SMART HOME SERVICE TERMINAL DESIGN FOR ELDERLY FAMILIES INTEGRATING THE KANO MODEL AND PERCEPTUAL ENGINEERING

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ABSTRACT

In recent years, smart homes have gradually come into our lives and have brought many positive impacts to our lives. However, in specifically targeted application design planning, the designer community is not always able to consider and analyze every factor. This paper proposes an integrated nonlinear design that incorporates the KANO model as well as a mathematical model of sensible engineering coupled with design science. The application of different design solutions in different types of households is evaluated after dividing the different types of living of elderly households into specific situations. The results show that for elderly households of type 1 versus 4, scenario 2 generally has more accurate application feasibility compared to scenario 1. The maximum increase in application accuracy for Scenario 2 compared to Scenario 1 was 6.28%. However, the frequency of use decreased by 3.09%. And for elderly households of type 2 and 3, which tend to live alone, the feasibility of application of scenario 2 is similar or even worse than that of scenario 1. The improved Scenario 3 both have higher application feasibility than Scenarios 1 and 2 and has a more user-friendly visual aid to understand the design, which helps the elderly group to better use the smart home service terminal system.

KEYWORDS

Smart home; terminal design; elderly home; KANO model; perceptual engineering

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1. INTRODUCTION

In recent years, smart homes have gradually come into our lives and brought a lot of positive impacts to our lives [1, 2]. Compared with ordinary homes, smart homes have been greatly improved, which can not only meet users' needs for living, provide a suitable, convenient, and reliable living environment, but also give intelligence to traditional living spaces [3, 4]. First of all, smart home products help us to save resources. Intelligent home lighting systems can realize automatic adjustment of the brightness of lamps and lanterns, which can ensure the brightness of the room while minimizing energy consumption [5]. In addition, the intelligent lighting system can achieve the light on when people come and go, giving us very much convenience, on the other hand, it can also prevent forgetting to turn off the lights and cause power waste [6, 7]. Secondly, in the smart home, the smart cat's eye can be installed on the home security door, which has a wider visual range, infrared night vision function, and can be connected to the network, which in turn can realize real-time monitoring of the situation at the doorstep [8]. The smart home is a technologically intelligent product closely related to people's daily life. The smart home is intended to serve our life and bring comfort and convenience to our life [9, 10]. With the development of new technologies such as the Internet of Things, cloud computing, and wireless communication, smart home has been developed rapidly more convenient for people's life [11-18]. Smart home enables users to control the devices in their homes using smartphones to achieve remote control, scene control, linkage control, and timing control. In terms of smart homes for the elderly, due to the arrival of aging and the special physiological, psychological, and social needs of the elderly group for smart homes, there are also some special needs for home products.

The smart home is mainly realized by applying the Internet of Things (IoT) technology, where many home objects in the home, etc. are connected to the Internet through sensors [19]. Secondly, for smart home, the main thing is that he has a variety of control methods [20]. For the elderly, the smart home has added many new functions and services, the smart home control is more abstract, and its control methods have changed a lot [21]. For these changes, it is generally difficult for the elderly to adapt. Compared with ordinary homes, the operation and control of smart homes require higher abstract thinking skills, and these increase the information burden of the elderly [22, 23]. Therefore, it is necessary to optimize the design of smart homes to meet the needs of the elderly. Dhanusha, C [24] detected Alzheimer's disease in the elderly by recording the daily activities of residents equipped with sensor devices in their home appliances as smart homes. To obtain deeper features of the sensor dataset that differ from the existing traditional supervised learning paradigm, they constructed an optimized self-learning model. The model produced better results on a smart home testbed and can be used to investigate the presence of Alzheimer's disease in the elderly. Huu, P . N [25] proposed a system for recognizing gestures and actions in smart homes. They used actions such as walking, sitting, backing, putting on shoes, waving, falling, smoking, infant crawling, standing, reading, and typing for recognition. In this system, data is captured from the camera of the

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mobile device used to detect the object. The results are obtained from the objects on the frame through the bounding box. The results show that the system meets the requirements with an accuracy of more than 90% and is suitable for practical smart home applications for the elderly. Alzahrani. T [26] explored the main barriers and facilitators to the use of smart home technology, remote monitoring, and telemedicine systems to support healthcare and enable older people to maintain their independence, and showed that lack of information about the functionality and usability of the technology was the main barrier to adoption. Human issues such as cost, platform management and infrastructure, and privacy are also barriers to the diffusion of smart homes. Heon. R.J. [27] systematically reviewed the adoption and user perception of health and environmental monitoring devices, highlighting the difference between wearable and non-wearable. We identify user perceptions based on usefulness, ease of use, and privacy. In terms of user experience, as wearable devices compensate for their limitations, making an integrated model can improve user perception. Kong, H [28] argues that the development of smart homes has driven the concept of user authentication. This not only protects user privacy but also provides personalized services to users. They developed a deep learning-based method to extract behavioral features of finger gestures for highly accurate user identification. The results of their study show that their optimized smart home achieves a great user experience. Enhancing the intrinsic human inclination towards nature for optimal health and well-being and supporting the physical, mental, and social health of the elderly are goals that smart homes need to strive for. Yang, H [29] develop a comprehensive research model that can explain the behavioral intentions of potential customers to adopt and use smart home services. This will enable people to access smart home services on the move using mobile devices through control and monitoring functions, enhancing the sense of user experience. Liu, J [30] argues that current smart home control terminals have many shortcomings and limitations in terms of interaction methods and level of intelligence. They combined the theories of context and behavior analysis to build a product design process based on behavior context analysis, and through the analysis of building and unit behavior context, they obtained the user's needs for control terminals in each context unit, and transformed them into design elements for product concept design, and then designed smart home control terminals to meet the needs of elderly people. Renaud, J [31] proposed that product design should be human-centered, and they suggest that product use should be considered through behavioral analysis and its user's behavior combined with functionality. In the above studies, we can see that systematic research has been made on the optimal design of smart homes for elderly families in terms of elderly user experience, elderly operation, and elderly health monitoring. In addition, in the smart home for the elderly, due to their safety protection, psychological and other special needs. We need to make more emotional designs and simpler service terminals for the elderly smart home so that they can have a better experience.

Traditional smart homes focus on improving reliability, functionality, usability, appearance, and other design features. For older adults, however, their satisfaction is influenced not only by perception but also by emotion. Therefore, in our research, we

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construct a framework through perception engineering to express the perception of services through users' own words to understand smart home product attributes and user perceptions. In addition, to better classify the needs attributes of the elderly on the client side, and then better design smart home products for the elderly according to their needs, we try to meet customer needs and improve customer satisfaction. We combine the Kano model and perception engineering. We hope our work can make some contributions to the application and service of smart homes for the elderly, and provide a reference for building a green, low-carbon, environmentally friendly, and low-cost smart home.

2. PRINCIPLE OF SMART HOME SERVICE TERMINAL

The main purpose of this study is to attach the smart home to the elderly living space, link the smart home devices involved in the elderly home living environment based on various smart home technologies, build a smart space suitable for the elderly, help the elderly manage the smart home devices in the living environment, and provide a multifunctional, reliable, and satisfactory living environment for the elderly. In addition, the smart home service terminal for elderly families designed in this study meets the multifaceted needs of the elderly living space. It has the following characteristics.

1. Networked elderly living environment and smart home device control

The smart home devices involved in the elderly living environment are networked online through the Internet of Things so that the elderly family members can not only share and communicate the internal information of the smart home devices but also control the working status of the smart home and obtain the required important information in the places covered by the network in the elderly living environment.

2. Intelligent elderly living environment and smart home device control

Intelligent home equipment control intelligence provides a lot of convenience to the elderly home life. First of all, the security of the living space for the elderly is greatly guaranteed, which can make the children of the elderly home a lot of worries; on the other hand, the addition of smart home devices can improve the quality of life of the elderly, and facilitate the elderly to remote control the smart home devices involved in the living environment, etc. Smart home device control intelligence can make the elderly enjoy the benefits of technological progress. Therefore, the research on smart home products suitable for elderly users has great practical significance.

2.1. PRINCIPLES OF PERCEPTUAL ENGINEERING

Perceptual engineering is a new product development technology that transforms the elderly's requirements for the quality of future family life into the design of home-smart homes and home-smart services. It is seeking the correlation between the

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elderly's response to the quality of life in the future home and the attributes of designing the home smart service to develop a quantitative model for smart home design and optimization.

Ergonomics establishes a framework through the self-expressed requirements of the elderly for their future home quality of life, and then uses experts in the relevant fields to design smart home functions; in addition, the special requirements of the elderly are measured and their smart home attributes are optimized to a certain extent to enhance their applicability and increase flexibility. There are two advantages of perceptual engineering for the design of smart home service terminals in elderly homes. One is to visually convey the real feelings of elderly users through smart home design; the second is to establish a regression analysis model to determine the interaction between customers' emotional responses and design features.

2.2. PRINCIPLE OF THE KANO MODEL

The main feature of the KANO model is to meet the requirements of the elderly for future home life quality as much as possible to provide a multi-functional, reliable, and satisfactory living environment for the elderly, but also to minimize the elderly's discomfort with the smart home. The attributes can be divided into five categories: charm attributes (A), expectation or one-dimensional attributes (O), essential or basic attributes (M), reverse attributes (Q), and undifferentiated attributes (I), as shown in Figure 1. The details are described as follows.

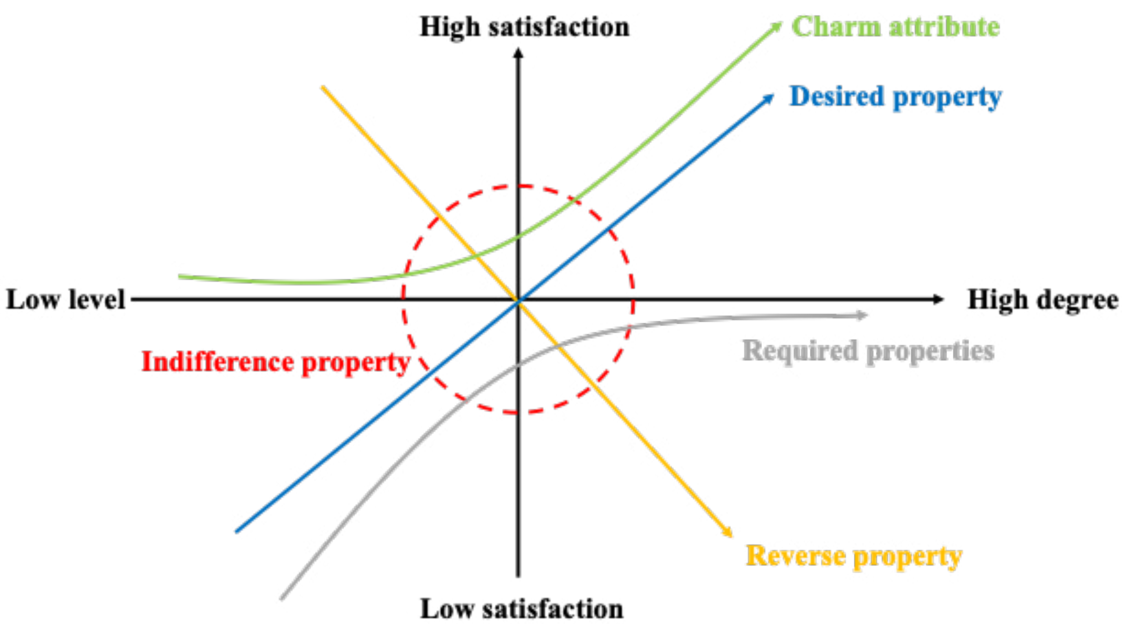

Figure 1. KANO model attribute diagram

Attraction attribute (A). This attribute intuitively expresses the elderly's expectation of the appearance of the smart home, and the improvement of the charm attribute of the home will bring great satisfaction to the elderly users.

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Expectation or one-dimensional attribute (O). This attribute shows the linear relationship between the satisfaction of the elderly with the smart home and whether the design concept of the smart home matches each other, i.e., the more the design concept of the smart home matches the actual conditions, the higher the satisfaction of the elderly with the smart home.

Essential or Basic Attributes (M). This attribute indicates the functional attributes that seniors take for granted in the smart home and that are not explicitly mentioned by the seniors' customers. The absence of this attribute causes a decrease in the satisfaction of the elderly with the smart home, but the addition of this attribute does not cause interest in the elderly.

Reverse attribute (Q). This attribute indicates that seniors do not want the functional attributes in the smart home, and providing this functional attribute will decrease seniors' satisfaction with the smart home, while the lack of this attribute will increase seniors' satisfaction with the smart home.

No difference attribute (I). This attribute indicates the functional attributes that seniors feel dispensable in the smart home, and providing this functional attribute or the lack of this functional attribute will not affect seniors' satisfaction with the smart home.

3. EVALUATION MODEL BASED ON LEAST SQUARES ALGORITHM (PLS)

This paper applies the PLS algorithm to evaluate the relationship between perceptual engineering and the KANO model coupled with each other to analyze the relationship between annual people's satisfaction with smart homes. the PLS algorithm needs to be tested by calculating the residual sum of squares after extracting the principal components, and the residual sum of squares needs to be smaller than the maximum allowable error r. firstly, n observations are made, i.e. n sample points are selected to study the relationship between the dependent and independent variables. The partial least squares-based correlation analysis is similar to the typical correlation analysis in that it requires the extraction of principal components in the independent variable X and the dependent variable Y, respectively, and calculates the specific computational procedure as follows.

$$r = min(p, q) \tag{1}$$

$$\mathrm{PRESS}_j(k) = \sum_{i}^{n} \left(y_{ij} - \hat{y}_{ij}(k) \right)^2 \tag{2}$$

Where $\mathrm{PRESS}_j(k)$ is the residual sum of squares; i denotes the i sample point j denotes the j indicator; k denotes the number of extracted principal components; p is

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the independent variable $X\{x_1, x_2, \ldots x_p\}$; and q is the dependent variable $Y\{y_1, y_2, \ldots y_p\}$.

There are q dependent variables $\{Y_1 \ldots Y_q\}$ and p independent variables $\{X_1 \ldots X_p\}$, and n sample points are observed, thus forming the data tables of independent variables and dependent variables $X = \{X_1 \ldots Xp\}$ and $Y = \{Y_1 \ldots Y_q\}$. Partial least squares regression extracts components t_1 and u_1 from X and Y respectively (that is, t_1 is the linear combination of $X_1 \ldots X_P$; u_1 is the linear combination of $Y_1 \ldots Y_Q$). t_1 and u_1 should represent the data table X and Y as well as possible, and the component t_1 of the independent variable has the strongest explanatory ability to the component u_1 of the dependent variable. After the first components t_1 and u_1 are extracted, the regression of X to t_1 and Y to t_1 is carried out respectively. If the regression equation reaches satisfactory accuracy, the algorithm terminates; Otherwise, the residual information after X is interpreted by t_1 and Y is interpreted by t_1 for the second round of component extraction. Such reciprocation, until a more satisfactory accuracy can be achieved. If m components $t_1 \ldots t_m$ are finally extracted for X, partial least squares regression will be implemented by implementing Y_k's regression of $t_1 \ldots t_m$, and then expressed as Y_k's regression equation about the original variable $X_1 \ldots X_m$, $k = 1{,}2 \ldots q$. This completes the modeling of partial least squares regression.

4. ANALYSIS AND DISCUSSION

In recent years, smart home has gradually come into our lives and brought a lot of positive impacts to our lives. Among them, smart home applications and services for elderly families are gradually being emphasized and put on the agenda in China. However, in the specific design planning of targeted applications, the designer community is not always able to consider and analyze every factor. At the same time, the overall process factors of the design are strongly non-linear in nature, and some of them are even coupled and influenced by each other. In some cases, some of these performance metrics are difficult to reconcile and may even conflict.

Imagine a real case scenario. When designing a smart home application and service system for the elderly, it is difficult to improve the accuracy and total usage frequency of the elderly group at the same time. As the memory of elderly users decreases, some shortcut operations to improve the accurate usage rate often cause tedious operation processes, which makes the total usage frequency decline. Therefore, it is necessary to make a trade-off between the accuracy rate and the total frequency of use in the design process. The weighting of the trade-off should be matched with the more sensitive index factor in the overall benefit of the elderly group. For the elderly, the error rate factor of smart home product usability is more important than the usage efficiency factor, that is to say, the error rate should be reduced as much as possible while meeting the basic usage efficiency of the elderly, which is more compatible with the special physiological and psychological characteristics and lifestyle of the elderly.

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4.1. DIVISION OF DIFFERENT TYPES OF FAMILIES

Therefore, in this paper, we envision an integrated nonlinear design that incorporates the KANO model as well as a mathematical model of sensible engineering coupled with design. Our design ideas are firstly divided into different types of life in elderly households in specific situations. The key points in different types of elderly households are screened out, and the key indicators with higher sensitivity in the smart home applied to elderly households are matched with the key features for the design. As we all know, the group of elderly people is generally divided by age, and people over 65 years old are internationally classified as elderly people. And in China, people over 60 years old are considered an elderly group. However, classifying older people only by calendar age makes the group of older people have great variability. Some groups are in the older age group by calendar age, but they are still physically functioning and thinking fast. Therefore, their physiological age does not exactly match the traditional elderly group. Therefore, the target population cannot be divided by calendar age in general but should be defined according to specific research needs. In this paper, we focus on the living environment, interpersonal relationships, and autonomy of the elderly group, and the division types and important characteristics are shown in Table 1. For the living environment and interpersonal relationships of the elderly group, we have identified four types: living with relatives, living alone, living with relatives, and living together. For the main characteristics of type 1, we collected information about 572 elderly households in a city in China based on an open questionnaire. The key characteristics were summarized to focus on family relationships and autonomy. For example, elderly families with relatives living together have good health status and relatively complex family relationships. The self-care type of elderly families has better self-care abilities and do not need more help and care from others.

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Table 1. Basic types of elderly households and smart home service terminal design scheme

Family Type	Description	Features	Design Solutions	Features
Type 1: Relative cohabitation	Living with their children or relatives	1. good for health; 2. relatively complex interpersonal relationships;	Solution 1: Infrastructure distributed intelligent system	Visualization of basic functions such as air conditioners, refrigerators, and switches for TVs and other devices
Type 2: Living alone	Living alone, largely independent of children or relatives	1. need strong self-care ability; 2. relatively single family relationship.	Solution 2: Infrastructure Intelligent Integration System	Such as air conditioners, refrigerators and televisions are controlled from a single mobile terminal.
Type 3: Relative Neighbor	Live separately from relatives, but take care of each other	1. maintain separate and independent lives with relatives; 2. visit and care for each other frequently	Program 3: Complete intelligent integrated system for home appliances and facilities	All appliances and other devices are integrated in the mobile terminal and have visual interaction function
Type 4: Centralized housing	Concentrated residence in service institutions	1. the cost is divided into three ways: government funding, social sponsorship and personal commitment; 2. but the number of institutions is small and the fees are high.	Intelligent Integration system with KANO model and perceptual engineering	All air conditioners, refrigerators and televisions are controlled by a general control system.

4.2. PLS ANALYSIS PROCESS

SmartPLS is an application running on the Java platform. It provides three different internal weight modes: centroid weight, factor weight, and path weight, as well as the default maximum number of iterations, iteration accuracy, and initial weight. It can process the original sample data. Therefore, this paper uses smartPLS2.0 path analysis software to calculate the model in this paper, obtain the path coefficient, and investigate the hidden variables and the relationship between the hidden variables and the measured variables. As for the path coefficient, it can directly reflect the influence of each implied variable. The higher the value of the path coefficient, the greater the direct influence of an implied variable on the implied variable pointed by the arrow. The path coefficient between functionality and perceived effect is 0.0893,

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which is explained by the non-linear relationship between these two implied variables, or the path coefficient is not obvious, indicating that the high functionality of smart homes has little direct impact on the perception of the elderly. For Figure 2, through comparative analysis, it is found that most of the observed variables have high Outer weights. This shows that the observed variables can better reflect their corresponding hidden variables. The specific results are shown in Table 2 and Figure 2.

Table2. Path coefficient

	Elderly satisfaction	Perceived effect	Smart home services	Reliability	Functionality
Elderly satisfaction	0.2641	0	0	0.4078	0.3192
Perceived effect	0	0	0	0.1288	0.0893
Smart home services	0	0	0	0	0.5351
Reliability	0	0	0	0	0.5763
Functionality	0	0	0	0	0.6242

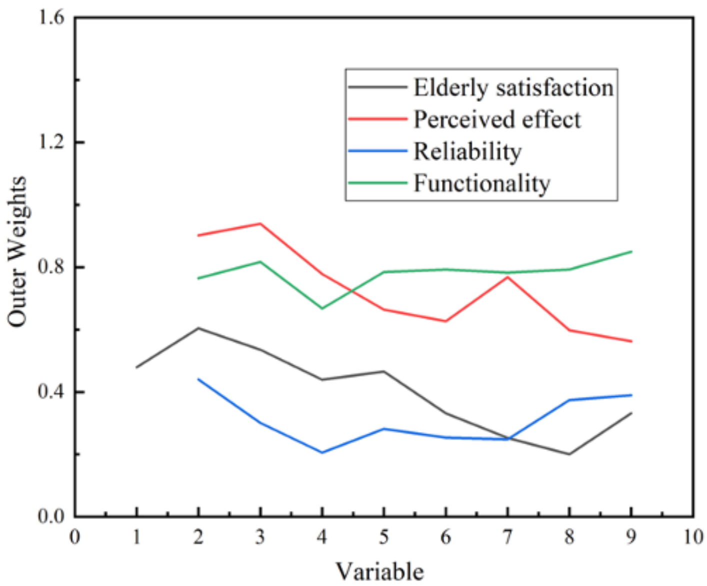

Figure 2. Outer weights of each factor

4.3. EVALUATION OF DIFFERENT CONVENTIONAL PROGRAM APPLICATIONS

We matched the built smart home service terminal system incorporating the KANO model as well as sensible engineering with the smart homes of 572 elderly households in a city in China. Different smart home service terminal systems were

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applied to different basic types of elderly households in Table 1, and the application accuracy and usage frequency percentages of each system design solution in different types of elderly households were observed. The statistical results of the application accuracy rate are shown in Figure 2(a), where it is observed that for type 1: elderly households with relatives living together, scheme 2 has more accurate application feasibility compared to scheme 1. The application accuracy rate of scenario 2 reached 88.98%, which is an improvement of 6.28% compared to scenario 1. However, in terms of application frequency in Figure 2(b), the usage frequency of Scenario 2 decreased by 3.09%. This indicates that the combined accuracy of air conditioners, refrigerators and TVs controlled centrally from mobile terminals has more room for application in elderly households with young people living with them, but is not often used by the elderly group when the young people are not at home. For type 2: elderly households living alone, the application accuracy rate of scenario 2 decreases to 69.58%, which is 4.31% lower than that of scenario 1. At the same time, the frequency of use of scenario 2 decreased by 26.55%. This indicates that such as air conditioning, for the traditional elderly group living alone, the overly intelligent design of Scenario 2 may make the application accuracy and frequency of use significantly lower. As for Type 3: Relative Neighbors, the family relationship with relatives living separately but taking care of each other makes the difference in application accuracy between Scenario 1 and Scenario 2 not significant. It can be surmised from the illustrations in Table 1 that frequent visits and mutual care among relatives somewhat alleviate the degree of convenience in application for the elderly group living alone. However, the frequency of use for scenario 2 still decreased by about 20.33% compared to scenario 1. As for the type of Type 4: Concentration, the application accuracy of Scenario 2 and Scenario 1 is not much different for the elderly group living centrally in service institutions as the communication between the groups becomes closer. It is 81.76% and 79.49%, respectively. And the gap between the frequency of use of scenario 1 and scenario 2 also gradually decreases, with 81.76% and 73.63%, respectively.

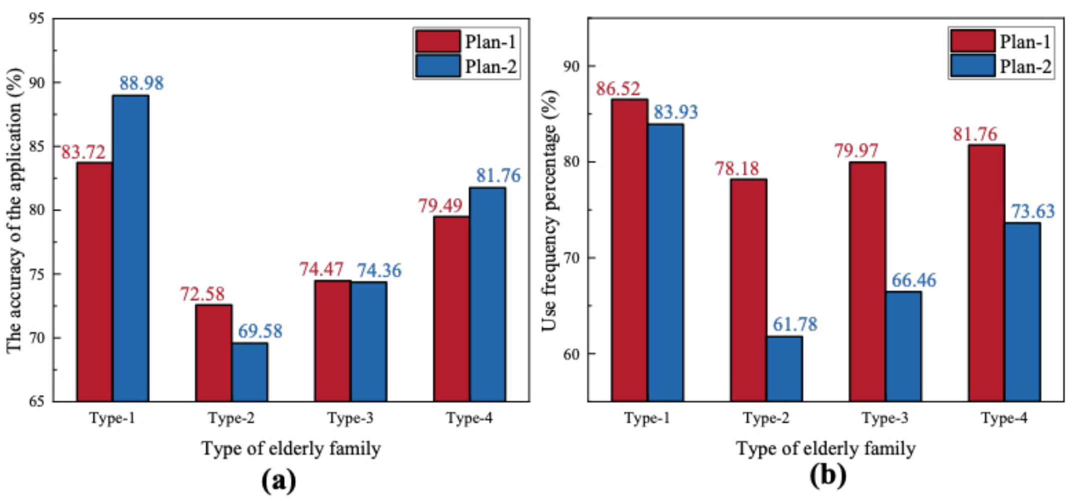

Figure 3. Evaluation of smart home service terminal design solutions for different types of households

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4.4. EVALUATION OF IMPROVEMENT PROGRAM APPLICATIONS

Finally, we improved and adapted Scheme 1 and Scheme 2, where we integrated all appliances and other devices into a mobile terminal and made them visual and interactive. The improved system design was named Scenario 3, which was applied to different basic types of elderly households, and the results are shown in Figure 3. It is observed that for type 1 households, scenario 3 has the most accurate application feasibility of 92.91%. For type 2, 3, and 4 households, the feasibility of the application of scenario 3 is higher than that of scenarios 1 and 2, with 73.58%, 76.9%, and 86.41%. In terms of frequency of use, Scenario 3 has a more friendly visual aid understanding design compared to the equally intelligent Scenario 2, which helps the elderly group to better apply the smart home service terminal system. Therefore, the application frequency of Scenario 3 is higher than that of Scenario 2 in the elderly households of Types 1, 2, 3, and 4.

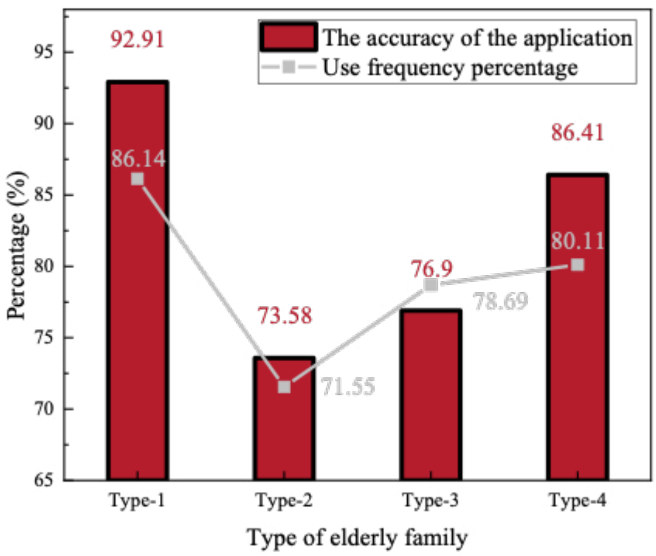

Figure 4. Evaluation of smart home service terminal improvement solutions for different types of households

5. CONCLUSION

In recent years, smart homes have gradually come into our lives and have brought many positive impacts to our lives. However, in specifically targeted application design planning, the designer community is not always able to consider and analyze every factor. In this paper, we envision an integrated nonlinear design that combines the KANO model and the mathematical model of sensual engineering with design coupling. The application of different design solutions in different types of households is evaluated after classifying the different types of life of elderly households in specific situations. The conclusions are as follows:

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1. The study population was defined according to specific research needs. In this paper, we focus on the living environment, interpersonal relationships, and autonomy of the elderly population and classify the types to match the important characteristics. The types of living environment and interpersonal relationships of the elderly group are cohabitation with relatives, living alone, cohabitation with relatives, and centralized living.

2. For elderly households of type 1 and 4, scenario 2 generally has more accurate application feasibility than scenario 1. The maximum improvement of Scenario 2 over Scenario 1 is 6.28%. However, for the application frequency, the maximum decrease of 3.09% was observed for Scenario 2. For elderly households living alone in Types 2 and 3, Scenario 2 has similar or worse application feasibility than Scenario 1. This suggests that, as in the case of air conditioning, overly intelligent designs may not be popular for the traditional elderly group living alone.

3. It is observed that for type 1 households, scenario 3 has the most accurate application feasibility of 92.91%. For Type 2, 3, and 4 households, Option 3 has a higher application feasibility than Options 1 and 2, at 73.58%, 76.9%, and 86.41%. In terms of frequency of use, Scenario 3 has a more friendly visual aid understanding design compared to the equally intelligent Scenario 2, which helps the elderly group to better use the smart home service terminal system.

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