RESEARCH ARTICLE

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Prototyping an IoT-Based Smart Home Network System

Taif Fadhil Hussein[1], Mohammed Issam Younis[1*]

Abstract: Smart home is type of Internet of Things (IoT) fields. In accordance with features and requests of smart home, the design of smart home system using IoT has been reviewed in this paper. IoT devices like Raspberry Pi, Arduino microcontrollers, XBee modules with Arduino XBee shields and a set of sensors with relay boards are integrated to produced energy efficient, low cost and easy to use system. Moreover, this paper describes the architectural design; the hardware and software components and the implementation. Raspberry Pi process the user commands using python programming language and send these commands to specific Arduino using ZigBee protocol. Raspberry Pi represents a coordinator of system network and Arduino with XBee module act as routers. Finally, the communication between the end user and the coordinator is done using WebSocket technology.

INTRODUCTION

There are a lot of related works in the field of smart homes, [1-4] this field of such systems are developed fast with the development of technology. Most of the researchers aim to obtain many features including the controlling and monitoring the home devices in flexible and easy to use manner. There are many challenges that face the smart home networking system, including the high cost of implementation and upgrading, high power consumption and supported limited features such as the limitation of access only single room and fixed the configuration of a system. Some of the current system using license bands like GSM and others using Wi-Fi or Bluetooth, all of its required high-power consumption, limited in the range of transmitting and required a separated web server for gateway node and data storage. Moreover, these systems utilized the unidirectional HTTP protocol. Fix and build from earlier works, this paper presents a wireless home network system based on IoT technology and combined the gateway node and web server in single Raspberry Pi unit. This system is used ZigBee communication to transmit and receive data between each node in-home and main station and real time WebSocket communication to connect between the remote user and main station.

This paper is organized as follows. Section 2 highlights the structure and features of the proposed system. Section 3 shows the hardware components. Section 4 shows the software implementation of the proposed system. Section 5 explains the testing and analysis of the proposed system. Finally, section 6 describes the conclusion and future work.

THE STRUCTURE AND FEATURES OF THE PROPOSED SYSTEM

The design of the proposed system requires a combination and integration of many hardware and software. It consists of the main station and ZigBee wireless home network as nodes connected to the main station as depicted in Figure 1. The main station of this scheme is a Raspberry Pi with IP connectivity and it has contained the gateway node, database and Webserver running on it. The use of Raspberry Pi helps to reduce the complexity and cost of the system by eliminating the need of dedicated PC. The Zigbee wireless home network includes multiple sensor nodes; each node represents a specific room in home and consists of sensors, actuators, Arduino microcontroller and XBee Shield with XBee model. The task of each node is to sense and collect the information from specific devices of home. The Arduino reads and processes the sampling data from sensors and send it to the main station through ZigBee technology in a contactless manner. The accessing of this system is done through any web browser from same local network or remotely from any devices have internet access. ZigBee is a wireless communication technology that is capable to verify such requirements with advantage of low cost, low power consumption, low transmission rate and wider coverage and therefore it is very convenient for the development and utilization of home network.

Ordinarily, when a browser visits a website page, an HTTP request is sent to the server that hosts the desired web page. The web server recognizes the demand and sends the response back to the web browser. In several cases, the data being come back, such as news, traffic patterns, home device readings and environment monitoring data, will be old by the time the browser renders the page. If the user's application requires getting the most up-to-date real-time data, they will continually manually refresh the page. However, that is an impractical and not an especially elegant solution. [5] So, the use of standard HTTP protocol is Inefficient and can cause suspended a system. WebSocket protocol considers as an upgrade to the HTTP protocol and enabling a two-way duplex real-time communication between a web server and its clients, thus the number of requests are greatly decreased when compared to standard HTTP, this will help to improve the performance and reduced the latency of network. [5]

In the design of proposed system, the gateway node of home network, database and webserver are combined and integrated in one hardware platform device (Raspberry PI), which leads to reduce the complexity and cost effective. User can access and perform any configuration and management on specific sensor node using web application interface. The proposed system has the ability to control and monitor the following items in home users:

1. Temperature and humidity.
2. Motion detection.
3. Fire and Gas detection.

[1]Department of Computer Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.
E-mail: younismi@gmail.com
*Corresponding author

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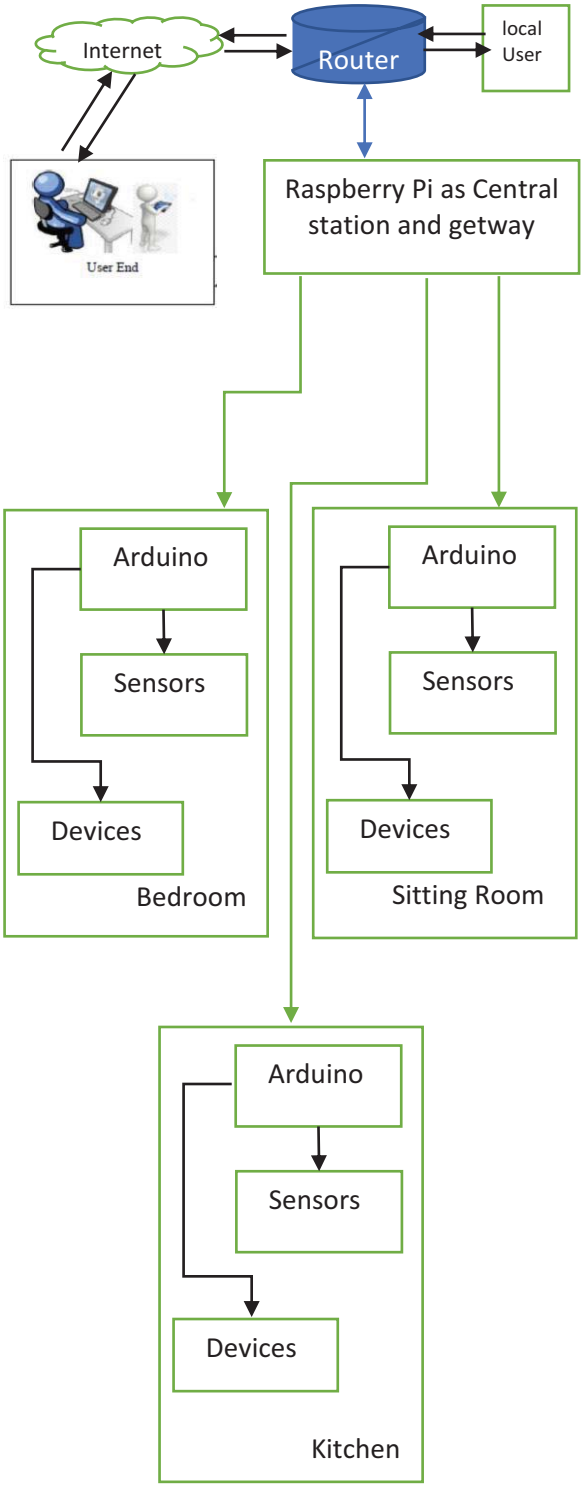

Figure 1: Architectural design of IoT-based smart home

4. Automatic control of water level.
5. Light control (on/off).
6. Fan control (on/off).
7. (On/off) any other devices.

THE HARDWARE COMPONENTS

Our proposed smart home system consists of two parts, the first part is the Raspberry Pi board which is the core of the system and the second part consists of a combination of Arduino Uno, XBee module and a set of sensors attached to Arduino according to each specific room. In addition, a relay board operating on 5 volts is needed to signal an actuating device. Raspberry pi 3 board model B has a good feature including small size, low power and 64-bit quad-core CPU with 1GB RAM which enough to do the actions of the server. [6] Arduino board is an open source microcontroller platform which consider a widely used, flexible and easy-to-use hardware and software

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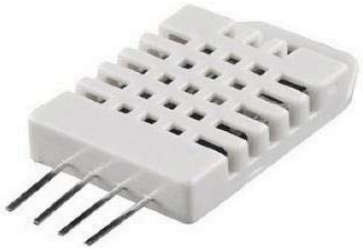

Figure 2: DHT22 sensor [9]

Figure 3: PIR sensor [10]

Figure 4: Flame sensor [11]

Figure 5: MQ-2 sensor [12]

Figure 6: HC-SR04 sensor [13]

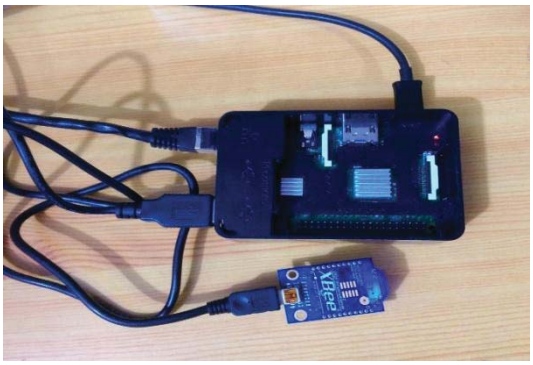

Figure 7: The main station node

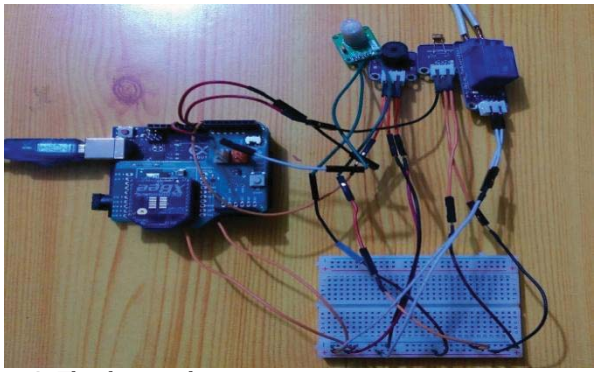

Figure 8: The door node

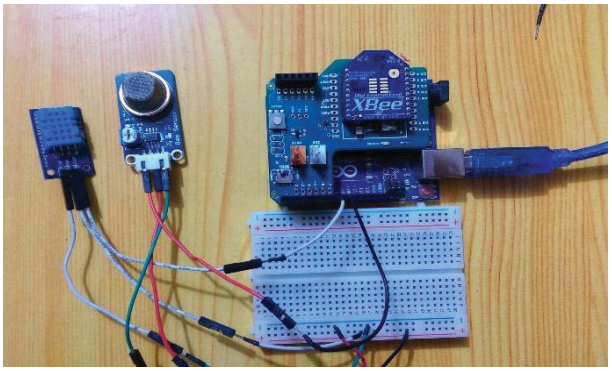

Figure 9: The kitchen node

components. It has 14 digital I/O pins, USB connection, a 16 MHz quartz crystal and a reset button. It has the ability to connect a number of sensors to each board and can connect to a shield which considers a special sensor extension put into the header pins of Arduino to extended features. [7] XBee Pro S2B is a ZigBee module commercially available used for wireless home communication and mesh networking. It offers from Digi and operates at 2.4 GHz with 250 kbps data rate and low power consumption. The indoor and outdoor ranges are 40 m and 120 m respectively. It is suitable for building star and mesh network structure and can be configured into three different type: coordinator device, router device and end device. It can be connected directly to Raspberry pi and Arduino through UART serial interface by using XBee adapter or Arduino XBee shield. [8]

There are different types of sensors used in each sensor node, these sensors are a low-cost, available and described briefly below.

DHT 22 Temperature and Humidity Sensor

The DHT22 is a very common sensor which is a digital temperature and humidity sensor as shown in Figure 2. [9] It uses a thermistor and a capacitive sensor to measure the environment temperature and humidity prediction. It has a high reliability and a good stability.

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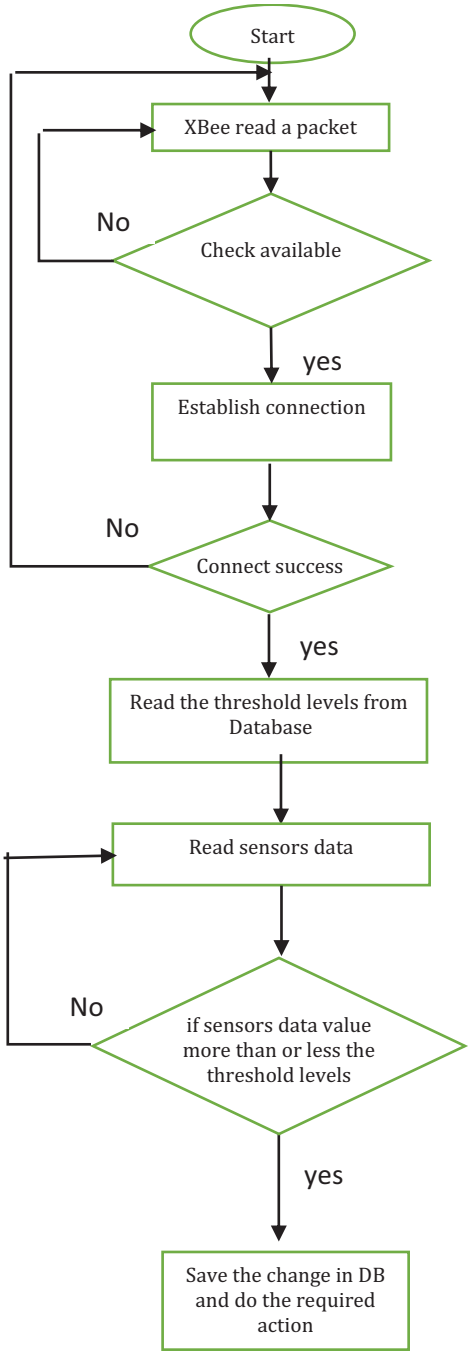

Figure 10: Flow chart of sequence activities for IoT-based smart home

PIR Motion Sensor

PIR sensor is a low-power, easy to use and have a wide range view as shown in Figure 3. [10] It senses the infrared rays emitted by the motion of human body within the discovery area of 7 m. Thus, it is a great sensor for developing any application needs to detect human movement.

Flame Sensor

Flame detector is a type of sensor that design to sense and respond to the existence of a flame and a fire as shown in Figure 4. [11] These type of sensor is used for short range fire detection and can be used to monitor application or as a safety precaution to cut devices off / on.

MQ-2 Gas Sensor

The MA-2 Gas sensor module is used to detect smoke and gas leakage in home and industry and it is shown in Figure 5. It sensitive to smoke, LPG, Butan, Methane, Alcohol and Hydrogen gases. It has a fast response time, high sensitivity, stable, long life, wide detecting scope. [12]

HC-SR04 Ultrasonic sensor

The HC-SR04 Ultrasonic sensor is affordable distance sensor used to determine distance to an object. This economical sensor offers 2 cm to 400 cm of contactless measurement functionality with high accuracy of readings in an easy-to-use way. It is used mainly in water level sensing, turret application, object avoidance application

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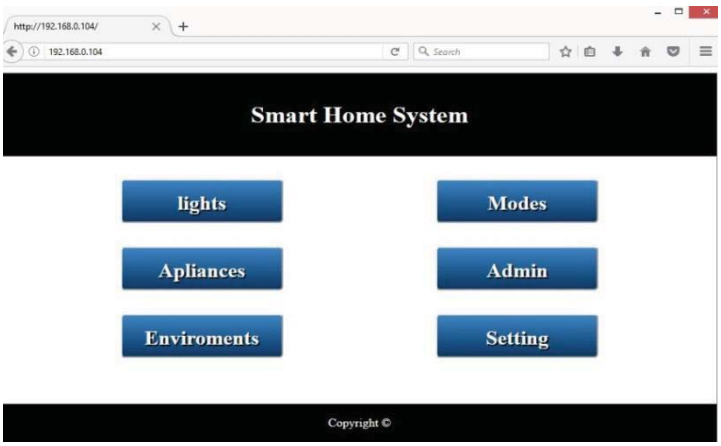

Figure 11: Main interface of IoT-based smart home

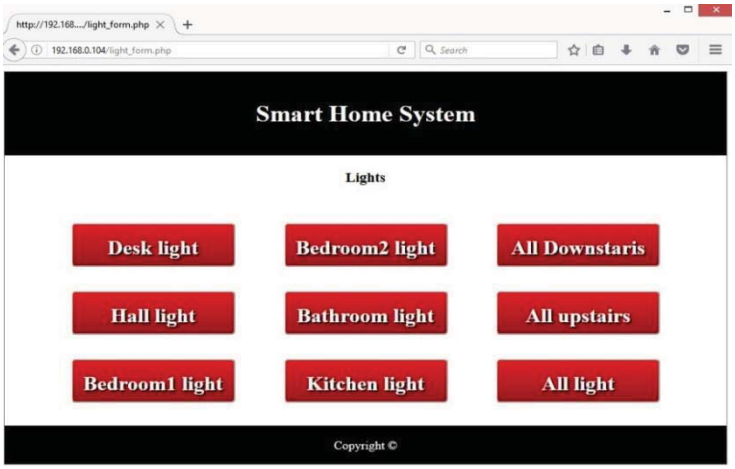

Figure 12: Light control interface of IoT-based smart home

and even as a parking sensor. [13] The HC-SR04 sensor is shown in Figure 6.

The XBee coordinator is connected to the main station which is Raspberry Pi through a USB adapter. The main station prototype is shown in Figure 7.

A motion sensor is firmed at the door of home to discover and detect any movement action. The light of door automatically turned on and off according to the density of light. The Ultrasonic sensor detects the level of water in tank and according to threshold value turn the motor on or off. A fan automatically turns on and off when the room temperature greater than a specific value (this value is set by software) and in turn reduces the room temperature. The door node prototype is shown in Figure 8.

In the kitchen node a gas sensor is used to detect the leakage of gas, an alarm in the hall is start when there is any detect of gas. Also there is a relay used to switch on and off the connected devices. The kitchen node prototype is shown in Figure 9.

THE SOFTWARE IMPLEMENTATION

Raspberry Pi is including and combining a web server, database server and gateway node. The gateway node is considered a middle layer between home nodes and main station node and used to send and receive data from database. It programmed in Python programming language. The implementation of server side of the proposed system is programmed in PHP to enable the accessing from the end user from user interfaces which programmed using HTML and CSS. The process of sending and receiving data between the main station and the home nodes is done by sending TX frame from XBee coordinator that connecting to Raspberry pi to a determined home sensor node, this frame contained 64-bit address of destination home sensor node and the reminding fields of TX frame contained a configuration data to send request to the destination home sensor node. The XBee module that connected to the receiver side receive the RX frame and send back two frames to the main station the first one is an ACK to ensure the receiving of frame and the second one is another TX frame contained the required payload data with the coordinator 64-bit address. The sequence of activities at the server side is shown in Figure 10. At first the XBee read a packet and check the availability of data and establish the connection if the data is ready and continuous reading the sensor value every period of time and compare this with thresholds value saved in database and if it exceeds these thresholds it will save in database and send to the webserver and the required control is done for the.

TESTING AND ANALYSIS OF THE PROPOSED SYSTEM

All the unconnected devices will be connected with new challenges which led to construct an intelligent network to make the ability to access these things. IoT technology has

much application on smart home systems and used an embedded technology to verify the connections between users and things.

After read the available XBee packet and establish the connection successfully, the values of sensors data sent to the web server and used for controlling and monitoring of the system appliances. Figure 11 and Figure 12 show the main page and light control page of the proposed system which will allow us to control the system. The users can use any web browser to access the real-time data of this system by using WebSocket technology. The main station gives information of temperature environment, motion state, gas detection and status of determined devices in each room and can monitor and control remotely. The home automation system using IoT has been testing successfully by connecting simple appliances to it and automatic control of connected appliances.

CONCLUSION AND FUTURE WORK

Real-time controlling and monitoring of various type of home appliances using Different types of technology have been discussed in this paper. One main advantage of our proposed system is the combination of the main station of wireless home network, web server and database server into one single Raspberry pi board. The collected data and sends commands from different home nodes in different locations were done successfully with a different type of sensors in each one. The strongest point of the presented system is the cost less, easy to be accepted by users and the integration and combination of many technologies and features to facilitate IoT-based smart home in practice, which make life easier, more convenient and comfortable to live. A part of our continuing developing of the system, we will consider developing intelligent nodes and connecting the gateway to cloud environment.

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