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DESIGN AND DEVELOPMENTOF A HOME AUTOMATION SYSTEM USING ZIGBEE

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ABSTRACT

Home Automation has gathered attention in delivering convenience and improving the quality of life for the past decades. People have easier access and feedback with their home appliances within their home networks. As these kinds of systems are emerging, it gave birth to the concept of the Internet of Things (IoT) which is also becoming a fast-disruptive technology for business opportunities, research, and hobbies wherein Machine-to-Machine (M2M) wireless communications are achievable. The most common wireless standards implemented in Home Automation Systems are IEEE 802.15.1 (Bluetooth), IEEE 802.11 (Wi-Fi), ZigBee, Z-Wave, and LoRa. This research aims to develop a home automation system that utilizes the ZigBee standard as the mode of communicating wirelessly to an Arduino microcontroller.

Keywords: automation systems, zigbee, internet of things (IoT), arduino microcontroller.

1. INTRODUCTION

Home Automation systems are widely sought-after owing to the integration of smart gadgets and appliances, network availability at homes, and open-source software. It allows consumers to remotely monitor and control smart appliances such as air conditioning units, lights, thermostats, Closed-Circuit Televisions (CCTV), and doors within the distinct home network. These smart systems are also able to interact, and store continuous sensory data, locations, power, and bandwidth consumption based on their activities and the user's commands. In comparison with customary homes, implementing automation in our homes not only extends functionalities but also provides a pleasant, secure, and high standard way of living [1]. One of the most upset about implementing a smart home is that devices that come from dissimilar manufacturers are unable to communicate with each other. As a result, smart home protocols are standardized to address this issue. Smart home protocols are described as a common language that smart devices should follow for devices to communicate with each other properly. For this reason, several wireless communication protocols are regulated such as IEEE 802.11 (Wi-Fi), IEEE 802.15.1 (Bluetooth), ZigBee, and Z-Wave.

This research focuses on the implementation of the ZigBee standard developed by the ZigBee Alliance [2] as a means of wireless communication among devices and the network. The ZigBee standard is designed to address the need for inexpensive implementation of low-data-rate wireless networks with ultra-low power consumption [3]. The differentiation of ZigBee among popular wireless communication protocols such as Wi-Fi and Bluetooth are that ZigBee provides power-efficient and modest data rates. One of the substantial applications of ZigBee is security, meter-reading, irrigation, light-control, and multi-zone HVAC (Heating, Ventilation, Air Conditioning) systems in the field of home automation. Security and light-control systems are the primary center of interest of this research paper which consists of several sensors, switches, and light bulbs.

2. BACKGROUND OF THE STUDY

The Zigbee protocol is developed by Zigbee Alliance used to create Personal Area Networks (PAN) and is famous for its numerous applications on Wireless Personal Area Networks (WPAN) that interconnects various devices within a certain range of ten to a hundred meters. It is not the same with the IEEE 802.15.4 standard but is mainly based on it and uses the transport services of the said IEEE 802.15.4 standard. The main difference between the two is that Zigbee supports and adopts the IEEE 802.15.4 standard that defines the Physical and Medium Access Control (MAC) layers. The Zigbee standard is comprised only of the networking, application, and security layers of the protocol.

Networks with the style of Zigbee began to emerge in the 1990s and paved the way for the industry to develop a self-organizing wireless ad hoc network that is a decentralized system of wireless networks. The IEEE 802.15.4 was born and completed back in May 2003 and is defined as the technical standard for Low Rate WPANs (LR-WPAN) and is maintained by the IEEE 802.15 group. Thus, the Zigbee specification was officially valid on the 14th of December 2014 and announced its availability on the 13th of June 2005. As a cutting-edge and leading device, the device needed to keep up with the demands and trends to its numerous users and applications in sensors, medical devices, smart homes, lighting, in-home patient monitoring, and a lot more.

The renowned standard is not just attractive due to its popularity but to its technical complexity, interoperability, device types and roles, range, frequencies of operation, data rates, access modes, and networking topologies. Zigbee plays a vital role in wireless sensor networks and is in increasing demand due to the growth of smart homes in this day and age.

3. STATEMENT OF THE PROBLEM

An abundance of smart appliances ranging from adapters, switches, lights, thermostats, and doors are widely available nowadays, yet they are not capable of communicating with each other properly. Secondly, the existing interfaces of smart devices differ from processes and ways of connectivity which leads to limited versatility at the users' end. Different devices from different manufacturers normally come up with divergent interfaces and pose confusion for consumers. Users will also have difficulty keeping track of what appliances are either turned on or off. Additionally, conventional switches are situated at different locations of the home that necessitates manual operations. This research proposes automation among these home appliances that retrofit their functionalities and can seamlessly communicate with each other from different parts of your home. It is also smart to keep in mind possible sources of interference that may affect the performance of the ZigBee standard. Possession of these powerful devices must be maximized at its full potential and configured properly to be able to communicate with other devices.

4. SIGNIFICANCE OF THE STUDY

Most people nowadays are pretty much preoccupied with different responsibilities, careers, hobbies in their daily lives in and out of their homes. People spent most of the time indoors at home 52% on working days (Monday to Friday) and 70% on weekends (Saturday and Sunday) [2]. People want to gain relief and convenience despite their busy schedules and one way that has significantly helped this concern is by being able to remotely control home appliances. Home automation reduces efforts and is beneficial to determine current states and behavior of several appliances connected to the control system and home network. ZigBee is a wireless communication protocol that is specifically catered for the need of very low-cost implementation of low-data-rate wireless networks with ultra-low power consumption, ideal for the application of home automation among appliances. The standard can also operate at a range of frequencies and data rates from 868 MHz, 915 MHz band, and 2.4GHz bands with 20 Kbps, 40 Kbps, and 250 Kbps respectively. This research proposes a smart environment within our homes that is capable of integrating desired functionalities and communicating with each other seamlessly. The goal is to alleviate the inefficiency of manually operating appliances and anxiety that we bring upon ourselves whenever they are left turned on or off to students, parents, families, and all people living in their homes.

5. DESCRIPTION OF THE SYSTEM

This research is about the simulation of a ZigBee-based home automation system that is capable of controlling home appliances and the detection of the distance of objects that can be applied in parking spaces in our homes. The XBee Series 1 module is based on the IEEE 802.15.4 protocol and can be configured to the necessary baud rate, sleep modes, and if it will act as a receiver or transmitter. The 2 XBee modules are powered via a dedicated adapter with a supply voltage of 2.8 - 3.4V and each is connected to an Arduino UNO microcontroller which is responsible for acquiring sensory data and transmitting control commands. Sensory and control data are transmitted and received via XBee communication operating in the ISM 2.4GHz frequency band by using Proteus for software simulation.

This system is comprised of a control unit, the remote unit, and Radio Frequency (RF) communication. The control unit consists of the HC-SR04 ultrasonic sensor, flame sensor module, and 4-channel 12V relay module that is connected to 4 different home appliances. The remote unit is made up of a 4x3 matrix membrane keypad connected to an Arduino microcontroller that is responsible for the commands which are transmitted via the XBee module.

There are numerous advantages in using ZigBee as our wireless communication protocol such as its supported network topologies (point-to-point, point-to-multipoint, and peer-to-peer), 16 available direct sequence channels, and an indoor range of up to 100 feet (30 meters).

6. METHODOLOGY

Figure-1 shows the General Block Diagram of the System.

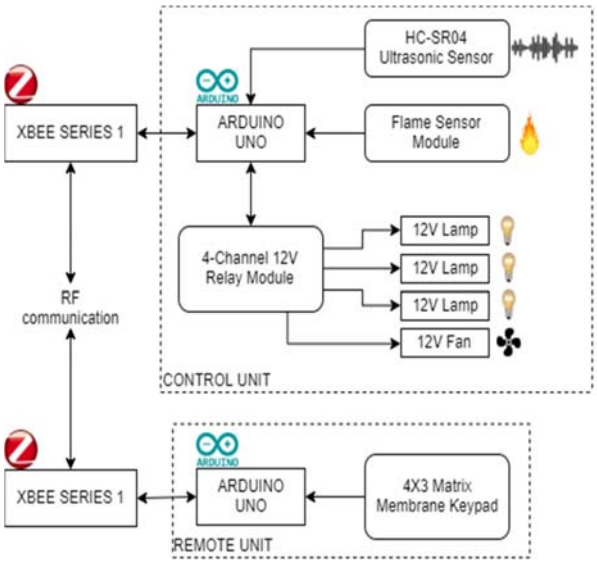

Figure-1. General block diagram.

6.1 Microcontroller

Figure-2 shows the Arduino UNO pinout

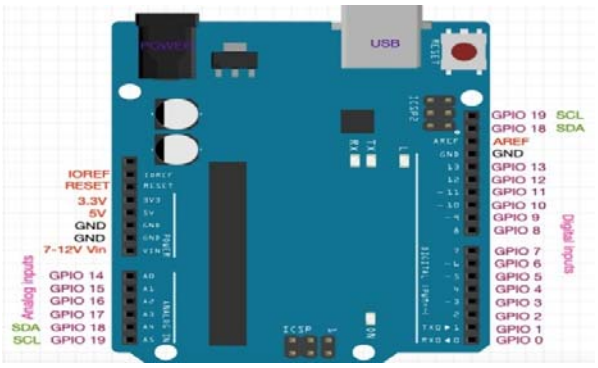

Figure-2. Arduino UNO pinout.

The Arduino UNO microcontroller is constructed on the ATmega328P and has 14 digital I/O pins in which 6 pins are capable of performing Pulse Width Modulation (PWM), 6 analog inputs, a USB connection power jack, power jack, and a reset button. The microcontroller can be powered via USB or with an AC-to-DC adapter that can be connected to its built-in power jack. This open-source hardware can be programmed with its companion Arduino IDE software to be able to communicate with a variety of components and is commonly used for prototyping.

6.2 Control Unit

Figure-3 shows the Control Unit Schematic.

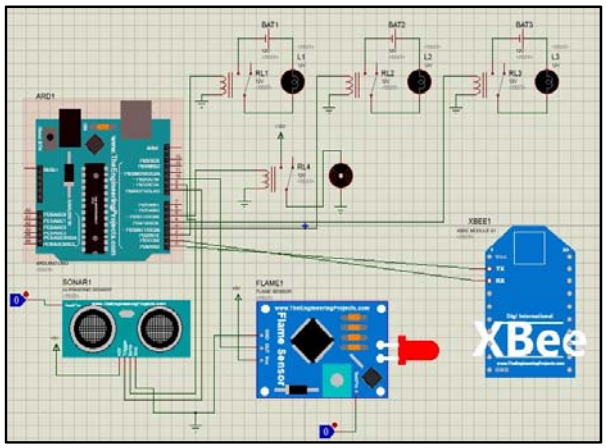

Figure-3. Control unit schematic.

The control unit is comprised of an XBee module, flame sensor module, HC-SR04 ultrasonic sensor, 4-channel 12V relay module which in turn is connected to 4 different loads. Its operation is on standby as long as there is no command being received from the remote unit. Whenever a command is sent from the remote unit, depending on the configuration, each state of the load will either be on or off. The flame sensor is installed for emergency purposes that whenever a fire is detected, the loads connected to the system will automatically be turned off. The ultrasonic sensor is located inside the premise just above the front door and is responsible for detecting whether the owner has entered or left the home. It will be the indication that the operations of the system will be able to start once the owner has entered while it will also cease the operations of the system when the owner has left.

6.3 Remote Unit

Figure-4 shows the Remote Unit Schematic.

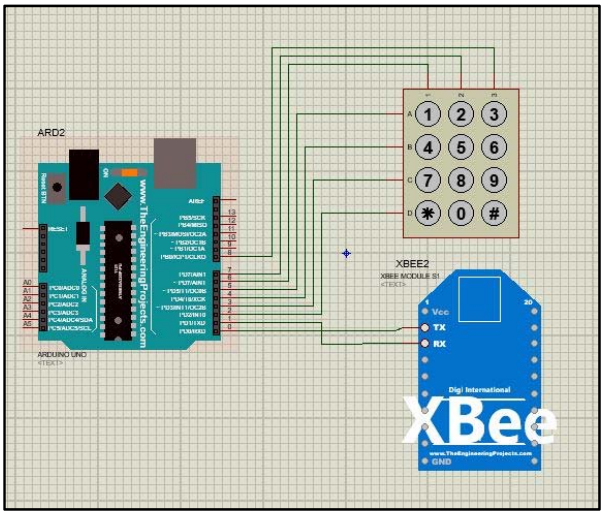

Figure-4. Remote unit schematic.

7. REVIEW OF RELATED LITERATURE

The paper of [4] proposed a home automation system that can monitor and control through a variety of commands from a remote control that is integrated with ZigBee. It can also accommodate any device that can be connected via Wi-Fi that is based on Java. The system includes a home gateway, virtual home, and device engine that are well defined and integrated throughout its design. The home gateway is constructed for devices to exchange and make use of information in conjunction with each other. It is the most important segment of the research in which the transmission and reception of data will heavily rely on. The virtual home developed is a way to handle and detect all communications before it enters the home automation system. Coordinators, routers, and end devices are the fundamental pieces that should be present and configured in a ZigBee network. A wireless ADSL modem router was utilized with a 4-port switch that provides communication within the home network wherein Wi-Fi devices are available. The home gateway is comprised of a Wi-Fi module and a ZigBee microcontroller and is powered by a dedicated power supply. Wi-Fi module yields embedded serial to Wi-Fi connectivity and are economical for the application of home automation systems. The ZigBee microcontroller supplies connectivity to the ZigBee network. The ZigBee end devices consist a conventional light switch in which its state can be detected and adjusts accordingly, a radiator valve that can be remotely monitored and controlled, a safety sensor composed of temperature, carbon monoxide, flame, and smoke sensors, and a Zigbee-based remote control made up of a ZigBee microcontroller, LCD, and push-button

switches. The implemented system was assessed quantitatively and qualitatively to validate the effectiveness within the home.

The paper of [5] published a comparative analysis on smart home systems based on wireless communication protocols such as GSM, Bluetooth, and ZigBee integrated with a PIC microcontroller. Adaptation to a smart home system is instrumental as it reduces workload, manages electricity consumption, lessens anxiety if appliances are left unplugged or open, and automates our lifestyle inside our homes. These kinds of systems are very achievable with the advancement of technology, utilizing open-source hardware, and choosing the right wireless communication protocol. It provides convenience to people of diverse ages, professions, lifestyles, and backgrounds. Global System for Mobile communication or commonly known as GSM, is a standard and developed for second-generation digital cellular networks. It is also utilized as a wireless communication protocol for several home automation systems in which home appliances can be controlled by sending messages to the system. Bluetooth is based on the IEEE 802.15.1 standard and used for exchanging data between fixed end mobile devices through short-wavelength radio waves. Every application of Bluetooth in home automation systems requires a mobile device based on Android operating systems and sends control signals to home appliances which are also based on Bluetooth. In comparison to other protocols, Bluetooth has a distance disadvantage and will not work beyond 100 meters. Implementation of ZigBee on smart home systems constructed with a PIC microcontroller is relatively inexpensive and a very efficient controller. It is ideal for short-range wireless networking and is composed of different networking techniques.

In the research of [6] the ZigBee standard in the application of a Wireless Sensor Network (WSN) system in a smart home application. Communication among sensors can be considerably influenced by electromagnetic noise which in turn affects the performance. This research analyzed the importance of the communication performance of a ZigBee-based sensor network and made use of a motor with a variable speed drive [7,8,9]. Implementation of ZigBee standard is most suitable for smart home systems as it can operate in 3 different frequency bands, low-cost, low-data-rate, modes of power-saving, and various networking topologies. Every ZigBee network involves three different device roles: coordinator, router, and end device [10, 11, 12]. Their experimental setup contains a computer for visual presentation of the system, the coordinator responsible for data collection, and multiple devices responsible for sensory readings on ZigBee communication links [13, 14, 15]. Measurements such as the Received Signal Strength Indicator (RSSI) are conducted to indicate the signal power at the receiving end device concerning the varying distance between nodes. The experiments are arranged with both Line of Sight (LOS) and Non-Line of Sight conditions to quantify the degradation of RSSI values accordingly in the ZigBee communication network [16, 17, 18].

8. THEORETICAL CONSIDERATIONS

Zigbee is well known for its communication protocols and low-data rate feature for wireless network systems. Power consumption of Zigbee devices uses at least 1mW and above that can still provide range notably large from 10 meters up to 100 meters [19,20,21]. Its physical layer which is based on the IEEE 802.15.4 standard supports up to 3 frequency bands (2.4Ghz, 915Mhz, and 868Mhz) with 16, 10, and 1 channel/s respectively. The different frequency bands employ different modulation techniques from BPSK, ASK, and O-QPSK [22]. Access modes are differentiated from beacon and non-beacon that makes data traffic organized and timely. The device is mostly in a power-saving or sleep mode which in turn makes it capable of functioning for a long period of time. Short-range networking has a broad range and under these are the Wi-Fi, Bluetooth, and ZigBee protocols which are normally compared for their data rate, typical range, and application examples. All wireless communication methods under the IEEE 802.15.4 uses Direct Sequence Spread Spectrum (DSSS) or Parallel Sequence Spread Spectrum (PSSS) techniques which improve the performance within a multipath environment [23, 24].

Implementation of the protocol ensures reliability and operation in conjunction with other wireless networks and devices due to its supported mesh networking ability. Two types of devices play a significant role within a ZigBee-based network and application namely the Full-Function Device (FFD) and Reduced-Function Device (RFD). The Zigbee gateway provides interoperability for devices to be able to connect from different standards and protocols to be able to translate it to Zigbee packets and vice versa [25].

Proteus 8 Professional is utilized as a means of software simulation for the whole system. It is primarily designed and used for Electronic Design Automation (EDA) that users can create schematics in which can be turned into a Printed Circuit Board (PCB) layout [26,27]. Microcontrollers can be used in the system by uploading a HEX file with any components connected to it [28]. The PCB layout can be utilized in the form of a netlist from the schematic layout and is equipped with Design Rule Checking (DRC) to determine if the layout satisfies the rules necessary for design manufacturing [29].

HC-SR04 Ultrasonic Sensor is utilized to determine the distance of an object with stable readings that comes up with an ultrasonic transmitter and receiver. The sensor is powered by the Arduino UNO microcontroller rated at +5 VDC with a current consumption of less than 15mA, ranging distance of 2cm - 400cm or 1 - 13 feet, and with dimensions of 45mm x 20mm x 15mm. The trigger pin is considered as the input and the echo as the output of the sensor.

9. DATA AND RESULTS

Tables 1 and 2 show the states of the home appliances and Ultrasonic Readings.

Table-1. States of home appliances.

DEVICE/ APPLIANCE	KEYPAD INPUT	STATE
LAMP_1	1	ON
	2	OFF
LAMP_2	3	ON
	4	OFF
LAMP_3	5	ON
	6	OFF
FAN	7	ON
	8	OFF

Table-2. Ultrasonic Sensor readings.

VOLTAGE INPUT	DISTANCE MEASURED
1V	223cm
3V	670cm
5V	1116cm

Figures 5, 6 and 7 show the virtual terminal readings.

Figure-5. HC-SR04 reading at 1V.

Figure-6. HC-SR04 reading at 3V.

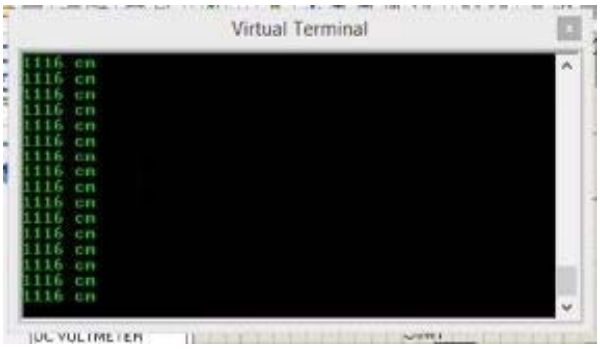

Figure-7. HC-SR04 reading at 5V.

10. ANALYSIS OF DATA

The most important aspect of the research is to be able to transmit and receive data wirelessly from one node to the other. To achieve this, the 2 XBee Series 1 module was utilized as the transmitter and receiver of the system. Each XBee module is connected to one Arduino UNO microcontroller through a serial connection to be able to communicate and perform commands accordingly. XBee modules are based on the 802.15.4 protocol and will only communicate using the specified protocol. 3 lamps and a fan were simulated as a representation of home appliances and it was connected to the control unit of the research. These home appliances are controlled through the user's inputs from the 4x3 matrix membrane keypad which have dedicated assignments to which appliance will it control. Appliances will only have 2 states which are on and off which will be controlled by the user. The home automation system is also equipped with an HC-SR04 (ultrasonic sensor) and a flame sensor for special purposes. The output of the sensors is displayed on a Virtual Terminal that is a handy feature of the Proteus software. The HC-SR04 (ultrasonic sensor) is simulated by applying 3 different values of voltages in which the sensor will produce output depending on the variation. When 1 Volt, 3 Volts, and 5 Volts is fed to the sensor, an output of 223 centimeters, 506 centimeters, and 1116 centimeters is produced respectively. The integration of these hardware and leading wireless communication technologies is very promising in terms of home automation. The necessity of manually operating home appliances can be significantly simplified and improved.

11. CONCLUSIONS

In conclusion, the utilization of ZigBee-based hardware and network systems are very reliable, economical, efficient, and has low power consumption. It has indeed many capabilities in communicating with other hardware and software which is an ideal aspect for versatility and reliability. This research paper has conducted an effective approach in employing ZigBee as a means of communication implemented in a remote-controlled home automation system. The proposed system is comprised of two major parts which are the control and remote unit. Sensors are also administered for detecting objects in a distance and senses if there is fire brought

about in the home. To evaluate the effectiveness and performance of the proposed methodology, the system is implemented in a software called Proteus Design Suite version 8. This software is mainly used for electronic design automation and to create schematics from many components produced by different manufacturers. Through the given features of the software, the design was successfully implemented and simulated from two different units. The sensors were able to produce the desired outputs through the Virtual Terminal present as a feature in the Proteus software. This system is most suitable for remotely monitoring and controlling home appliances that are connected within the home network. It is an advantage for various people, families, and mostly to the elderly that are feeling distressed in manually operating their home appliances. Anxiety is relieved by being able to see on-hand which devices are operating whenever people either are in or out of their homes rather than by being seriously affected by an unpleasant feeling if appliances are left operating.

12. RECOMMENDATIONS

This home automation system can indeed enhance and self-operated the manual operations within our homes but there are several rooms for improvement and additional features to consider. An improved and well-designed Graphical User Interface (GUI) can be implemented and significantly uplift the experience of the system. It can easily give a visual representation of what is happening within the system and improve the manner as to how we interact with the system. It can be easily integrated with the system as long as it is compatible with the sensors, microcontrollers, and XBee module that is utilized. A smart home energy monitoring and management is one way to carry out that can be implemented or integrated into the system. Over time, these devices are on-demand to be able to give feedback and operate consistently. It is important to determine the [power consumption behaviour of each device whenever it operates and is in sleep mode. Energy consideration can greatly benefit every user in the home as they can estimate their costs and not to overlook such power fees. Home security is also one of the demanding duties and detail that every person contemplates about. We can see it the same way in our home automation systems and security breach is an outlying threat that we cannot accept and handle. (These are just many applications and considerations in further improving this system that can upgrade and refine performance and reliability. This home automation system can indeed enhance and self-operated the manual operations within our homes but there are several rooms for improvement and additional features to consider. An improved and well-designed Graphical User Interface (GUI) can be implemented and significantly uplift the experience of the system. It can easily give a visual representation of what is happening within the system and improve the manner as to how we interact with the system. It can be easily integrated with the system as long as it is compatible with the sensors, microcontrollers, and XBee module that is utilized. A smart home energy monitoring and management is one way to carry out that can be implemented or integrated into the system. Over time, these devices are on-demand to be able to give feedback and operate consistently. It is important to determine the [power consumption behaviour of each device whenever it operates and is in sleep mode. Energy consideration can greatly benefit every user in the home as they can estimate their costs and not to overlook such power fees. Home security is also one of the demanding duties and detail that every person contemplates about. We can see it the same way in our home automation systems and security breach is an outlying threat that we cannot accept and handle.

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