Developing a Smart Home System

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***Abstract*—This paper describes the design of a smart home system. This design is able to talk wirelessly with radios attached to each end node and the base station. The end nodes collect data and send it back to the base station where an 8051 microcontroller and an Arduino board interpret the information. The intent is to make a person can feel safer in their home, and provide them with a way to monitor their home from a computer or smart phone while away.**

Keywords- microcontroller; Arduino; wireless sensor network

I. Introduction

This project is about developing a smart home system. A smart home is a system that is set up in someone's house that alerts the home owner if something is not right at their house or can allow a person to change something, such as temperature, in their house while they are away. Its design is for ease of access in one's home. Within this particular design there are multiple radios that talk wirelessly back and forth to each other with help from an 8051 microcontroller [1] and an Arduino board [2], which is then interfaced with a website and text messaging system. All this together helps create a safe environment for the home owner that can allow them to call the police before anything extremely bad happens.

This project was undertaken during a 10-week Research Experiences for Undergraduates (REU) program to gain more knowledge on embedded systems, get work experience as an undergrad, and have something fun and intellectually challenging to do during the summer.

Section II provides an overview of the project, and Section III presents the results, conclusions, and future work.

II. Overview

The smart home monitoring system is composed of several different sensors and nodes. These sensors and nodes, which will be in different destinations of the home, are in essence the subsystems of the smart home. These nodes are designed to communicate between two 8051 microcontroller boards through xBee radios and an Arduino board to perform pre-determined programmed tasks. The nodes are composed of an RFID tag reader, infrared sensors, xBee radios, Arduino, cellular module, web interface, temperature sensor, smoke/ CO detector, buzzer, voice recorder, security camera, and a stepper motor. Using these nodes the home owner will be able to keep track of activity in the house.

The basic look of the house will have an RFID reader at the door that the owner can use to turn on and off the security sensor without typing in a key code. The RFID will also let the base station know that the owner is in the house. This will cause the base station to alter its usual functions between homeowner present and away.

The end nodes will also monitor temperature, humidity, smoke, and CO for comfort and safety. This information will allow the homeowner to monitor his/her house. The information will be updated periodically on a webpage and if certain conditions are met, text messages will be sent to alert the homeowner of possible alarming conditions and the message recorder will sound with a message saying that motion was detected. To further assist the homeowner a camera will have some range of motion that will allow them to further inspect the conditions of the monitored environment.

There will be several infrared sensors throughout the house. The infrared sensors inside the house will be set to detect movement inside the house while the owner is away. The owner reserves the right to activate the security system while he/she is still in the house. If unwanted motion is detected the alarm (a buzzer) will sound and flashing lights will be set off. The buzzer which is connected to the Arduino will sound when the end nodes' safety and environment with infrared sensors on them detect motion. By setting up enough nodes around the house the owner will know of an intruder before the intruder can realize the owner is in the house. This will allow the owner to get to a safer room in the house and alert the police, if necessary. On the other hand, if the homeowner is away anytime motion is detected a text message will inform them of the occurrence.

All of these nodes communicate wirelessly with the base station. This is done using a series of xBee radios. Every node has one radio associated with it. The end node radios transmit data to the coordinator in packages, and the coordinator sends the packages out through UART to a microcontroller. A diagram of a network is shown in Fig. 1.

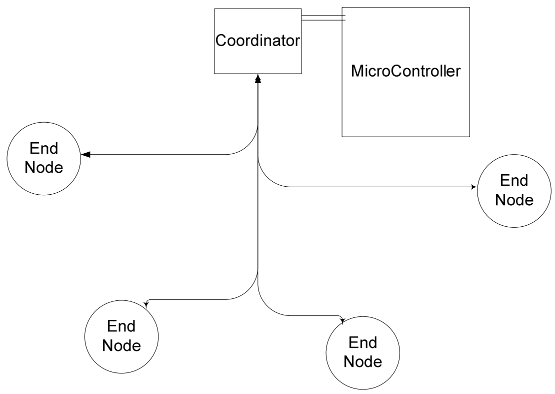

Figure 1. Wireless Network

This is an approach for creating a smart and safe house for an owner to enjoy without the need to run wires throughout the entire house.

A. Base Station

The base station has two main parts, the information retrieval and decoding, and the networking and remote user interface part. The information retrieval and decoding was processed on a DS89C450 8051 microcontroller. The networking and user interface was accomplished on an Arduino main board with an Arduino Ethernet shield and a cellular shield. The base station also has a LCD screen, an xBee radio, a message recorder, and a buzzer for an alarm. The diagram of the base station is shown in Fig. 2.

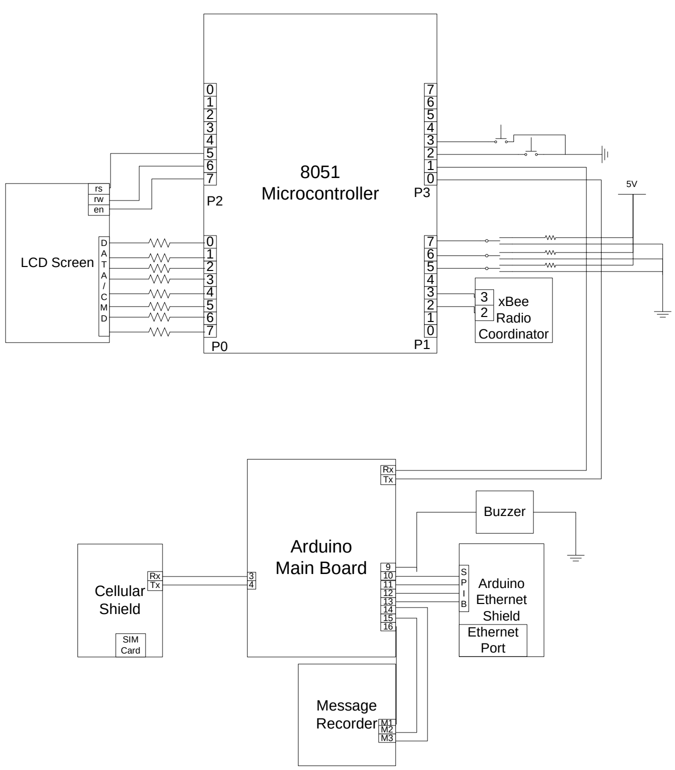

Figure 2. Base Station Block Diagram

1) Information Retrival and Decoding

This subsystem is run by the 8051 microcontroller and is in charge of retrieving RF data from the end nodes and decoding the RF packages as well as allowing some user interface through an LCD screen. The microcontroller receives the information from the wireless network coordinator radio through a UART and processes the information. This information is then decoded by the 8051 and certain functions are preformed depending on the data. The 8051 actions are dependent on several settings that are set either by the user at the base station, with RFID tags at the entrance node, or online. These settings include changing the time at the base station, setting a time dependant alarm, and resetting and clearing the microcontroller’s variables.

The microcontroller works almost entirely on interrupts. This allows the base station to receive transmissions at anytime while still operating the LCD screen properly. Using the serial interrupts allows the receiving and sending of data at random when needed, while using the external interrupts for setting and changing features of the LCD screen. The last interrupt is a timer interrupt used to create a clock and also used as a counter for several operations.

The base station receives environment data, motion data, and RFID data. Depending on what information is received, different tasks are performed and different alarms are triggered. It also alternates every five seconds between displaying RFID, and temperature and humidity data, on the LCD screen.

When motion sensor data is received the microcontroller performs two separate tasks. It decodes all the motion sensor data and saves it to memory for further use. This prototype has four motion sensors throughout the nodes. The base station holds one bit of information for each one but it packages it all together in one byte. This allows for easy transmission of the data to the networking section, while also allowing for easy individual changes in memory of each motion sensor. The other function the microcontroller performs is turning on/off lights at the remote camera node. These lights are turned off when the all clear is received from the networking section.

Another simple type of digital data that is received from the end nodes is information on the smoke and CO detector incorporated on the safety node. This information sets off the same alarms in the environment, but the networking section alerts the user in different manners.

When environment data is received the microcontroller performs two operations. First it saves the data to its own memory, and then it passes the data through another UART to the networking and remote user interface section. The environment data consists of humidity and temperature levels in the monitored environment. The microcontroller displays the data on the LCD screen as mentioned before.

When RFID data is received the microcontroller saves it to memory. The RFID tags are used for turning on and off the alarm, working as key passes or fobs for the user. Therefore, when an RFID tag is read the memory changes the state of that card from away to present or vice versa. This allows for the alarm system to be on when no one is home, and turned off when people are present. Using the push buttons and switches on the base station, the user can clear all the RFID tags effectively turning on the alarm. The RFID information is also transmitted to the networking and interface section for the purposes of the web page.

Another way to set the alarm is by using the clock and time dependent alarm. The clock is created using a timer on the microcontroller. Once this was created it allowed for extra time dependant features to be added. One such feature is a time dependant alarm. Using the switches and pushbuttons the correct time can be set and then an alarm on time and alarm off time can be set. The interface of the switches can be observed in Table I. The switches are read by the microcontroller whenever one of the pushbuttons is pressed.

Table I: LCD Interface

Switches			Push Buttons	
1	**2**	**3**	**One**	**Two**
1	0	0	Increase Hour	Increase Minutes
0	1	0	Increase Hour of Alarm time Off	Increase Minutes of Alarm time Off
0	1	1	Increase Hour of Alarm time On	Increase Minutes of Alarm time On
1	1	1	no operation	system reset/start up
0	0	0	RFID tags cleared	no operation

The pushbuttons are connected to the external interrupts of the microcontroller which cause the microcontroller to run a certain section of code asynchronously. Once the microcontroller is running one of these code sections, it checks the switch inputs and decides what operation to perform. All these actions are visible on the LCD screen as well.

2) Networking and Remote User Interface

This subsystem is controlled by the Arduino microcontroller which was chosen to be used in conjunction with the 8051 microcontroller for its ability through peripherals to easily host a web server and provide cellular service. Using the Ethernet shield, which contains the Wiznet W5100 Ethernet chip, the Arduino can perform TCP/IP processes. It can easily host a web server with the use of the webduino library, written by Ben Combee, and can generate the GET and POST parameters for a web page. Cellular service is provided by the SM5100B cellular module and SIM card on the cellular shield. The Arduino can communicate with the cellular module by sending AT commands across software serial ports to send and receive text messages and make phone calls. In addition to the Ethernet and cellular shield, the Arduino has a buzzer to signal either intrusion detected or if someone has approached the entrance node and a message recorder to play recorded voice messages for alerting authorities or fire fighters.

The web server generates two web pages: one that asks for a combinational pass code and another that generates the main page with the processed data and user controls if given the correct pass code. The main web page displays the humidity and temperature sensor data, the RFID tags that are present, the security camera along with buttons to pan left and right, and conditional statements with buttons that allow for responses when motion, smoke/CO, or someone at the entrance, is detected.

The cellular module uses simple AT commands transmitted serially from the Arduino to the cellular module. Text message warnings can be sent/received and emergency calls can be made. When an ePIR sensor is tripped the Arduino sends some strings of serial data to the cellular module which uses a SIM card to connect to a cellular network and send a “motion detected” text message. If the home owner is monitoring the web page and a motion sensor goes off then they can decide by pressing a button whether or not to call the police for the detected motion. This call is also made by sending AT commands via the soft serial ports. The cellular module is used to receive text messages as responses to alarms and makes meaningful phone calls with audio recordings via the message recording chip. Also, if smoke/CO are detected the cellular module calls the fire fighters.

B. Android Web Application

The android web application was constructed to allow ease of access for the home owner. With this application the home owner will be able to access the internet from anywhere in the world by use of a cellular phone. The application itself is a web browser that, when opened, will automatically allow the home owner to gain access to their home’s private information. The first page that appears is a log in page for the home owner. This assures that the person accessing the data is an authorized party and not someone trying to gain access to someone’s private information. The application itself is a general view of the web page. It is a general view because the home owner will not be able to view the security camera through the application, at least not at first. If the home owner wants to view the security camera they will have to click the Go button that is at the top of the application. The Go button will cause the application to forward the embedded URL to the phone’s default web browser. To aid in the security, the home owner will have to reenter their security code to view the web page. After they have gained access to the web page they will have to use their log in access code to view the camera. If they do not enter their code they will not be able to view the security camera.

C. End Nodes

The system has four end nodes and a base station. The end nodes have various sensors on them to monitor the environment. This system has an environment, safety, camera, and an entrance end node. Each end node has an xBee Radio that does the necessary transmissions of data to and from the base station. The settings for the xBee Radio are different for each end node; however, as a similarity, each radio has an LED connected to it to indicate its status.

1) Environment Node

The environment end node consists of temperature and humidity sensors to monitor the environment. This end node also has an ePIR motion sensor on it. The purpose of the ePIR is to cover more area of the room/house.

The radio for this end node has several settings different from the rest. First of all, the radio has to read analog inputs from the temperature and humidity sensors, and also monitor the motion sensor. The radio's settings were for reading two analog inputs, and sending the information collected once every minute. It also has digital change detection enabled for the motion sensor. Therefore, this end node sends two types of data packages to the base station. It sends the analog information periodically and the digital information when there is movement detected. The analog to digital conversion takes place in the radios' own microprocessor. However, the analog inputs on the radio have a range from 0 to 1.2V, while our sensors outputted voltages in the range of 0 to 5V. A simple voltage division was used to convert the 0-5V sensor outputs to 0-1.2V. For the motion sensor an inverter was used, therefore logic high is motion, and logic low is the no detection state.

The radio was programmed to go into cyclic sleep and wake up periodically. If something requires action it then proceeds to do it. This behavior can be observed on the associated LED, and all the rest of the radios have this capability as well. This LED can show if it is awake, asleep, or looking for a network to join. The diagram for this node is shown in Fig. 3.

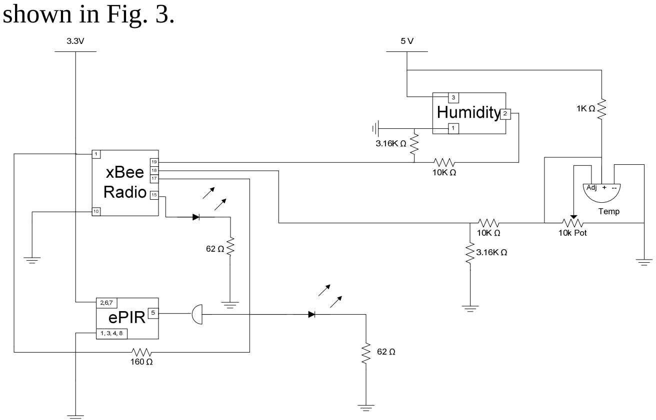

Figure 3. Environmental Node

2) Safety Node

The safety end node consists of a smoke/CO detector and two ePIR motion sensors. The purpose of this node is to keep the home owner safe from fire related occurrences. The smoke/CO detector is a commercial one with an alarm pin. The detector itself comes with an alarm to alert people in the house, but the alarm pin gives the opportunity of connecting it to a bigger system. The ePIR are introduced in this module for the same reason as the last, just to cover more area.

The end node will alert the base station when there is movement or smoke/CO via the radio. This information will then be processed by the base station. The diagram for the node is shown in Fig. 4.

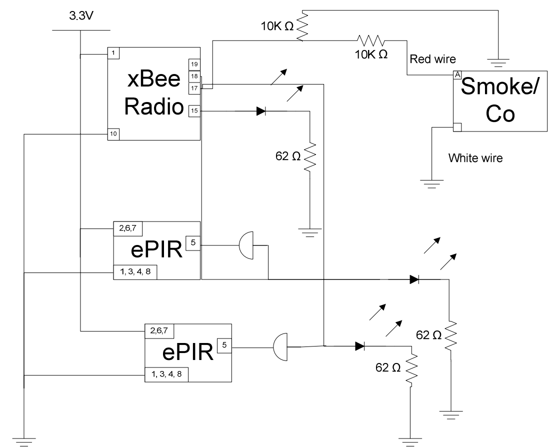

Figure 4. Safety End Node

3) Entrance Node

The entrance end node consists of an RFID reader and a motion sensor. The purpose of this node is to work as an enable/disable for the system when the user exits or enters the house. The motion detector has a dual purpose: one to function as a doorbell to tell the homeowner there is a visitor and/or wake up the radio to transmit RFID data.

This node transmits two types of data packages to the base station. One package is the RFID data, which tells the base station which RFID tag was just read, and the other is the motion sensor data, both of which are edge triggered. The RFID tag is decoded in the base station. Unlike the other radios this one is programmed to have Pin wakeup. This is configured so that the radio wakes up when the motion sensor is tripped to be ready for the RFID read to take place. The radio also does cyclic sleeping just to stay in the network. The diagram for this end node is shown in Fig. 5.

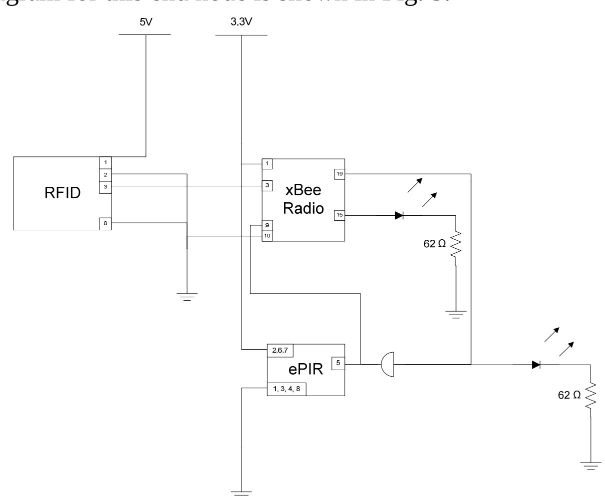

Figure 5. Entrance Node

4) Camera Node

The camera node's purpose is to provide a video feed into the house allowing the home owner to view their house via the internet. For a larger viewing angle a stepper motor was added to the node that allows the camera to pan to different locations on the owners command. For control of the motor there is the Easy Driver that provides easy control for the motor, and an xBee radio to receive remote commands from the base station. However, some decoding to interface between the radio and motor was required so another microcontroller was utilized. This allows for simple left/right control of the motor, and since there is already a full processor on the node, more advanced commands can be implemented in the future.

The radio on this end node is configured to receive data from the base station with instructions on what to do with the camera. Since the radio can be sent data at any time, sleep mode was disabled. This makes sure that no data sent by the base station is lost.

Another difference for this node is that the motor needed a 12V supply, therefore a 12V wall jack was used, and the motor draws its current and voltage directly from it, and not from a voltage regulator like the other components.

The camera, axis 2100 network camera, was chosen for this prototype because of its simplicity. The camera has its own networking capabilities and web server. Therefore, the camera just needs an Ethernet cable and it's good to go. Not only does it show its live video feed online, but it also gets its power from the Ethernet cable. The live video feed was then embedded in the webserver of the base station and there is only one website that is needed for the system.

The stepper motor is simple and small size but at the same time supplies sufficient torque for the prototype. This motor is also compatible with the easy driver, which allows for very effortless control. The diagram of the camera node is shown in Fig. 6.

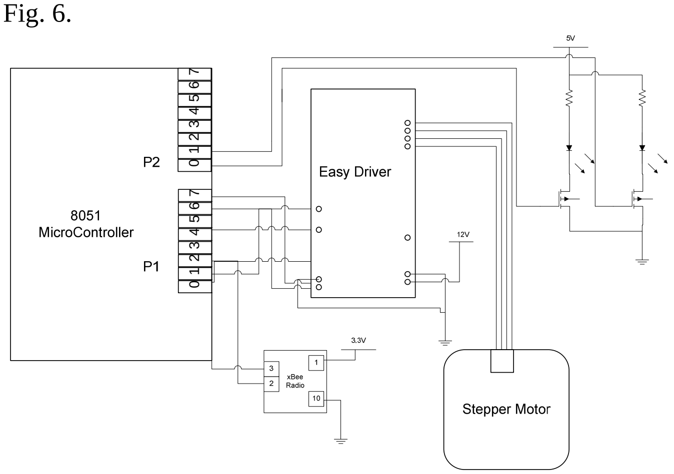

Figure 6. Camera Node

III. RESULTS, CONCLUSIONS, AND FUTURE WORK

The smart home described in Section 2 was successfully designed and a complete working prototype system implemented by the end of the 10-week summer REU program. The smart home security system implements many different sensors to provide a safe environment for home owner and all that may reside with them. As stated earlier in the paper, these sensors include a motion sensor, temperature sensor, security camera, and various other sensors. All of the sensors work together to provide maximum coverage for the home owner. An android app and a security web page have also been constructed to aid in providing protection and enhanced monitoring.

In the future, several improvements can be added to the smart home security system to allow for more comfort and protection. These include but are not limited to: a full climate control interface to provide a comfortable living condition for the home owner, a lighting control system to allow the home owner to turn off/on lights when they are not at home, more security cameras to view more of the house at one time, and a keypad to allow the user to add more RFID tags to the database without reprogramming the base station's microcontroller. Various other nodes can also be implemented to add to the coverage area.

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