STM JOURNALS

Journal of
Telecommunication, Switching Systems and Networks

ISSN: 2454-6372
Volume 11, Issue 3, 2024
September–December
DOI (Journal): 10.37591/JoTSSN

https://journals.stmjournals.com/jotssn

Research JoTSSN

Application of DTMF and Zigbee Wireless Communication in a Smart Home

Jo Gyong Il[1,*], Ri Chol Ryong[2], Ri Hua[3], Pak Chol Ryong[4], Kim Hyon Chol[5]

Abstract

This paper presents the method of monitoring and controlling the smart devices in a smart home using dual-tone multi-frequency (DTMF) signal and Zigbee wireless communication. Today most of homes are equipped with relatively prefect phone lines. Thus, DTMF is very helpful in decreasing the cost of smart homes. DTMF is a signal used in the telephone network in calling with numbers. If this is used, not only can we control the smart terminal devices, but we can also do the state checkups, thus it is very appropriate for the smart home. Smart devices used in smart homes are various and distributed in some areas and therefore it is easy to set up the system combining with short range wireless communication such as Zigbee. This paper suggests constructing the system using gateway with DTMF generating and decoding abilities, and smart terminal devices with many functions. The components use Zigbee wireless communication. The main objective of using DTMF signal and Zigbee wireless communication in a smart home is to reduce the cost of the whole system setup and develop more effective system than before. This paper implemented the smart home system consisting of gateway and smart terminal devices such as smart connector, fire alarm, and door monitor and analyzed its operating accuracy through the test. The results show that the smart home system with DTMF and Zigbee wireless communication uses the telephone line that is firm in the substructure foundation so the original installation costs are significantly reduced and it also provides more effective performance for smart homes.

Keywords: Dual-tone multi-frequency (DTMF), Zigbee, smart home, gateway, wireless communication

INTRODUCTION

The rapid development of electronic automation technology and information technology (IT) has made it possible to realize the requirements of the people who want to live a more comfortable and civilized life. Today people are introducing the advanced information technology, providing the suitable interior and exterior environment and controlling all the home appliances conveniently as they please. Smart building technology is the one that offers people more convenient, safer and more effective building environment by introducing IT to the buildings. People live in the newer environment by the introduction of smart building technology to home [1–3].

A smart home makes people's life more comfortable with home monitoring and controlling abilities. Another main characteristic is that it has an advanced security system which alerts and deals with emergencies such as fire, intruding, etc. To put

***Author for Correspondence**
Jo Gyong Il
E-mail: HC.Kim@star-co.net.kp

[1-5]Faculty, Department of Information Technology and Science, Kim Il Sung University, Pyongyang, DPR Korea

Received Date: July 11, 2024
Accepted Date: September 09, 2024
Published Date: September 18, 2024

Citation: Jo Gyong Il, Ri Chol Ryong, Ri Hua, Pak Chol Ryong, Kim Hyon Chol. Application of DTMF and Zigbee Wireless Communication in a Smart Home. Journal of Telecommunication, Switching Systems and Networks. 2024; 11(3): 1–10p.

the smart home into practice, one needs to build the integrated control system combined with equipment managing system, information install system, IT application system, and security system [4–12].

Equipment managing system controls all kinds of equipment at home by putting safe management and energy saving into practice. Equipment managing system is composed of terminal sensors or drive components such as heating, plumbing and electrical systems, a controller, a projector and a computer, etc. The most important thing here is the information network technology. All the components and systems are united through the private network [13].

Information install system is the IT system infrastructure for information processing such as acceptance, exchange, transfer, storing, retrieval and displaying of all kinds of information of the inside and outside of the building, in accordance with the habitants [14].

IT application system is composed of all kinds of information terminal devices and application programs such as a computer and a telephone etc., for home tasks and management.

Security system of the building is a system which protects the people's lives and properties. It provides alarms and effective measures to deal with fire, robbery, natural disasters, and other accidents. For example, the robbery alarm system uses the infrared body sensors or door open-close identifiers and informs the user or certain members.

The most important thing in smart home formation is providing effective communication between the habitants and the smart devices. Modern wireless communication technology, such as LoRa, Wi-Fi and LTE-A etc. are widely used. But these long-range transmission technologies take up a lot of expenses in primary formation. It is because it needs communication infrastructure such as LoRa Station, Wi-Fi AP and 4G Station etc. In cities which have these infrastructures, it might be effective but in places without it, there are some limitations in application.

However, if dual-tone multi-frequency (DTMF) is used instead of these technologies, the installation costs are reduced much more. In most of the areas such as the cities and countryside, wire telephone line is set up completely. Appliance of DTMF does not require special communication infrastructure, therefore, reduces the smart home installation costs drastically. DTMF is a signal used in the telephone network in calling with numbers. If this is used, not only can we control the smart devices, but we can also do the state checkups, thus it is very appropriate for the smart home. The types and numbers of the smart devices are various according to the smart homes and the devices are all spread to different rooms, so if we properly combine the short-range wireless communication network technologies, we can form a more effective system.

RELATED WORKS

Since the appearance of the concept of smart homes there have been many research studies for system construction using various wire and wireless communication technology. In smart homes, the habitant uses information terminal devices such as a computer and a telephone etc. to control and check-up the states of home smart devices. For information exchange between these information terminal devices and smart devices, long-range communication technologies such as wired Ethernet, Wi-Fi, LoRa and LTE etc. and short-range communication technologies such as Zigbee wireless communication and Bluetooth are used.

A study [15] discussed the smart home health care system, using Wi-Fi/3G/4G communication technology, Zigbee, and Bluetooth communication technology. Zigbee and Bluetooth are used to connect terminal servers and home server. Wi-Fi or Bluetooth is used to connect mobile and home server. Wi-Fi and 3G/4G communication technology is used to connect home server with data center and data center with physician's terminal device. As one can see, to accomplish this system, Wi-Fi and 3G/4G communication infrastructure is required [16].

A study [17] discussed home automation using Wi-Fi wireless communication technology and speech recognition. In this system, the user's speech command is transmitted through Wi-Fi wireless communication and individual terminal devices are controlled according to the command. The speech command transmitted by the user is sent to the central control device through the Wi-Fi AP, which is set at homes. The central control device monitors the audio, abstracts the control commands, runs the corresponding relay modules and controls the smart devices.

Studies [18, 19] have also discussed home energy management system composed of Wi-Fi terminal devices and Wi-Fi AP and smart home monitoring system. Studies [20, 21] have discussed the NB-IoT and LoRa and Zigbee wireless communication of the object internet system, which is similar to smart home system. In this research, using NB-IoT and LoRa communication technology, we have done long range transmission or formed the Zigbee AP network and made similar transmission.

In the above research studies, we have solved the long-range transmission problems using 3G/4G, Wi-Fi, LoRa, etc. and in constructed environments, these could be effective methods. But in some areas, the necessary communication infrastructure is not constructed, so installing the infrastructure for the smart home is costly.

However, wire telephones have been researched and introduced since long ago, so it is nearly fully installed everywhere in the world. If we install a system based on this wire telephone network, then the installation cost will be reduced a lot. From this, there have been many researches to make home automation system, using the wire telephone network, especially the DTMF.

Typically, a study [22] researched on home automation system based on DTMF. In this research, we have used MT8870, the DTMF decoder, to analyze the habitant's control commands and drive the corresponding terminal equipment according to the results. Habitants use the mobile or wire telephones to transmit the control commands of the home terminal equipment and terminal control devices, which are installed at home, use the DTMF decoder MT8870 to analyze the control commands. Then it controls the terminal equipment through the relay according to it. This system uses the wire telephone line and thus the primary installing costs are low. But this system can only control certain equipment but not analyze their states. That is because DTMF decoder MT8870 can only decode the Dual-tone-multi-frequency and not generate it. Furthermore, this system drives the relay directly from the terminal controlling devices carrying DTMF decoder and performs control inputs and blocks of the terminal equipment, so the controlled equipment must be all connected close by.

A smart home must not only remotely control the home appliances such as TV, heater etc. but it needs to check certain appliances' operating state. Importantly, well-timed input of security-related signals such as fire and burglar alarms mean a lot to the habitants. It not only does DTMF decoding, but also generates it, so it is important to control and drive the functions. Also, the equipment might not be all in one place, but is spread to many rooms, and in this case, full control of relays with only one terminal control device is illogical.

This paper concentrates on these kinds of matters. This paper suggests constructing the system using gateway with DTMF generating and decoding abilities, and smart terminal devices with many functions. The components use Zigbee wireless communication [23–25].

DESIGN AND WORKING

Structure and Function of the System

Structure

The suggested structure of the system is shown in Figure 1. As shown in Figure 1, a smart home system is composed of smart terminal devices, gateway, and wire telephones. Gateway is connected in parallel with home wire telephones and gateway and smart terminal devices are connected by Zigbee wireless communication. Gateway decodes the control commands transmitted in DTMF mode using

mobiles or wire telephones and transmits the corresponding terminal drive commands to the smart terminal devices in Zigbee wireless communication mode. Smart terminal devices receive terminal drive commands sent by gateway and gives corresponding controls. If alarm signals such as fire alarms are discovered by the smart terminal devices, it is sent to gateway in Zigbee wireless communication mode and in gateway the corresponding DTMF signal is generated and sent to the user.

Smart home system with this composition remote control terminal equipment, such as TV, heater, lights etc. using wire telephones and mobiles from anywhere. And send the operating state and alarm signals, such as fire and burglar alarms, to the user at the right time.

Function

The system shown in Figure 2 includes the following functions:

- *Remote control and state survey function:* The user can use the mobile and wire telephone in any place to power on/off control the terminal equipment at home. If it is necessary, it can also survey the operating state of the equipment.
- *Alarm sending function:* If the alarm goes off from the alarm devices such as fire alarm, door monitor and infrared body sensors, then it generates DTMF signals and sends the note at the right time by calling the user's phone.
- *Setting function:* Necessary control commands and state reports can be put in DTMF code according to the needs of the user, according to the types of the equipment to be controlled and monitored.
- *Security function:* Using the user's password, it prevents illegal control and monitoring of an unauthorized user. Here, the user's password is also sent in DTMF mode.

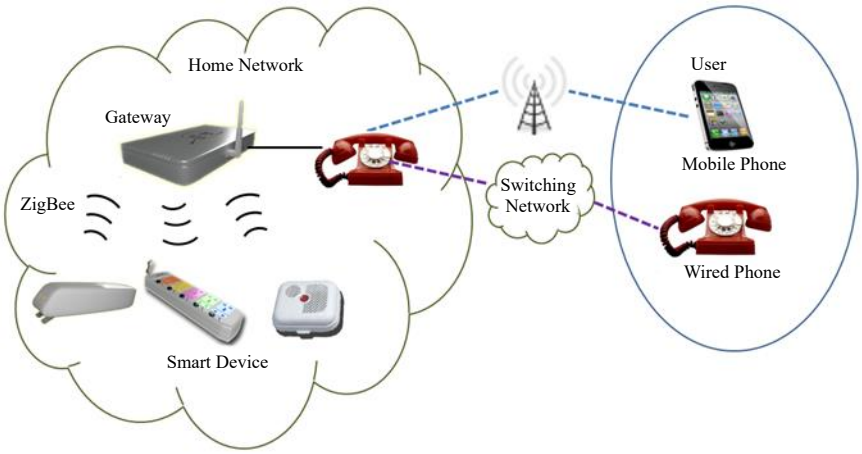

Figure 1. Structure of the system.

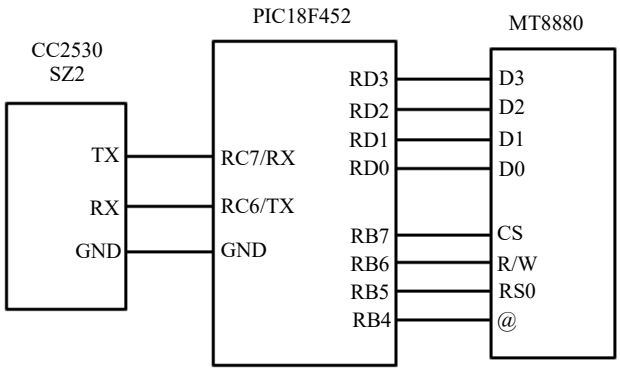

Figure 2. Gateway's device composition.

Setting and Appliance

The setting and appliance manual is as follows.

- First, the gateway is connected in parallel with the wire telephone or directly to the telephone line at home.
- Next, the smart terminal devices are set in an appropriate place at home. Especially, smart adapter for remote controlling must be installed where TV, heater etc. are and certain home equipment cords are plugged in the smart adapter. In this way, the installation of the system is finished.
- To use it, first the user must use mobile or wire telephone to call the wire telephone installed at home. When the wire telephone at home rings for a certain amount of time, (the user can choose how long it rings) the gateway then changes the telephone line to busy.
- Next, the user presses the keys on the mobile or the wire telephone to give control or state survey commands. Here, the gateway decodes the DTMF signals, received through the telephone line, generates corresponding terminal drive commands and sends them to certain smart terminal devices in Zigbee wireless communication mode.
- Smart terminal devices drive the relay and turns on or off the certain equipment, according to the drive commands sent from the gateway.
- When the smart terminal devices get fire alarm signal, they send it to the gateway through Zigbee wireless communication method. So, the gateway generates DTMF signal, sends it through the telephone line and calls the set phone number. The user knows about the alarm state at the right time through the telephone line.

Gateway

The gateway in a smart home decodes the DTMF signals sent by the user through the telephone line, makes the corresponding terminal drive commands, and sends them to certain smart terminal devices or vice versa.

As one can see in Figure 3, the gateway has the PIC 18F452 for the main controller and uses MT 8880 to receive or send DTMF signals. It uses CC2530-SZ2 to perform Zigbee communication. The MT8880 is a monolithic DTMF transceiver with call progress filter. Figure 3 shows MT8880 interface circuit, the important part in the gateway.

Figure 4 shows the operating algorithm of gateway. As one can see in Figure 5, the gateway distinguishes the source if data receiving event is detected.

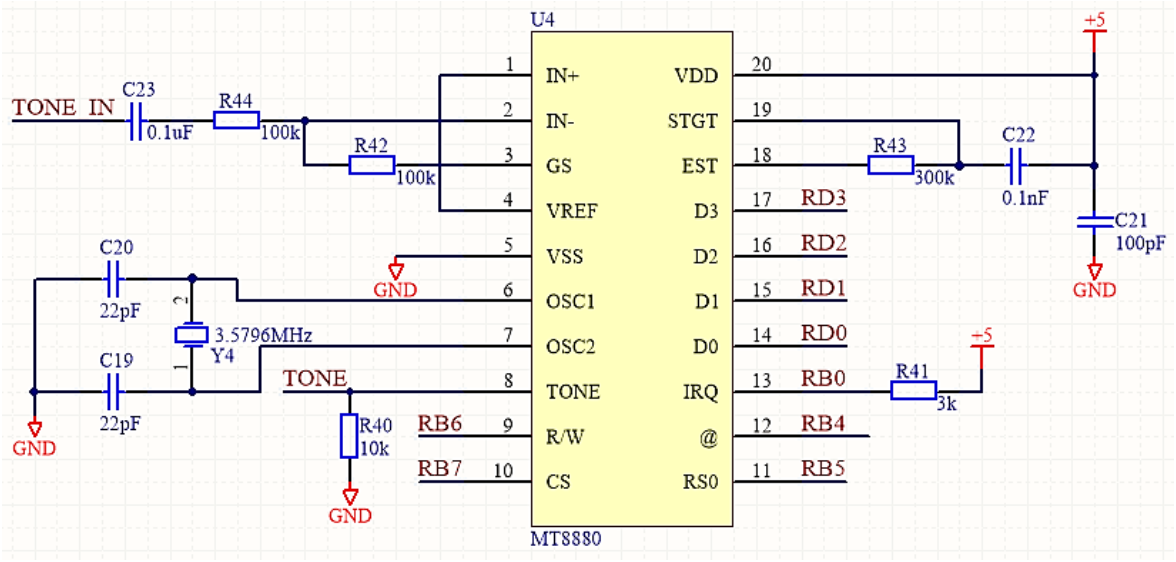

Figure 3. MT8880 interface circuit.

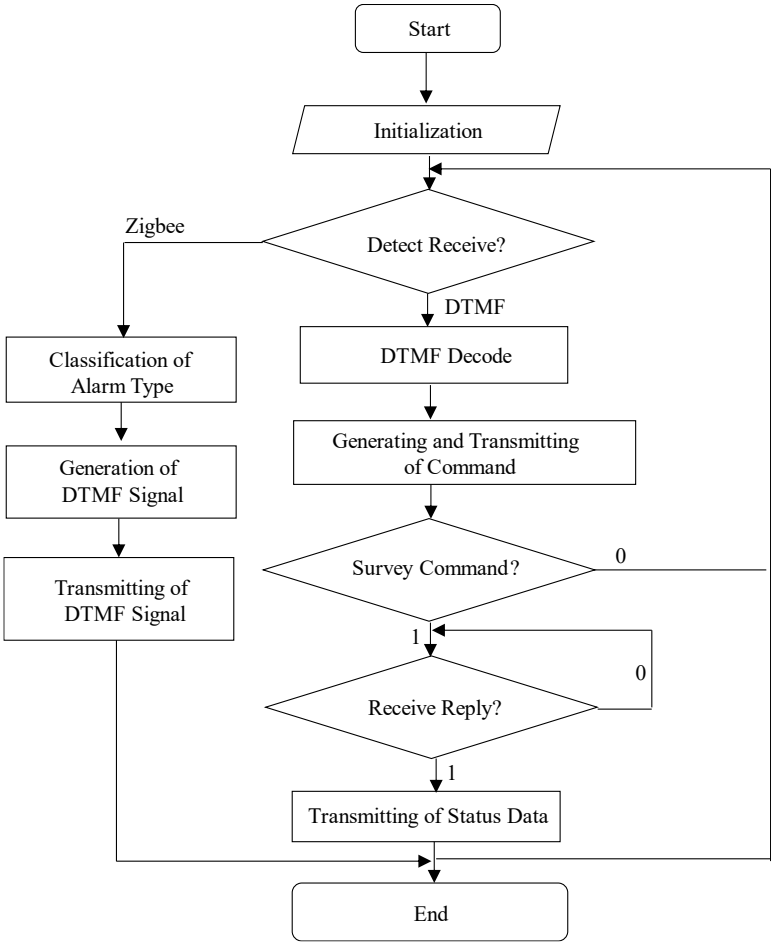

Figure 4. Gateway's operating algorithm.

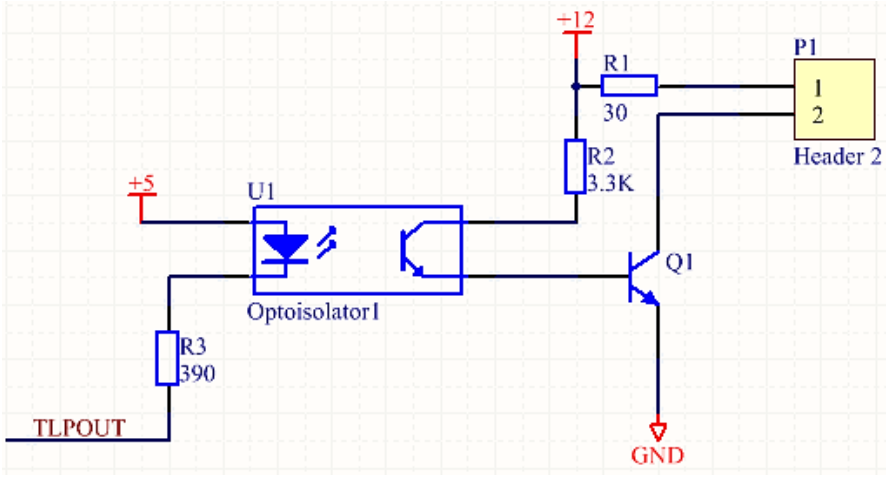

Figure 5. Terminal drive circuit of the 1-channel connector.

If an alarm signal is received using Zigbee communication, it is analyzed and then the corresponding DTMF signal is generated and transmitted so the user telephone is called and its state is reported. If a control command is received through phone line, DTMF signal is decoded and according to it the command is generated and transmitted to the smart terminal devices using Zigbee communication. If the command is a survey command, it is on standby until the response is received. After the response is received, DTMF signal is generated according to it and is delivered to the user by transmitting through the phone line.

Smart Terminal Device

Four kinds of smart terminal devices are designed for the smart home system suggested in the paper-smart connector, fire alarm, door monitor, and infrared body sensor. Smart terminal devices exchange information through the gateway and Zigbee communication mode.

Smart Connector

Smart connector receives terminal drive command transmitted from gateway through Zigbee wireless communication and offers the function of switching on and off home electrical appliances such as TV, heater, lights, and so on.

It has to satisfy the following requirements:

- First, it has to receive the terminal drive command from gateway and switch on and off according to the command.
- Second, it has to save the operating state information of the corresponding equipment so that it could be restored to the former state even if the device is switched off and on again.

From these requirements terminal controller is consisted of Zigbee communication module, a terminal drive module and a main controller. Especially the main controller has to be equipped with EEPROM memory to store the operating state information.

PIC16F877A is used as the main controller of the smart connector. PIC16F877A has UART module that can transmit data to CC2530-SZ2, Zigbee communication module, in series and 256-byte EEPROM. Thus, it can satisfy the above requirements.

A smart connector is divided into a 1-channel connector and a 4-channel connector according to the number of channels providing on/off control.

Figure 5 shows the terminal drive circuit of the 1-channel connector. As one can see in Figure 5, photocoupler (PC817) is used to insulate the power level of the device (5 V) from the relay drive voltage level (12 V). JZC-23F is used as a relay.

A 4-channel connector is only different from 1-channel connector in its number of channels. The operating algorithm of smart connector is shown in Figure 6.

In Figure 6, the smart connector receives the control command transmitted from gateway using Zigbee wireless communication and analyzes the command type. If it is the device control command, the corresponding drive on/off signal is transmitted and then its state is stored in EEPROM memory. If it is the state survey command, the response command is generated from the state information and transmitted to gateway.

Fire Alarm

Fire alarm performs the function of transmitting the fire information to the user via gateway in case of fire at home. Figure 7 shows its device composition. For the physical realization of a fire alarm, optical fire alarm module, SS-168 and Zigbee communication module, CC2530-SZ2 is used.

SS-168 uses DC 9-V battery as a power source and detects the fire from the light signal caused by the fire. In case of fire, SS-168 can report the information using indicator light and the speaker. Therefore, if SS-168 is used, it can perform the function of both fire sensor and alarm signal driver at a time. A 9-V battery can be used as a device power source as it is.

CC2530-SZ2 is equipped with 8051 processor so fire sensor information is received and transmitted to gateway through Zigbee transmitter using the processor. The operating algorithm of a fire alarm is quite simple and it is not necessary to be described here.

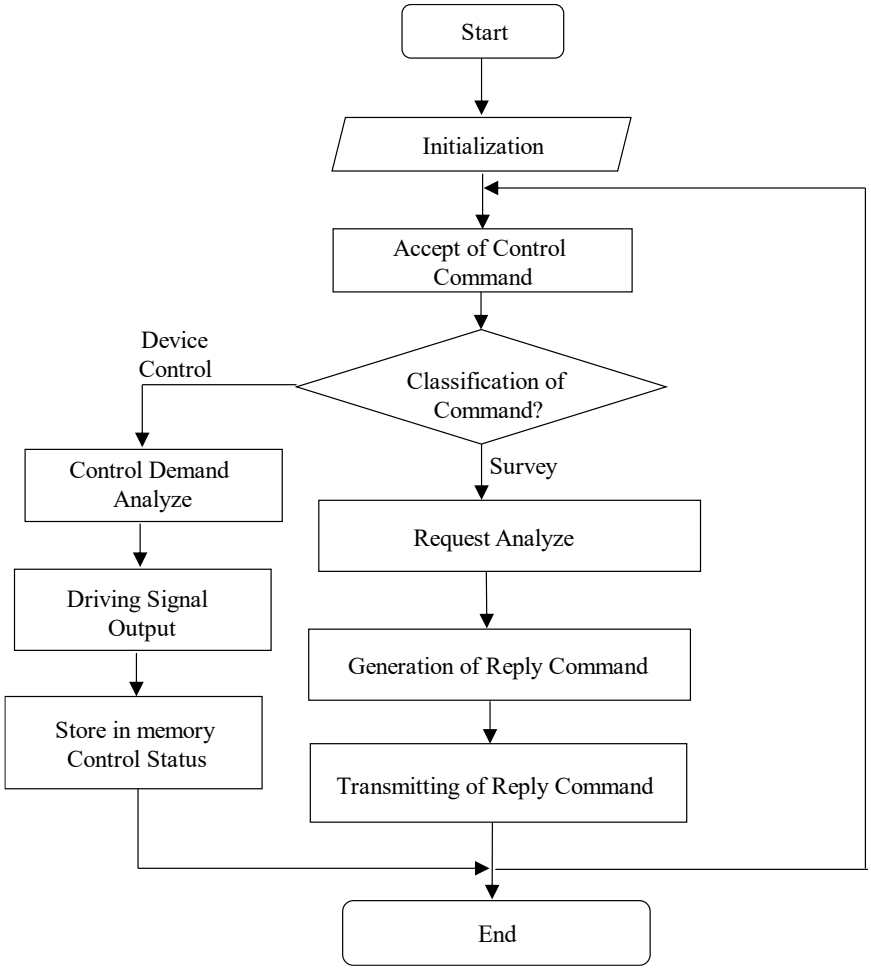

Figure 6. Operating algorithm of smart connector.

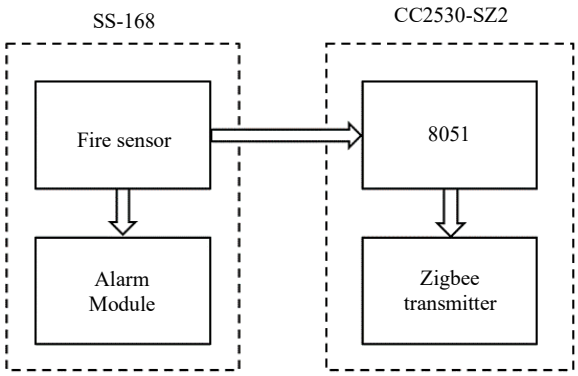

Figure 7. Device composition of fire alarm.

Door Monitor

The door monitor detects open-close state of the door or the window of home and transmits its warning to gateway. Especially if it detects the door-open-state, it has to transmit that information to the user via gateway.

The door monitor also uses 8051 processor equipped in CC2530-SZ2 as the main processor as well as the fire alarm. Zigbee transmission method is the same as above but only the open-state sensor circuit of the door is added. The circuit and algorithm of the door monitor is too simple to describe.

CONCLUSION

This paper realized the smart home system consisted of gateway, smart connector, fire alarm and door monitor described above and analyzed its operating accuracy through the test. For the test all devices are set up in their given positions as described above.

First of all, home wire telephone was called by mobile phone. Gateway connected to the wire telephone in parallel detected the phone call signal exactly and switched the line to the busy state. After that, when DTMF signal was generated using the keypad in the mobile phone, the command was correctly transmitted to the gateway and on/off control was given according to it.

When the state survey command was transmitted, the message about the given state was sent to the mobile phone by DTMF signal. When the fire alarm and door-open-state alarm worked, its signal was transmitted to the gateway and the gateway called the user's mobile phone by generating DTMF signal. The user could check if there was any alarm from the mobile phone.

As described so far, the smart home system with DTMF and Zigbee wireless communication uses the telephone line that is firm in the substructure foundation so the original installation costs are significantly reduced and it also provides more effective performance.

REFERENCES

1. Singh AK, Singh K, Dixit JP. Automatic communication control configuration system through lay outing system bus. Int J Eng Sci Comput. 2017; 7 (6): 12822–12829.
2. Agrawal A, Saurabh S. Traffic control system using Zigbee module. Int J Eng Sci Comput. 2017; 7 (4): 11150–11153.
3. Gunge VS, Yalagi PS. Smart home automation: a literature review. Int J Computer Appl. 2016; RTDM: 6–10.
4. Biswas T, Saha A, Saha D. DTMF and GSM based home automation system. Adv Ind Eng Manag. 2017;6(2):111–6. DOI: 10.7508/aiem.2017.02.010.
5. Madhuri K, Sai BL, Sirisha BS. A home automation system design using hardware descriptive tools. Int J Eng Res Technol. 2013; 2 (7): 385–393.
6. Bissey S, Jacques S, Le Bunetel J-C. The fuzzy logic method to efficiently optimize electricity consumption. in individual housing. Energies. 2017; 10 (11): 1701.
7. Chekired F, Mahrane A, Samara Z, Chikh M, Guenounou A, Meflah A. Fuzzy logic energy management for a photovoltaic solar home. Energy Procedia. 2017; 134: 723–730.
8. Soetedjo A, Lomi A, Nakhoda YI. Implementation of optimization technique on the embedded systems and wireless sensor networks for home energy management in smart grid. In: Proceedings of the 2016 IEEE Conference on Wireless Sensors (ICWiSE), Langkawi, Malaysia, October 10–12, 2016. pp. 26–31.
9. Arikiez M, Alotaibi F, Rehan S, Rohouma W. Minimizing the electricity cost of coordinating houses on microgrids. In Proceedings of the 2016 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), Ljubljana, Slovenia, October 9–12, 2016. pp. 1–6.
10. Shareef H, Ahmed MS, Mohamed A, Al Hassan E. Review on home energy management system considering demand responses, smart technologies, and intelligent controllers. IEEE Access. 2018; 6: 24498–24509.
11. Marin I, Goga N, Vasilateanu A. A novel indoor positioning using smart luminaires. In: Proceedings of the 9th International Conference on Information, Intelligence, Systems and Applications, Zakynthos, Greece, July 23–25, 2018. pp. 1–5.
12. Marin I, Goga N, Draghici I, Pavaloiu I, Nitu M. Ambient assisted control using smart luminaires. In: Proceedings of the Zooming Innovation in Consumer Electronics International Conference, Novi Sad, Serbia, May 30–31, 2018. pp. 123–127.
13. Kelly SDT, Suryadevara NK, Mukhopadhyay SC. Towards the implementation of IoT for environmental condition monitoring in homes. IEEE Sensors J, 2013; 13 (10): 3846–3853.

14. Piyare R. Internet of things: ubiquitous home control and monitoring system using Android based smart phone. Int J Internet of Things. 2013; 2 (1): 5–11.
15. Ghasemi F, Rezaee A, Rahmani AM. Structural and behavioral reference model for IoT-based elderly health-care systems in smart home. Int J Commun Syst. 2019; 32 (12): e4002.
16. Deng D-J, Gan M, Guo Y-C, Yu J, Lin Y-P, Lien S-Y, Chen K-C. IEEE 802.11ba: low-power wake-up radio for green IoT. IEEE Commun Mag. 2019; 57 (7): 106–112.
17. Balkhande BW, Dhakate KR, Iphode UG, Junghare RA. Home automation using speech recognition in Android framework. Int J Eng Sci Comput. 2017; 7 (1): 4871–4873.
18. Soetedjo A, Nakhoda YI, Saleh C. Embedded fuzzy logic controller and wireless communication for home energy management systems. Electronics. 2018; 7 (9): 189.
19. Bassoli M, Bianchi V, De Munari I. "A plug and play IoT Wi-Fi smart home system for human monitoring. Electronics. 2018; 7 (9): 200.
20. Kaur N, Singh B. A survey on wireless body area network and human machine control. Int J Eng Sci Comput. 2017; 7 (5): 11581–11585.
21. Feng X, Yan F, Liu X. Study of wireless communication technologies on internet of things for precision agriculture. Wireless Pers Commun. 2019; 108: 1785–1802.
22. Jogdand RR, Choudhari BN. DTMF based home automation system. Int J Eng Sci Comput. 2017; 7 (2): 4328–4331.
23. McCormick DK. IEEE Technology Report on wake-up radio: an application, market, and technology impact analysis of low-power/low-latency 802.11 wireless LAN interfaces. 802.11ba Battery Life Improvement: IEEE Technology Report on Wake-Up Radio. 2017. pp. 1–56.
24. Piyare R, Murphy Al, Kiraly C, Tosato P, Brunelli D. Ultra low power wake-up radios: a hardware and networking survey. IEEE Commun Surv Tutorials. 2017; 19 (4): 2117–2157.
25. Gomez K, Rasheed T, Riggio R, Miorandi D, Sengul C, Bayer N. Achilles and the tortoise: power consumption in IEEE 802.11n and IEEE 802.11g networks. In: 2013 IEEE Online Conference on Green Communications (OnlineGreenComm), Piscataway, NJ, USA, October 29–31, 2013. pp. 20–26.

