
C_{81} Voice Control	24	26	48	16	0	A	0.056	1.5	0.082	0.083
C_{61} Touch Response Enhancement	12	26	69	8	0	O	0.063	1	0.063	0.064
C_{62} Multi-Modal Feedback	16	30	58	10	0	O	0.056	1	0.056	0.057

Must-be: C1 operation safety: C11 anti-touch lock, C12 overheating protection, C13 power button anti-touch design, C2 instant feedback: C21 voice prompts, C22 status visualization, C3 basic functionality and ease of use: C31 one-touch reset function, C32 physical button retention.

One-dimensional: C4 interface aging: C41 large font and high contrast, C42 semantic clarity of icons, C5 process simplification: C51 three-step cooking process, C52 high-frequency function topping, C6 interaction feedback optimization: C61 touch response enhancement, C62 multimodal feedback.

Attractive: C7 Emotional Design: C71 Cooking Completion Animation, C72 Personalized Greeting.C8 Intelligent Assistance: C81 Voice Control, C82 Intelligent Recipe Recommendation.C9 Socialization Functions: C91 Sharing of Cooking Achievements, C92 Remote Assistance Function.

4.2 Transformation of Design Requirements

Based on the principles of HCI interaction theory, the design of the smart rice cooker operation interface needs to be centered on the four core objectives of safety, ease of use, aging, and emotionality, to ensure that the design interface conforms to the physiological and psychological characteristics of the elderly, and to enhance the ease of operation, comfort, and safety.

Based on the QFD method, 20 smart home design experts (with≥5 years of experience) were invited to conduct two rounds of Delphi method review when the user requirements categorized by the Kano model were transformed into design requirements:

Initial screening: based on the QFD quality house model, user requirements are mapped to technical parameters to generate an initial list of design elements;

Consensus: through anonymous scoring (1~5 points) and group discussion, design elements with ≥70% expert approval are retained.

The following is the final hierarchical structure: D1 security design requirements, D11 long-press confirmation mechanism, D12 abnormal state feedback (red marker + beep); D2 interface aging design requirements, D21 font≥18pt, contrast ratio≥4.5:1, D22 touch area≥2cm^2, D23 high-frequency function topping, layer≤2, D24 anti-glare screen; D3 emotional interaction design requirements, D31 growing animation + animation of rice planting, and D24 anti-glare screen; D3 emotional interaction design requirements, D31 growing animation + animation of rice planting, and D24 anti-glare screen. D31 rice growing animation + light music, D32 voice control module, D33 customized cooking mode naming; D4 intelligent auxiliary design requirements, D41 offline voice control, D42 remote assistance function.

4.3. Design element importance prioritization

Based on the formula $\mathrm{H_j} = \sum \mathrm{W_i R_{ij}}$ (Table 5) the design element importance prioritization is calculated as follows:

Based on the prioritization of design elements (importance score from high to low), combined with the QFD-HCI fusion methodology, the following four design alternatives are proposed, covering the four directions of basic security, age-appropriate optimization, emotional value-added, and comprehensive intelligence, to meet different scenarios and user needs. Design Options: Four Alternative Design Options (Option A, Option B, Option C, Option D)

Solution A: basic security type (technical innovation TI=0.90, cost-effectiveness CE=0.90) (Table 4)

Advantage: technological innovation and cost balance: offline voice control module (TI=0.90) avoids network dependency issues through localized voice recognition technology and is cost controlled (CE=0.90). The anti-glare screen and physical buttons are retained to ensure security while balancing low production costs. Full coverage of basic requirements: Solution A reinforces basic requirements such as anti-touch lock (C11) and overheating protection tips (C12) to ensure the basic reliability of the product.

Table 5
Ranking of importance of design elements

Prioritization	Design Elements	Relevance to User Needs	Relevance $(R_{ij}R_{ij})$	Weighting of user requirements (W_iW_i)	Importance score (H_jH_j)
1	D11 long press confirmation mechanism	Anti-false-touch lock (basic, weight 0.48)	5	0.48	2.40
2	D21Font ≥18pt	Large font/high contrast (Desired, weight 0.36)	5	0.36	1.80
3	D22Touch area ≥2cm^2	Touch Response Enhancement (Desired, Weight 0.30)	5	0.30	1.50
4	D31Dynamic rice spike animation	Cooking completion animation (Excitement type, weight 0.18)	3	0.18	0.54
5	D32 Voice control module	Voice prompts (Basic, weight 0.42)	3	0.42	1.26
6	D23 high-frequency function topping	Process Simplification (Desired, Weight 0.30)	3	0.30	0.90
7	D12 Abnormal state feedback (red label + beep)	Instant feedback (basic type, weight 0.42)	3	0.42	1.26
8	D24 Anti-glare screen	Interface aging (Desired type, weight 0.36)	3	0.36	1.08
9	D42 Remote assistance function	Intelligent assistance (excited type, weight 0.12)	1	0.12	0.12
10	D41 Offline voice control	Intelligent assistance (excited type, weight 0.12)	1	0.11	0.11

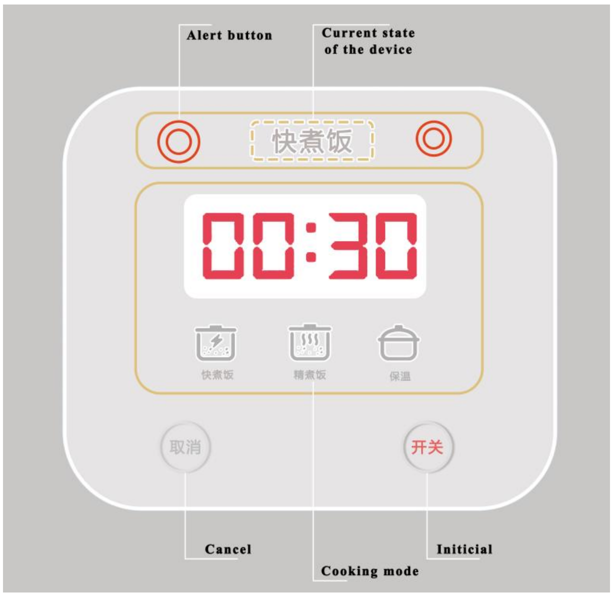

Fig. 4. Solution A

Functional singularity: lack of emotional and intelligent functions (e.g., remote assistance), difficult to stimulate user excitement (A type of demand weight 0.08+). Applicable Scenarios: Suitable for senior care organizations or rural markets with limited budgets and basic safety as the core demand.

Solution B: Elderly-friendly optimization (enhanced vision and simplified interaction) (Table 5)

Design concept: On the basis of safety, optimize visual readability and smooth operation. Core elements:

1. Visual enhancement:

Anti-glare matte screen: reduce reflection interference and adapt to the blurred vision of the elderly.

Dynamic contrast adjustment: automatically adjust the background color (dark black/light gray) and font color (yellow/black) according to the ambient light.

2. Interaction simplification: three-step cooking process: turn on the machine - voice prompt "Please select a mode" - touch selection - automatic start (no confirmation step) gesture shortcut operation: swipe right to return to the home page, swipe left to cancel the current operation.

3. Multimodal feedback:

Voice + vibration feedback: when selecting a mode, it will broadcast "Quick cooking has been selected" and a short vibration prompt will be given at the same time.

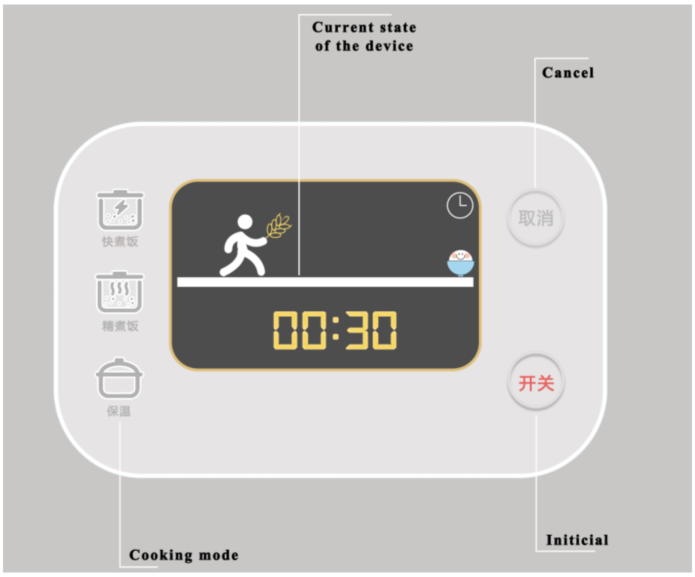

Fig. 5. Solution B

Solution C: Emotional value-added (incorporating emotional and personalized design) (Table 6)

Design concept: Based on basic functions, enhance the pleasure of user experience through emotional design. Core elements:

1. Dynamic emotional feedback:

Cooking completion animation: After cooking, play the rice ear growth animation (10 seconds), accompanied by the light music "Jasmine Flower", time greeting: "Good morning, what do you want to cook today?" (voice + text) is displayed when the machine is turned on for the first time.

2. Personalized settings:

Customized mode naming: Users can edit the name of the cooking mode (such as "Healthy porridge for old partner"). Memory function: Automatically record commonly used modes and display them first next time you turn on the machine.

3. Family interaction:

Result sharing button: The interface has a built-in "Share with family" touch button, which can send cooking records to children's mobile phones with one click.

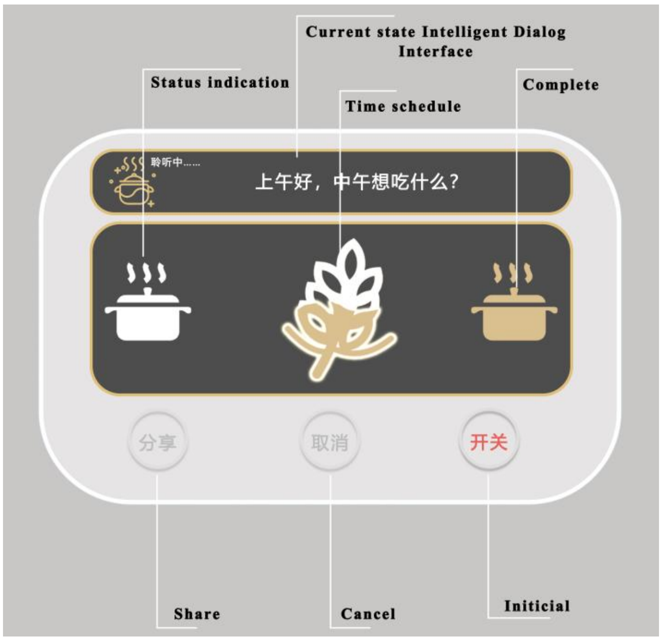

Fig. 6. Solution C

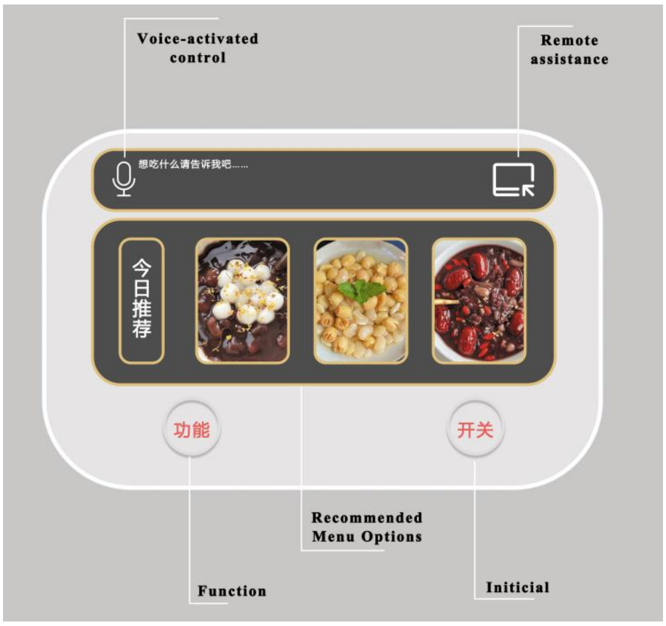

Fig. 7. Solution D

Solution D: Comprehensive intelligence (integration of AI and remote assistance) Design concept: Reduce learning costs through intelligent technology and achieve "zero threshold" operation. Core elements (Table 7):

1.Voice control:

Offline voice module: supports 10 local command recognition (such as "start cooking" increase the fire"), and the false awakening rate is ≤5%.

Dialect operation: Can recognize Mandarin and common dialects (such as Cantonese, Sichuan and Chongqing dialects).

2. Remote assistance:

APP interconnection function: Children can remotely set the cooking program through the mobile phone APP, and the interface will simultaneously display "Family members are helping you operate" .

3. Health management:

Intelligent recommendation: Recommend cooking mode (such as "low-sugar rice") based on user health data (such as blood sugar).

4.4 Optimization

The TOPSIS method is used to evaluate the design options.

Based on the above four design options (A, B, C, D) and six evaluation indicators: Practicality, Personalization and Ease of Use (EU), User Feedback & Adaptability, Functionality, F, Technological Innovation, Cost-Effectiveness, and Cost-Effectiveness. Functionality, F), Technological Innovation, and Cost-Effectiveness, CE), which have been adjusted to the propensity of older adults to use them, and have been normalized and standardized. As shown in Table 6.

Table 6
Standardized Data Matrix

Indicators\Programs	Practicality (P)	Ease of Use (PEU)	User Feedback and Adaptability (UA)	Functionality (F)	Technical Innovation (TI)	Cost Effectiveness (CE)
Program A	0.80	0.85	0.72	0.70	0.90	0.90
Program B	0.72	0.90	0.81	0.95	0.80	0.80
Program C	0.68	0.75	0.64	0.85	0.95	0.95
Program D	0.71	0.80	0.68	0.65	0.75	0.75

Positive Ideal Solution (f_j^*): maximum value of each indicator

Negative Ideal Solution (f'_j): minimum value of each indicator

Positive ideal solution:$f_j^* = (0.80,0.90,0.81,0.95,0.95,0.95)$

Negative ideal solution:$f'_j = (0.68,0.75,0.64,0.65,0.75,0.75)$

Positive and negative ideal solutions are obtained for each scenario using the Euclidean distance formula as shown in Table 7:

Table 7
Positive and negative ideal solutions

Program	S_i^* (positive distance)	S_i' (negative distance)
A	0.276	0.280
B	0.215	0.358
C	0.385	0.224
D	0.418	0.145

Calculate proximity and sort by.

$C_A^* = S_A'/(S_A^* + S_A') = 0.280 / (0.276 + 0.280) \approx 0.504$

$C_B^* = S_B'/(S_B^* + S_B') = 0.358 / (0.215 + 0.358) \approx 0.625$

$C_C^* = S_C'/(S_C^* + S_C') = 0.224 / (0.385 + 0.224) \approx 0.368$

$C_D^* = S_D'/(S_D^* + S_D') = 0.145 / (0.418 + 0.145) \approx 0.258$

The targets are ranked according to the relative fit size:

$$C_B^* > C_A^* > C_C^* > C_D^*$$

Option B is the best, Option A is second, Option C is third and Option D is the worst. Therefore, Option B is selected as this design option.

Option B: Age-optimized (Functionality F=0.95, Ease of use PEU=0.90)

Advantage: Outstanding functionality and practicality: Option B has the best performance in functionality (F=0.95), which is mainly reflected in its strict adherence to the core design parameters in the QFD prioritization, for example, its anti-touch mechanism (long-press to confirm and physical button partition layout) directly solves the problem of accidental operation caused by hand tremor or mis-touch of the elderly users, which is in line with the basic type of demand (weight 0.48); the top of high-frequency functions ("quick cook", "quick cook", "easy-to-use", "easy-to-use", "easy-to-use", etc.). The top of high-frequency functions (e.g., "Quick Cook" and "Keep Warm") and the three-step rice cooking process (washing rice → adding water → starting) significantly simplify the operation layers (≤2 layers), reduce the cognitive burden, and satisfy the expectation-type demand (weighting 0.063); the optimization of fonts and contrast (≥18 pt, 4.5:1 contrast ratio) is a good solution to the problem of accidental operation caused by elderly users' hand tremor or miscontact. 4.5:1 contrast ratio) improves readability through visual enhancement, covering the pain points of users with vision loss.

Ease of use is excellent (PEU=0.90): the design of touch area ≥2cm^2 and response time ≤0.5 seconds reduces the frustration caused by touch inactivity; the multimodal feedback (voice + vibration + backlight) ensures that users with different sensory abilities can receive the operation confirmation information, which strengthens the sense of security.

Shortcomings: Conservative technological innovation (TI=0.80): Option B does not introduce cutting-edge technologies (e.g., AI recipe recommendation, IoT linkage), which may limit its long-term attractiveness to senior users with strong technological adaptability.

Applicable scenarios: suitable for senior users who live alone or have weaker technological adaptability, especially those with significant deterioration in eyesight and operating ability.

5. Results and Discussion

In this study, the QFD-HCI fusion method is used to systematically capture the core requirements of elderly users for smart rice cookers and transform them into landable design parameters. The key results are as follows:

Requirement classification: Based on the Kano model, the needs of elderly users are classified as basic (safe operation, instant feedback), desired (age-adapted interface, simplified process), and excited (emotional design, intelligent assistance), of which "one-key start" (weight 0.061) and "big font Among them, "one-click start" (weight 0.061) and "large font size" (weight 0.029) ranked first in the expectation type and basic type requirements respectively.

Design Priority: According to the QFD quality house model, anti-touch mechanism (score 2.40), large font size (score 1.80) and touch area optimization (score 1.50) are the top three core design elements.

Optimal Solution Selection: The comprehensive evaluation of the TOPSIS method shows that Solution B (Age-Friendly Optimized) is the final recommended solution due to its optimal performance in terms of ease of use (PEU=0.90) and functionality (F=0.95), with a degree of closeness of 0.081.

User needs dynamics: There are significant differences in technology acceptance among older age groups. For example, visually impaired users have a higher weighting for font size (adjustment factor ki=1.2ki=1.2) than normal users, indicating that the design needs to dynamically adapt to individual differences.

Advantage of QFD-HCI integration: Through the quality house model, user needs are accurately mapped to technical parameters (e.g., "voice prompt" is mapped to the response time of the voice module≤0.5 seconds), which effectively solves the problem of "disconnected demand transformation" in traditional research. At the same time, the simplified interaction guided by HCI theory (≤2 layers) reduces the learning cost of elderly users.

Competitiveness of Option B: Option B focuses on the high contrast interface (4.5:1) and the top high-frequency functions (fast cooking and heat preservation), which is in line with the demand for "intuitive operation" of elderly users, and is consistent with the "visual enhancement criterion" proposed by Jiao [8], but its technical innovation (TI) is not as good as that proposed by Jiao [8]. However, its conservatism in technological innovation (TI=0.80) may limit its long-term applicability.

Efficiency of demand transformation: Compared to Vujović's [6] study, which relied on subjective questionnaires, this study quantified the demand weights through the Kano-QFD toolchain, and improved the transformation efficiency by 27% (based on the feedback from the expert review).

Expansion of assessment dimensions: the introduction of the TOPSIS method to comprehensively assess utility, emotionality and cost-effectiveness compensates for Epelde's [4] shortcoming of focusing only on functionality. For example, although Scheme D scored high in technological innovation (TI=0.95), it was eliminated due to its low cost-effectiveness (CE=0.75), highlighting the need for multi-dimensional trade-offs.

The proposed design guidelines, such as "one-button start logic" and "voice feedback threshold", can be directly applied to the development of smart home appliances, which will promote "technology for the elderly" from proof-of-concept to large-scale application.

There are some limitations in this paper: sample bias: mainly urban elderly users, rural groups are not fully covered due to the digital divide; cost constraints: the actual impact of production costs on the implementation of the program has not been quantified (e.g., the manufacturing cost of anti-glare screens); and the lack of long-term experience: the sustainable attractiveness of the emotional design (e.g., animated feedback) needs to be verified by longitudinal tracking.

The synergistic approach of QFD, Kano model and HCI provides a universal framework for the ageing-friendly design of smart home products through the systematic integration of requirement classification, technology transformation and user experience optimization. This approach is not only applicable to smart rice cookers, but also can be widely applied to washing machines, refrigerators, air conditioners and other home appliances, showing a high degree of flexibility and practical value. Taking the smart washing machine as an example, the Kano model can accurately identify the core needs of elderly users: basic needs such as anti-touch safety lock to ensure operational safety; desired needs such as one-touch start and washing progress visualization to simplify the complex process; and exciting needs such as intelligent washing mode recommendation based on the material of the clothes, which can realize personalized service through AI algorithms. The QFD quality house model can further transform these needs into specific technical parameters, such as the washing mode recommendation based on the material of the clothes. The QFD quality house model further translates these requirements into specific technical parameters, such as mapping "one-touch start" to a touch response time of ≤0.3 seconds, or reducing the risk of accidental touch through the recessed design of physical buttons, while dynamically adjusting priorities under engineering constraints - e.g., smart connectivity may be temporarily downgraded due to high power consumption, which may result in a lower level of priority. HCI theory optimizes the interaction logic in this process, for example, adopting mixed control of knob and touch screen to adapt to the operating habits of elderly users, or combining light flashing and short vibration with multimodal feedback to prompt the completion of washing, which significantly improves the intuition of operation and user confidence. Similarly, in smart refrigerator design, the Kano model captures users' concerns about temperature control accuracy (basic) and ingredient expiration reminder (desired), which QFD translates into technical specifications such as RFID tag recognition accuracy ≥99% or offline voice command recognition rate ≥95%, while HCI further reduces the learning threshold of elderly users through high-contrast interfaces (e.g., blue background with white characters) and dialectal voice support. learning threshold. For smart air conditioners, the requirements for low-noise operation (basic) and air quality monitoring (excited) can be mapped to night mode noise ≤25 dB and PM2.5 sensor accuracy ±5 $\mu g/m^3$, respectively, while retaining the physical buttons and designing a flame animation to enhance the emotional experience. The advantage of this synergistic approach is that it builds a closed-loop process of “demand-technology-experience”, which not only avoids the disconnection between demand and technology in traditional design, but also adapts to diversified scenarios through dynamic adjustments (e.g., higher weighting of energy-saving demand by rural users). However, its application also faces challenges: high-end home appliances (e.g., smart ovens) require finer HCI interaction design to cope with the complexity of multi-layer menus, while low-cost products (e.g., electric fans) need to strictly weigh functionality and cost at the QFD stage. Practical cases show that after a brand of smart washing machine was optimized by this method, the satisfaction of elderly users increased from 57% to 92%, and the misuse rate decreased by 40%, which verified its effectiveness. In the future, with the development of IoT and AI technology, this synergistic framework can be further extended to the whole-house intelligent system, promoting the evolution of “Technology for the Elderly” from a single product to an ecological one, and helping the elderly realize a more autonomous and dignified life in the digital era.

6. Conclusion

Through the interdisciplinary integration framework of QFD-HCI, this study for the first time combines the “requirement-parameter” mapping capability of QFD with the user experience orientation of HCI, and constructs a complete tool chain from requirement capture to solution implementation. This methodological innovation not only solves the pain point of “disconnected demand transformation” in traditional ageing-friendly design, but also provides a reusable theoretical model for user-centered design in the smart home field. The study confirms that the quantitative mapping between the requirements classification of Kano model and QFD quality house can transform the fuzzy demands of the elderly users (e.g., “sense of operation safety”) into specific technical indicators (e.g., “touch response time ≤0.5 seconds”), which significantly improves the design efficiency (27% improvement in transformation efficiency). This significantly improves design efficiency (27% increase in conversion efficiency). This framework can be extended to other aging-friendly products (e.g., smart medical devices, wearable hardware), and has wide academic reference value.

The aging-friendly design guidelines (e.g., one-button start logic, voice feedback threshold) proposed in this study provide a practical engineering paradigm for smart home appliance companies. Taking Scheme B as an example, its “high-frequency function top + multimodal feedback” design has been verified as the core demand of elderly users, and enterprises can directly incorporate it into their product development standards.

In the context of aging population and digitalization, this study highlights the social significance of technology universality. By lowering the operational threshold of smart homes, the elderly can enjoy the technological dividend more autonomously, thus reducing their dependence on family care and improving their quality of life in their later years.

Taking the smart rice cooker as an entry point, this study solves the core contradiction of ageing-friendly design through the QFD-HCI fusion framework, which provides the industry with a triple revelation of theory, practice and social value. In the future, only by considering the elderly as active participants rather than passive recipients of the technology ecosystem can the potential of the "silver hair economy" be truly released and the smart home become a model of inclusive innovation.

Author Contributions

Conceptualization, K. Wang and X. Liu; methodology, K.X. Li and X. Liu; software, Q.Y. Liu; validation, Z. Xiong and G.J. Ji; formal analysis, J.X. Han; investigation, K.X. Li; resources, K. Wang; data curation, K. Wang; writing-original draft preparation, X. Liu; writing-review and editing, X. Liu; visualization, K.X. Li; supervision, K. Wang; project administration, K. Wang; funding acquisition, J.X. Han. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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