

DEVELOPING A VOICE CONTROL SYSTEM FOR ZIGBEE-BASED HOME AUTOMATION NETWORKS

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Abstract

This paper presents the design and implementation of a voice control system for ZigBee-based home automation networks. In this system, one or more voice-recognition modules have been added to the ZigBee-based networks. The recognized control messages are sent by these modules then be routed to the target device, and finally be carried out by controlling circuit. In our work, SI-ASR (Speaker-Independent Automatic Speech Recognition) has been used; making it requires no training of recording. This speech recognition control system uses human-computer interaction to realize multiple menu choose function. Also, a function of speech recognition for ordering songs is realized which is based on the SD memory card and its file system on the module. To improve the accuracy of the speech recognition control, button trigger mode, voice password trigger mode and circle recognition mode are provided to be selected, so users can choose different modes under different conditions. A prototype of speech recognition module following the proposed architecture and a simple home automation network has been implemented. Some experimental results validate the basic functions of the proposed system. It turns out to be easy and flexible to control the multiple household appliances for people, especially the elders and people with disabilities, such as quadriplegia patients.

Keywords: home automation, voice control, speech recognition, ZigBee-based wireless sensor and actuator networks, ordering a song through speech recognition, file system, SD memory card

1 Introduction

Home automation designates an emerging practice of increased automation of household appliances and features in residential dwellings, particularly through electronic means that allow for

remote controlling. Many new communication technologies such as GSM/GPRS networks, wireless sensor networks, Bluetooth, power line carriers and the Internet have been applied to home automation. For example, wireless sensor networks based on ZigBee protocol is widely used in smart homes and it has become the focus in this field. It consists of comfort and home automation, security and safety at home, ambient assistance (intelligence) and remote health monitoring [1]. Guangming Song (etc)[2] developed a wireless-controllable power outlet system. The proposed power outlet module has mesh networking capabilities by adding a ZigBee radio into its architecture. Therefore, it successfully realizes remote control of home appliances. Wan-Ki Park(etc) [3] have proposed a ZigBee based universal remote control unit and a ZigBee to IR conversion module for controlling multiple legacy consumer electronics devices. Also, Il-Kyu Hwang[4] designed an integrated remote controller to control electric appliances in the home network with no extra attachment of communication device to the appliances using ZigBee protocol and infrared remote controller technology.

However, their systems are not so perfect. In these days, many household appliances such as computers, televisions, DVD players, home theater systems, stereo components, air conditioners are popular. These devices are generally operated using remote controls based on IR (infra-red) signal. However, each remote/device usually uses a different device code, which prevents signals from being crossed [5]. Although a universal remote control unit can transmit multiple device codes and control several home appliances in a house, it's not necessarily optimal. Modern entertainment systems also have complicated control menus, which can require special buttons not found on the universal remotes. The elders, children or disabled people may be confused (find it laborious and inconvenient) when they need to find the remote controller and repeatedly press the control buttons

to execute.

In this paper, we propose a novel application of smart home automation: voice control system for ZigBee-based home automation networks. Our work applies speech recognition technology to ZigBee-based wireless sensor and actuator networks, which can easily control all of the home appliances in the networks. When speech recognition modules are deployed reasonably, users can give voice orders at any position of the house. For example, when you wake up in the morning, even when you are still in bed, you say ‘Open the curtains’, ‘Open the window’ and ‘Music on’, then you will enjoy beautiful music and fresh air at the same time. The voice control system consists of a speech recognition module as well as some sensors and actuators which establish the wireless sensor networks based on ZigBee. Besides, speech recognition for ordering a song has been added to this system, which sufficiently improves the home automation systems proposed by[2][3][4]. This system features its easy and flexible operation, making it suitable especially for the elders and the disabilities, such as quadriplegia patients.

2 System architectures

2.1 System overview

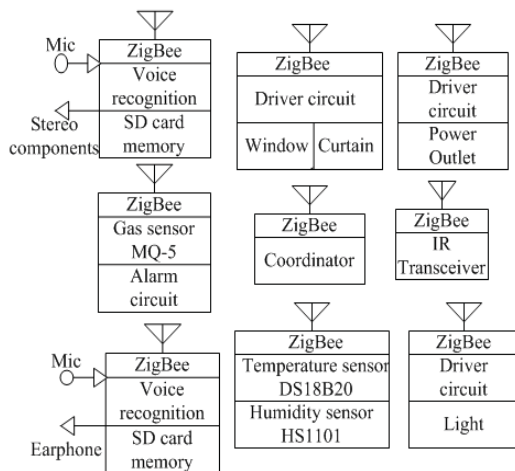


Figure 1. System architecture

The proposed voice control system architecture is shown in Figure 1. This system is realized on the basis of a wireless sensor and actuator network based on ZigBee protocol. The home automation network is composed of a (or several) voice recognition module(s), several sensor nodes, actuator nodes (such as wireless power outlet modules) and a network coordinator. Each node or module is added to the ZigBee network. The sensor nodes and the actuator nodes connected to each corresponding home appliance or even windows and curtains are deployed in the home environment and they autonomously form a mesh network. The

network coordinator can provide multiple interfaces to the mesh network for local user interactions and remote network management. When the user speaks to the microphone, the module recognizes the words and sends control messages to the target ZigBee module through the network. The corresponding ZigBee module will operate the connected appliance via the connected driver circuit.

2.2 Voice recognition module

The speech recognition system uses a single-chip solution for voice recognition. LD3320 is a voice chip for speech recognition based on SI-ASR(speaker-independent automatic speech recognition) technology. LD3320 has a highly effective speaker-independent speech recognition search engine module and a complete speaker-independent speech recognition feature library inside. It is designed with hardware optimization and acceleration for speech recognition, without any external auxiliary devices such as Flash, RAM, etc. It can complete speech recognition at an accuracy rate of 95%, not even requiring users to do their own voice training to generate speech features for training library. So the cost of voice recognition module is lower than SUNPLUS SPCE061A in [6].

The speech recognition process of LD3320 is shown as Figure 2. It first analyses the spectrum of the voice input by MIC and then extracts the voice features. After that, it's compared with words in the list of key words. Finally, the key word with the highest score is output as the recognition result.

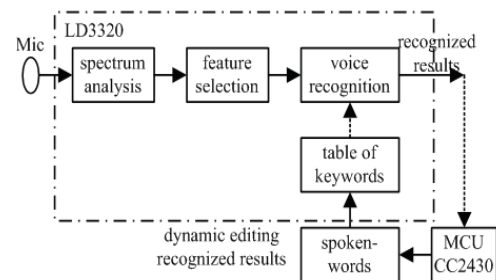


Figure 2. Speech recognition process

The hardware schematic of the voice recognition module is shown as Figure 3. LD3320 and CC2430 communicate with the parallel port to improve the speed. When people send a voice order, LD3320 can identify the words and give the recognition result to micro-controller, CC2430. CC2430 takes the corresponding operations according to the recognition result. For example, the command of turning on the lights is sent to the actuator through the ZigBee network.

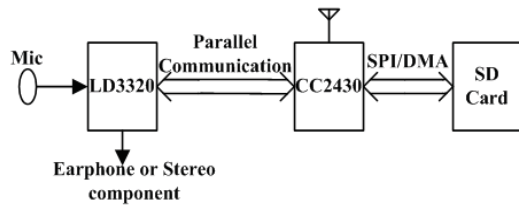


Figure 3. Schematic of the voice recognition module

LD3320 integrates speech recognition processor and some external circuitry, including AD, DA converters, microphone interface and audio output interface. It supports MP3 playback with no need of external auxiliary devices. On this basis, we propose a function of ordering songs through speech recognition based on file system on SD memory card, as is shown in Figure 3. SD memory card, the most common data storage card, is widely used in daily life. The SD card has many advantages, such as low price, a large storage capacity, convenience to use, and it's universal and safe. Therefore, it makes the smart home system more intelligent to add a function of ordering songs through speech recognition based on SD memory card to the voice recognition module.

SD card supports two bus modes: SD mode and SPI mode. SD mode means a 6-wire, using CLK, CMD, DAT0 ~ DAT3 for data communication. And a 4-wire SPI mode, using CS, CLK, DataIn, DataOut for data communication. SPI mode is used when CC2430 read and write the SD card.

The module is a flexible application of FAT16 file system on the SD card, which makes it easier to find and read music files from the SD card. FAT file system is very useful to create files, write files, modify files, delete files, and create a FAT file directory. It's the biggest advantage to identify the data of the SD card from the computer. So you can easily copy your favorite music files from your computer to the SD card, and the speech recognition module can identify and play them out. As the key words of the recognition list can be dynamic editing and it supports users to organize their 50 key words, we can edit and update the 50 key words according to different circumstances and demands. So we can switch between two scenes of home appliances controlling and speech recognition for ordering songs.

Figure 4 shows the software control flow of the proposed voice recognition module. According to the procedure, According to the procedure, the speech recognition module has three kinds of working modes, so that users can choose different modes through DIP switch under different conditions. Under a quiet environment, the user can choose the circle recognition mode, which detects the user's voice order all the time. So the user can

order the speech recognition module anytime.

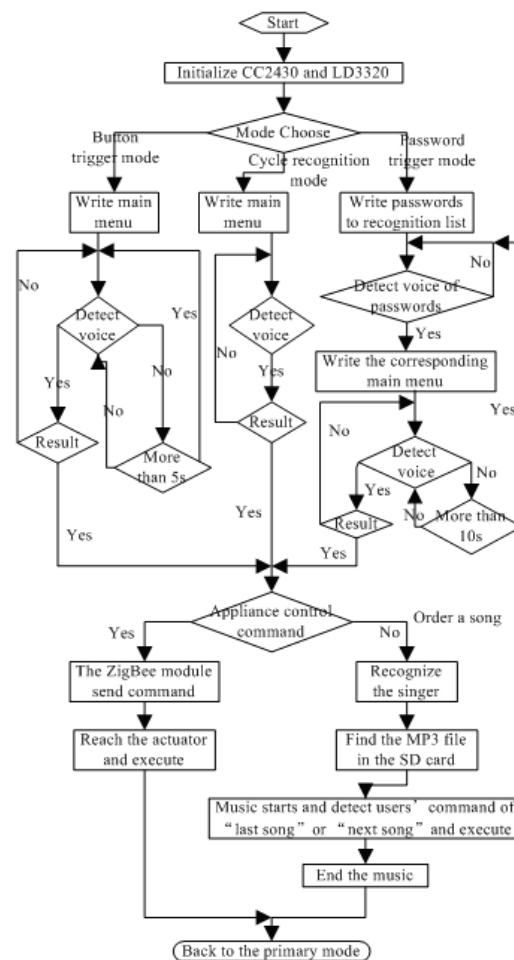


Figure 4. Control flow of the voice recognition module

However, it is likely to lead to errors because of other voices. If it's noisy at home, button mode should be selected so that only when the button is pushed down, the module collects voice information. This mode has high recognition accuracy as well as low power consumption, but it is only suitable for handheld operation. Often voice password trigger mode is recommended. For example, two passwords "Enjoy music" and "Home control" has been written to recognition list. The user only can activate the module via this two voice password. Therefore, it's more suitable for operation in a larger range, because it cause fewer errors and doesn't require users to manually push any buttons.

Multi-level menu speech recognition operation is realized with the selection of this modes and the voice prompt of the module. When the user activates the recognition module, the module edits and updates the recognition list and prompts the user to go to the next level menu, until the completion of the user's order. When the user says "Enjoy music", the module prompts the user to tell

the singer name. After recognizing the singer name, the corresponding folder will be found out on the file system of the SD card. Then it updates the recognition list with words such as "Last song", "Next song ", "Volume up", "Volume down", "Music off" and so on, and prompts the user for the relevant operation. When the user says "Home control", it means the user want to operate some home appliances. Then it updates the recognition list with some common operating orders such as "All light on", "All lights off", "Bedroom light on", "Bedroom light off", "Curtain up", "Curtain down", "Window open", "Window close", "Bathroom water heater on" and so on (the total orders on the list should be less than 50, if not, Multi-level menu can be used). For example, when the user says "Bathroom water heater on", the module answers "Yes" if it's recognized and the control message is sent to the actuator. So the water heater in the bathroom will be turned on. The user then says "Water temperature 30 degrees", the module answers "Yes" again if it's recognized and the control message is sent to the temperature sensor, so it can adjust the work of the water heater.

The speech recognition module can be set to sleep mode and be activated easily. So it has low power consumption. Besides, it can also recognize some dialects.

3 System implementation

3.1 Smart power outlet module

The smart power outlet module is shown as Figure 5. It plays an important role in accomplishing flexible control of the home appliances. It is designed to be an actuator node to perform voice control functions, which combines a ZigBee module and the conventional power outlet. The module is composed of a AC / DC converter, a ZigBee RF transceiver, a relay and a current transformer. The AC/DC converter supplies power to the module. The ZigBee module joins to the wireless sensor and actuator network and keeps wireless communication with other nodes in range. It also control the relay to turn on/off the home appliance connected to the power outlet. The design of this module preserves the original buttons on the conventional power outlet, so it can be controlled by both buttons and voice. Besides, the working state of the load can be detected by current transformer and then be sent to network coordinator as well as remote thermals, which makes it easy to monitor the state of the load and to realize remote control or voice control.

3.2 Smart lights

A prototype of the smart lights module is shown as

Figure 6. It consists of three lights and a switch with three buttons, while the ZigBee control module is designed under the switch. These three lights can be controlled by mechanical switch as well as voice or remote control since ZigBee module has been added to the system

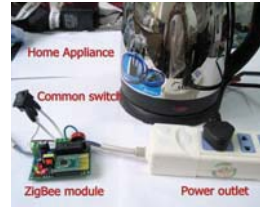


Figure 5. Smart power outlet module at work



Figure 6. Smart lights at work

3.3 ZigBee to IR (Infra-Red) conversion module

The ZigBee to IR conversion module is shown as Figure 7. This module converts a control message transferred through the ZigBee network into an IR typed control signal; so that all the home appliances operated using remote controls based on IR can be controlled by the ZigBee network. It is composed of a ZigBee module and a learning IR remote module. This IR module can learn and record nearly all the IR codes of common devices. After learning, CC2430 can control the IR module to transmit the IR command code to the corresponding device if speech command is received. This module has been used to test successfully controlling the air

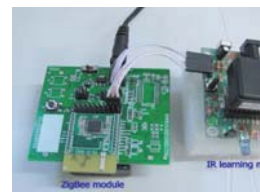


Figure 7. ZigBee to IR Conversion Module



Figure 8. Temperature and Humidity Sensors Module

conditioner and TV.

3.4 Temperature and humidity sensors module

The temperature and humidity sensors module is shown as Figure 8. We use DALLAS DS18B20 as the temperature sensor, which can measure temperatures from -55°C to +125°C. HUMIREL HS1101 is used as humidity sensor. It's based on a unique capacitive cell and has high reliability and long term stability. The temperature and humidity sensors we use are cheaper than SHT1x/SHT7x. With this temperature and humidity sensors module, We can have real-time monitoring of the temperature and humidity in the house, and get better control of the home appliances such as air conditioners.

3.5 Gas sensor and alarm module

The gas sensor and alarm module is shown as Figure 9. It is composed of a ZigBee module, a gas sensor, an alarm and a ventilator. This module is designed to detect gas leak such as CO, methane in the kitchen room. If the gas leaks, there will be an alarm sound, meanwhile, a emergency message will be sent to the user terminal through the ZigBee module.

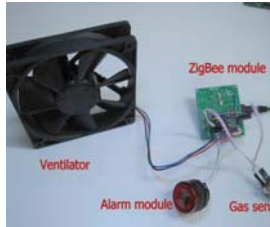


Figure 9. Gas Sensor and Alarm Module



Figure 10. The Voice Control System

3.6 Experiments on the voice control system

Figure 10 shows all our nodes and modules in the voice control system. On this basis, a ZigBee-based Home Automation Network is established. Finally, all the functions described above are realized and tested. The proposed system is confirmed to be feasible. The experiments are done as follow:

The user first chooses one work mode of the system according to the condition. For example, the voice password trigger mode is selected. "Success", the system prompts interactively.

User: "Home control".
System: "Success. Order?".
User: "Light all on".
System: "Success".
User: "Power outlet off".
System: "Success".
User: "TV next channel".
System: "Success".
User: "Return". (The system returns to voice password the trigger mode.)
User: "Enjoy music".
System: "Success. Song name?".
User: "Take me to heart".
System: "Failure. Pardon?".
User: "Take me to your heart".
System: "Success". (The music is playing.)
User: "Volume up".
System: "Success".
User: "Music off". (The music stops and the system returns to voice password the trigger mode.)

4 Conclusions

In this paper, we proposed a voice control system for zigbee-based home automation networks. In our

work, SI-ASR (Speaker-Independent Automatic Speech Recognition) has been used; making it requires no training of recording. This speech recognition control system uses human-computer interaction to realize multiple menu choose function. Also, a function of speech recognition for ordering songs is realized which is based on the SD memory card and its file system on the module. The users can choose different modes from button trigger mode, voice password trigger mode and circle recognition mode under different conditions. The implemented voice system is realized on the basis of ZigBee-based wireless sensor and actuator networks. The experiments validate the easy and flexible control of all household appliances for people, especially the elders and people with disabilities, such as quadriplegia patients. All in all, the voice control system must be popular applied to home automation.

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