Wireless Sensor Networks in Smart and Secure Homes

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Abstract

Recent advances in wireless networks and electronics have led to the emergence of Wireless Sensor networks (WSNs). These networks consist of small battery–powered motors with limited computation and radio communication capabilities. Each sensor in a sensor network consists of three subsystems: the sensor subsystem which senses the environment, the processing subsystem which performs local computations on the sensed data, and the communication subsystem which is responsible for message exchanges with neighboring sensors. WSNs comprise tiny wireless computers that sense, process, and communicate environmental stimuli, including temperature, light, and vibration.

Educational excellence requires exposing students to the current edge of research. To ensure that student projects are along the same trajectory that the industry is moving, educators must continually introduce emerging techniques, practices, and applications into the curriculum. The field of wireless sensor networks is growing rapidly, and there is increasing interest in providing undergraduate students with a foundation in the area. It is crucial that the emerging field of wireless sensor networks be integrated into the undergraduate computer science and engineering curricula. This paper presents the details of two WSN projects that our undergraduate computer engineering students have done in their senior capstone course.

Background Information

Utah Valley University (UVU) is a comprehensive regional university with over 40,000 students charged with serving Utah county, which is the second largest county in the state. UVU has a dual mission – that of a comprehensive university offering 91 bachelor's degrees and 11 master's degrees, and that of a community college offering 65 associate degrees and 44 certificates.

Engineering and Computer Science Departments

To meet one of the region's most pressing workforce needs, UVU initiated three new engineering programs in Fall 2018. The new bachelor's degree programs in Electrical Engineering, Civil Engineering, and Mechanical Engineering have joined UVU's established programs in Computer Engineering and Pre-Engineering in a new Department of Engineering. The new programs were immediately popular with students, with 300 students enrolling for Fall 2018. Currently, the new Engineering Department has more than 800 students in five programs which are housed in that department. Before forming the Engineering Department at UVU, Computer Engineering program was housed in the Computer Science department which offers a bachelor's degree in Computer Science with two areas of specialization – Computer Science (traditional) and Computer Networking. It also offers a Software Engineering degree. The Bachelor of Science in Computer Science program was one of the first Bachelor of Science programs implemented at UVU in 1993.

Capstone Projects in Computer Engineering Program at UVU

It is common practice to incorporate one or two semester long senior capstone design projects in undergraduate computer engineering courses. The goal of these capstone design project courses is to provide graduating students with the opportunity to validate understanding of the concepts they have learned during their studies and for instructors to measure the achievement of established learning goals. As with many computer engineering programs, students of the computer engineering program at Utah Valley University complete their degree programs with a semester long capstone design experience. The intent is for students to utilize competencies developed in the first three years of the curriculum in the solution of a design problem.

The goal of projects in our Capstone Design course is to provide our students with a realistic embedded design experience and to teach them the tools and methodologies that can help them be successful. Our senior design course is structured as a collection of independent student projects. This course is offered every semester. Usually, the students in the Computer Engineering program take this course during their last semester. Students have the option of working individually or in group of twos. Students either can come up with an embedded project themselves or work on a project that is given to them by their advisor. Students write a proposal to define problems and identify solution approaches for their project and the hardware and software that is needed for their project. After several iterations, the advisor approves their project proposal. The project proposal should contain the following elements:

- A brief description (abstract) of the proposed project.
- A detailed description of the proposed project, including the research methodology used. This description will be used as the primary criteria for determining whether the project achieved the intended goals.
- A list of the applicable tools, operating systems, hardware platforms, parts, etc.
- A list of the proposed deliverables, such as source code; hardware design, executables; progress reports; final project report; oral presentation; daily journal/work log detailing what work was done, how much time was spent that day, and any technical details that might be needed for later reference; and any other relevant items.
- A detailed project schedule with dates for the completion of each major project element/milestone.
- The name of the project advisor and the semester that the project will be completed
- Anything else relevant to the project.

After approval of their proposals, students start working on their projects. Students are required to write weekly progress reports and meet with their advisor during a weekly scheduled time for each student. At the end of the semester, each student will turn in a final written report and does a 45 minutes final presentation which is evaluated by several faculties and students from the department. The following are samples of Senior Design Projects which reflect common student projects.

Wireless Sensor Networks

A wireless sensor network consists of many wireless-capable sensor devices working collaboratively to achieve a shared goal [4]. A WSN may have one or multiple base-stations which collect data from all sensory devices. These base-stations serve as the interface through which the WSN interacts with the outside world [2]. The basic premise of a WSN is to perform networked sensing using many relatively rudimentary sensors instead of utilizing the more conventional approach of developing a few expensive and sophisticated sensing modules [2]. The potential advantage of networked sensing over the conventional approach, can be summarized as greater coverage, accuracy and reliability at a possibly lower cost [2, 4].

Wireless Sensor Network is an active area of research with various applications. Some of the applications of WSNs includes homeland security, environmental monitoring, safety, health care system, monitoring of space assets for potential and human-made threats in space, ground-based monitoring of both land and water, intelligence gathering for defense, precision agriculture, , civil structure monitoring, urban warfare, weather and climate analysis and prediction, battlefield monitoring and surveillance, exploration of the Solar System and beyond, monitoring of seismic acceleration, temperature, wind speed and GPS data [1, 4]. For each application area, there are different technical issues that researchers are currently resolving. Open research issues and challenges are identified to spark new interests and developments in this field. However, the design of wireless sensor networks introduces formidable challenges, since the required body of knowledge encompasses a wide range of topics in the field of electrical and computer engineering, as well as computer science [3, 4]. The use of WSNs has improved the functionality and smartness of many existing applications.

Home Security and Automation

Home security is a growing industry in the world. This industry is getting more popular in the residential properties because according to Assaf: “A home security system will reduce the chances of intrusion and thus, can protect both lives and property” [5]. “According to statistical data of 2007, there were four million household break-ins in the United States, of which 500,000 resulted in bodily injuries and 20,000 resulted in homicides” [5]. Home security systems are becoming an important part of every home. Securing home from outside threats is only part of the solution. Threats that originate from inside the home such as carbon monoxide levels or smoke are equally dangerous to the home and its occupants. Wireless sensor networks provide a flexible solution to monitor, detect, and give alerts about dangerous levels of these environmental conditions in a home.

Home automation is a hot topic right now-both in commercial projects and in private Internet of things (IOT) projects. People are fascinated with the ability to control many things in the home from their smart phones. However, this is not the only draw for smart home integration. Consumers are drawn to a variety of functionalities, one of which reductional of power consumption in homes. Recently, some of our computer engineering students have shown interest in conducting research in the area of home security and automation. The following sections presents the details of two projects that our computer engineering students have done in the area of home security and automation.

First Project: Home Security with Zigbee

The objective of this project was to build a security system using wireless sensor networks. The system had several nodes with different types of sensors at each node. The sensors communicated information through Xbee radios to a main controller called a coordinator node. The coordinator node was connected to an Arduino Uno to process the information that was sent from the Xbee radios. Sensors that was used include magnetic door sensors, PIR sensors (motion detector), break beam sensors, and a tilt sensor. Figure 1 depicts the System View of this project [11].

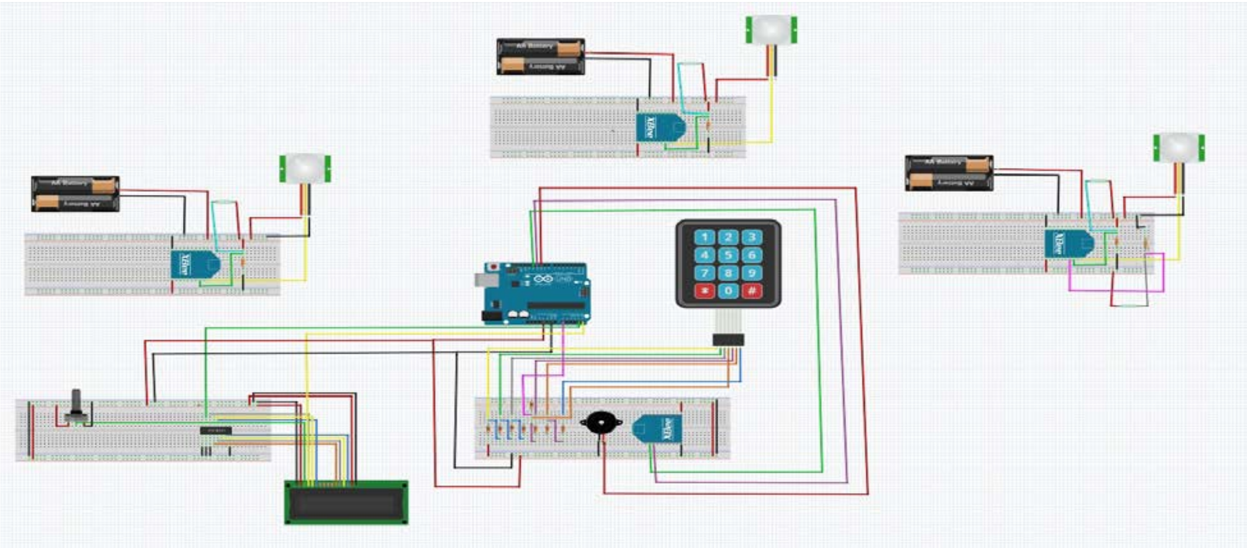

Figure 1: System View [11]

A model home was designed and built. The model home is portable and simulates the entire security system which is shown in Figure 2.

Figure 2: Project Overhead View [11]

The project utilized an Arduino Uno microcontroller. The Arduino processed the information from the nodes. The location of the node that was triggered was displayed on an LCD. The system could sound an alarm. The alarm that was used in this project was a piezo buzzer. The entire system was enabled and disabled using an analog keypad [11]. The Blynk [8] phone application was used to provide a way to control hardware remotely. Blynk app can store, analyze, and display information. The three components of Blynk are [8]:

1. Blynk app - allows a user to create a controller through a phone.
2. Server - handles communication between the hardware and the phone being used to control the system
3. Libraries - allow hardware devices to be programmed to communicate with the server and process the commands.

A second Arduino Uno was used for phone communication purposes. If a node was triggered in one area of the home, an alarm would be triggered. A message displaying which alarm was set off was displayed on an LCD. A text message was also sent to a cell phone when the alarm system was triggered. The system is enabled by either a keypad or the phone application. Any time a sensor in the home is triggered, an alarm will sound. The alarm will sound until the security system is disabled by either the keypad or the phone app [11].

This project was successful, and the student commented that "there was a lot of learning that had to be done in order to complete this project. I started out not knowing anything about Arduino or Android app development and now I feel pretty confident in using them." [11]

Project 2: Sensor Network with Home Automation Solution

The objective of this project was to provide a low-cost wireless sensor network with home automation solutions, create a server to hold the data, and make a client that can change the settings of the node as well as see the data reported by each node. Figure 3 depicts the block diagram of this system.

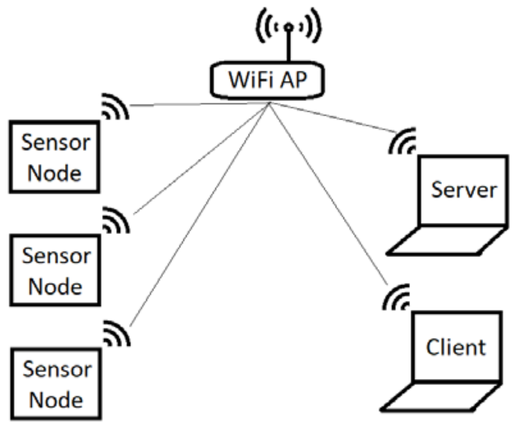

Figure 3: Block Diagram of System

This system was considered a low-cost alternative because it had a few of the most important features people look for when considering home automation solutions, without the overhead costs of a commercial systems. Temperature, room occupancy, and light level data was collected from sensors attached to each node and reported to a local server. The server provided each node with unique configuration data to set the trigger points, LED light strip brightness, and color. This configuration data can be set from a computer on the same WiFi network as the sensor nodes.

Each node consisted of WiFi module, a temperature sensor, a light sensor, and a motion detector. The ESP8266 module was chosen to provide means of communication with the server. This provides WiFi connectivity for a fraction of the price of what Zigbee or other WiFi solutions would have cost—with the trade-off of having a more complicated implementation and higher power consumption. Each node will have one WiFi module—adding $3.00 per node.

Next, a temperature sensor needed to be chosen. For this, ease of use was factored in as well as functionality. The two sensors that were considered here were the DHT11 or DHT22 sensor compared with a DS18B20 sensor. These were discussed in detail by one source [9], who tested each sensor using Arduino—and concluded that the DS18B20 sensor was best for projects that just require temperature. However, upon doing more research it was apparent that there was more support for the DHT series sensors (they are more popular in IoT project), to the DHT11 sensor was chosen. The DHT11 is similar to the DHT22, but with slightly lower accuracy/range and slightly lower cost. This will add $2.50 per node.

For the light sensor, cost was the main concern. There are a large variety of light sensors available—ranging from $0.25-8.00 [10]. After reviewing a few high accuracy IC's that cost more, a simple photoresistor and resistor combination was chosen for a few reasons. One, the cost per node was significantly lower than any of the other options. Two, using a photoresistor in series with a resistor and a microcontroller pin connected in between creates the need to use the analog to digital converter—a system that would be beneficial to learn how to use on the microcontroller. This adds $0.25 to the total cost per node.

Finally, a motion detector was needed. By far the most popular option for a motion detector is a Passive Infrared (PIR) motion sensor. Other viable options might have come up through more thorough research, but PIR was settled on quickly because of the convenient controls commonly built onto the ICs as well as the low cost of each sensor. These add $2.00 per node.

In total, the sensors and modules will cost $7.75 per node. This can be rounded up to $8 per node, factoring in the wires needed to connect them to the microcontroller. Adding the cost of the TI Tiva Launchpad, this brings the total cost up to $20.75 per node. This is not including the LED lightstrip or MOSFETs, as those are variable depending on what MOSFETs and lights are used (as well as the length of the light strip). For the purposes of this project, we will assume the cost of the light setup to be $4.25 or less, making the cost per node and even $25. Figure 4 depicts a circuit diagram of a node and Figure 5 shows the assembled sensor/controller node.

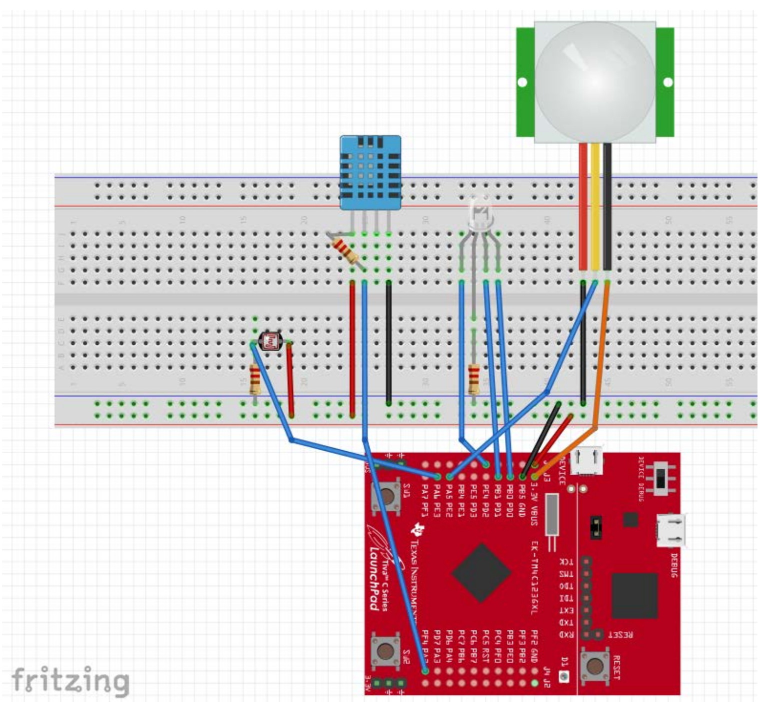

Figure 4: Circuit Diagram of a Node

Many systems were used on the microcontroller to collect data from the sensors and communicate over WiFi. These include: Universal Asynchronous Receive/Transmit (UART), General Purpose Input/Output (GPIO), Timer, Hardware and GPIO triggered interrupts, Analog to digital conversion, and Pulse Width Modulation systems.   Figure 6 shows the full system view.

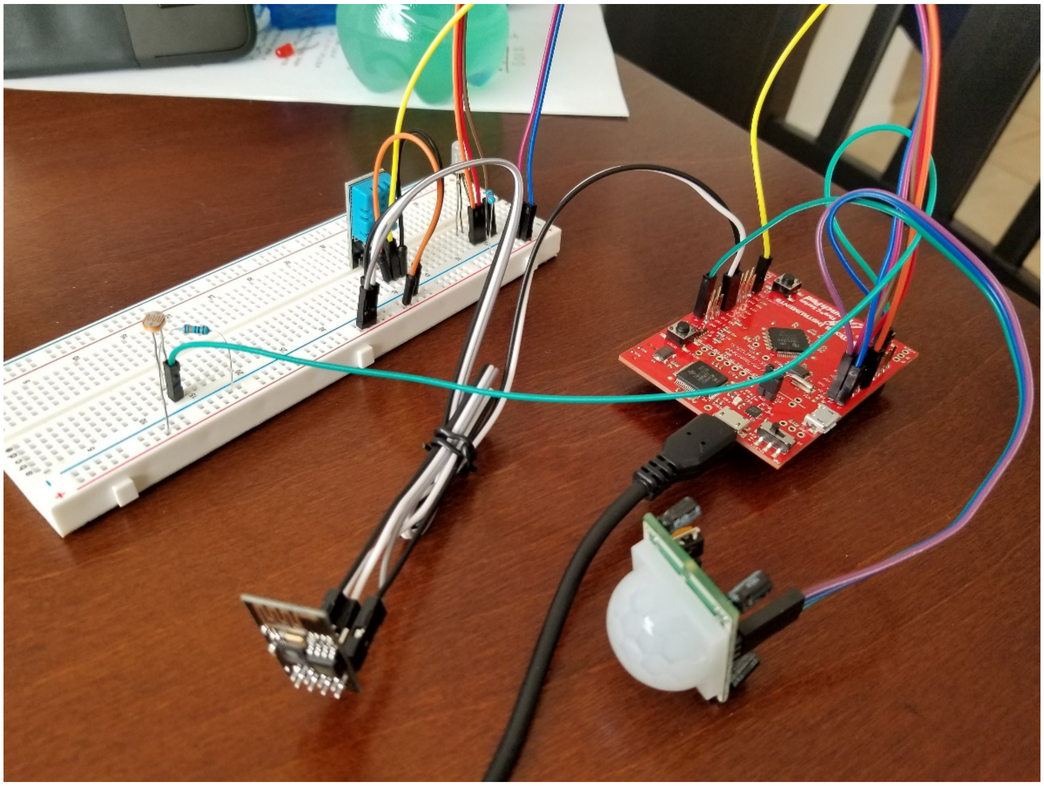

Figure 5—Assembled Sensor/Controller Node

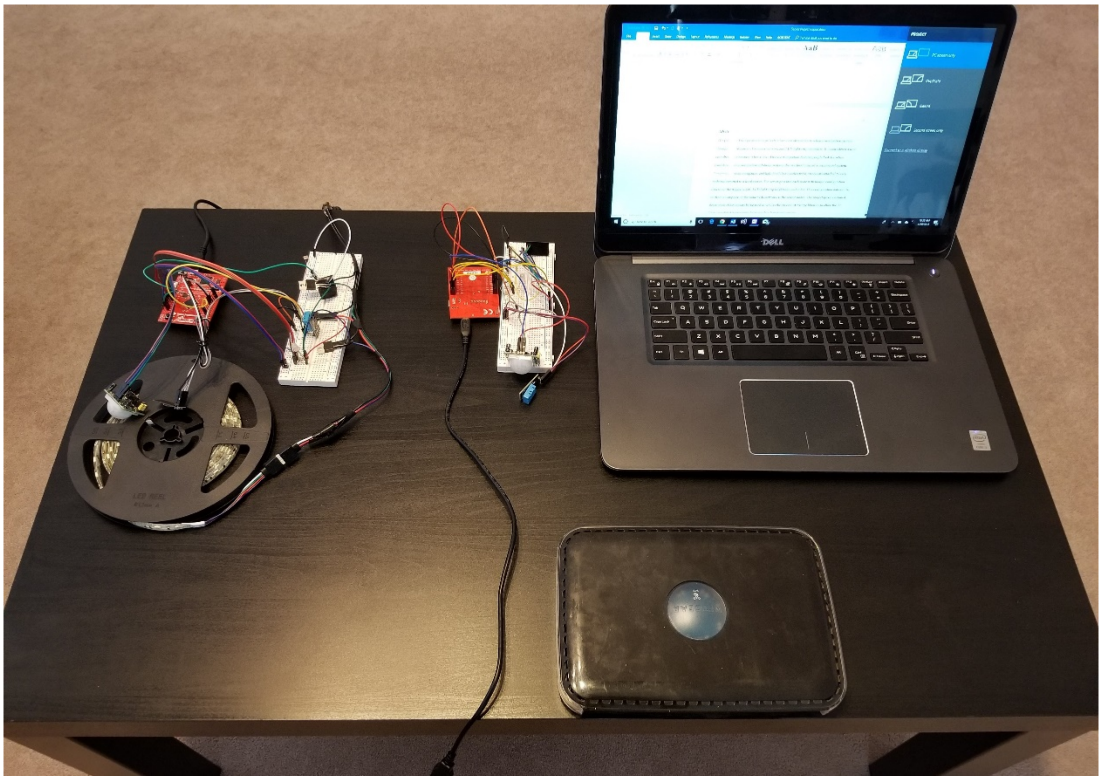

Figure 6: Full System View. Two Sensor Nodes, Laptop (used for Server/Client), WiFi Access Point

Three sensor/controller nodes were set up, and each were able to communicate the data they collected to a local server. A client was able to connect up to the server and configure each of the node's light controls (brightness and color) as well as the trigger point for the photoresistors to allow the LED strips to turn on. The project leaves room for expansion—possibilities include adding features to the server and more peripherals to each sensor node.

This project was successful, and the student commented that "this project was enjoyable and very rewarding when it all came together at the end. For a while in the middle of writing the libraries for the sensors, I didn't know if I would be able to complete the project by the end of the semester—the third party libraries I had tried to use weren't working and needed lots of patches (and in some cases be rewritten) to be compatible with the latest TivaWare libraries and Tiva Launchpad. Most of the time spent working on the project was spent writing and debugging the libraries for the sensors. Throughout the duration of this project, I was able to apply the knowledge I've gained from all the technical courses taken here at UVU. Writing the firmware applied the things I learned in Computer Science and Embedded systems courses, the server/client implementation applied the knowledge I gained from Networking and Python courses, and finally the hardware and electronics courses helped me to design and implement the module/sensor circuits. Overall, this project provided a great way to cap off the education I have received at Utah Valley University."

Summary and Conclusion

This paper discussed recent senior design projects in the area of smart and secure homes where wireless sensor networks have been utilized in our undergraduate senior design course. Our senior design course is structured as a collection of independent student projects. Students find this course both challenging and rewarding as they are required to design, build and troubleshoot a fully functional embedded project. These projects give the students the chance to use their technical expertise and knowledge gained during years of study. Students work very hard to have a working project by the end of the semester. These projects provide students many opportunities to engage in self-directed learning. They develop the ability to debug, seek and find information they need, and the ability to understand and reverse-engineer poorly written documentation. The students' feedback and their final project presentation indicate that they have pride in their project accomplishments and have gained confidence in their engineering abilities.

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