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Integration of Domestic and Foreign Technologies in Smart Home Systems for the Elderly in China

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Abstract. The development of the Internet and artificial intelligence promotes smart home systems been used widespreadly in modern society, which effectively improves people's life quality. However, limitations in functionality, closed ecosystem, and high costs make smart home systems are very impractical for the elderly. This article conducts a comprehensive analysis of the smart home development globally, summarizes the characteristics of smart home systems in different regions in the world, then considers the background of Chinese future aging population, and points out the trend of smart home technology in China. This article systematically evaluated the advantages and disadvantages of smart home systems in Europe and Asia. As a response to the aging population situation in China, this research proposes the "Smart Network" residential system, an integrated all-house smart home framework. This system aims at providing a cost-effective solution for the elderly and those people with limited self-care ability. It achieves the goal through excellent compatibility and an efficient intelligent platform, demonstrating the potential to enhance the life quality by incorporating localized those care needs of old age, intelligent environment adaptation, and predictive fall detection systems.

Keywords: Smart Home, Population Aging, Embedded Systems, Internet of Things

1. Introduction

With the advancement of technology and an increasing will for a better life quality, more and more individuals embrace the idea of purchasing smart home systems to monitor and manage their residences. The goals of smart home systems include reducing the usage of electricity and fuel, lowering carbon emissions, enhancing energy efficiency, improving residential comfort, and lightening the burden of household significantly [1].

China's smart home industry has developed for nearly 12 years, and progressed through four distinct stages: the initial stage, the pioneering stage, the stagnant stage, and the stage of integration and evolution. As follows:

• The embryonic stage (1994–1999): Focused on understanding the concepts, and only a few companies produced the products;

• The Pioneering Stage (2000–2005): Saw the establishment of domestic enterprises concentrated in select cities, with market and training systems maturing;

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• The Stagnation Stage (2006–2010): The enterprises were thriving and emerging Chinese brands (such as Huawei and Xiaomi) had boosted the progress of the industry. Although there was substantial potential for the future, there were still many shortcomings, including the miss of standards and poor compatibility;

• Integration and Evolution Phase (2011–Present): AIoT (Artificial Intelligence and Internet of Things) technology accelerated the implementation of China's smart home industry, made the integration between the real estate and home appliance sectors deeper [2].

As Chinese technological capability improving continually, China's smart home industry becomes more and more mature. However, due to variations in economic development levels and living environments across countries, different regions prioritize distinct aspects in the development of smart homes.

Furthermore, in next 30 years, China will face the accelerating challenge of an aging population. As the cohort born during the second baby boom (1962–1975) enters old age, China's aging rate is projected to rise sharply. According to research reports on China's aging population, Figure 1 illustrates the future trends of aging in China. China became an aging society in 2000 (with the proportion of the population aged 65 and above exceeding 7%) and entered a deeply aging society in 2021 (with the elderly population exceeding 14%). It is anticipated that China will enter a super-aged society around 2032 (just 11 years from now), with the elderly population exceeding 20% [3]. Based on current technology, developing smart home systems suitable for the elderly and those with limited self-care capabilities undoubtedly presents a significant challenge.

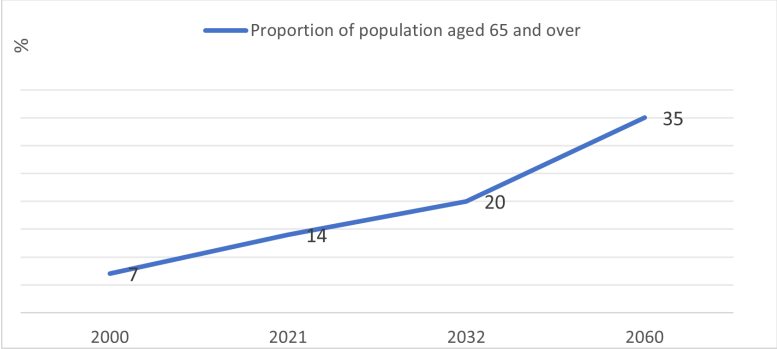

Figure 1. Trend chart of China's aging population ratio

This study analyzes the current situation and future trend of smart home design for the elderly comparing the technical aspects of various domestic and international solutions. Basing on framework of smart senior apartments, the concept of "Smart Network" is brought out to offer a theoretical foundation and some practical methods for advancing aging-friendly smart home researches in China.

2. Fundamental principles of smart homes

2.1. Core concepts and definitions

Smart home system bases on residential spaces, and integrates technologies such as Internet of Things (IoT), embedded systems, artificial intelligence (AI), and cloud computing in order to establish an efficient, comfortable, secure, and convenient residential atmosphere. This system aims to achieve rapid information collection, intelligent control and automated management of equipment through the integration of wiring technology and control methods based on intelligent cloud, thereby

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optimizing energy strategies and enhancing work efficiency. It integrates door/window sensors, cameras and smoke detectors to achieve real-time security monitoring, and supports voice commands, mobile applications and personalized scene modes, thereby providing users with a convenient and personalized experience [4].

2.2. System framework and key components figure

A smart home system is composed of software and hardware components. As shown in Figure 2, the hardware infrastructure contains modules that carry out functions, handle communications, and connect to appliances and sensors. The software part comprises modules for inputting signals, gathering data, and issuing commands.

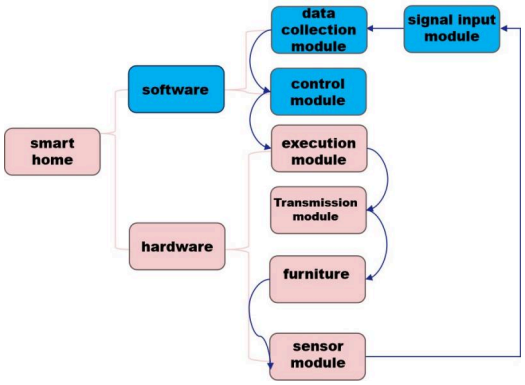

Figure 2. Smart home system architecture diagram

2.3. Smart home system workflow

Smart home systems generally follow a workflow of "perception - transmission - decision-making - execution". In this process, various sensor modules first collect users' physiological data (such as body temperature, heart rate) as well as environmental information. These data are then transmitted to the processing platform through the network layer. Next, the control logic or AI algorithms located in the platform layer conduct real-time analysis of the data and generate corresponding control instructions. These instructions are finally distributed to terminal execution devices, such as smart switches and automatic alarm systems, through the Internet of Things (IoT) network (such as Zigbee and Wi-Fi), thus forming a complete closed-loop automatic control system. This workflow not only facilitates remote control and intelligent management of household appliances, but also improves the accuracy of system response significantly by integrating multimodal data.

The advancement of technology facilitated the integration of AI (artificial intelligence) and the IoT (Internet of Things), and their combination is AIoT. AIoT overcomes the limitations of manual setting parameters and has the ability to perform intelligent predictive analysis. For example, by learning the behavior patterns of users continuously, the system can adjust indoor environmental parameters automatically (such as brightness, temperature, and humidity). Moreover, the integration of computer vision technologies enables the system to identify more complex scenarios accurately (such as accidental falls) and activate intervention mechanisms. The fundamental shift from "passive response" to "active service" is regarded as a milestone in the development of smart home systems, which means systems have higher intelligence and more personalization [5].

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3. China and developed countries' smart home system development

3.1. Development of age-friendly smart homes in developed countries

The research on smart home systems for the elderly in Europe started with the "Eureka Project" in 1986. This systematic research established the technical standards for the smart home industry. In the 1980s, through the conception of digital standards for household applianced, the early interaction framework emerged, which led to the establishment of smart home standards subsequently.

The "Tango Project" in Sweden 2001: it used movable walls which could dynamically adjust the family layout according to the activity patterns of elderly residents.

In 2005, Spain introduced smart residences that adopted an adaptive environment system: combining intelligent lighting with weather monitoring to effectively alleviate physical discomfort caused by sudden environmental changes.

At the International Consumer Electronics Show in 2025, Samsung launched "AI Home: Future Life, Instantly Achievable": Through three AI modules, it achieved full home intelligence. This enabled smart appliances to achieve automation - for example, "home mode", where the robot vacuum cleaner coordinated with the air conditioner and curtains - and through LED display screens and portable touch-screen TVs, realized remote control, facilitating interaction between elderly users and household devices [6].

It is worth noting that the early practices in Spain and Sweden revealed the core principles of smart residences suitable for the elderly: while taking into account ecological sustainability and health considerations, priority was given to the scalability of the system to adapt to different living spaces.

3.2. Development of age-friendly smart homes in China

Although the research on smart home in China lagged behind that of the similar industries in Europe and the United States, it has developed mature technical solutions within just three decades. A creative example is the "Qinyuan Elderly Apartment" in Shanghai in 2008. This apartment adopted a combination of infrared detection system and intelligent building management system (IBMS), featuring emergency call function and remote monitoring capabilities.

Currently, Alibaba's "Tmall Genie" project plans to transform its voice assistant into a "home manager" with predictive capabilities by 2025. This system integrates an artificial intelligence system and can predict users' needs based on their usage habits. For instance, if the system detects that a resident turns off the desk lamp at 10:30 PM every night and this happens for three consecutive days, then the system will activate the "night reading mode" - adjusting the ambient lighting, regulating the climate control, and setting the appropriate position of the curtains to help elderly people who are not familiar with electronic products automatically adjust the electric furniture [7].

3.3. Summary and outlook

China's smart home systems are characterized by high integration and diversity. However, they have limitations in terms of function customization for the elderly. Moreover, developed countries typically adopt decentralized and fragmented smart home architectures, which can rarely address whole-house challenges and result in high construction costs. Therefore, developing a platform that

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combines the advantages of these two systems (system-level integration and personalization) is a major technical challenge in the industry.

4. The "smart web" solution based on smart homes

In order to achieve a balance among system integration, cost and security in elderly care facilities, this chapter introduces the concept of "intelligent network". This system combines the customization features of European smart residences with the scalable deployment and integration advantages of Chinese smart residences. It adopts a modular architecture framework, effectively overcoming many problems existing in current smart homes, such as high costs, limited interoperability and poor compatibility.

From a functional perspective, prioritizing the prevention of falls - this is the main cause of injury-related deaths among the elderly, so the "intelligent network" incorporates a fall detection module as a safety feature. As shown in Figure 3, in China, falls are the leading cause of accidental death among people aged 65 and above. The fall detection module can immediately detect the situation of an elderly person's fall and promptly trigger an alarm, which can significantly increase the medical response rate for elderly people after a fall and reduce deaths caused by neglect.

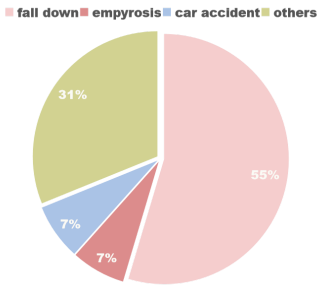

Figure 3. Pie chart showing the proportion of deaths among people aged 65 and above caused by various accidents

The "Smart Network" adopts a layered architecture, comprising a foundation layer and a functional layer:

• Foundation Layer: Using IBMS (Intelligent Building Management System) as the central orchestration hub. This layer manages and coordinates all system components, ensuring unified scheduling of data flows and command executions.

• Functional Layer: Integrating diverse personalized smart modules—including innovative systems such as the multimodal fall detection module—through standardized interfaces.

This architectural approach has two notable advantages: high integration and modular scalability. In addition, by integrating fall detection technology based on cutting-edge research, this system can achieve real-time environmental perceptions and action prediction functions in complex scenarios. Ultimately, those modules can provide more intelligent and efficient safety guarantee services for the elderly.

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4.1. Hierarchical synergy and core integration: analysis of IBMS system architecture

4.1.1. Modular design: synergy between foundation and functional layers

The IBMS framework of the "intelligent network" intelligent residential community adopts a modular hierarchical structure. Through collaboration of the foundation layer and the functional layer, this system can achieve centralized management of multiple residences and customization of each module within a single framework.

Its overall architecture adopts a two-layer system model of "centralized control at the foundation layer + expansion at the functional layer". The foundation layer is responsible for the unified management functions of the apartment complex and deploys a centralized IBMS. Through a parallel management mode, it monitors multiple apartments. This IBMS system adopts an integrated design architecture, integrating BAS (building automation system), EMS (energy management system), FAS (fire alarm system), and operation management systems. It establishes communication with apartment facilities (such as air conditioning systems, lighting systems, escalator systems, water supply/drainage systems, and power systems) through industrial standard protocols such as Modbus and BACnet. The system uses PLC (programmable logic controller) and DDC (direct digital controller) as the front-end data acquisition and control execution units. The IBMS collects real-time data from devices, then feeds the data back to software management platform by using B/S or C/S architecture. Ultimately, the instructions can adjust systems dynamically, thereby achieving closed-loop control and global management [8].

The functional layer focuses on meeting the customized needs of residents. It connects with customized modules through standardized interface protocols and provides specialized services for specific groups (such as individuals requiring care). Specifically, this layer includes three core personalized modules: First, the health monitoring module uses wearable devices like smart wristbands to collect real-time physiological parameters, such as heart rate and activity level; second, the intelligent monitoring module uses infrared radar and other sensing equipment to conduct dynamic safety monitoring of the living space; third, the environmental control module automatically adjusts indoor parameters, such as temperature, humidity, and lighting, based on the user's habits and health conditions. All functional modules connect the main network of the system through industrial protocols such as Modbus and BACnet to ensure stable data transmission and efficient coordination of equipment. By this way, system can provide targeted intelligent support for special populations while meeting basic living needs.

In summary, the modular architecture of the "smart network" intelligent apartment realizes parallel control functions and personalized scalability through collaborative cooperation of the infrastructure layer and the functional layer. The integrated framework not only improves the operational efficiency of the modules but also ensures the system's compatibility. By managing the core functions and adding customized modules through hierarchical design uniformly to meet the specific needs of residents, this system provides a feasible solution for the large-scale deployment of intelligent residences and customized services.

4.1.2. System core: IBMS integrated management platform

Figure 4 illustrates the workflow of the Intelligent Building Management System (IBMS). Users interact with the system through an application and can monitor the operation status of the smart home in real time and issue instructions.

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The gateway module is responsible for protocol conversion, converting the control signals sent by the server into a format that can be recognized by various intelligent devices. This enables devices of different brands and with different communication protocols to achieve compatible connection and centralized management. The execution module receives the converted control instructions from the gateway and drives various terminal devices (such as lighting, air conditioning, curtains, etc.) to perform corresponding operations. Therefore, residents are able to adjust the parameters of the home environment (such as temperature, brightness, humidity) according to manual control instructions, and controlled through AI automatically [9].

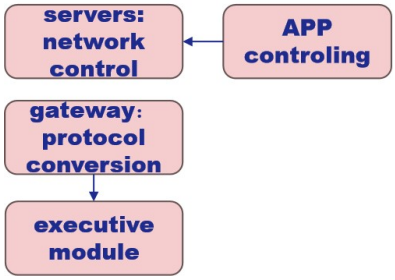

Figure 4. Control schematic of IBMS for smart home modules

As shown in Figure 5, the comprehensive building management system of the elderly-friendly intelligent home system has four layers:

• Perception Layer: Perception Layer: Collecting data through sensors such as cameras, temperature sensors and environmental monitors.

• Data Layer: Converts sensor data from multiple platforms into standardized formats via IoT, enabling data visualization and unified management. The server collects and monitors data, then processes it at the platform level to support more advanced operations.

• Platform Layer: This layer processes data at the IoT server level, analyzes information collected by sensors, and triggers responsive actions - serving as the central processing tier of the system.

• Function Layer: Signals from the IoT processor activate smart home devices, ultimately enabling AI-driven regulation and remote monitoring based on big data analytics.

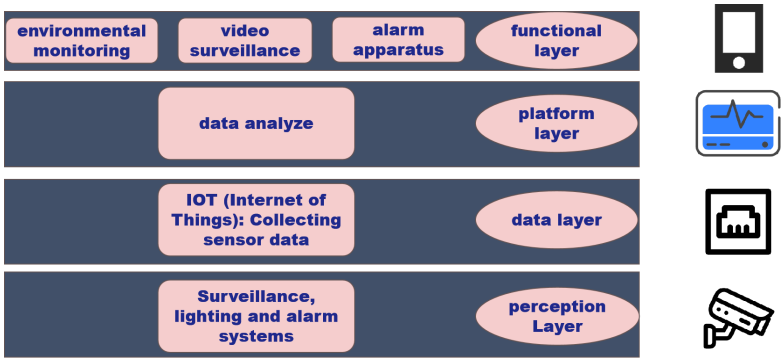

Figure 5. Schematic diagram of IBMS application in smart homes

Compared with BA (building automation systems) and BMS (building management systems), the main advantages of IBMS are parallel operation of multiple systems and better compatibility, enabling smart home systems from different brands and protocols to operate collaboratively. Table 1 shows the comparison of the characteristics among IBMS, BA and BMS.

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Table 1. Comparison table of IBMS with BA and BMS

	cross-system linkage response speed	number of subsystem connections	reduction of energy consumption	data analyze	compatibility
IBMS	multi-system interconnection	8+	28%	strategy optimization	multi-protocol
BA/BMS	single-system interconnection	3-5, and only electromechanical devices usable	10%-15%	no	brands' proprietary agreement

4.2. "Smart Network" fall detection technology based on computer vision and scene sensors

Based on the latest laboratory data, the platform layer of the "Smart Network" IBMS system adopts computer vision and sensor-based fall detection technology. This system will immediately trigger an alarm when an elderly person falls, reducing rescue time and improving survival rates for seniors living alone after accidents at home [10].

4.2.1. Computer vision detection technology

In computer vision detection, mainstream research approaches fall into three categories. Figure 6 illustrates the operational principle of a prevalent hardware platform based on computer vision technology.

• Initial screening via skeletal distance thresholds: followed by posture recognition using elliptical parameters (major/minor axis ratios). However, this method has extremely high requirements for the detection accuracy of the equipment used for extracting skeletal features.

• Replacing traditional elliptical representations with contour angles: integrating rectangular features with Hu invariants, and combining support vector machine algorithms enables more precise judgments. The detection rate increases to 93.3%, and the processing speed reaches 18 frames per second.

• The convolutional neural network algorithm collects data through cameras and uses it to identify fall behaviors. The training data of the intelligent algorithm covers various actions, including movement, walking, and falling, and ultimately achieves an identification accuracy of 92%, while the response time is only 0.413 seconds. Current researches focus on three directions: multimodal fusion, lightweight deployment, and adaptive threshold setting. Researchers improve the reliability and the response speed of system by combining accelerometer data with visual information, optimizing edge devices' CNN models and adjusting detection parameters dynamically [11].

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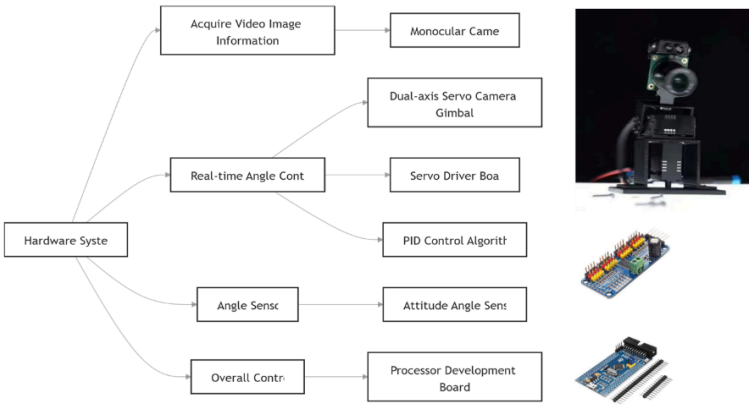

Figure 6. Computer vision-based fall detection

4.2.2. Scene sensor-based fall detection technology

The fall detection technology bases on environmental sensors, and they are used to monitor the states of the elderly through two kinds of sensor: environmental sensor and wearable sensor.

• Significant advancement has been achieved in the utilization of environmental sensors within traditional sensor technology. Vibration signal captured by a three-channel seismometer is filtrated by wavelet denoising and SVM (support vector machine) algorithms, the detection accuracy rate reaches 97.22%. Another innovative method involves integrating the MAD-LTP feature descriptor with a bidirectional LSTM (long short-term memory) network, showcasing a strong resilience in dynamic environments. The performance on the test dataset reached 98.29% and 93.5%, respectively. These acoustic detection techniques extend the application possibilities of environmental sensors, offering a reliable monitoring solution for complex scenarios.

• Wearable sensor incorporates small-scale devices like accelerometers and gyroscopes, which are characterized by their compact size, affordability, and ability to monitor in real-time. These sensors identify instances of falling by capturing traits such as sudden changes in acceleration, angular velocity, and heart rate. Research shows that the method of measurement through a single accelerometer has some limitations, while the fusion of multiple sensors significantly improves accuracy: by combining acceleration and angular velocity features with a DAG-CNN model, the detection accuracy rate reaches 99%. Another study achieves a detection accuracy rate of 92.5% to 98% by integrating data from acceleration, angle, and direction sensors [12].

The fall detection technology can prevent those individuals with poor self-care abilitiy from dying due to accidental injuries caused by negligence when they are living alone, thereby ensuring the safety of residents [13].

5. Conclusion

The study on the development of global smart home systems reveals that the development paths in different regions. Developed countries are leading in the researches of application modules, such as possessing integrated designs, diverse sensors and monitoring systems. However, these systems have some limitations, especially the high cost that hinder their widespread application. Meanwhile, China's systems have achieved large-scale application through a modular architecture, mature network technologies, and effective cost control. However, one drawback is those systems lack functional modules suitable for the elderly. Therefore, "Smart Network" proposes a balanced

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solution bases on China's aging population background, combining mature modulars' capabilities and advanced detection modules, especially adding an innovative monitoring module bases on "fall detection technology", it can greatly enhance the safety and "comfort level" of elderly living alone, and maintaining a reasonable price. The main goal of this study is providing a theoretical framework and practical path for Chinese smart home industry, integrating various feasible theories to solve the housing adaptability problems brought by population aging, and providing some valuable references for this industry. Although a theoretical framework already been established in this paper, it still has a limitation that the "fall detection technology" is still in the research stage, related sensors and algorithms have not yet been put into practice. Future researches should focus on overcoming the accuracy and reliability issues in fall detection, exploring efficient monitoring methods that protect users' privacy, and strengthening industry-university-research cooperation to accelerate the transformation of innovative technologies from laboratory to industrial application. The technologies mentioned in this article are expected to be applied in practice in the future.

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