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Research on the Interactive Design of Smart Home Interface for the Elderly Based on QFD and HCI

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Abstract: In an aging society, the interface design of smart home products is crucial to the quality of life of the elderly. This paper combines Quality Function Deployment (QFD) and Human-Computer Interaction (HCI) theories, taking smart washing machines as an example, to explore new paths for the interface design of smart home products for the elderly. An interdisciplinary approach is adopted to construct a design process centered on elderly users, introduce the Kano model to classify requirements, realize the mapping and sorting of requirements to design parameters, and adopt the PUGH model for comprehensive evaluation. This study provides practical and theoretical support for the interface design of smart home products for the elderly.

Keywords: Smart home and aging; Integration of QFD and HCI; Interface interaction; Design optimization

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1. Introduction

As the global aging trend intensifies, smart home technology provides opportunities to improve the quality of life of the elderly. However, the elderly often feel confused when using smart home products such as smart washing machines because the product interface design does not fully consider their particularities. Currently, products on the market pursue diverse functions and modern interfaces, but ignore the needs of the elderly user group. To improve this situation, domestic and foreign scholars have conducted in-depth explorations on the aging-friendly design of smart home products in recent years. Zhang *et al.* proposed to enhance the perception and operation ability of elderly users of smart products by introducing color sequence memory and optimizing icon design [1,2].

These methods aim to make it easier for elderly users to understand and use smart home products by improving interface design. Wang *et al.* focused on lowering the operational threshold between elderly users and smart products through non-contact interaction methods such as voice recognition and gesture control [3]. These non-contact interaction methods can reduce the physical burden of elderly users during use and improve the convenience and safety of operations. However, these studies mostly remain at the theoretical level, and the needs of elderly users vary greatly. The design needs to consider multiple factors comprehensively, which is complex and challenging.

Therefore, this study focuses on the difficulties faced by elderly users in using smart washing machines, integrates QFD and HCI theories, and proposes targeted interface interaction design solutions, aiming to optimize the design of smart washing machines, improve the convenience and happiness of elderly users, and provide practical guidance and theoretical support for aging-friendly design.

2. Literature review on the design of smart home products for the elderly

The current situation of the design of smart home products for the elderly shows a trend from automation to more humanization, but the adaptability to the special needs of elderly users is still insufficient. Although the early smart home washing machines have achieved automation in the washing function, their operation interface is complex and puts high demands on the user's interface operation ability, which often brings confusion and anxiety to elderly users with visual impairment and memory loss. Therefore, designing simpler, more intuitive, and convenient products has become the key to the design of smart home products for the elderly.

To this end, to improve the user experience of smart home products, especially for the elderly user group, the QFD method has been widely used in the design of smart home products. Studies have shown that the QFD method can effectively optimize the user experience of smart home products and achieve a sustainable user experience optimization strategy [4]. The Fuzzy-QFD model combined with grey correlation analysis further analyzes the relationship between the needs of the elderly and technical characteristics, providing strong support for the design of the elderly care service platform [5]. At the same time, the Kano model identifies the levels of needs of elderly users, including basic needs, expected needs, and exciting needs, thereby guiding product design and improving the overall performance and user experience of the product. Cheng *et al.* used the Kano model to classify the functional requirements of the main home automation equipment, providing empirical support for the functional planning and design optimization of smart home products [6]. Liu *et al.* took connectivity as the core element to build a smart home system for the elderly in the future and demonstrated the application effect of the Kano model in improving product user experience and happiness [7].

HCI theory also plays an important role in the design of smart home products for the elderly. Huang *et al.* introduced advanced technologies such as voice recognition and gesture recognition to create a more natural and intuitive interactive experience [8]. At the same time, with the help of data analysis and user feedback mechanisms, the design team can continuously optimize the interface layout and operation process to make it more in line with the usage habits and needs of elderly users. Zhou and Hu, along with Reig have studied how to reduce the difficulty and cognitive load of elderly users when using smart home products by optimizing the position and size of the touch screen and simplifying the operation gestures [9,10].

In addition, with the increasing application of miniaturized, basic sensors and voice control technologies in smart homes, these technologies also provide elderly users with a more convenient and safe home environment. The research of Tapia *et al.* demonstrated the great potential of sensors in improving the convenience and safety of the lives of the elderly [11]. Portet *et al.* studied and developed a system based on voice recognition, which promoted communication between the elderly and family members through remote voice control and enhanced the intelligent experience of the home environment [12].

In terms of environmental intelligence and multimodal interaction, Epelde *et al.* combined customized graphical interfaces, intuitive navigation menus, and multimodal interaction methods to build a natural and barrier-free interactive environment for the elderly [13]. This interactive method not only improves the user experience of elderly users but also provides them with more abundant interactive options.

In summary, QFD, Kano model, HCI theory, and smart home design direction play an important role in the design of the interactive interface of smart washing machines, and will continuously improve the user experience of the elderly.

3. Research methods

Firstly, the Kano model is used to analyze the demand information of the elderly group and determine the importance of user needs. Secondly, based on QFD, user needs are converted into design needs, the "user needs-design needs" quality house is established, and the correlation matrix is obtained. In this process, the theoretical principles of human-computer interaction (HCI) are closely followed to ensure that the interface design fully considers the physiological limitations (such as vision and hearing deterioration) and psychological characteristics (such as changes in learning ability and emotional needs) of the elderly, to create a barrier-free and warm interactive experience, and give an optimized design scheme for the operation interface of the smart washing machine.

Using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, through comprehensive evaluation and comparison among multiple candidate design schemes, the design scheme closest to the ideal solution and with the best overall performance is selected. Finally, according to the PUGH concept selection method (or Pros and Cons Charting), the selected optimal scheme is further verified and refined, and its potential advantages and disadvantages are deeply analyzed. Through iterative optimization, it is ensured that the design scheme is not only highly practical, but also smooth in actual operation, and finally, the best design scheme is determined and implemented.

4. Design and experiment

4.1. Demand acquisition

This study focuses on the elderly group aged 60 and above who have experience in using smart washing machines, and a total of 127 representative users were selected. Based on relevant research and authoritative reports on geriatric psychology and physiology, the target users are divided into four levels: young healthy period (60–64 years old), middle-aged self-care period (65–74 years old), elderly assistance period (75–84 years old) and super-elderly care period (over 85 years old). At the same time, differences in gender, region, economic level, and educational background are considered to ensure the diversity and representativeness of the sample.

Through questionnaires and in-depth interviews, the needs and usage habits of elderly users for smart washing machines are obtained. The Kawakita Jiro (KJ) method is used to classify the information, and 6 first-level needs and 18 second-level needs are obtained.

(1) Operational requirements: Large font display, the laundry process is simplified, one-click laundry operation.

(2) Security requirements: Anti-mistouch design, emergency stop.

(3) Visually friendly needs: Height contrast, the icons are clear, and the color is mild.

(4) Personalization: Customize your laundry routine and memory function.
(5) Voice accessibility features: Voice control and verbal feedback.
(6) Guidance and tips: How-to guide, error message, stability alerts.

4.2. Demand analysis and classification

The Kano model was used to classify the needs of elderly users. A total of 500 questionnaires were distributed, and 492 valid questionnaires were collected, with a collection rate of 98.4%. Based on quantitative analysis, essential needs, expected needs, and attractive needs were obtained.

(1) Essential needs include: C11 Large font and clear interface, C12 Simplified operation process, C22 The icons are clear, C23 The color is mild, C41 Anti-mistouch design.
(2) Expected needs include: one-dimensional requirements like C13 One-click laundry operation, C21 Height contrast, C31 Voice assistance function, C41 Anti-mistouch design, C43 Stability prompt, C44 Environmental protection and energy saving design, C42 Emergency stop button, C61 Operation guide, C62 Error prompt and solution.
(3) Attractive needs include: C33 Intelligent interconnection function, C52 Memory function, C51 Personalized customization service, C53 Healthy washing mode.

There are no different needs and reverse requirements.

4.3. Design transformation and priority setting

Based on HCI interaction theory, QFD is used to transform user needs into design requirements and build a quality house model. Design requirements include six directions: basic operation optimization, auxiliary function enhancement, smart interconnection experience, health care, environmental protection and energy-saving design, and safety design.

The first-level design requirements are “D1 basic operation optimization direction,” including a series of style and appearance requirements of the operation interface, fonts, font sizes, icon clarity, interface layout style, etc. At the same time, the design of “D2 auxiliary function enhancement direction” is to enhance the user experience of the elderly. The addition of personalized settings, voice assistance functions, operation guides, and other functions is more in line with the operation and use habits of the elderly and better meet their daily use needs. The first-level design requirements of “D3 smart interconnection experience direction,” “D4 health care direction,” “D5 environmental protection and energy-saving design direction,” “D6 safety design direction,” and other requirements are aimed at improving the safety, convenience, comfort, and experience of the elderly during use, and increasing the user satisfaction of elderly users.

A relationship matrix was constructed to associate user needs with design requirements, and the design requirements were prioritized based on the scores. Simplified operation processes and voice assistance ranked high among the design requirements.

Table 1. Order of importance of design elements

Prioritization	Design elements	n_{ji}	v_{ij}
1	D12 Simplified operation process	2.35	0.1003
2	D22 Voice assistance function	2.26	0.0974
3	D23 Error prompts and solutions	1.96	0.0783

4	D52 Water-saving technology	1.93	0.0716
5	D61 Anti-accidental touch design	1.82	0.0685
6	D11 Large font and clear interface	1.74	0.0618
7	D13 Emergency stop button	1.63	0.0579
8	D24 Operation guide	1.58	0.0532
9	D21 Personalized settings	1.51	0.0513
10	D41 Healthy washing mode	1.46	0.0482
11	D42 Hightemperature disinfection function	1.41	0.0475
12	D51 Energy efficiency rating	1.39	0.0426
13	D53 Low noise design	1.38	0.0421
14	D62 Unbalance detection	1.32	0.0368
15	D63 Shockproof design	1.03	0.0257
16	D32 Smart interconnection	0.86	0.0212
17	D31Wi-Fi connection function	0.69	0.0197

4.4. Design plan

Based on the analysis of design elements and the priority ranking of the smart washing machine interaction interface in the previous section, this section designs the smart washing machine interaction interface based on hierarchy, operability, clarity, readability, and ease of use. The four design schemes are shown in **Figure 1**.

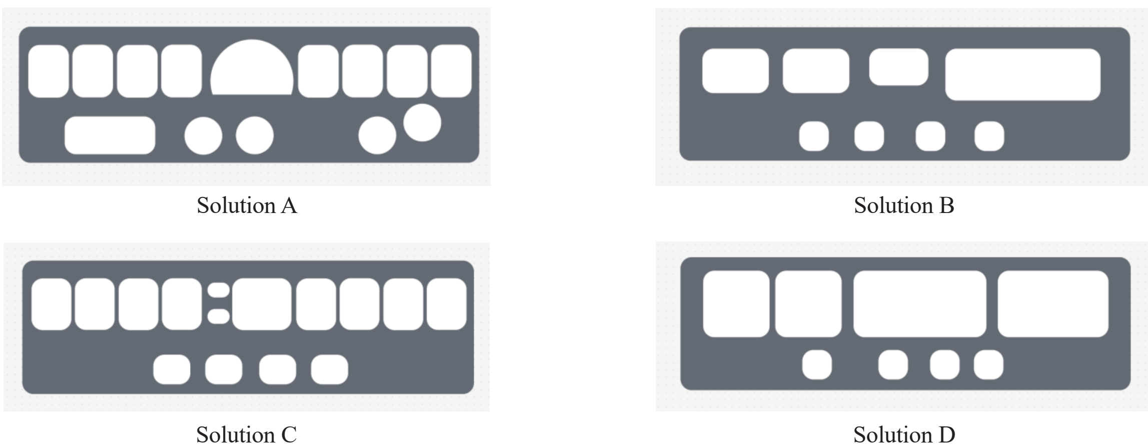

Figure 1. Four design options

(1) Solution A (practical): focuses on meeting essential needs, with stable performance and reliable basic operating functions. The operation interface is intuitive and physical buttons are added.
(2) Solution B (personalization and ease of use): On the basis of meeting the necessary needs, add personalized settings and optimized user interface. Provide adjustable options, allow users to customize the location of frequently used programs, and use clear and easy-to-understand icons and animations.
(3) Solution C (innovative technology and environmental protection and energy saving): Focus on the realization of attractive needs, such as intelligent interconnection functions, environmental protection and energy-saving design, etc. Support Wi-Fi connection, automatically adjust the washing plan, and provide

energy-saving mode.

(4) Solution D (comprehensive and balanced): Comprehensively consider all levels of needs and continuously optimize interface design and function settings through user research and feedback mechanisms.

4.5. Scheme evaluation

The TOPSIS method was used to evaluate the four design schemes. The relative closeness was calculated based on indicators such as practicality, personalization, ease of use, user feedback and adaptability, functionality, technological innovation, and cost-effectiveness, and Solution B was found to be the best.

The PUGH concept selection method was used to fine-tune Solution B, maintaining the current status of font size, simplifying operation steps and emergency stop function, adding voice control command options, and removing the interconnection function to reduce costs.

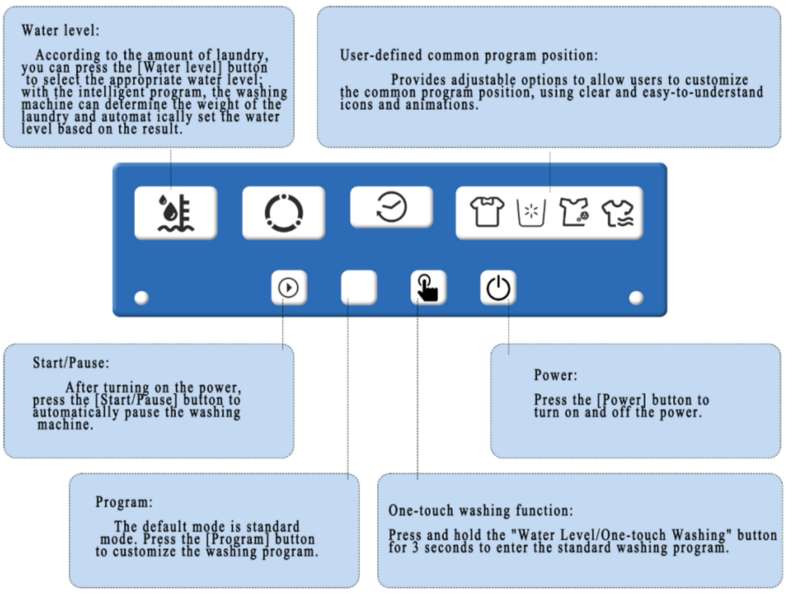

Figure 2. Specific design details of Solution B

(1) Interface visual design: Use large fonts (Arial Bold, 28 pt or more) and high contrast color (black and white or dark blue and light white). Simplify the operation steps, set one-button operation mode, and intelligently recommend washing programs. Set emergency stop function and eye-catching emergency button. Support voice command input and result feedback, and provide operation guidance.

(2) Advantages: The interface is simple and clear, and the operation steps are simple and easy to understand. Equipped with an emergency stop button and voice prompt function. Find a balance between functionality and cost-effectiveness.

(3) Disadvantages: Compared with other solutions, it may lack some high-end intelligent or interconnected functions.

Through the above content deletion, the meaning of the article and the design results remain unchanged, and at the same time, it is more concise and clear.

5. Results and discussion

Under the evaluation of TOPSIS and PUGH methods, Solution B became the optimal design of the interface of the smart washing machine for the elderly. Its highlights include barrier-free reading, simplified operation, emergency safety guarantee, and voice assistance system, achieving a balance between ease of use, safety, and economy. Competitive product analysis shows that although Solution A is concise, the font is not optimized, Solution C is comprehensive but the operation is complicated, and Solution D is low-cost but lacks optimized design for the elderly. With the intensification of aging, the design of smart washing machines for the elderly is crucial [14,15]. Solution B can improve the quality of life, safety, and family harmony of the elderly, and has guiding significance for the design of the smart washing machine industry and the entire smart home product for the elderly, promoting technological innovation, industrial upgrading, and enhancing social attention and respect for the elderly. This study provides strong support for the design of the elderly and promotes social progress.

6. Conclusion

This study integrates QFD and HCI theory, taking a smart washing machine as an example, to explore and practice a new path for the interface design of smart home products for the elderly. Through the combined application of the TOPSIS method and the PUGH model, the optimal design plan was innovatively evaluated and selected. This plan fully considered the special needs and usage habits of the elderly and significantly improved their quality of life, safety, and family harmony. The research not only provides practical guidance for aging-friendly design but also points out future research directions, including deepening research on elderly users, exploring new technology applications, and strengthening cross-field cooperation, providing strong support for the sustainable development of the smart home industry.

Disclosure statement

The authors declare no conflict of interest.

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