ZIGBEE BASED VOICE CONTROLLED WIRELESS SMART HOME SYSTEM

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ABSTRACT

In this paper a voice controlled wireless smart home system has been presented for elderly and disabled people. The proposed system has two main components namely (a) voice recognition system, and (b) wireless system. LabView software has been used to implement the voice recognition system. On the other hand, ZigBee wireless modules have been used to implement the wireless system. The main goal of this system is to control home appliances by using voice commands. The proposed system can recognize the voice commands, convert them into the required data format, and send the data through the wireless transmitter. Based on the received data at the wireless receiver associated with the appliances desired switching operations are performed. The proposed system is a low cost and low power system because ZigBee is used. Additionally the proposed system needs to be trained of voice command only once. Then the system can recognize the voice commands independent of vocabulary size, noise, and speaker characteristics (i.e., accent).

KEYWORDS

Wireless, smart home, voice recognition, ZigBee, low power, low-cost, LabView,

1. INTRODUCTION

Home automation system has been around for more than a decade [1]. The main concept is to form a network connecting the electrical and electronic appliances in a house. This is a growing technology, which has changed the way people live. According to the data published by the market research and market intelligence firm ABI about 4 million home automation systems were sold globally in 2013 [8]. It is also estimated by the same organization that 90 million homes worldwide will employ home automation systems by the end of 2017. There have been several commercial and research versions of smart home system introduced and built [2,3,4,5,6]. But, none of the versions has broken through the mainstream yet other than security systems [7]. Smart home systems have captured many disparate technologies so far and products have been in the market for more than one decade. Many companies have entered in this field including Google. Google has announced an ambitious project named Android@Home [15] for smart home platforms. Despite over a decade of disparate activity in the industry no company has yet succeeded to launch home automation as a popular technology. The reasons of this failure have been comprehensively studied and listed in [1,16,17]. Some of the reasons are as follows: (a) cost: the existing systems are expensive and are owned by rich family with large house and estates, (b) difficult to install: expert professionals are needed to install and configure the system, (c) difficult to use: the control interfaces have poor quality and are not user friendly, (d) vendor dependency:

need to use separate systems for different companies' appliances, (e) less functionality: most of the system can either monitor or control the functions, and (f) not customized: most of the systems are not customized with the needs of the users. In addition to the above mentioned applications there are also some other reasons including security issues and multi-user problems [18,19].

Wireless communication based home automation system has gained a high momentum for the last couple of years. Wireless communication reduces the complexity related to the installation and maintenance compared to its wired counterpart. A typical wireless home automation system comprises battery operated and low power wireless sensors and actuators. Bluetooth, WiFi, and ZigBee are the popular choice for the backbone of such systems. Wireless network based smart home systems have become very popular as they provide comfort, security, and safety. Moreover, they support remote monitoring facilities. The availability of cheap wireless sensors, actuators, and modules has reduced the gap between the luxury and mass market segmentations of home automation technologies. However, wireless home automation system has some limitations too. The hostile radio channel, resource limitation, and mobility impose challenges for wireless home automation systems. Despite these limitations several organization and companies have developed wireless home automation system for diversified applications namely light control, remote control, smart energy, remote care, security and safety [21]. Especially, this industry has changed drastically since the introduction of cheap computers and laptops. The user interfaces of the home automation systems are much cheaper and user friendly now [20]. A typical wireless home automation system should have to deal with the following constraints: (a) high node density, (b) multipath radio wave propagation, (c) high interference, (d) multihop end-to-end connectivity, (e) dynamic topology, (f) various traffic patterns, (g) internet connectivity, and (h) secured communication. The major challenge is to deal with these constraints by using nodes that not only have limited memory and processing power, but also have limited operating life.

A typical wireless home automation system consists of two main parts namely (a) communication protocols, and (b) the user interfaces. The communication protocols are used for getting data to and from the home appliances. The user interfaces are used for monitoring and controlling them. There have been many solutions proposed for wireless home automation industry in the past few years. Some of them include (i) Z-wave, (ii) Insteon, (iv) Waveins, and (v) IP based solutions. The Z-wave is a wireless solution developed by Sigma Design. This wireless protocol has been promoted by the Z-wave alliance [12]. The main purpose of the Z-wave is to ensure a reliable transmission of short messages from a control unit to one or more nodes in the networks. Insteon is a home automation solution developed by SmartLabs and promoted by the Insteon Alliance. The major feature of Insteon is that it defines mesh topology composed of radio frequency (RF) link and power line link. The nodes can be RF only or power line links only or can support both types of communication. Waveins is a low power wireless protocol developed for controlling and monitoring appliances in a home. It is currently managed and promoted by Wavenis Open Standard Alliance [22]. This protocol defines physical, link, and network layers. Wavenis services can be accessed from the upper layer through an application programming interface. The IP-Based solutions have been initiated by Low Power Wireless Personal Area Network Group of Internet Engineering Task Force (IETF). This working group has defined mechanism for transmission of IPv6 packets on top of IEEE 802.15.4 networks. These networks have been named as LowPAN. The LowPAN follows the mesh topology and a routing protocol is used for its operation. The work on LowPAN is still in its infancy level and it is predicted that it will be an emerging technology for wireless home automation system in future.

Recently, ZigBee based solutions have drawn considerable attentions in the wireless home automation industry. This technology was developed by the ZigBee Alliance for low-data rate and short-range applications. ZigBee was designed for a suite of high level communication protocols used to create personal area networks. The initial version of ZigBee was based on IEEE 802.15.4

standard. It operates in the 868 MHz, 915 MHz, and 2.4 GHz bands in Europe, North America, and worldwide respectively. The ZigBee protocol stacks composed of four layers namely physical layer, network layer, medium access control, and application layer. The physical layer and the medium access control layer are based on IEEE 802.15.4 standard. The ZigBee Alliance has defined the application layer and network layer. The ZigBee defines three roles for the devices namely (i) co-ordinator, (ii) router, and (iii) end device. The co-ordinator and router have more functionality compared to the end devices. The ZigBee end devices can transmit data over longer distances via the router devices. The network layer supports both addressing and routing for tree and mesh topologies. In tree topology the coordinator acts as root. In mesh topology routes are discovered and maintained on-demand. The Ad hoc On-Demand Distance Vector (AODV) [23] has been chosen as the routing protocol in ZigBee networks. Two routing strategies are used namely point-to-point, and many-to-one. There are several application profiles in ZigBee. One of the profiles is Home Automation Public Application Profile, which makes ZigBee a suitable technology for home automation systems [24]. This application profile defines device descriptions, commands, and attributes for ZigBee applications in residential and commercial environments. Some of the applications of ZigBee include residential and commercial lighting, HVAC, security, wireless light switches, electrical meters, traffic management systems, and other consumer and industrial equipment that require short-range wireless transfer of data at relatively low rate. Considering all the above mentioned advantages we have selected ZigBee.

Voice controlled home automation systems have drawn considerable attention in the recent years. Initially, home automation systems were designed for the people seeking luxury and sophisticated home. But, there was always a need to develop home automation system for the people with special needs like the elderly and the disabled. According to a report published by the World Health Organization (WHO) around 785 million people of 15 years and older live with disability [49]. Of these, the World Health Survey reports that 110 million people have significant difficulties in functioning. Another report published by the Population Division of United Nations show that about 10% of the World's population is older than 60 years and it is estimated that this figure will reach up to 21% by 2050 [50]. In order to assist the old people and the people with disability home automation technologies are adopting voice control or voice recognition techniques. The main idea is to control and monitor home appliances by using voice command. The motivation behind this work is also the same. The rest of the paper is organized as follows. Section 2 presents some related works. System model has been presented in Section 3. Section 4 contains system operation, circuit details, and implementations. Finally, this paper is concluded with Section 5.

2. RELATED WORKS

One of the early experimental works on the ZigBee based home automation system was presented in [25]. This system was capable of monitoring door and window, smoke, gas leak, and water flooding in a home from remote location. Some simple control systems such as operating a valve and sending signal to security network have also been associated with this application. A ZigBee based home network system to track a user has been proposed in [26]. This system periodically tracks a user by using three systems namely Indoor Positioning System (IPS-M), Indoor Positioning System Infrastructure (IPS-M), and Indoor Positioning System Gateway (IPS-G). In ZigBee based wireless home automation system a gateway is an important component. One of such gateway architecture has been proposed in [27] to interconnect Digital Living Network Alliance (DLNA) compliant home appliances and a ZigBee network. In a similar work [28], another type of gateway architecture has been proposed to connect a low-rate home work with the internet. A user can control the home appliances via internet from a remote location through this gateway. A ZigBee based power monitoring system (PMS) has been proposed in [29]. In addition

to ZigBee wireless communication the PMS also utilizes Digital Signal Processing (DSP) and Web services. DSP is used for real-time power parameters computation and Web Services are used for the communication infrastructure among distributed systems across a network. The proposed system has been constructed and validated for the power management in a campus. Another power management system has been proposed in [30]. This system stores the measurement data of current and voltage of the electric outlets in an embedded board. It can detect any overload in the system and send signal to a circuit breaker to turn off the power. A real-time home security system has been proposed in [31]. The system is able to detect intruder in a home and send messages via GSM network. The system also can receive instruction from a remote location to control the house appliances. A wireless smart home system based on ZigBee has been introduced in [32]. The system composed of three main components (i) home server with GSM module; (ii) intelligent environment detection sensor modules, and (iii) intelligent home appliances. By using these modules a home can be monitored remotely and an alarm message can be sent to a remote location. Most of the wireless home automation systems are constrained by limited operating range. Such constraints can be overcome by using multi-hop communication system. This was the main motivation of the work presented in [33]. In this work a home control system (HCS) based on multi-hop mesh network is presented. Three different interfaces based on ZigBee, Bluetooth, and GPRS have been used in HCS. The hardware architecture and software protocol have also been proposed. Some techniques to save battery life and hence maximize operating life of such network have also been proposed in the same work. A ZigBee based embedded remote control system has been implemented in [35]. The main advantage of this system is that it provides the wireless communication capabilities on an embedded board rather than on a PC. This kind of embedded board has made system smaller in size and power efficient. The interference between the home appliances and the home network has been investigated in [36]. The authors have shown that the presence of the home appliances in a Personal Area Networks (PAN) environment significantly affect the performance of the home network system which also operates in the same frequency band. A ZigBee based home automation system and Wi-Fi network have been integrated in [37]. The home automation system has been implemented by using Texas Instrument's MCU device LM359B96 in [38]. Users can access the system by a dynamic webpage of LwIP TCP/IP protocol stack or GSM sms. The performances of a ZigBee based home automation system have been compared with those of other technology based (i.e., WiFi and Bluetooth) systems in [39]. The authors claimed that ZigBee based system has longer life compared to WiFi and Bluetooth based home automation system. An energy efficient wireless sensor network has been proposed for smart home in [40]. This system uses energy efficient sensors. This system is situation based self-adjusting to reduce the energy consumption in home automation system. An automatic embedded software generation framework has been proposed in [41] to create and evolve ZigBee applications. The main target is to enhance the quality of digital home living environments. This framework allows rapid deployment of the supporting software for energy control and sensing devices to monitor energy usage in a home at any time. The performances of ZigBee technology have been investigated in [42]. The performances of this system such as latency, received signal strength indicator, and round trip delay have been investigated in this work.

Voice control system for ZigBee based home automation has been introduced in [34]. Speaker independent automatic speech recognition technique has been used. A number of modes have been used for convenience namely button trigger mode, voice password trigger mode, and circle recognition mode. A user can use any of the modes depending upon the conditions. A low power voice control system for home automation system has been proposed in [43]. In this system ZigBee network receives voice command as input to an ARM9 controller, which converts the data into a required format to be used in the microcontroller. Finally, the system generates some control characters to switch ON/OFF the home appliances. A client server based voice control system for home automation has been presented in [44]. Voice command is captured by a client

system and is sent to a server via Wi-Fi wireless network. The server system converts the voice command into a form that is used to control the home appliances. Microsoft Speech (SAPI) has been used in this work for implementing voice recognition system. Mobile based voice command control and monitoring system has been implemented in [45], in which artificial intelligence has been used for voice recognition system. A multi-layer feed forward neural network has been used. Another similar work has been presented in [46]. Two controlling methods have been proposed namely time and speech. For speech recognition Microsoft voice engine tool has been used. A wireless home automation system has been designed for physically challenged to control the home appliances in [47]. Fault identification system has also been integrated in this system to monitor the conditions of the appliances. To provide security RFID based authentication system has been used. The results presented therein show that the system can control up to 20 appliances and 40 voice commands can be recognized by this system. In another recent work [48] the authors implemented a ZigBee based home automation system that could recognize up to 1225 voice commands with a success rate of 80%.

In this work we also presented voice controlled based wireless home automation system for elderly and people with disability. Our work is different from other related works in the following ways. We used National Instruments' LabView software. We have the following advantages due to LabView. The user interface is easier to design and implement. The system can be remotely controlled by a mobile or a computer. The system can easily be extended to include more appliances. The system is easy-to- install and configurable. Unlike other related system no expertise skill is required to install and configure the system. Microsoft's rich voice recognition library has been included in our work. The system needs to be trained only one time. Once it is trained, the system can system can recognize the voice commands independent of vocabulary size, noise, speaker characteristics or accent. The data acquisition is performed by using DAQ provided by the National Instruments. The use of DAQ simplifies the hardware implementations of this proposed system compared to other existing similar systems.

3. SYSTEM MODEL

The system model of this work is shown in Figure1. The system model consists of the following basic components (i) automatic speech recognition system, (ii) control units, (iii) wireless system, and (iv) application and home appliances.

Automatic speech recognition (ASR) system can be defined as an independent and computer-driven transcription of spoken language that allows a computer to identify the spoken words captured from a microphone or telephone and convert it into written texts. The main components of an ASR are (i) a microphone, (ii) speech recognition software, (iii) a computer, and (iv) a sound card. The ultimate goal of ASR is to allow a computer to recognize in real-time, with 100% accuracy, all words that are spoken by any person, independent of vocabulary size, noise, speaker characteristics or accent. Through a speech recognition program/application, the computer is able to process words one says and turn them into text that is displayed on the screen. There have been many research activities on the speech recognition system. The fundamental reasons of these research activities are (i) accessibility for the deaf and hard of hearing, (ii) cost reduction through automation, and (iii) searchable text capability.
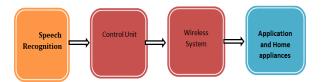
Figure 1. The system model

The control unit (CU) coordinates the components of a computer system. It fetches the code of all of the instructions in a program. It directs the operation of the other units by providing timing and control signals. All computer resources are managed by the CU. It directs the flow of data between the Central Processing Unit (CPU) and the other devices. There are different types of control program available including MatLab, C++, and LabView. In this work we choose LabView because of the following reasons: (a) it is easier to build a large program piecewise using small amounts of code, (b) it is easy to control the interfaces between hardware, (c) it is easy to find compatible hardware in the market, (d) it is simple to integrate with other hardware and software, and (d) it is easy to create the user-interface.

Wireless networks and sensors are playing important roles in emerging pervasive computing technologies that are required for the realization of smart homes. Effectively all wireless technologies that can support some form of remote data transfer, sensing, and control are candidates for inclusion in the smart home portfolio. In this work we used ZigBee wireless system. Compared to other wireless systems like Bluetooth and Wi-Fi, ZigBee has some advantages as follows: (a) ZigBee aims at automation whereas other two technologies aim at the connectivity of mobile devices in close proximity, (b) ZigBee uses low data rates, and consumes low power, (c) ZigBee networks support devices with longer range, and (d) ZigBee network is a robust network and that is easily scalable.
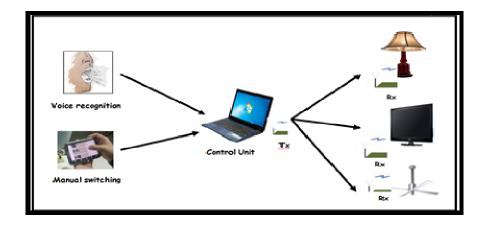

Figure 2. System operation

Applications and home appliances are the last step of the proposed system. Each device connected with the network must have a switching circuit to turn it On\ OFF. The status of each device is monitored by using toggle circuit. In addition to the switching devices a Data Acquisition Card (DAQ) has been used in this work. A typical commercial DAQ card contains ADC and DAC that allow input and output of analog and digital signals in addition to digital

input/output channels. There are many types of DAQ cards are available to provide interface between the LabView software and the hardware. In this project NI USB 6008 DAQ card has been used.

4. SYSTEM OPERATION

The basic system operation of the proposed system is shown in Figure 2. A user has two options for controlling the home appliances (a) by using manual switching and (b) by using voice recognition. The control unit is an interface program that must satisfy the following two conditions (a) the output from the interface program is forwarded to a wireless transmitter and sent to a receiver through wireless channel, and (b) the receiver at the appliances accept the receive signal to turn ON or OFF the device. The front panel of the LabView program is shown in Figure 3. The system operation can be described based on this front panel in the following steps:

- The voice command is captured by using a microphone and sent to the computer.
- Voice recognition is performed by using LabView with the help of Microsoft's rich speech library.
- Upon recognition of the voice command control characters are generated and sent through ZigBee wireless communication protocol to specified application address.
- At receiver side, application can turn ON or OFF a relay controlling circuit depending on the received controlled characters.
- A hardware switching toggle circuit is added to simplify the switching process and to allow for ON/ OFF switching with a single word voice command.
- As an additional feature the system can be controlled using smart devices.

Figure 3. The front panel of the program.

The circuit block diagram of the transmitter system is shown in Figure 4. The speech recognition is dealt with LabVIEW. So the program recognizes the speech with library inside it. Then the output from LabView is sent to the DAQ. The DAQ connects the microcontroller and transmitter.

The transmitter sends commands to the wireless receiver that is connected with the switching circuit.
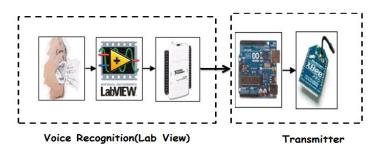

Figure 4. Transmitter Circuit.

The LabView takes input commands from the voice recognition system, compares the command with each stored command inside the library of LabView. The comparison is done in terms of the frequency. If the frequencies of the commands are matched, the LabView will generate an output pulse that is sent via DAQ. The detail operation of the transmitter is illustrated in Figure 5.
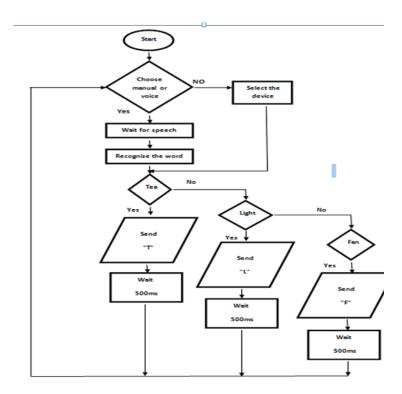

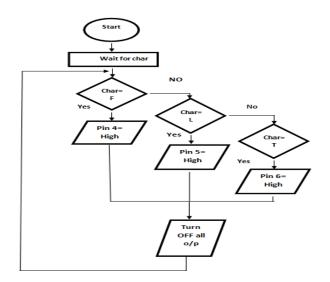Figure 5 The flowchart for the operation of the transmitter.

Figure 6 The flowchart for the operation of the receiver

The wireless transmission unit consists of Xbee and Arduino. The Arduino is programmed in such way that if it receives the pulse code 100 from labVIEW program, it will generate a character "T". If it receives the pulse code 010, it will generate a character "L". If it receives the pulse code 001, it will generate a character "F". Then the program will wait for 500ms after transmitting a new data. The receiver module is connected with the switching circuit of the appliances. We connect the pins of the receiver module to the home appliances as follows: Pin 4 to the fan, Pin 5 to the light, and Pin 6 to the tea machine. The program waits for receiving a character. For example, if the program receives character "F" it will turn ON the fan. If the program again receives the same character, it will turn OFF the fun by using the switching circuit. Similar procedure is followed for switching ON or OFF the other appliances (i.e., light and tea machine). Figure 6 shows the flowchart of the processes of wireless receiver.
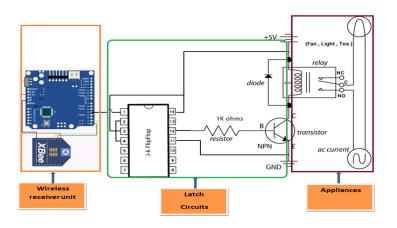

Figure 7. The latch circuit

In this work, we use the same word to turn ON/OFF the appliances. Since the LabView cannot turn ON/OFF the appliances by using the same word, we use a switching circuit to switch an appliance between the two states. It means that if a character is received for the first time, the program will turn on the device. If the same character is received for the second time, the program will turn off the device. We have designed a latch circuit for this type of switching operation. The latch circuit is connected with the relay that switches ON\OFF the device. The latch circuit is shown in Figure 7. The latch is a basic storage element in a sequential logic. Flip-flops and latches are the fundamental building blocks of digital electronics systems used in computers, communications, and many other types of systems. The latch circuit used in this work has been implemented by using a J-K flip-flop. In electronics, a flip-flop or latch is a circuit that has two stable states and can be used to store state information. The circuit can be made to change the state by applied signals. When used in a finite-state machine, the output and next state depend not only on its current input, but also on its current state (and hence previous inputs

5. CONCLUSIONS

In this work, we have implemented a voice controlled Zigbee-based home automation system. We used speech recognition system to implement this work. The LabView software has been used to implement the voice recognition system. The main advantage of the system is that it does require training of voices for only one time. At the same time LabView software has been used to support human-computer interactions to realize multiple functions. The system is designed for elderly and disabled people so that they can monitor and control the home appliances with their limited ability. The wireless part of the system has been implemented by using Zigbee RF modules. Hence, the system is highly efficient and it consumes low power. This system can be easily extended to remotely control the home appliances through smart devices like iPhone/ iPod and others phones so that one can remotely check the status of the home appliances and turn ON or OFF the same. The proposed system has been tested with three home appliances. But, it can be easily expanded to include more home appliances.

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