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A Study on Interaction Optimization of Home Service Robots Based on Generative AI: Focusing on the Aging Population

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ABSTRACT

The rapid advancement of smart home technologies, increased market demand, and policy backing have facilitated the extensive deployment of home service robots. However, the complexity of domestic environments has gradually exposed the shortcomings of traditional household robots. With the advancement of generative AI, home robots can now better comprehend natural language and handle diverse data, enabling them to deliver more personalized intelligent services. This paper explores the applications of generative AI-based robots in multimodal interaction, emotional computing, and intelligent services through the analysis of typical domestic robot product cases from both home and international markets. To improve user experience, this paper proposes innovative strategies that integrate emotional intelligence, personalized services, adaptive learning, and augmented reality technologies, with the goal of enhancing the performance of robots in interacting with elderly users, offering emotional companionship, and adapting to smart homes, thus improving elderly users' experiences with intelligent, personalized, and emotional services.

INTRODUCTION

Propelled by the “Internet Plus” initiative and advances in intelligent manufacturing, home service robots are being deployed in a growing number of households. By integrating speech recognition, computer vision, and multimodal perception, home service robots deliver convenient, personalized assistance and have become pivotal components of smart home systems[1]. Generative artificial intelligence (Gen AI), via advanced natural language processing, has substantially advanced home service robots capabilities, enhancing language comprehension, affective expression, and context-sensitive reasoning.

Concurrently, accelerating population aging further complicates inherently complex household environments, drawing increased attention to home service robots. On 9 June 2025, China’s Ministry of Industry and Information Technology and Ministry of Civil Affairs jointly issued the “Notice on Paired Key-Problem Tackling and Scenario-Application Pilot Work for Intelligent Elderly-Care Service Robots,” aiming to direct home service robots development toward improving older adults’ quality of life and alleviating the burden of family

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Table 1 | Differences in Interaction Experience with Smart Devices Between Younger and Aging Groups

Dimension	Younger	Aging
Technology Acceptance	High, quick adaptation, strong understanding	Lower, resistance to complexity, adaptation difficulties
Language Interaction Ability	Natural, fluent, easy comprehension	Weaker comprehension, pronunciation barriers
Emotional Feedback Needs	Rational, efficiency-oriented, functional	Highly dependent on emotional responses, prefers humanized interactions
Tolerance for Complexity	High, able to accept complex features	Low, prefers simple, intuitive interfaces
Visual Perception Ability	Average, strong visual functions	Weaker, needs larger fonts, higher contrast
Auditory Perception Ability	Average, good hearing	Weaker, needs amplification, clearer speech
Physical and Mobility Abilities	Strong, free interaction	Weaker, may need supportive devices
Safety Awareness	High, knows how to operate safely	Highly sensitive to safety, aware of risks
Cognitive Response Time	Fast, quick to react and adapt	Slower, needs more time to process and respond

caregiving[2]. Globally, governments and enterprises are advancing innovations in home service robots, with research focusing on human–robot empathy, multimodal interaction, and proactive service.

Despite the growing adoption of Gen AI in home service robots, the literature largely emphasizes isolated technological breakthroughs, with limited attention to holistic interaction optimization and to the needs of users across age groups. Among older adults, cognitive, affective, and physiological heterogeneity means that conventional robots often fail to provide adequate socioemotional companionship and intelligent interaction[3]. Consequently, leveraging Gen AI to improve the interaction experience of home service robots has become a pressing challenge for the smart home domain.

The present study examines how Gen AI can optimize interaction in home service robots—particularly for older users—proposes targeted strategies, and offers theoretical and practical guidance to advance the field.

USER EXPERIENCE THEORY AND AGING POPULATION

User experience (UX) theory originates in the field of human–computer interaction (HCI) and is among the core topics of contemporary design research. Cognitive psychologist Donald Norman introduced the concept in the 1990s, arguing that user experience extends beyond product usability to encompass users' emotions, psychological responses, and subjective satisfaction during use[4].He further maintained that design should shift from a product-centered to a user-centered orientation, explicitly considering users' needs, expectations, and emotions to achieve harmony between technology and people[5].Given heterogeneity in users' needs and affect, their experiences necessarily vary with context of use.

With the advent of an aging society, the application of UX theory has become increasingly important. Older adults differ markedly from younger users in cognitive, emotional, and physical status, implying that the design of intelligent products must address not only functionality and intelligence but also the physiological and psychological needs of older users[6].

Moreover, the challenges older adults face when using intelligent products differ from those encountered by younger users[7]. First, sensory abilities often decline in later life, especially vision and hearing[8].Such sensory decline can lead to incomplete information transmission or misinterpretation of instructions. Second, age-related reductions in cognition and memory make it difficult for older adults to understand and execute complex instructions[9].

Furthermore, the affective needs of older adults warrant careful attention. With advancing age, social networks tend to contract, intensifying loneliness and affective needs[10].Emotional design is therefore particularly important for improving user experience. The application of Gen AI enables home service robots to more accurately identify older adults' affective needs and to provide personalized interactive feedback, thereby mitigating loneliness and strengthening trust and reliance. The differences in the interaction experience with smart devices between younger and aging groups are shown in **Table 1**.

As home service robots technologies advance, the interaction experiences of older adults have become a central consideration for design and optimization[11]. In home service robots design, user experience (UX) theory provides a theoretical framework and practical methods for improving the quality of interaction between robots and older adults. home service robots should be conceived not merely as tools but also as companions for older adults.

Table 2 | Core Differences Between 'Traditional Robots' and 'Gen AI-powered Robots' in the Field of Service Interaction

Dimension / Comparison	Traditional Robots	Robots Empowered by Gen AI
Interaction Ability	Rule-based, fixed interaction, pre-set scripts	Natural language generation, open-ended dialogue, adaptable
Emotional Perception And Expression	Simple emotional algorithms (e.g., facial expressions, tone)	Wide range of emotional expressions, empathetic communication
Learning And Adaptation Ability	Pre-programming, manual intervention required	Self-adaptation, few-shot learning, contextual reasoning
Knowledge Reasoning And Creativity	Predefined knowledge bases, limited creativity	Reasoning, content generation, suggestions, multimodal creativity
Multimodal Interaction Ability	Basic perception (voice, images), weak fusion	Multimodal integration (voice, text, images, video), strong understanding
Service Personalization Level	User tags, manual rules, weak adaptability	Dynamic adjustments based on history and feedback, high personalization
Self-Explanation And Transparency	No explanation, execution process shown	Explanatory text, enhanced decision-making transparency

Figure 1 | Bionic Robots Appeared at the Zhongguancun Forum Annual Conference (http://www.bkmedia.cn/)

GEN AI-ENABLED HOME SERVICE ROBOTS

Traditional home service robots, due to their functional limitations, have gradually failed to meet the increasingly complex demands and changes in modern household environments. Through its strong natural language understanding and content generation capabilities, Gen AI is emerging as a key technology reshaping human–computer interaction. It leverages large-scale deep neural networks to model and reason over multidimensional data—including language, knowledge, and affect—thereby enabling complex tasks such as natural dialogue, affective support, knowledge integration, and multimodal content generation[12]. As large-scale AI models advance, Gen AI applications in the home service robots domain are deepening, driving more personalized, affective, and intelligent interaction experiences. The core differences between "traditional robots" and "Gen AI- powered robots" in the service interaction domain are shown in **Table 2**.

At the Zhongguancun Forum Annual Conference in March 2025, several leading technology companies showcased home service robot (home service robots) technologies built on large-scale Gen AI models[13]. These systems demonstrate deep understanding of natural language and multimodal data, deliver personalized intelligent services, and exhibit strong interactive and autonomous capabilities. They perform well in language understanding, image recognition, and multimodal processing, enabling precise and efficient intelligent support across diverse domestic scenarios.

Drawing on the robots exhibited at the event and on comparable products abroad, this paper compiles nine representative home service robots driven by large-scale Gen AI models. The **Table 3** summarizes their application scenarios, advantages, and distinguishing features.

Through the research conducted on the above content, Gen AI has prominently demonstrated its substantial advantages in enhancing the natural dialogue capabilities of home service robots. Traditional human–computer interaction systems typically follow an "instruction-

Table 3 | Functions and Products of Gen AI-based Home Service Robots at Home and Abroad

Company	Large Model	Application Scenarios	Product Advantages and Features
Baidu	ERNIE	Search, smart assistants, content creation	Strong language capabilities, multimodal input/output, enhanced personalization
Alibaba	Qwen	Customer service, education, finance, smart speakers	Multi-scenario integration, home schedules, health advice, user engagement
Amazon	Alexa+	Security, reminders, voice control	Natural dialogue, complex tasks, mobile platform, home monitoring integration
LG	EXAONE	Home management, companionship, monitoring	Movable AI agent, multimodal perception, conversational interaction
Tencent	Hun Yuan	WeChat, QQ, responses, multimedia, retail, healthcare	Chinese reasoning, multimodal interaction, multi-platform applications
ECOVACS	YIKO-GPT	Floor cleaning, remote control	Natural language interaction, multi-turn conversation, real-time control
iFlytek	Spark Desk	Voice assistants, education, speech recognition	Strong recognition, multilingual adaptability, AI+education, AI+healthcare
SenseTime	Sense Nova	Digital humans, virtual assistants, facial recognition	Humanized interaction, virtual expressiveness, emotional computing
Megvii	Brain++	Smart cities, security, robot perception	Enhanced perception, Gen AI technology, multi-scenario integration

Figure 2 | Home Service Robots Doing Household Chores (https://news.cnr.cn/)

response" model, lacking deep contextual understanding and personalized expression, which makes it challenging to effectively address users' evolving needs. However, by leveraging contextual situational awareness, Gen AI enables multi-turn dialogues and autonomous knowledge generation, allowing for smoother and more natural communication based on users' historical behavior, conversational context, and tonal shifts[14]. In the smart home application scenario, users can engage in real-time communication with robots via voice for tasks such as life reminders, health management, and household chores. Gen AI not only allows for more precise understanding of user needs but also proactively offers suggestions and adapts to user preferences over time, ultimately achieving the goal of adaptive service.

Furthermore, Gen AI has introduced more advanced emotional computing and companionship functions to home service robots. As mental health issues such as loneliness become increasingly prominent within the elderly population, emotional services are gradually emerging as a key design focus for robots. By leveraging emotion recognition algorithms and emotion generation models, Gen AI can analyze multimodal signals such as users' voice, facial expressions, and body movements to assess their emotional states and generate comforting and caring responses appropriate to the situation[15]. This emotional interaction significantly enhances users' sense of belonging and well-being. Currently, several leading products can automatically generate care reminders or emotional support based on elderly users' daily routines and health status, even

proactively encouraging communication with family members to alleviate social isolation.

On the other hand, Gen AI's multimodal interaction capabilities have brought innovative advancements to the smart home experience. In addition to supporting text and voice interactions, Gen AI can also automatically generate images, videos, audio, and other content as needed[16]. While meeting the cognitive training and entertainment needs of elderly users, Gen AI can create personalized puzzle games, targeted content recommendations, or memory albums, thereby greatly enriching the product's entertainment and emotional value. In addition, by integrating Internet of Things (IoT) technology, Gen AI enables environmental awareness and intelligent adjustment[17]. For example, based on user behavior patterns, Gen AI can automatically adjust home lighting, temperature, and security settings, creating a smart and adaptive living environment for users.

INTERACTION EXPERIENCE OPTIMIZATION STRATEGIES DRIVEN BY GEN AI

Through case studies of typical home service robot products currently on the market, we have conducted an in-depth analysis of the actual performance and main issues of Gen AI-driven robots in service interaction experiences. Based on the above analysis, this paper proposes targeted strategies for optimizing interaction experiences.

Emotional Intelligence

Gen AI demonstrates significant potential in emotion recognition and processing, capable of analyzing and assessing speech, facial expressions, and behavioral patterns. Home service robots utilizing this capability can possess emotional intelligence, making their interaction more diverse and nuanced. The inclusion of emotional intelligence enhances the adaptability of robot functionalities and endows them with emotional companionship characteristics, fostering a more natural and humanized interaction with users.

Traditional home robots mostly function as tools, responding based on fixed programs or instructions, lacking emotional understanding and resonance. The emotional intelligence module can capture and analyze the user's emotional state in real-time, recognizing emotions such as anxiety, happiness, anger, and fatigue through voice tone, facial expressions, and body posture, and adjusting tone, content, and environmental parameters accordingly. When users experience anxiety or fatigue, the robot can offer emotional support through a gentle tone, soothing language, or by playing relaxing music.

Traditional home robots often struggle to meet the emotional needs of elderly individuals, such as loneliness, emotional emptiness, and mood fluctuations. However, home service robots with emotional intelligence can provide detailed and considerate companionship by accurately identifying emotions and offering personalized responses. When loneliness or anxiety is detected, the robot can not only comfort the user with voice but also utilize facial expression recognition to further assess emotional changes, adjusting its interaction strategies in a timely manner to offer a more humanized companionship experience.

Adaptation and Personalization

Compared to traditional intelligence, the enhanced data processing and learning capabilities of Gen AI offer new opportunities for innovation in service robots. Service robots can utilize adaptive learning technologies to deeply learn from the behaviors, contexts, and life patterns of household members, providing personalized services and predicting actions. By combining adaptive learning with personalized predictions, robots can not only respond more quickly to user needs but also proactively provide services even before users express their requirements, thereby preemptively meeting needs.

The key to this innovative strategy lies in the personalized behavior prediction model, which allows robots to forecast future needs based on users' historical behavior data. After analyzing users' daily activity logs, robots can continuously optimize service strategies and identify potential needs in advance. For instance, by understanding users' wake-up times, dietary habits, and work schedules, robots can automatically send health reminders, adjust the home environment, and even inquire if help is needed. In addition to regular tasks, this prediction can address special situations, such as reminding elderly users to take medication or schedule health check-ups. The robot's proactive involvement can improve users' quality of life, particularly for elderly individuals, reducing emergencies and enhancing their independence and sense of security.

For instance, with elderly individuals living alone, home service robots can analyze their daily wake-up time, eating habits, and routine activities to automatically adjust their schedules. The robot can remind the elderly to eat breakfast, take medication on time, suggest suitable walking and home activities, and coordinate with smart home devices to adjust indoor temperature and lighting, creating a more comfortable living environment to enhance life quality.

Immersive Interaction With XR Technology Integration

With the rapid development of extended reality (XR) technology, home service robots, through integration with XR, can provide users with a more immersive interaction experience. XR encompasses augmented reality (AR) and virtual reality (VR), and when combined with Gen AI, it not only enhances the robot's ability to

perceive vision and space but also improves the user interaction experience.

Traditional interaction methods primarily rely on voice and touchscreen; however, with XR devices, users can gain a more immersive experience. For example, after wearing a VR headset, users can interact with robots, enter virtual environments, and break free from the constraints of text or voice. AR technology overlays virtual information onto the real world, allowing users to see real-time guidance and advice from the robot through AR glasses or screens, enabling more intuitive spatial interaction.

This innovative strategy overcomes the limitations of traditional interaction, granting robots stronger intelligent perception capabilities to sense and understand user needs in three-dimensional space. This XR-integrated interaction method provides users with a novel sensory experience, especially for elderly users, as XR technology can effectively reduce their unfamiliarity with high-tech devices and ease of use, increasing engagement and interest.

For example, elderly users can experience "virtual tourism" at home through VR devices, interact with family members remotely, and enjoy family time. AR technology also helps them learn daily living skills, such as using kitchen appliances or performing basic home care tasks, with AR glasses providing real-time operational guidance and feedback when difficulties arise.

Multimodal Collaborative Interaction

Traditional home service robots typically rely on voice recognition or touchscreen input, which, while simple and intuitive, prove inflexible and limited in complex environments. To address this issue, multimodal interaction systems have emerged as a key technology for enhancing user experience.

Multimodal collaborative intelligence systems integrate various sensory modalities such as vision, touch, and hearing, enabling multidimensional interactions between humans and devices. Home service robots, through this technology, can automatically switch interaction modes based on the environment and user needs. For example, by combining visual recognition, speech recognition, gesture control, and haptic feedback technologies, robots can provide more natural and seamless responses during user operations, enhancing both interaction quality and convenience.

In practical applications, robots work in synergy through various sensory technologies. By combining eye-tracking and voice commands, they can accurately capture user intentions. For example, when a user gestures with their eyes to direct the robot, the robot not only understands the intent but also responds according to the voice command, improving the flexibility and accuracy of interaction. Furthermore, the inclusion of gesture control technology allows users to operate devices through simple gestures without needing voice commands. Adjusting volume, lighting brightness, or temperature can be done effortlessly, greatly improving operational convenience.

Smart Device Integration

The widespread adoption of smart home devices has created an extensive data network of various household devices, such as smart locks, lighting systems, and appliances. Traditional smart home devices typically perform simple collaborative functions through single commands, often resulting in fragmented user experiences. To enhance the level of smart living, Gen AI improves the collaboration between different smart devices, thereby enhancing the intelligence and personalization of home services.

The core of this innovative strategy is to establish an efficient smart home system integration platform using Gen AI, enabling devices to seamlessly connect and collaborate effectively. Through this platform, home service robots are no longer limited to single tasks but can interact and collaborate with other devices. For example, the robot can automatically adjust the home's temperature, humidity, and lighting based on the user's behaviors, habits, and external environmental changes. When the user leaves home, the robot links with the security system and activates the security mode automatically.

Data Privacy Protection

Home service robots are indispensable in areas such as health monitoring and emotional companionship. These robots, when providing services to users, need to collect and process large amounts of sensitive personal data, such as daily activities, health conditions, and emotional changes. Ensuring the privacy and security of this data has become an urgent issue that needs to be addressed. Especially in Gen AI decision-making processes, the "black-box" effect makes it difficult for users to understand how data is collected and used, which may reduce their trust in the robots and, in turn, impact their adoption.

To address this issue, this paper proposes a new solution that combines Explainable Artificial Intelligence (XAI) technology with a transparent data privacy protection mechanism. With XAI, the decision-making process of Gen AI models can be visualized and explained, enabling users to understand how robots collect, process, and use personal data. In health monitoring scenarios, users can clearly see how the robot provides personalized recommendations based on health data such as weight and blood sugar, and the purpose of each piece of data used. This transparent mechanism not only enhances user trust but also alleviates concerns regarding privacy issues.

In addition to explainability, a transparent data privacy protection mechanism is also crucial. The system should allow users to view and adjust the robot's data access permissions at any time. The robot can present the privacy policy through a simple interface, clearly

outlining the processes of data collection, storage, and processing to ensure users understand every step. Users should also be able to control data access and decide whether to share certain information. For example, in health monitoring, users can decide whether to share data such as weight and blood sugar with the robot and whether to accept personalized health advice.

CONCLUSION

This study combines industry practice, academic research, and user experience (UX) theory to propose strategies for optimizing the interaction experience of Gen AI-driven home service robots, which primarily include emotional intelligence, personalized adaptability, XR-enhanced immersion, multimodal collaboration, smart device integration, and privacy-preserving explainability.

Emotion-aware AI plays a crucial role in improving the mental health of elderly users. Through multimodal emotion recognition (such as voice, facial expressions, and gestures), generative AI robots can adjust their interaction styles based on the user's emotional state, alleviating feelings of loneliness and anxiety. The adaptive learning capability of Gen AI enables robots to predict and proactively respond to the needs of elderly users, thereby enhancing task compliance and service personalization.

XR technology offers an immersive environment for elderly users, reducing cognitive load and social isolation, while bridging the "digital divide." By combining eye-tracking, gesture control, and voice recognition, multimodal collaboration technologies enable robots to better adapt to users with sensory impairments. With the help of explainable AI (XAI) models, robots enhance the transparency of decision-making processes, thereby increasing user trust and addressing data security concerns.

This study expands user experience theory by integrating the adaptability of generative AI and affective computing as core elements, proposing design strategies for home service robots focused on elderly populations, thus addressing gaps in prior human-computer interaction research. Furthermore, it offers practical guidance to the industry and provides scalable solutions for global markets. Future studies should investigate the long-term effects of these robots in real-world settings, explore the influence of cultural differences on emotional interaction norms, and address energy efficiency issues in generative AI models to facilitate cost-effective deployment.

In conclusion, Gen AI-driven home service robots meet the household needs of elderly users through personalized, emotionally resonant, and user-centered services. Implementing the strategies outlined in this study will help create more inclusive, trustworthy, and emotionally engaging robots to address the challenges of the aging global population.

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