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Research Article

Intelligent residential models and humanized design for youth consumer groups

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ABSTRACT

In order to address the emotional and entertainment needs of empty nest youth during their stay at home, a smart living model and humanized design method targeting the youth consumer group have been proposed. This study focuses on the experience of young consumer groups in smart home entertainment scenarios, exploring the combination of intelligent living models and humanized design. With the application of the Internet of Things and artificial intelligence technology, smart home systems have achieved active interaction capabilities, optimizing the balance between information transmission and user experience. In terms of hardware, we ensure comfort, safety, and practicality by developing smart devices with high cost-effectiveness and stable performance, while achieving personalized scenario mode control. In the software field, an interactive platform has been designed that is easy to install, maintain, and expand, supporting intelligent control of various user scenarios and needs. Finally, combined with user participatory content generation, develop the open source ecological human interaction, and realize personalized adaptive operation interaction. The aim of this study is to improve the social status of young consumer groups, alleviate their feelings of loneliness and anxiety, broaden their channels for home life happiness, and promote the development of smart home scene experience towards a more human-machine inclusive interactive mode. This achievement contributes to the construction and development of a digital society, promoting the deep integration of information technology and modern life.

Keywords: humanization; smart home; intelligent control terminal artificial intelligence

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1. Introduction

In recent years, the advancement of technologies like artificial intelligence, (Internet of Things, IoT), and cloud computing, along with their growing application reach, has been notable, the purchasing users in the smart home industry have shown a trend of youthfulness. On the one hand, for the smart home industry, user youthfulness has a different preference for retail methods from the past[1], which is both an opportunity and a challenge[2]. Facing these young users who have become the mainstream group of home appliances, "diversification, personalization, and customization" is the trend for the smart home industry to respond to consumer changes. Multiple smart home appliance brands are seeking to break through the smart home industry. In recent years, the innovative changes attempted at the levels of products, channels, and multiple brands, as well as the continuous emergence of customized home appliances launched by multiple brands, are just new starting points.

The future smart home industry needs to continuously explore innovative and personalized user experiences that are more in line with the interests of young users. This also requires the smart home industry to maintain interaction and communication with young customers, and continuously explore customer needs to create unique home scene experiences. However, the replacement cycle of household appliance products is relatively long, and users need to weigh the pros and cons from multiple perspectives during the usage stage[3].

Currently, smart homes are developing towards interconnected intelligence and are committed to moving towards fully intelligent smart homes. Smart home takes the residence as the platform, and applies computer, internet, automatic control, communication technology, intelligent hardware, intelligent terminal and other technologies to realize the intellectualization of home system[4]. In this transitional period, the industry is exploring the experience of wisdom around scenarios. From the perspective of development stage, China's smart home industry has gradually evolved from a single control based intelligent single stage to the initial stage of interconnection and interoperability based on scenario diversification and spatial intelligence. The smart home system adopts wireless/wired communication technology to network and connect smart facilities related to home life with terminal devices such as smartphones, achieving centralized and efficient management and control of the home system, and improving the convenience, comfort, and security of the home system[5].On this basis, achieve proactive perception of specific user needs and provide personalized services to users. Although the technology related to smart home is currently very mature and the development of the entire field is also very rapid, the promotion effect of the product is not good, mainly due to the insufficient level of product intelligence and poor user experience. How to improve the intelligence level of smart home products, enhance their user experience, and lower the practical threshold for users is the key to solving the current bottleneck in promoting smart home products[6]. Applying speech recognition technology, image processing technology, and indoor positioning technology to smart home systems to achieve voice control, visual control, and other humanized control methods can greatly improve the intelligence level and user experience of products. The core idea of this section is to combine behavior with home scenarios, analyze the behavior of empty nest youth users in different categories of situations, and obtain their needs. After collecting, organizing, and analyzing factors, specific scenarios are selected based on the content that needs to be studied to further analyze the behavior of empty nest youth users in a concrete manner. The specific process of scenario analysis is discussed through **Table 1**, and entertainment scenarios are divided into three main scenarios: audio-visual entertainment, social entertainment, and game entertainment. Analysis is conducted around these three scenarios.

Table 1. User behavior in smart home entertainment scenarios.

Home entertainment field View to experience the user behavior	Home entertainment scene experience user behavior characteristics	Home entertainment scene experience operation example
Video entertainment	Perform operations related to watching movies and listening to music in video-visual, non-audio-visual products or APP	Open the Cool Dog Music APP to play music and open the TV screen to play the TV series
Social entertainment	Do social-related operations in social, non-social products or APP	Open the WeChat APP to send a message
Game entertainment	Implement game-related operations in game, non-game products or APP	Open the fitness ring big Adventure to choose a mode, open the game

This project focuses on the design strategy research of empty nest young users' experience in smart home entertainment scenarios. Chapter 1: Elaborate on the background, research objectives, and significance;

Chapter 2 reviews the current research status, existing problems, and methodological processes related to home care for empty nest youth, in order to identify innovative points for the project; Chapter 3 explores humanized control methods, with a focus on introducing a smart home control system based on speech recognition technology. The system integrates voice recognition technology into the smart home platform, allowing users to directly control home appliances through voice commands, thus breaking away from traditional remote control and touchscreen operation methods; Chapter 4 focuses on system testing, aiming to verify the functionality, reliability, and stability of the system. The testing covers multiple aspects, including speech recognition performance testing to evaluate its accuracy and response speed to different voice commands; Voice control scheme testing to ensure that the system can effectively execute user voice commands; Test the button control scheme and check the operating experience under traditional control methods; And video surveillance testing to verify the effectiveness and stability of the system in terms of security monitoring; Chapter 5 summarizes the main achievements of this project and looks forward to future development directions.

2. Literature Review

Since the beginning of the new century, following products such as smartphones, computers, and iPads, smart TVs and the smart home market they occupy have become the object of competition for technology giants and the mainstream of home furnishings for new modern young users. With the development of artificial intelligence, human-computer interaction home products are rapidly occupying the market, represented by products such as Amazon Alexa, Tmall Genie, Xiaomi Xiaoai, etc. The business model of voice interaction intelligent products has gradually become clear. In today's increasingly mature speech recognition technology, artificial intelligence companies are also placing greater emphasis on users' emotional expression and response. The smart home entertainment scene serves as the daily residence for empty nest young users and an important place for users to express their emotions. In the information age, traditional home furnishings can no longer meet market demand, and users are increasingly concerned about the overall, humanized, and intelligent home environment. At present, the interaction forms of smart home entertainment products are mainly divided into four categories: touch interaction, information interaction, voice interaction, and behavioral interaction.

(1) Touch interaction type. Refers to the user's need to press or touch the product while operating it. Typical cases in the market include Xiaomi smart home screens, Huawei whole house intelligent control panels, smart robots, smart toys, smart balance cars, and other carriers. The application of interaction design in smart homes allows for simple interface operations through the most primitive interaction method of touch, which not only saves time and effort, but also brings users a good life experience. Humanized smart home entertainment products will improve the quality of life and happiness index.

(2) Type of information exchange. Information interaction refers to the process of sending and receiving information, which is the most basic form of interaction experience between users and smart device systems. It is also the most primitive form of interaction for digital home entertainment products. The common manifestation is that users use their mobile phones, computers, or smart panels to bind with smart home products and control them through linkage.

(3) Voice interaction type. Voice interaction is a modern way of interaction, and more and more entertainment products are using it to improve user experience and convenience. Dialogue based technology is a multi-level interaction technology based on speech recognition. After years of technical breakthroughs, the current voice control technology has become relatively mature and stable. In the product market favored by empty nest youth, many smart home entertainment products for living alone have high speech recognition, which provides great convenience for people.

(5) Behavioral interaction type. With the rapid development of technology at present, many new technologies continue to emerge, requiring traditional entertainment products to no longer be limited to a single level of design and color. Intelligent mobile and wearable hardware devices are gradually becoming popular, such as smart glasses, smart watches, motion sensing gaming all-in-one machines, smart bracelets, etc. At the same time, the emergence of VR and AR head mounted intelligent entertainment devices and their return in the context of the metaverse enable users to focus on visual, auditory, tactile and even more sensory stimuli, greatly improving the experience and interest of young users. Qiao, M. *et al.* achieved personalized and humanized design of IoT technology in the internal environment of buildings through the design of a personalized smart home system based on IoT. The system focuses on using Apriori algorithm to mine association rules of users' preferences for the internal environment of buildings[7]. Cui, J. *et al.* designed an application scenario of Internet of Things in smart home design, integrated smart home, Internet, Internet of Things and other technologies, designed the overall architecture, topology and IP address allocation scheme of the system, and realized the intelligent door control and temperature control system of smart home based on the simulation platform. The whole network is connected to ISP Internet through home gateway and mobile data. After testing, the overall operation of the system is stable, providing a solution for the application of the Internet of Things in smart homes[8]. Shi, G. *et al.* first introduced the security scope of IoT technology applied in the field of smart home security, and then introduced the typical IoT communication network Zigbee. Then, the sensors involved in environmental monitoring and smart door locks in the Internet of Things were introduced[9]. Intelligent products are transitioning from passive interaction to active interaction. Active interaction, through technologies such as big data and deep learning, can enhance the intelligence of machines or systems in the process of bidirectional interaction between humans and machines.

3. Research Methods

3.1. Research on humanized control methods

3.1.1. Principles of speech recognition technology

The schematic diagram of the speech recognition system is shown in **Figure 1**. During the recognition stage, the user's input speech needs to go through the following steps:

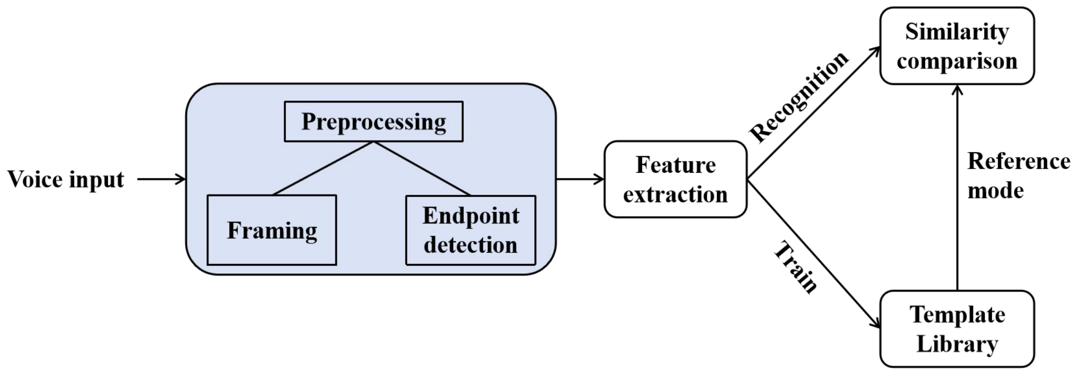

Figure 1. Principle of speech recognition system.

(1) Preprocessing: After the microphone converts the speech signal (vibration signal) into an electrical signal (subsequent speech signals refer to the converted electrical signal), the preprocessing stage performs framing and endpoint detection on the speech signal.

(2) Feature extraction: The features encompass the short-term average energy and zero crossing rate. Additionally, we delve into three crucial coefficients: linear prediction coefficient (LPC), linear prediction cepstral coefficient (LPCC), and MEL frequency cepstral coefficient (MFCC)[10].

(3) Similarity comparison: Matching and comparing speech patterns with speech reference patterns stored in a template library yields the best match, which is the result of speech recognition. The commonly used pattern matching methods include Dynamic Time Warming (DTW), Models such as Hidden Markov Model (HMM), Gaussian Mixture Model (GMM), and Artificial Neural Network (ANN) have been widely used in the field.

3.1.2. Recognition pattern matching and recognition algorithm

Smart home platforms face limitations in hardware resources, leading to restricted computing and storage capacities. Speech recognition in smart homes often depends on personalized speech recognition systems, utilizing methods like DTW or discrete HMM for recognition. While the DTW matching algorithm performs well in small vocabulary recognition algorithms tailored to specific individuals, its trained model is limited to such individuals. In contrast, contemporary smart home platforms require features that cater to a broader spectrum of individuals. In contrast to DTW, the HMM model provides a more comprehensive acoustic speech model representation. Utilizing statistical training methods, the lower acoustic model is combined with the upper language model to create a unified speech recognition search algorithm. This method produces outstanding results without individual-specific constraints. Within the smart home control system, the study integrates HMM-based speech recognition technology tailored for non-specific users with limited vocabularies, specifically emphasizing isolated word recognition[11].

Assuming an HMM model has N states $S=\{S_i|1\le i\le N\}$, at time t, the state q_t in which HMM is located can only be in one of these N states, obviously, $q_t\in S$; The number of possible observations corresponding to each state of HMM is set to M, M observations are set to $V=\{V_i|1\le i\le M\}$, and the observed values at time t are o_t, obviously, $o_t\in V$; If the length of the observation sequence is denoted as T, the output observation sequence can be represented as $O=\{o_t|1\le t\le T\}$. The HMM model is usually represented by three sets of model parameters $\lambda=(\pi,\ A,B)$, with each parameter defined as follows:

(1) The initial state probability $\pi=\{\pi_i\,|\,1\le i\le N\}$, where

$$\begin{cases}\pi_i=P(q_1=S_i),1\le i\le N\\ \sum_{i=1}^{N}\pi_i=1,\pi_i\ge 0\end{cases} \tag{1}$$

From equation (1), it can be obtained that the initial state probability π represents one of the N initial states.

(2) State transition probability $A=\{a_{ii}\,|\,1\le i,j\le N\}$, where

$$\begin{cases}a_{ij}=P(q_{t+1}=S_j|q_t=S_i),1\le i,j\le N\\ \sum_{j=1}^{N}a_{ij}=1,0\le a_{ij}\le 1\end{cases} \tag{2}$$

In equation (2), a_{ii} represents the probability of transitioning from state S_i to S_i from time t to time t+1.

(3) Probability of observation value $B=\{b_{ii}(k)|1\le j\le N,1\le k\le M\}$, where

$$\begin{cases}b_{ij}(k)=P(o_t=V_k|q_t=S_j),1\le j\le N,1\le k\le M\\ \sum_{k=-1}^{M}b_{ij}(k)=1,0\le b_{ij}(k)\le 1\end{cases} \tag{3}$$

In equation (3), $b_{ii}(k)$ represents the output probability with an observed value of V_k when transitioning from state S_i to S_i at time t.

It is not difficult to find that the HMM model can be divided into two parts. The first part is a Markov chain described by the initial probability π and the state transition matrix A, which outputs a state sequence

$S = q_1, q_2, ..., q_T$. The second part is a random process, described by the probability of observed values B, the output result is the sequence of observed values $O = o_1, o_2, ..., o_T$, as shown in **Figure 2**.

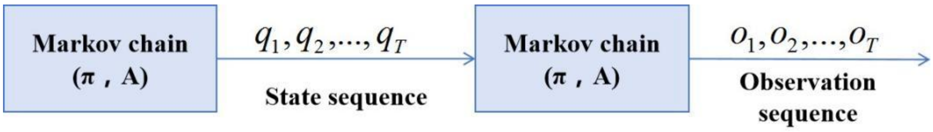

Figure 2. Schematic diagram of HMM composition.

3.2. Overall system plan design

Employing speech recognition technology, the study devised a smart home control system enabling users to directly command household appliances through voice control within the smart home environment[12]. The intelligent home control system designed by the study based on speech recognition technology mainly consists of three parts: illustrated in **Figure 3**, the comprehensive system design includes the main control center, control nodes, and intelligent terminals.

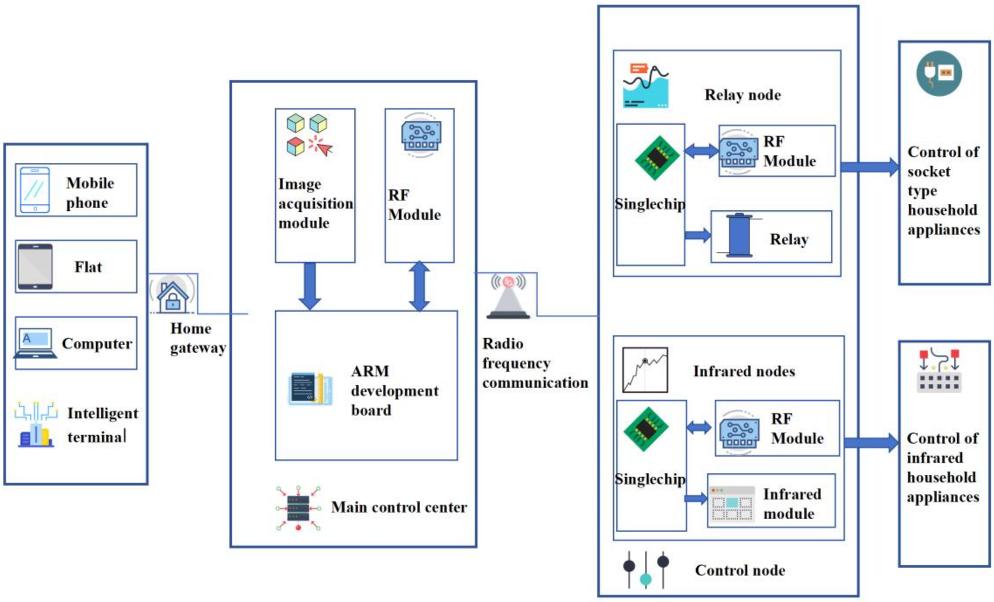

Figure 3. Smart home control system based on speech recognition technology.

The main control center includes an ARM development board, RF module, and image acquisition module. The ARM development board is the core of the main control center, the RF module is used for communication with control nodes, and the image acquisition module is a camera used to monitor the home environment. Control nodes include two types: relay nodes and infrared nodes. Electrical nodes mainly consist of microcontrollers, RF modules, and relays, used to control socket type household appliances (household appliances without infrared), such as lamps, hot water kettles, etc; The infrared node mainly consists of a microcontroller, an RF module, and an infrared module, used to control infrared appliances (appliances with infrared), such as air conditioners, televisions, fans, electric curtains, etc. The RF module in the control node is used for data communication with the main control center.

Choose smartphones, tablets, and computers for smart terminals. Install smart home system software on the terminal, which provides two sets of control solutions, one is voice control solution and the other is remote control solution as an alternative solution, providing a friendly human-machine interaction interface for the smart home system. There are two workflow processes in the system, one is the control process and the other is the feedback process. The main purpose of the control process is to enable users to issue control commands to household appliances through smart terminals. The process is as follows: First, set up the home gateway (including WIFI password, etc.), by linking the main control center and smart terminal, they function as if located within the same local area network, facilitating wireless communication via the TCP/IP protocol; The intelligent terminal sends a voice command or button command to the main control center, such as the command to control the air conditioning "temperature increase"; Once commands are received from the smart terminal, the main control center deciphers them and proceeds to relay them to the appropriate control node using radio frequency communication. As the command requires infrared control, the node must be an infrared node; after receiving the instruction, the infrared node converts it into an infrared code for "temperature increase", and finally sends the infrared code to the air conditioner through the infrared module to achieve "temperature increase" control. Similarly, the control principle for socket appliances is the same. The main purpose of the feedback process is to notify the user that the control command has been sent after the user sends it. The system workflow is shown in **Figure 4**.

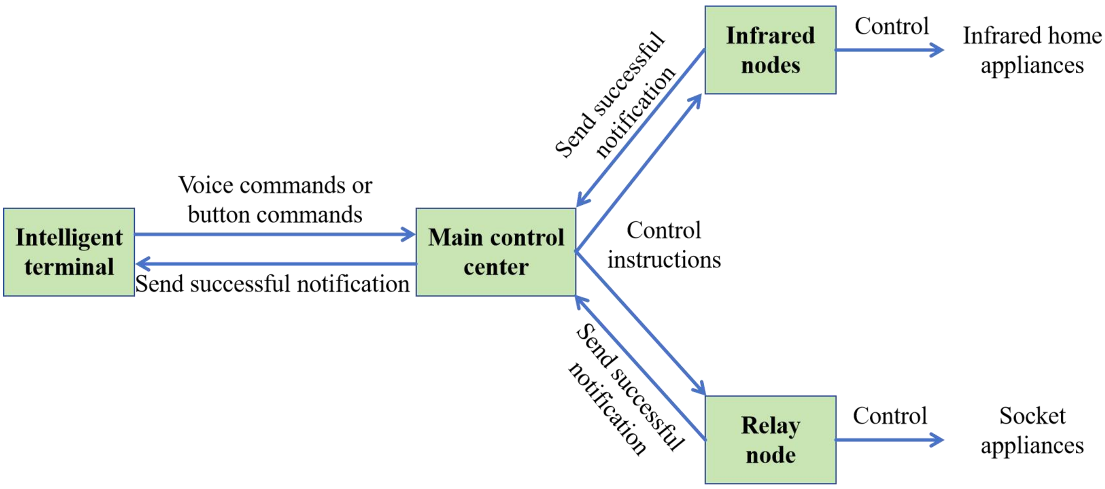

Figure 4. System workflow.

3.2.1. Indoor wireless networking protocol selection

If wiring is used to control devices in smart home control systems, it is necessary to wiring inside the wall, which is difficult to construct and can easily cause damage to the wall, and the maintenance cost in the later stage will also be high[13]. Therefore, in smart home control systems, wireless networking is preferred to control home devices. WiFi technology, Zigbee technology, and Bluetooth technology are currently the mainstream wireless communication technologies. Below is an introduction to these wireless communication methods:

(1)WiFi technology

With the development of mobile Internet technology, almost everyone now has smart phones, which have built-in WiFi network protocols. It can be considered that WiFi technology is the most common of the three wireless networking technologies. Therefore, using a mobile phone can be very convenient for household appliances. In addition, WiFi technology has a long communication distance of about 100m and a speed of up to 100Mb/s, making networking very convenient. However, WiFi technology also has drawbacks, such as high power consumption, high heat generation, and low security, which limit its application in smart homes.

(2)Zigbee technology

Zigbee is a low-power, low-speed wireless networking communication protocol. Compared to WIFI technology, it is simpler to network and supports multi node configuration. At the same time, in terms of data security, it adopts more mature encryption algorithms, making the transmission layer very secure. And Zigbee's power consumption is very small, and one battery can work for a long time. Therefore, Zigbee technology is widely used, but there is no built-in Zigbee protocol in existing mobile phones. Therefore, using mobile phones to connect to Zigbee networks requires additional devices, which limits Zigbee's advancement in smart homes.

(3) Bluetooth technology

The most common application between mobile devices such as mobile phones is a point-to-point, short distance wireless communication method. Its power consumption and cost are between WiFi and Zigbee. Due to the short transmission distance of Bluetooth, it is not suitable for building large home networks[14].

The comparison of the technical characteristics of three wireless networking methods is shown in **Table 2**. Through the comparison of several wireless communication methods mentioned above, WIFI wireless communication technology meets the requirements of the research system in terms of transmission distance, node configuration, transmission rate, and data security. Therefore, this study chose WIFI wireless communication technology as the wireless communication method.

Table 2. Comparison of technical characteristics of three wireless networking methods.

Name	WIFI	Zigbee	Bluetooth
Working frequency band (Hz)	2.4G、5G	868/915M,2.4G	2.4G
Number of RF channels	14	27	40
Transmission rate (bps)	54	20-250k	1M
data encryption	WEP、WPA-SK、WPA2-SK	AES-128	AES-128
Transmission distance (m)	100	10-100	60-100
Wireless on time	3s	15ms	3ms

3.2.2. Hardware design of intelligent gateway

The functional diagram of the intelligent gateway in this system is shown in **Figure 5**.

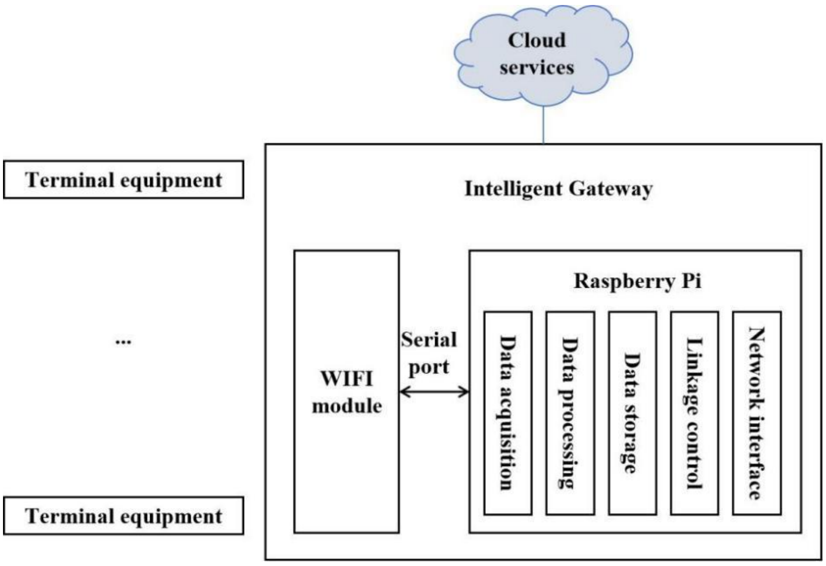

Figure 5. Intelligent gateway function diagram.

The functions of the intelligent gateway in the smart home control system include:

1) Interacting data with intelligent terminals;

2) The communication gateway connecting the external network and the internal network is the only channel for home and external communication;

3) Data storage, data reception, and data transmission.

Considering both cost and stability, this design adopts Raspberry Pi based on Linux system for design. Raspberry Pi is a highly cost-effective microcomputer widely used in real-time video processing, the Internet of Things, and robotics. The comparison table for each model of Raspberry Pi is shown in **Table 3**.

Table 3. Comparison table of raspberry pi models.

Model	Raspberry Pi B	Raspberry Pi B+	Raspberry Pi A+	Raspberry2 Model Pi B	Raspberry Zero	Raspberry Pi 3B
release	2011-12	2014-07	2014-11	2015-02	2015-11	2016-02
CPU	ARM11	ARM11	ARM11	Cortex-A7	ARM11	Cortex-A53
ESoc	BCM2835	BCM2835	BCM2835	BCM2836	BCM2835	BCM2837
GPU	Broadcom Video Core IV,Open GL ES2.0					
RAM	512MB	512MB	256MB	1GB	512MB	1GB
USB	USB2.0*2	USB2.0*4	USB2.0* 1	USB2.0*4	USB2.0*1	USB2.0*4
GPIO	26PIN	40PIN	40PIN	40PIN	40PIN	40PIN
network	10/100MM	10/100M	not have	10/100M	not have	10/100M

3.3. System hardware design

3.3.1 Hardware design of the main control center

The main function of the main control center is to achieve communication with intelligent terminals, communication with various control nodes, and video monitoring functions. The hardware of the main control center is designed on the basis of the core module development board, with the extension of some peripherals (such as RF module, network interface module, camera image acquisition module, and display screen). The hardware diagram is shown in **Figure 6**.

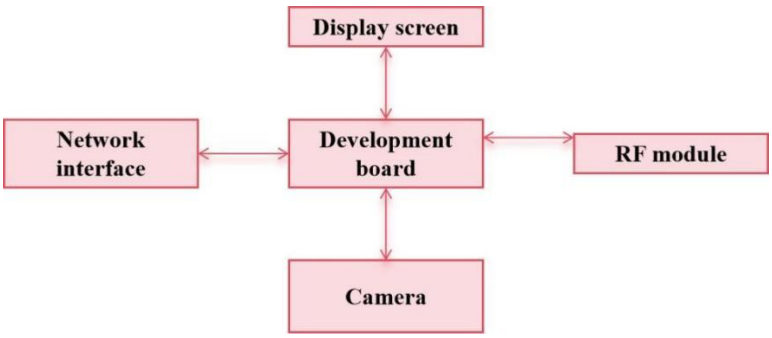

Figure 6. Hardware of the main control center.

The main control center of the system communicates with intelligent terminals through wireless technology, while the main control center communicates with various control nodes through radio frequency. The development board connects the network interface to the router through Ethernet cables to form a home network. This home network is equivalent to a local area network, and the smart terminal can connect to this home network by opening WIFI. The main control center can then communicate with the smart terminal through TCP/IP network protocol[15].The cameras in the main control center are used for video surveillance and transmit the captured content to intelligent terminals or displays.

3.3.2. Image acquisition module

This study added a video surveillance module in the main control center to address security issues and improve the safety of residential buildings. From the introduction of the core modules of the main control center, the development board comes with a camera interface and an interface. Although using a camera that matches the development board makes it easy to control the camera, it is not conducive to later development and maintenance. Moreover, there are various types of cameras with USB, which can be freely selected. For

USB interface cameras that support MIPEG compression format output, video transmission performance can be greatly improved without lagging. Therefore, this project uses a camera with USB interface as the image acquisition module.

While ensuring clear images and affordable prices, this project uses a USB camera module as the image acquisition module. The block diagram of the image acquisition module is shown in **Figure 7**. The image acquisition module is connected to the development board through a USB interface, and the collected videos are stored in SD cards in different time periods. At the same time, the videos are displayed in real-time on the display screen, and the video content can also be transmitted to the terminal through network communication.

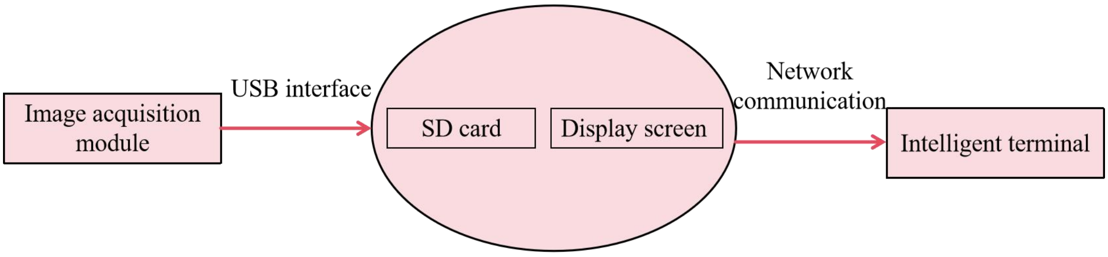

Figure 7. Image acquisition module.

3.3.3. Hardware design of control nodes

The control node's main function is to directly control household appliances and send status feedback to the main control center. The control node diagram is shown in **Figure 8**, consisting of an STM32F103 microcontroller and its peripheral modules. Among them, the RF module is used for communication with the main control center, and the control module is used to control household appliances. According to whether the controlled household appliances have infrared function, control nodes can be divided into infrared nodes and relay nodes. Infrared nodes are used to control household appliances with infrared function, while relay nodes are used to control non infrared household appliances such as sockets.

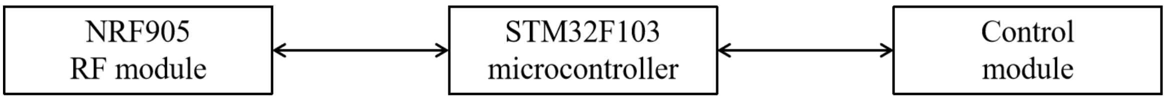

Figure 8. Control nodes.

This project uses the STM32F103C8T6 microcontroller as the processor for the control node. The chip integrates a 32-bit ARM processor based on the Cortex-M3 core from the STM32 series, renowned for its low power usage, affordability, exceptional real-time capabilities, and efficiency. Operating within a voltage range of 2V to 3.6V and enduring temperatures from -40°C to 85°C, this chip boasts a clock frequency potential of up to 72MHz. Additionally, it encompasses 64K FLASH memory, 20K SRAM memory, an array of enhanced I/O ports, and peripherals linked to two APB buses. These features render it versatile for embedded system solutions[16].

3.3.4. Hardware design of infrared nodes

The infrared node mainly consists of STM32F103 microcontroller, nRF905 RF module, and HXD019D. The HXD019D infrared module is the infrared control module of the node, and the infrared node diagram is shown in **Figure 9**.

3.3.5. Hardware design of relay nodes

The relay node mainly consists of STM32F103 microcontroller, nRF905 RF module, and relay module. The relay module is a non infrared control module for nodes, and the relay node diagram is shown in **Figure 9**. The relay module is equivalent to a smart socket. When the smart socket works, the current amplifies, driving the relay to work, thereby closing the normally open contacts of the relay. After the relay contacts close, the live wire ends of the home appliance and the smart socket are connected, allowing the home appliance to be powered on normally. The normally open contact of the relay is in the open state, and the live wire ends of the household live wire and smart socket are disconnected, thereby cutting off the current leading to the smart socket.

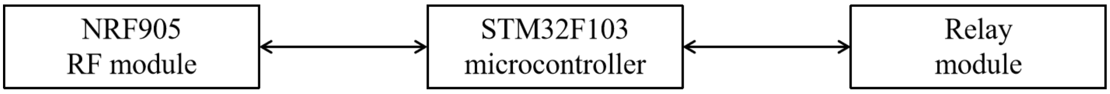

Figure 9. Control nodes.

3.4. System software design

The software design encompasses six distinct components: building the software development environment, overall system software design, main control center software design, control node software design, RF communication protocol design, and intelligent terminal software design.

In **Figure 10**. feature extraction, pattern matching, and post-processing, speech signals are recognized by intelligent terminals as specific speech instructions. Then, the command is sent to the main control center for parsing and processing to obtain voice commands. Utilizing radio frequency communication, the main control center transmits voice commands to the appropriate control nodes[17].

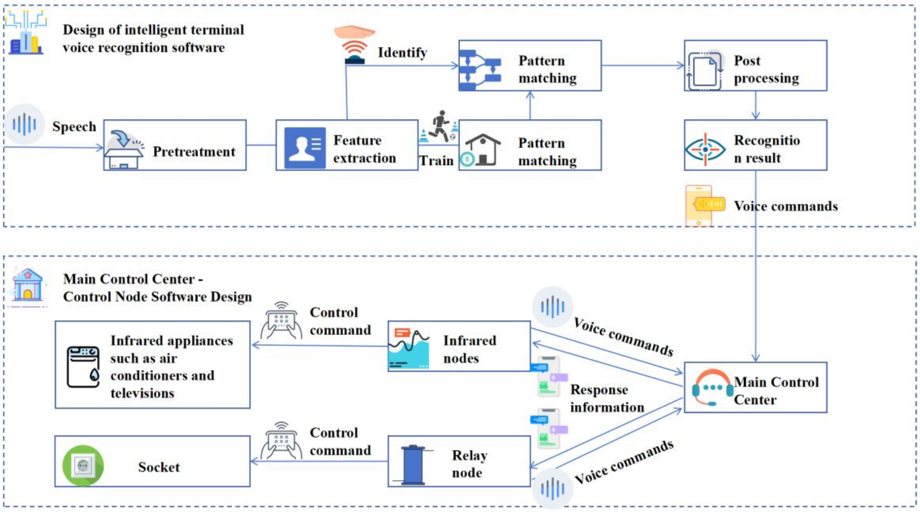

Figure 10. Overall software scheme design.

This system adopts a C/S (Client/Server) software architecture, which uses intelligent terminals as clients, the wireless communication method between the client, server, and controller is illustrated in **Figure 11**. In this setup, the main control center acts as servers, while the control nodes serve as controllers. Specifically, TCP protocol is used for communication between clients and servers, while radio frequency protocol is used for wireless communication between servers and controllers.

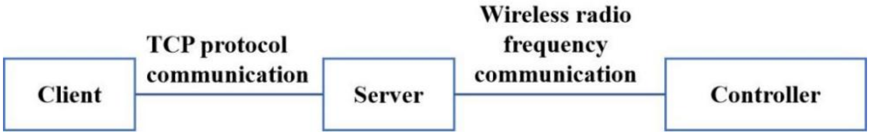

Figure 11. Wireless communication mode between client, server, and controller.

4. System Testing

System testing mainly emphasizes the functionality of the system to confirm its reliability and stability. The testing includes evaluating speech recognition performance, evaluating speech control strategies, checking button control plans, and conducting video surveillance tests. These tests are conducted to verify the functionality and accuracy of the system in practical scenarios.

4.1. Speech recognition performance testing

The testing of speech recognition requires prerecording the speech, extracting speech features, establishing a speech database through speech training, and finally matching the speech to be recognized with the speech database. Because the voice control function is executed on smart terminals and a voice database needs to be established before speech recognition, it cannot be implemented on smart terminals. Therefore, the speech recognition performance of the system was tested through experimental simulations conducted in Matlab[18].

4.1.1. Accuracy testing of speech recognition

The voice test samples are control command phrases for the system, including: 1. Open, 2. Close, 3. Temperature increase, 4. Temperature decrease, 5. Heating, 6. Cooling, 7. Wind speed, 8. Up and down sweeping, 9. Left and right sweeping, 10. Channel increase, 11 channel decrease, 12. Volume increase, 13. Volume decrease, 14. First gear, 15. Second gear, 16. Third gear.

Table 4. Recognition rate of each control command in laboratory environment.

Identifying words	Recognition Rate	Identifying words	Recognition Rate
open	50/50	Left and right sweeping	44/50
close	50/50	Channel Plus	46/50
Temperature plus	48/50	Channel Plus	45/50
Temperature reduction	47/50	Volume increase	46/50
Heating	48/50	Vol	47/50
refrigeration	49/50	First gear	49/50
wind speed	49/50	Second gear	47/50
Up and down sweeping air	45/50	Third gear	48/50

Record the above phrases into a 32-bit encoded, 16kHz sampling frequency, wav format mono audio file. The pronunciation of the training sample is composed of 5 young males and 5 young females, while the pronunciation of the test sample is composed of 5 young males and 5 young females. Each control instruction is pronounced 5 times per person and recorded in a laboratory environment, resulting in 800 test and training samples. **Table 4** shows the recognition rate of each control command in the laboratory environment.

The number before "/" in the table represents the correct number of recognitions, while the number after "/" represents the total number of recognitions. According to the above table, according to statistics, out of 800 test samples, 760 samples were correctly identified, and the average recognition rate of the system reached 95%, which can already meet the needs of users.

4.1.2. System noise resistance performance testing

To test the system's noise tolerance, Gaussian noise was introduced to the test speech. This involved incorporating five distinct signal-to-noise ratios of Gaussian noise: -5dB, 0dB, 5dB, 10dB, and 15dB. The speech recognition rates for each signal-to-noise ratio are detailed in **Table 5**.

Table 5. Speech recognition rates under different signal-to-noise ratios.

Signal to Noise Ratio (SNR)	-5dB	0dB	5dB	10dB	15dB
Recognition rate	95.34%	95.34%	95.77%	96.21%	96.22%

Table 5 shows the speech recognition rates under different signal-to-noise ratio (SNR) conditions. Signal to noise ratio refers to the ratio of signal strength to noise strength, usually expressed in decibels (dB). Five different signal-to-noise ratios were used in the experiment: -5dB, 0dB, 5dB, 10dB, and 15dB to test the system's noise resistance. From the table, it can be seen that the recognition rate of the system is 95.34% at signal-to-noise ratios of -5dB and 0dB, indicating that even in noisy environments, the system can still maintain high recognition accuracy. This indicates that the system still has a certain anti-interference ability under low signal-to-noise ratio conditions. As the signal-to-noise ratio increases, the recognition rate gradually improves, reaching 95.77%, 96.21%, and 96.22% respectively at 5dB, 10dB, and 15dB, demonstrating the sensitivity of the system to improved clarity.

4.2. Stability testing

This test mainly completes the stability test of the system, considering that the intelligent gateway requires long-term power supply and must ensure stable operation without human supervision.

4.2.1. Test plan

Simulate users using smart home control systems to control household appliances from time to time, set random values internally in the testing software, trigger a complete control at random intervals, and record the number of failures and the total number of controls. To ensure the reliability of the results, power analysis is usually required, which can determine the sample size so that the true effect can be detected at a certain level of significance (such as 0.05) and expected effect size.

4.2.2. Test results

The test results are shown in **Table 6**. It can be clearly seen that during the three days of operation, irregular attempts were made to control the device every day, and occasional communication failures were found, but within an acceptable range. Even if there are network issues, the gateway can automatically reconnect.

Table 6. System stability test results.

time point	Control frequency	Number of failures	Success rate
first day	1000	10	99.0%
the next day	1000	12	98.8%
On the third day	1000	8	99.2%

5. Conclusion

This study aims to enhance the intelligence level and user experience of smart homes, especially exploring and implementing humanized control in voice control, while conducting research and experiments on indoor positioning technology for home environments. The main work and innovations of this article include: (1) Implementing voice control for smart homes: As the most familiar and comfortable way of expression for humans, voice recognition technology has become a research hotspot in artificial intelligence. This article delves into and simulates speech recognition algorithms, achieving voice control of household appliances through information extraction and matching. It also provides the function of calling up the home appliance control interface through voice, simplifying the user's operation process and eliminating tedious menu selection. (2) Designed a smart home control system based on speech recognition technology: proposed the design of a smart home control system using WiFi wireless communication, which enables the system to have strong wall penetration ability, thereby improving the flexibility and anti-interference ability of the system.

Although the developed system performs well in smart home control and user experience, there are still some limitations. Firstly, the speech recognition performance of the system may be affected by environmental noise, dialects, and accents, resulting in a decrease in recognition rate. Therefore, future research can consider combining advanced noise suppression techniques with adaptive learning algorithms to enhance recognition capabilities in complex environments. Secondly, the current system mainly relies on WiFi for communication, which may cause control delays or failures in some environments with unstable signals. Therefore, future research can explore combining other communication technologies such as Zigbee or LoRa with WiFi to enhance the stability and flexibility of the system in different environments. Finally, the research on indoor positioning technology has not yet been fully integrated into the system. Future research can further integrate this technology to achieve more accurate device control and scene switching, in order to enhance the personalization and intelligence of user experience.

References

1. Cvitić I, Peraković D, Periša M, *et al*. Novel classification of IoT devices based on traffic flow features. Journal of Organizational and End User Computing (JOEUC) 2021; 33(6): 1-20. http://doi.org/10.4018/JOEUC.20211101.oa12
2. Ona A, Gkhan E, Kranl C, *et al*. A smart home energy monitoring system based on internet of things and inter planetary file system for secure data sharing. Computer and Communication 2023; 11(10): 64-81.
3. Yin J, Huo X, Cao X, *et al*. Intelligent electronic password locker based on the mechanoluminescence effect for smart home. ACS Materials Letters 2023; 5(1): 11-18.
4. Handelzalts S. New ferroelectric material technology in remote electrical control system of smart home. Distributed Processing System 2021; 2(1): 58-74. https://doi.org/10.38007/DPS.2021.020105.
5. Wu C, Yang L, Cai M, *et al*. Security evaluation method of smart home cloud platform. International Journal of Pattern Recognition and Artificial Intelligence 2023; (6): 37.
6. Huynh ND, Bouadjenek MR, Hassani A, *et al*. Jarvis: A voice-based context-as-a-service mobile tool for a smart home environment. 2022 23rd IEEE International Conference on Mobile Data Management (MDM) 2022; 318-321.
7. Qiao M, Lv Y, Li S, *et al*. Personalized and humanized design of building interior environment using Iot technology. Applied Mathematics and Nonlinear Sciences 2024; 9(1).
8. Cui J, Du Z, Liu K, *et al*. The simulation design of smart home system based on internet of things. Journal of Computational Methods in Sciences and Engineering 2023; (6): 23.
9. Shi G. Development of internet of things in the field of smart home security. SHS Web of Conferences 2023; 5(1): 22.
10. Limited PR. Voice-controlled light bulb socket adapter: Semitech Technology Ltd: Semitech Technology Ltd. Hardware Auto & Machinery 2022; (4): 6.
11. Guha S, Iqbal R. Desco: Detecting emotions from smart commands. 2022 IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC) 2022; 1620-1625.
12. Laird R, Maynard T. Is your utility ready for the industrial internet of things? OpFlow 2023; (5): 49.
13. Paulauskas D, Eleyan A. Knock pattern based door lock with amazon alexa on raspberry pi. 2022 International Symposium on Networks, Computers and Communications (ISNCC) 2022; 1-4.
14. Bortz D. Make every room in your home smarter. Kiplinger's Personal Finance 2022; (8): 76.
15. Kunekar P, Deshmukh A, Gajalwad S, *et al*. AI-based desktop voice assistant. 2023 5th Biennial International Conference on Nascent Technologies in Engineering (ICNTE) 2023; 1-4.
16. Prongnuch S, Sitjongsataporn, S. Voice controlled comparator improvement based on resource utilization in soc ecosystem for parking assist system. J. Mobile Multimedia 2022; 18: 1079-1098.
17. Rikhye R, Wang Q, Liang Q, *et al*. Closing the gap between single-user and multi-user voicefilter-lite. 2022.
18. Crispiatico V, Baldanzi C, Napoletano A, *et al*. Effects of voice rehabilitation in people with ms: A double-blinded long-term randomized controlled trial. Multiple Sclerosis: Clinical And Laboratory Research 2022; (7): 28.