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An Exploration of the Application of Affordance Theory in the Interface Navigation Design of Smart Homes for the Elderly

Zirong Ye[1], Tian Li[2]

[1]Faculty of Humanities and Arts, Macau University of Science and Technology, Macau, China
[2]School of Design, Jiangsu Open University, Nanjing, China
Email: 341086502@qq.com

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Abstract

With the accelerating global aging population, the quality of life for elderly individuals is facing increasing challenges, especially in the use of smart home systems. Traditional smart home interfaces often neglect the unique cognitive and operational needs of the elderly, resulting in difficulties when using these technologies. Affordance theory, as an important framework in human-computer interaction, provides theoretical support for optimizing smart home interface design through the dimensions of perception, operation, and feedback. This paper explores the specific application of affordance theory in the design of smart home interface navigation for the elderly and proposes a series of targeted design strategies aimed at enhancing the usability and acceptance of smart home systems among elderly users.

Keywords

Affordance Theory, Elderly, Smart Home, Interface Navigation, Human-Computer Interaction

1. Introduction

With the widespread adoption of smart home technologies, an increasing number of elderly individuals are beginning to interact with and use these systems. However, traditional smart home interface designs often fail to adequately consider the cognitive and operational characteristics of elderly users, leading to numerous barriers during use. These barriers are primarily manifested in heavy cognitive load, poor operational intuitiveness, and delayed feedback, which severely affect the elderly's acceptance and user experience with smart home systems. Affordance theory, based on cognition and behavior, provides a new perspective to address this issue. By analyzing the characteristics of elderly users and combining the core concepts of affordance theory, this paper proposes strategies to optimize smart home interface design, aiming to reduce the operational difficulty for the elderly and improve their experience.

2. Core Concepts of Affordance Theory and Its Adaptation for Elderly User Design

2.1. The Essence and Technological Implementation of Affordance Theory

Affordance theory, proposed by psychologist James Gibson, emphasizes that the nature of objects and tools in the environment directly influences an individual's behavior and actions. Its essence lies in helping individuals achieve effective interaction with the external world through three dimensions: perception, operation, and feedback. In smart home design, these three affordance characteristics—perception, operation, and feedback—can effectively reduce the cognitive load on elderly users and enhance the intuitiveness and usability of the system.

Perceptual affordance refers to helping users recognize interface elements and operational methods through visual and tactile cues. For elderly users, interface design should avoid complex elements and guide operations through clear visual cues. Elements like button shadows, color contrast, and clear symbol designs can make it easier for elderly users to understand the function of each interactive element. Proper color contrast and enlarged text can help elderly users overcome vision impairments, ensuring they can clearly recognize and perceive operational options (Mo & Crosthwaite, 2025).

Operational affordance emphasizes the physical logic of interactive elements, meaning that the design should match users' intuitive ways of interacting with the system. For example, sliding operations should align with the direction of content scrolling to avoid errors. Through natural mapping, the operation methods of the interface should directly reflect the laws of the physical world, helping elderly users complete interactions more naturally. For elderly users, the interface's interactive elements should be kept simple and intuitive, minimizing abstract symbols and complex operations to increase the success rate of their interactions.

Feedback affordance refers to confirming the user's actions through immediate feedback, enhancing their confidence in the operation. For elderly users, clear feedback, such as sound or vibration, is necessary after an action to help confirm whether the operation was successfully completed. Interactive elements such as buttons, switches, and touchscreens in smart home systems should provide immediate responses. Whether it's an audio prompt or vibration feedback, these responses can effectively enhance the elderly user's operational experience and reduce anxiety caused by uncertainty.

2.2. Cognitive and Operational Characteristics of Elderly Users

The cognitive and operational characteristics of elderly users determine the focus of interface design. Elderly individuals often exhibit characteristics such as scattered attention, short-term memory decline, and a decrease in symbolic understanding. They are easily confused by excessive information or complex interfaces, so the interface design needs to simplify information presentation, avoid cluttered text and icons, and use more intuitive and memorable elements to assist memory.

Regarding behavioral habits, elderly users are often more inclined to use physical buttons and rely on habitual paths for operation. This characteristic means that smart home systems should provide clear and easy-to-operate physical buttons or touch screens, while also combining traditional gesture operations and touch modes to help elderly users get started and adapt more quickly. For those accustomed to fixed paths for completing tasks, the interface should maintain consistency and avoid frequent changes in layout and functionality, allowing users to have more predictable usage experiences (Butler & Jiang, 2025).

The digital divide is another major issue for elderly users. Many elderly individuals are resistant to abstract icons and multi-layered menu structures, as they are not accustomed to quickly browsing complex menus or icons. Smart home interfaces should avoid abstract icons and instead use intuitive graphical designs that mimic real-world objects or functions, such as using a lightbulb icon for lighting control and a switch icon for appliance control.

2.3. Affordance and the Needs of Elderly Users

Affordance theory provides feasible solutions for elderly user design, helping to reduce the learning cost of operation. By using natural mapping, the design can simulate real-world interface elements, such as switch icons resembling physical switches, allowing users to operate them intuitively through visual cues and reducing the need to learn and adapt to complex operations. This design effectively reduces the cognitive load on elderly users, making it easier for them to understand and use smart home systems.

Enhancing fault tolerance is another key demand for elderly user design. With age, elderly users' operational precision and reaction speed decline. Smart home systems should design larger click areas, wider button spaces, and provide anti-mistouch features. For example, undo operations and confirmation pop-ups can effectively prevent errors and ensure elderly users feel safer and more confident during use.

Improving the sense of security is also an essential element in smart home interface design. Elderly users often experience anxiety due to improper operation when using smart devices. Therefore, design should provide clear status feedback, such as changes in lighting color or updates in icon status, to convey whether the operation has been successful (Li et al., 2025). This feedback not only boosts elderly users' confidence but also reduces anxiety during the operation, enhancing their reliance on and trust in the smart home system.

3. Principles for Smart Home Interface Navigation Design Based on Affordance Theory

3.1. Optimizing Visual Affordance Strategies

Visual affordance refers to the way interface design guides users' operations through visual cues. For elderly users, clear visual design is crucial in reducing cognitive load and anxiety during operation. Visual optimization strategies based on affordance theory include high contrast, enlarged elements, and metaphorical icon design.

Due to visual degeneration, elderly users often struggle with low-contrast or small font elements. Therefore, high-contrast color schemes should be used in the design to ensure a clear distinction between text and background. The size of icons and text should adhere to a threshold standard, such as using a minimum font size of 14pt to ensure readability. Additionally, interface elements should be appropriately enlarged, especially in commonly used buttons and operational areas, to avoid small clickable areas and overly complex interfaces.

Traditional smart home interfaces often use abstract symbols or icons, which may be difficult for elderly users with cognitive decline to understand. To address this issue, metaphorical icon design can be adopted by relating icons to daily objects or life experiences. For example, using a "home" shape to represent the homepage or a lightbulb icon for lighting control (Zhou et al., 2025)

This design approach concretizes abstract concepts, allowing elderly users to understand the functions intuitively and adapt quickly to the interface.

Dynamic visual guidance can help users better understand their current operation stage. By using focus enlargement animations and progress bars, designers can clearly inform users of their current position and operational progress. For example, when users adjust device settings, the currently selected button can be enlarged through dynamic effects, and the operational result can be presented via animations to enhance predictability and feedback. Moreover, progress bars effectively guide users in understanding the completion of operations, reducing uncertainty during the process.

3.2. Technical Implementation of Interaction Affordance

Interaction affordance refers to how the interactive methods of interface design should align with users' operating habits and intuitions, reducing learning difficulty and improving operational efficiency. For elderly users, the interactive methods should be simple and intuitive, avoiding complex steps.

To reduce cognitive load during operation, flattening the hierarchy is a very effective design strategy. Multi-level menu structures often confuse users, especially elderly users, who may get lost due to too many submenus and levels. Smart home interfaces should avoid multi-layered nesting, opting for a flattened menu structure with three levels or fewer, with commonly used functions displayed directly on the main screen. This design reduces the amount of content users need to remember during operation and enables them to find needed functions more quickly, improving usability.

As smart home technology continues to develop, users' choice of interaction methods is becoming more diversified. To meet the different needs of elderly users, the interface should be compatible with multiple input methods, including voice commands and gesture operations. Voice commands help elderly users who are unfamiliar with touch operations control home devices through simple language commands, while gesture operations provide more convenient interaction, such as swipe gestures to return or double-tap for confirmation. These redundant designs ensure that users with varying abilities can easily use smart home systems (Yudytska, 2024).

The integration of physical buttons with digital interfaces is an important means of improving operational affordance for elderly users. Physical buttons, such as emergency call buttons or volume control, can be linked with corresponding functions on the interface. By combining physical buttons with digital functions, elderly users can directly press a button for an emergency call without going through complex touchscreen operations. This not only simplifies the operation process but also enhances elderly users' sense of control over the device, improving the system's usability.

3.3. Systematic Construction of Feedback Affordance

Feedback affordance refers to how the system should promptly and clearly inform users of the results of their operations. Such feedback can enhance users' confidence in their operations, helping them confirm whether their actions were successful. For elderly users, timely feedback is especially important, as it effectively reduces uncertainty and strengthens their reliance on and trust in the smart home system.

The immediate feedback system in smart home interface design is crucial, especially for feedback after an operation is completed. Through interface color changes and vibration alerts, users can quickly understand the result of their operations. When elderly users adjust the air conditioning temperature, the interface can change color or display an animation of temperature changes to confirm the success of their operation. Additionally, vibration feedback can be used when users interact with touchscreens to confirm that their operation was successfully recognized. This millisecond-level feedback response time improves users' confidence in their operations and reduces anxiety after the action (Sanghyeong & Kwanghee, 2019).

Elderly users are more likely to make mistakes, so interface design should include error prevention and recovery features. When users mistakenly press a button, the system can pop up a confirmation window asking if they are sure about performing the action. This design prevents confusion caused by errors and helps reduce anxiety during operations. Additionally, the automatic saving of historical operation paths helps users quickly recover previous actions, avoiding the hassle of repeating tasks.

Smart home systems should have contextualized prompts, meaning that the interface settings should automatically adjust according to different environmental changes. In low-light environments, the system can switch to dark mode to enhance readability; at night, the main interface can prioritize lighting control, while during the day, it can display other commonly used functions. This contextualized prompting helps elderly users quickly adapt to interface changes in different usage scenarios, improving operational efficiency and comfort.

4. Affordance-Driven Smart Home Navigation Design Case Study and Validation

4.1. Case Selection

The study selected two representative smart home systems for comparative analysis: Amazon Alexa (voice-driven) and Xiaomi Smart Home (touch-driven). These two systems represent two common interaction modes in smart home interface design: voice interaction and touch interaction. By analyzing these two systems, key affordance-related design features for elderly users can be identified, providing a basis for designing for elderly users. The comparison of the two typical systems is shown in Table 1.

Table 1. Comparison of two typical systems.

Feature	Amazon Alexa (Voice-Driven)	Xiaomi Smart Home (Touch-Driven)
Interaction Method	Voice commands, voice feedback	Touchscreen, physical buttons
User Input Method	Wake word, voice commands	Touch, swipe, button operations
Operation Mode	Voice-driven, controlled via voice commands	Touch-driven, controlled via icons and swipe actions
Interface Complexity	Simple, based on voice commands	More complex, provides multiple functional menus
Elderly User Adaptability	High, voice operation is simple and intuitive	Medium, requires some learning effort
Affordance Design	Emphasizes clarity of voice feedback and wake word	Emphasizes icon design and usability of physical buttons

To evaluate the affordance of the two systems, this study selected the following three evaluation metrics: learning time, task completion rate, and user satisfaction (NPS score). To ensure the scientific and fair evaluation process, standardized testing methods were followed, and a detailed analysis was conducted based on actual user experience.

The evaluation methods are as follows: Learning Time: By observing and recording the time users take from their first interaction with the system to their ability to independently complete basic operations. In the test, users started the system for the first time without any external help and attempted to complete basic tasks such as adjusting the temperature or controlling the lights. Task Completion Rate: A series of common tasks (such as setting appliances, voice control, scene switching, etc.) were designed. The task completion rate was evaluated by recording how many times users successfully completed these tasks. Clear task goals were set during the test, and the completion status of each user was recorded. User Satisfaction (NPS Score): User feedback was collected through surveys and one-on-one interviews, measuring their overall satisfaction with the system. After the test, users rated their experience on a scale from 0 to 10, and the final NPS score was calculated.

The evaluation process is as follows: User Recruitment: 30 elderly users aged 60 and above were recruited, ensuring a diverse group representing different cognitive abilities, technological acceptance, and daily usage habits. Testing Environment Setup: The tests were conducted in the same environment to ensure all devices and software versions were consistent. Each user experienced both the Amazon Alexa and the Xiaomi Smart Home system. Task Design and Testing: Tasks mainly involved adjusting devices (such as lights, temperature control, audio, etc.) and using voice commands or touch operations for control. Each user's operations were video recorded, and their steps and time were tracked through system logs. The results are shown in **Table 2**:

Table 2. System evaluation results analysis.

Evaluation Metric	Amazon Alexa (Voice-Driven)	Xiaomi Smart Home (Touch-Driven)
Learning Time (minutes)	12.4	18.7
Task Completion Rate (%)	91%	75%
User Satisfaction (NPS score)	78	65

The results show that Amazon Alexa performs significantly better than Xiaomi Smart Home in terms of learning time, with an average learning time of 12.4 minutes, compared to Xiaomi Smart Home's 18.7 minutes. This difference is mainly because Amazon Alexa relies on voice control, allowing users to complete tasks with simple voice commands, while Xiaomi Smart Home requires touch screen operations with relatively more steps. Amazon Alexa's task completion rate is 91%, indicating that voice operations are more intuitive and easier for elderly users to understand. In contrast, Xiaomi Smart Home has a task completion rate of 75%, with elderly users potentially facing difficulties in understanding icons or dealing with overly complex operations when using the touchscreen. Amazon Alexa's NPS score is 78, indicating higher user satisfaction with its operation. In contrast, Xiaomi Smart Home's NPS score is 65, reflecting slightly lower satisfaction due to its interface complexity and operational difficulty.

4.2. Key Technological Features of Successful Design

The evaluation results of the two systems—Amazon Alexa (voice-driven) and Xiaomi Smart Home (touch-driven)—highlight several key technological features that enhance the user experience, particularly for elderly users. The results emphasize the advantages of voice interaction in reducing cognitive load, simplifying the operation process, and improving user satisfaction, especially for elderly users, where voice-driven operations significantly enhance usability.

One of the key features of Amazon Alexa's successful design is its reliance on voice control. The use of voice commands to complete tasks significantly reduces the learning time for elderly users. According to the test results, Amazon Alexa's learning time is 12.4 minutes, compared to 18.7 minutes for Xiaomi Smart Home. This difference is mainly due to the simplicity of voice commands, where users only need to issue simple voice instructions to complete tasks, without the need for complex interface navigation or multi-step operations. Elderly users often encounter difficulties with small touchscreen operations and multi-step interfaces, but voice control eliminates these steps, greatly reducing the complexity of operations. Amazon Alexa's task completion rate reaches 91%, indicating that voice control is more intuitive and easier for elderly users to understand. In contrast, Xiaomi Smart Home's task completion rate is 75%. Elderly users may struggle to understand icons or find the operation process too complicated when using the touchscreen, leading to lower task completion rates.

An important design feature of Amazon Alexa is the clarity of its voice feedback, which can immediately confirm the user's action. For elderly users, feedback after performing an operation is crucial, as it helps confirm whether the task was successfully completed and reduces uncertainty and anxiety. Amazon Alexa provides voice feedback, voice confirmation, and operation prompts, helping users verify that their commands have been correctly recognized and executed. This instant feedback greatly enhances the confidence of elderly users, allowing them to quickly understand the results of their actions and improving their overall experience. In contrast, while Xiaomi Smart Home provides effective touchscreen feedback, it lacks the immediacy and clarity of voice feedback. Touchscreen feedback typically relies on visual cues, which can sometimes be unclear due to the complexity of icons or the ambiguity of text, leaving elderly users confused and uncertain during use.

Amazon Alexa's voice command system greatly reduces the cognitive load on elderly users. As elderly individuals often experience cognitive decline, they may find it difficult to understand and remember complex interfaces. The voice command system avoids the common issues of menu navigation and complex steps found in traditional touchscreen operations. Users only need to issue short voice commands like "turn on the lights" or "adjust the temperature." This natural operation method significantly reduces cognitive load and makes it easier for elderly users to operate. In contrast, Xiaomi Smart Home's touchscreen operations require more steps to complete similar tasks, and the interface is more complex. Especially for elderly users with declining vision and cognitive abilities, excessive menu layers and icons can increase their learning costs and operational difficulties.

The evaluation results highlight Amazon Alexa's advantages in providing a better user experience for elderly users. The simplicity of voice control, instant and clear feedback, and design that reduces cognitive load enable Amazon Alexa to perform excellently in terms of task completion rate, learning time, and user satisfaction. In comparison, although Xiaomi Smart Home provides the convenience of touchscreen operations, its more complex interface design and operational steps present more challenges for elderly users. This comparison underscores the user-friendliness of voice-driven systems for elderly users in smart home operations, offering valuable insights for future age-friendly design.

4.3. User Testing and Iteration Suggestions

During user testing, an A/B test was conducted to evaluate the impact of different icon designs on elderly users' interactions. The test compared the task completion rates between the metaphorical icon group and the abstract icon group. The experimental design for the A/B test is as follows:

Participant Selection 60 elderly users (aged 60 and above) were recruited, with varying levels of experience using smart home devices. To ensure the scientific validity of the test, participants were randomly assigned before the test to ensure each group represented a variety of cognitive abilities, technology acceptance, and daily usage habits. During analysis, the research team examined task performance across gender and age subgroups (60 - 69, 70 - 79, 80+). It was observed that participants over 70, especially those with limited digital experience, tended to exhibit longer learning times and higher error rates, particularly in touchscreen-based operations. Female users showed slightly better accuracy and confidence in voice-based tasks, while male users demonstrated marginally faster reaction times in touch interaction. These observations suggest interaction preferences may vary by subgroup and warrant deeper stratified analysis in future work.

Participants were randomly divided into two groups: one group used metaphorical icon designs, while the other group used abstract icon designs. The metaphorical icon group used icons resembling real-world objects (e.g., a lightbulb for lighting, a house for the homepage), while the abstract icon group used abstract symbols (e.g., geometric shapes or simplified patterns). The study designed 10 common tasks, including adjusting appliance settings, controlling temperature, and turning lights on/off. Each task required the user to complete it independently without external help, using the corresponding icons for interaction.

Experimental Process: Users received a brief operational guide before the test, including a unified video demonstration and verbal explanation, ensuring that all participants understood the basic operations in a consistent manner before proceeding with the tasks. Each user independently completed the assigned tasks. After successfully completing each task, the user received feedback and was guided to the next task. During the test, researchers recorded the time users spent on each task, the task completion success rate, and their understanding of and response to the interface. After completing all tasks, users filled out a satisfaction survey to further gather their feedback.

Evaluation Criteria: Task Completion Rate: Measures the proportion of tasks successfully completed by users on their first attempt. Learning Time: Measures the time it takes users to become proficient at completing tasks from their first exposure to the system. User Satisfaction: Satisfaction data was collected via a survey, with ratings from 0 to 10, to obtain an overall evaluation of the icon design. The results are shown in Table 3:

Table 3. A/B test results.

Evaluation Metric	Metaphorical Icon Group	Abstract Icon Group
Task Completion Rate	91%	64%
Learning Time (minutes)	12.3	18.5
User Satisfaction (NPS Score)	82	63

The task completion rate for the metaphorical icon group was 91%, compared to 64% for the abstract icon group. This difference indicates that systems using metaphorical icon design are easier for elderly users to understand and operate. Users in the metaphorical icon group were able to more quickly identify and understand each function, while abstract icons caused confusion due to their complexity, impacting task completion. The learning time for the metaphorical icon group was 12.3 minutes, compared to 18.5 minutes for the abstract icon group. Metaphorical design reduces cognitive load by simulating real-world objects, making it more intuitive for elderly users to understand the operation, thus shortening learning time. The NPS score for the metaphorical icon group was 82, indicating high user satisfaction, while the abstract icon group's NPS score was 63, showing lower satisfaction. This demonstrates the significant advantage of metaphorical design in enhancing the user experience, especially for elderly users with declining cognitive abilities.

5. Conclusion

Guided by affordance theory, smart home systems can be designed to better align with the needs of elderly users, particularly in reducing cognitive load, improving operational intuitiveness, and providing timely feedback. Integrating visual, interaction, and feedback affordances into smart home design not only enhances the elderly user experience but also promotes their acceptance and dependence on new technologies. Future designs should pay more attention to individual differences, flexibly adjust interaction methods and interface layouts, and ensure a balance between the widespread adoption of technology and the actual needs of elderly users. Affordance theory provides strong theoretical support for designing for elderly users, advancing the smart home field in a more intelligent and human-centered direction.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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