Optimization of Smart Home Based on Human Computer Interaction Perspective

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Abstract: Smart home products have become a "must-have" in home renovations, with particularly high penetration rates among younger demographics and high-income households—exceeding 50% in some cities. However, due to limitations in artificial intelligence technology, internet of things technologies human-computer interaction technology and related technological advancements, current smart home systems still fall short of fully meeting user demands. Today, smart homes face challenges such as complex operation and insufficient personalization. This article focuses on optimizing smart homes in two key areas: personalization and emotional engagement. Enhancing daily convenience and emotional value through intelligent color-based and interface-size-adaptive layouts. Also by improving personalized connections between smart devices and users, such as self-regulating living environment, automatic equipment operating, and voice service the system can better adapt to individual needs, deliver tailored services, address emotional requirements, and ultimately achieve the goal of convenient and comfortable living for users. Through the above optimization measures, we aim to make smart homes more convenient for daily life and achieve higher levels of automation.

1 INTRODUCTION

Smart Home refers to a residential environment where household devices are interconnected through IoT (Internet of Things) technologies, artificial intelligence (AI), and automated control systems, enabling intelligent management and remote operation. Its core objectives are to enhance living convenience, comfort, and security. With advancements in 5G, IoT, and AI technologies, coupled with strong governmental policy support, smart home adoption rates are steadily increasing. China's smart home market size surpassed hundreds of billions of Chinese yuan in 2019 and is projected to exceed one trillion yuan by 2025, with a compound annual growth rate (CAGR) exceeding 20%. Meanwhile, smart home products have become a standard configuration in home decoration, particularly demonstrating higher penetration rates among younger demographics and high-income households, with adoption exceeding 50% in some cities.

With the rapid advancement of artificial intelligence (AI), IoT technologies, and big data analytics, smart home systems have evolved from standalone device control into holistic ecosystems. The core objective of smart homes lies in delivering user-centric automated services, where human-computer interaction (HCI) technologies serve as the critical bridge between users and devices. The implementation depth of HCI directly determines system efficiency and user satisfaction. However, constrained by current technological limitations, smart homes primarily fulfill basic functions such as remote appliance control and intelligent security systems, yet fall short of addressing comprehensive user demands. Challenges persist, including operational complexity, insufficient personalization, and privacy vulnerabilities. Modern users increasingly expect smart homes to proactively perceive human states (e.g., activity patterns, emotional cues) and autonomously adjust device configurations, while demanding heightened personalized adaptability. Consequently, the continuous expansion of functional capabilities is imperative to better align with consumer expectations and enhance lifestyle convenience.

In recent years, there have been many explorations in human-computer interaction for smart homes. In smart home, because many devices need to collect a large amount of personal life information and share it with multiple devices through the Internet,

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personal privacy has become a core area of smart home. The optimization of smart homes requires ensuring efficient living for users while not infringing on their privacy. Hua Du with other authors aim to reduce excessive privacy collection and maintain user security by using discrete selection (Du et al., 2023). Speech recognition is the foundation for smart homes to communicate with users. In order to improve smart homes' ability to recognize and understand speeches, Chandra Irugalbandaraand others suggest a recognition system called "HomeIO", which can be able to achieve voice activity detection and automatic speech recognition while reducing the demand for cloud services (Irugalbandara et al., 2023). Sensors provide useful information for the personality or services of smart homes by collecting data on the user's life information. The data set designed by Gibson Chimamiwa and other investors can better collect the data recorded by different sensors, and improve the accuracy of smart home services (Chimamiwa et al., 2020). Xu Huan developed an age-adaptive smart home human-computer interaction system by constructing a multi-source data fusion framework through advanced data fusion technology, implementing control optimization protocols for elderly-oriented interaction commands, which achieves a rapid-response capabilities for senior users' daily operational demands (Xu, 2022). Nuno Costa and other researchers addressed the challenges of elderly individuals living alone through a large project called Aging Inside a Smart Home (Costa et al., 2014).

Optimizing smart homes from the perspective of human-computer interaction can promote the development of multimodal interaction and related technologies. Through natural interaction (voice, gestures) and emotional computing technology, the personalization of smart home services can be enhanced and emotional value can be provided to users, creating a more comfortable and convenient life.

The second part of this article will explain the core technologies required for optimization, the third part will explain the optimization plan, the fourth part will discuss the optimization plan for smart homes, and the fifth part will summarize the optimization plan.

2 RELATED TECHNOLOGIES

2.1 Concept and Application of Human Computer Interaction

Human-Computer Interaction (HCI) is an interdisciplinary field that studies information exchange and collaboration between humans and computer systems, integrating computer science, psychology, design studies, and other disciplines. Its primary objectives are to enhance technological usability and user experience. The core of HCI lies in achieving natural and efficient information communication through interface design and optimization of interaction modes. In smart home applications, HCI enables natural interactions via voice recognition, touch-sensitive interfaces, and AI algorithms, facilitating automated control of interconnected smart devices to improve daily convenience.

Multimodal Human-Computer Interaction (MHCI) is a technology that integrates multiple sensory modalities such as speech, tactile input, vision, and gestures to enable natural and efficient information exchange between humans and machines. Interaction using a single sensory modality is called unimodal, while employing three or more modalities is referred to as multimodal (Liu & Liang, 2024). Touchscreen control, video control, and voice control stand as the three most prevalent human-computer interaction methods in smart homes (Zhou et al., 2022).

2.2 The Development of AI Technology and Its Application in Smart Homes

Artificial intelligence technology has achieved leapfrog development in recent years through deep learning, breakthroughs in computing power, and big data. In the field of smart homes, AI enables voice assistants to achieve human-machine voice interaction through voice processing. Meanwhile, computer vision technology supports facial recognition, which can be applied in security monitoring and other scenarios. Machine learning algorithms enable devices to have autonomous learning capabilities, analyze user habits, and change the operating mode of household appliances by combining with IoT technology. Intelligent cameras enable high-definition filming and remote monitoring, and integrate monitoring and alarm through AI to ensure the safety of individuals living alone. In the future, with the continuous development of AI, smart homes will present more natural human-machine collaboration and better service capabilities.

3 OPTIMIZATION STRATEGIES

3.1 Optimizing Smart Homes with Emotional Resonance and User Centered Personalization Principles

3.1.1 Emotionality

Emotional Experience Design refers to design methodologies and principles that prioritize and cultivate users' positive emotional experiences during interactions with products, services, or environments. This approach specifically focuses on creating meaningful affective responses through intentional design interventions (Xu & Huang, 2024). Emotional Design was first proposed by American cognitive psychologist Donald Norman as a design philosophy. He categorized emotional design into three levels: Visceral Level Design, Behavioral Level Design, and Reflective Level Design.

Visceral Level Design emphasizes the sensory experience evoked by the design itself. In the current development trend of smart homes, enhancing the direct sensory impact of smart home systems allows users to derive greater emotional value. This can be achieved through personalized interface layouts and unique voice interaction features in smart home ecosystems, which elevate users' trust and affinity toward these systems.

Behavioral Level Design focuses on the functionality and efficiency of products. By optimizing the operational efficiency of smart home devices, users' daily life efficiency and comfort are significantly improved.

Reflective Level Design involves post-usage reflection, where users evaluate whether the product aligns with their needs and fulfills their emotional expectations, thereby influencing their purchase decisions or continued usage.

3.1.2 Personalization

The personalized needs of smart home systems stem from the diversity of user scenarios and requirements. People's lifestyles, habits, and emotional appeals vary significantly, demonstrating inherent heterogeneity. Single-mode devices cannot satisfy the demands of all user groups, necessitating customized services tailored to different demographics to better accommodate diverse user needs.

Figure 1 illustrates the structural framework for smart home optimization strategies.

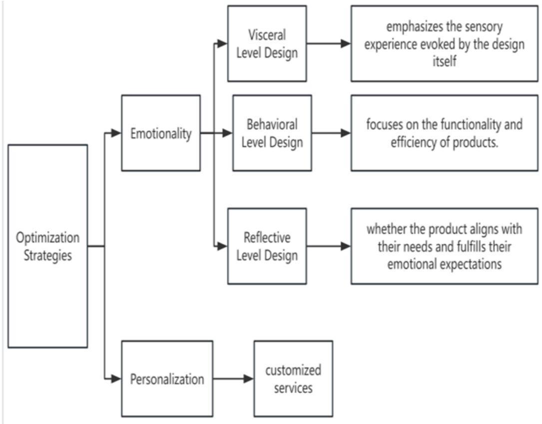

Figure 1: Structural framework for smart home optimization strategies (Picture credit: Original).

3.2 Optimization

Based on the principles of emotional engagement and personalization, researchers can optimize smart home systems to better align with users' needs and preferences.

Drawing on the visceral level of human perception, smart home interfaces should adopt an intuitive layout design, ensuring that application information is presented in a clear and concise hierarchy. This allows users to quickly and accurately locate desired functions during interaction. By analyzing usage frequency data for different features over time, frequently accessed functions can be emphasized through enlarged icons or highlighted colors for enhanced visibility. As a critical element in interface design, color significantly influences users' emotional responses to smart home systems. Implementing zonal color coding and incorporating user-preferred color schemes can elevate both the aesthetic appeal and emotional acceptance of smart interfaces, thereby improving overall user engagement and satisfaction. For elderly users, red and orange should be predominantly used as layout color schemes. This is because older adults experience relatively less impairment in distinguishing red and orange hues. Additionally, red can evoke a sense of warmth for seniors living alone long-term, while orange helps elders perceive vitality (Zhao, 2024).

The goal of optimizing smart home systems is to enhance their operational efficiency and improve users' quality of life. According to IDC's smart home research, 72% of users desire devices capable of autonomously learning their habits rather than requiring manual configuration. Optimization can be achieved through environmental sensors that detect human behavior under varying weather conditions and identify users' preferred temperature, humidity, and other parameters in different settings. Once environmental changes are detected, the system automatically adjusts to provide the most comfortable conditions. By employing LSTM (Long Short-Term Memory Networks) to build a user behavior prediction model, smart homes collect data on users' daily activities over the past week, analyze unique patterns and variations, and generate predictions for the next day's behavior through big data analytics. This enables smart homes to proactively adapt indoor environments to users' optimal preferences during different activities, thereby better safeguarding their quality of life. Figure 2 illustrates the structural framework of this process.

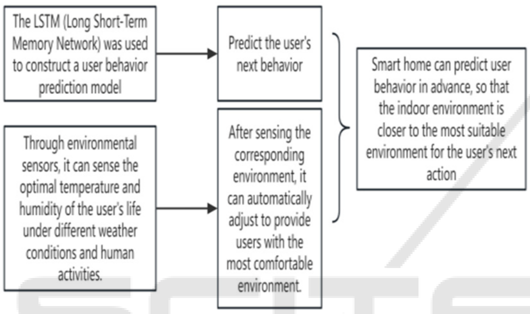

Figure 2: The system structure of intelligent control of the indoor environment (Picture credit: Original).

Smart home systems enable devices to operate proactively, reducing user waiting time and enhancing daily efficiency. Taking coffee machines as an example—an essential part of daily life—87% of users believe that the automatic coffee preparation feature significantly enhances daily convenience. By integrating smart home technology with the Internet of Things (IoT), devices are connected via Wi-Fi, Bluetooth, and other protocols to enable data sharing. A smart hub (e.g., Amazon Echo, HomePod) consolidates data from multiple devices, and computational analysis of this data identifies precise usage patterns and frequencies in user behavior. This allows the system to preemptively activate devices like coffee machines, saving time. The diagram below illustrates the automated process of a coffee machine preparing beverages for users. First, IoT technology is employed to collect data on the coffee machine's operating hours and users' activity patterns. By analyzing the peak frequency of coffee consumption times, the system can prepare coffee in advance, as shown in Fig. 3.

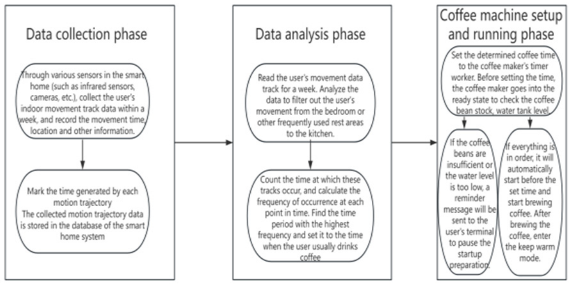

Figure 3: Coffee machine automatic operation flow chart (Picture credit: Original).

Over half a century ago, Weizenbaum developed a simple yet powerful chatbot called ELIZA (Chkroun & Azaria, 2021). It delivers substantial emotional resonance to users. Therefore, our smart home optimization incorporates voice-controlled interactive communication capabilities between smart home systems and occupants. Voice control is one of the most popular control methods for smart homes, accounting for 56.55% of usage. Consumers expect voice assistants to recognize the voices of different family members and provide customized services based on personal preferences. Through voice recognition and sentiment analysis algorithms, the system can capture users' tone, intonation, and emotion-specific keywords to identify their emotional state and adapt its responses accordingly. Additionally, by monitoring users' body language via cameras, it can achieve multimodal interaction, such as integrating speech, facial expressions, and physical movements—to more accurately assess whether the current environment aligns with user comfort and make real-time adjustments. For users living alone, elderly individuals, and children, smart home systems can infer their emotional states from their facial expressions and provide emotional value through conversational interactions, thereby reducing feelings of loneliness. Figure 4 illustrates the communication flow between smart home devices and users.

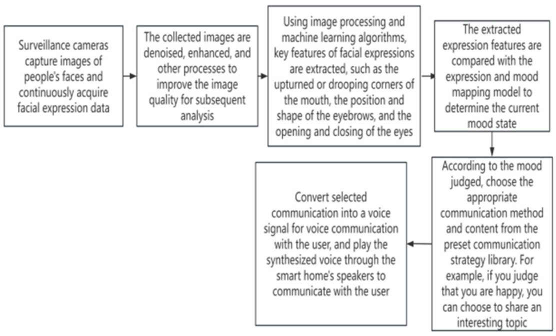

Figure 4: Smart home and user communication flow chart (Picture credit: Original).

4 DISCUSSION

4.1 Advantage

Smart homes, through voice control and remote operation capabilities, liberate human labor and optimize the efficiency of daily life management. Moreover, smart home systems that regulate temperature and humidity enable people to live in their most comfortable environment, significantly enhancing daily comfort and quality of life. Smart home systems provide personalized services that bring people a more convenient lifestyle. For example, smart coffee machines can automatically prepare beverages for users without requiring manual operation, significantly enhancing daily convenience. Furthermore, smart homes can provide emotional value to people, enabling individuals of all ages to feel a sense of companionship and enhancing their overall happiness in daily life.

4.2 Limitation

Smart home devices offer many advantages, but they also have significant limitations. These limitations manifest at multiple levels. Firstly, smart homes are heavily reliant on technology, with these systems widely employing cloud-based services such as those provided by Google and Amazon—a dependency that exposes them to cyber attacks. Internet outages or system failures can result in complete device malfunctions. To ensure proper operation, these systems require both stable internet connectivity and a secure environment free from cyber threats (Irugalbandara et al., 2023, Huang, 2023). Additionally, as smart homes require the collection of users' daily life data and even facial expressions, privacy and data security emerge as critical concerns, with potential leaks posing severe consequences for users. Furthermore, incompatibility between different brands of smart home products often forces users to remain within a single ecosystem, highlighting the urgent need to reduce technical barriers between manufacturers and improve cross-brand interoperability.

5 CONCLUSION

The paper proposes personalized layout design for smart homes while optimizing their emotional resonance and personalized features. Through optimization, smart homes can better enhance personalized services tailored to individual user needs. Personalization is a critical pathway toward optimizing user experience. By integrating voice emotion recognition and facial expression analysis， smart systems achieve affective computing capabilities, supporting emotional well-being and adaptive environmental adjustments. The evolving computational capabilities of artificial intelligence, coupled with progressive developments in Internet of Things (IoT) architectures, empower smart home systems to process user behavioral data through sophisticated algorithms, thereby delivering context-aware services tailored to individual preferences. Optimizing smart homes from a human-computer interaction perspective can not only enhance the convenience of people's lives but also unlock broader market opportunities for smart home technologies. In the future, it will be essential to continuously break down barriers between different smart home brands, enabling seamless data sharing across platforms to avoid redundant data collection.

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