2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #38266

# Efficient and Smart Home Projects in Computer Engineering Program Using Wireless Sensor Networks and Internet of Things Technologies

**Dr. Afsaneh Minaie, Utah Valley University**

Afsaneh Minaie is a Professor of Electrical and Computer Engineering at Utah Valley University. She received her B.S., M.S., and Ph.D. all in Electrical Engineering from the University of Oklahoma. Her research interests include gender issues in the academic sciences and engineering fields, embedded systems design, mobile computing, wireless sensor networks, and databases.

**Dr. Reza Sanati-Mehrizy, Utah Valley University**

Reza Sanati-Mehrizy is a professor of Computer Science Department at Utah Valley University, Orem, Utah. He received his M.S. and Ph.D. in Computer Science from the University of Oklahoma, Norman, Oklahoma. His research focuses on diverse areas such as: D

# Efficient and Smart Home Projects in Computer Engineering Program Using Wireless Sensor Networks and Internet of Things Technologies


## Abstract

An efficient and smart home is a ubiquitous computing system that controls any device in the home from everywhere. Wireless Sensor Network (WSN) and Internet of Things (IoT) technologies can be used to implement efficient and smart homes. IoT technologies allow home devices to be connected to the internet through Wi-Fi to be remotely monitored and controlled. WSN technologies allow placing different sensors and actuators around the home to gather information and process it to monitor and control the home efficiently.

As mankind has evolved, technology has grown and expanded with it. 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 fields of IoTs and WSNs are growing rapidly, and there is increasing interest in providing undergraduate students with a foundation in these areas. This paper presents IoT and WSN projects that our undergraduate computer engineering students have done in their senior capstone course.


## Introduction

A smart home uses internet-connected devices to enable the remote monitoring and management of appliances and systems. An efficient and smart home is a ubiquitous computing system that controls any device in the house from anyplace. The field of smart home automation and security is growing rapidly as many new ideas and possibilities are emerging from new advances in technology. For example, through the voice recognition service, it is possible to control the devices in the house by voice and remotely control the devices in the home using the individual smartphone through the remote-control system. As the usage of smart home devices increases, the urgency for safety, security, and error correction also increases. Smart home devices contain many sensors which gather important data that determine the behavior of the entire system. Sensors within the smart home must remain accurate and operational to ensure safety and functionality. Currently, smart home technology has developed into various fields such as safety, energy conservation, and health care [1].

Today, smart homes are gradually becoming mainstream in new houses, because of their many convenient functions to help people to obtain a better quality of life such as smart light, smart air conditioner, smart curtains, smart appliances, etc. In smart homes, the data from the sensors are transmitted using WSNs. The rapid increase and use of mobile technologies and wireless communications has opened the door for many smart home applications that monitor and control energy consumption.

## Internet of Things

As mankind has evolved, technology has grown and expanded with it. One of the largest marks of this evolution is the development of the Internet of Things. According to Wikipedia, "IoT describes physical objects (or groups of such objects) that are embedded with sensors, processing ability, software, and other technologies, and that connect and exchange data with other devices and systems over the Internet or other communications networks [2-6]." IoT is one of the most important technologies that can change the future. IoT has been under rapid development and has become essential in such domains as industrial operations, health care, environmental, infrastructure and military as well as for research and development.

The IoTs is an emerging topic of technical, economic, and social importance. The term IoT generally refers to situations where network connectivity and computing capability extends to objects, sensors and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention. By adding Internet connectivity and data analytics capabilities to durable goods, automobiles and trucks, industrial components, utility parts, sensors, and everything that are used these days is transforming the way that we live, work, and entertain. This rapid technological evolution has impacted the daily lives of people through expected IoT services. IoT is getting smarter and smarter day by day by venturing into different aspects of human life.

IoT has evolved from the rapid convergence of traditional research areas of embedded systems, WSN, control systems, automation, and sensors. It is a self-configuring and adaptive system of interconnected, intelligent, and programmable networks of sensors. IoT has been an evolutionary progression of the internet, enabled through the deployment of connected devices for humanitarian, environmental, industrial, and smart city use-cases, and applications. Projections for the impact of IoT indicate 100 billion connected devices with a global economic impact of more than $11 trillion by 2025 [7]. The IoT sensor costs are rapidly decreasing over time. According to Microsoft's "2019 Manufacturing Trends", the average IoT sensor cost has decreased from $1.30 in 2004 to $0.38 in 2020 [8]. The IoT links people and things from all around the world. IoT has many applications, including automobile response, building automation, acute stress, fast health services, and smart cities [9]. The interesting thing about IoT might be its limitless possibilities. Rapid growth in related technologies continues to fuel more and more use cases. Smart home construction based on IoT has been actively performed, and smart devices including various sensors have been used for building a smart home.

**Wireless Sensor Networks**

Recent advances in wireless networks and electronics have led to the emergence of 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. WSNs have been under rapid development and has become essential in such domains as industrial operations (factory, production, supply chains), health care (home monitoring, biomedical, food safety), environmental (agriculture, habitat preservation), infrastructure (energy, traffic and transportation, flood gauges, bridge stress, power grids, water distribution), and military, as well as for research and development.

A WSN consists of many wireless-capable sensor devices working collaboratively to achieve a shared goal [10]. 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 [11]. 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 [11]. The potential advantage of networked sensing over the conventional approach can be summarized as greater coverage, accuracy, and reliability at a possibly lower cost [10, 11]. WSN 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 [10, 13]. 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 WSNs 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 [12, 13]. The use of WSNs has improved the functionality and smartness of many existing applications.

**Background Information**

Utah Valley University (UVU) is a comprehensive regional university with over 43,000 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 91bachelor's degrees and 11 master's degrees, and that of a community college offering 65 associate degrees and 44 certificates. To fill its community college mission, the institution maintains an open-enrollment policy. To facilitate academic robustness, UVU has implemented a structured enrollment policy that establishes requirements which students must meet before they can engage in all the courses of their major and provides additional access to advising and other resources. These additional preparatory courses increase students' time to graduation but help them succeed. As a large public university UVU has a very high number of low-income students – the largest proportion in the state [14]. Around 35% of students are classified as non-traditional students (age 25 or older). Nineteen percent of the students have children under the age of five [15]. UVU's students live at home or in off-campus housing, which makes it very difficult to organize activities for them. Many students do not have time to spend much time outside of class on campus, leading some to feel little connection with other students. About 80% of UVU's students will remain in their communities and pursue employment in this region [14, 15].

**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, the Computer Engineering program was housed in the Computer Science department which offers a bachelor's degree in computer science, computational data science, and software engineering. The Electrical and Computer Engineering as well as Computer Science degree programs are accredited by Accreditation Board for Engineering and Technology (ABET).

## Computer Engineering Program's Capstone Course

Our computer engineering capstone course serves as a project-oriented course. This required course emphasizes major hardware and software co-design. This course satisfies the ABET requirements for providing students with significant hands-on design experience. Our senior design course is structured as a collection of open-ended independent student projects which are mutually selected by the faculty supervisor and student. It is shown that this type of student-driven, open-ended project requires a great deal of instructor's flexibility, deep familiarity with available components, and ready suggestions for potential projects. However, for instructors who are willing to make the effort, a student-driven design project can provide significant experience for students in problem specification and engineering design.

Our computer engineering capstone course is offered every semester. The students in the computer engineering program take this course during their last semester. Students have the option of selecting their own embedded project or to work on a project that is given to them by their advisors. During the first week of the semester, students write a proposal to define a problem and identify solution approaches for their project in addition to identifying the hardware and software that is needed for their project. After several iterations, the advisor approves their proposal. The faculty adviser will meet with each student individually on a weekly basis at a regularly scheduled, mutually agreeable time. These meetings are considered mandatory for the students. Occasional conflicts are inevitable, but the students need to understand that a portion of their grade for participation is based on attendance at the weekly meetings. At each meeting, issues associated with the project will be discussed and a status report will be provided by the student to the advisor. Students will keep a daily journal/work log detailing the work that was done, how much time was spent that day, and any technical details that might be needed for later reference. The faculty advisor keeps notes of each meeting as well as action items to be accomplished for the next meeting. Reviewing the log sheet from the previous meeting is a great way for the faculty to prepare for the upcoming one and provides further evidence to the student of the meeting's importance. At the end of the semester, students turn in a final written report and a final presentation which is evaluated by several faculty members from the department.

## Integration of Efficient and Smart Home Research in Computer Engineering Programs at UVU

Home efficiency, automation, and security is a hot topic right now - both in commercial projects and in private Internet of Things 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 is a reduction of power consumption in homes. Recently, some of our computer engineering students have shown interest in conducting research in home efficiency, security, and automation. The following sections present the details of two projects that our computer engineering students have done in home efficiency, security, and automation.

**First Project: Efficient and Smarter Homes Through Presence-Based Control**

The pupose of this capstone project was to design and implement a low-cost, easy-to-use, efficient, secure, and flexible ESP32 based home automation system. A team of two computer engineering students worked on this project for a semester. They implemented their design in one of the student's home. The goal of the project was to reduce energy consumption of home lighting and wireless and remote controling of lights and also make the home more secure. The system tracked the presence of the user and turned on/off lights depending on the user's travel through the home. Their WSN had three nodes that could be easily expanded to any number of nodes, making their design flexible and scalable. Their system was Wi-Fi capable allowing homeowners to control and monitor appliances remotely over the internet via a smart phone. The function of this design was to allow homeowners to control and monitor the lighting and security system remotely over a Wi-Fi connection from a smartphone through a web server (Blynk server). The system infrastructure was composed of a mesh network allowing the communication between nodes, this mesh was connected serially to a central node which allowed the mesh to connect to the Blynk server over the internet. The Blynk server was operated as a point of connection between the app operated from the smartphone and their home automation system [16].

In each room's exisitng light switch, sensors were added to detect motion inside the room. Figure 1 depicts the node in the bedroom where a PIR sensor and a powerful ESP32 development board is connected to the light switch. Each node reported such presence to a central node. The central node determined what lights in the house should be turned on or off based on movement to and from each room node using an adjacency matrix specified by the user. A relay was connected to each room node which allowed for control through the central node's djacency algorithm or through an Android mobile application [16].

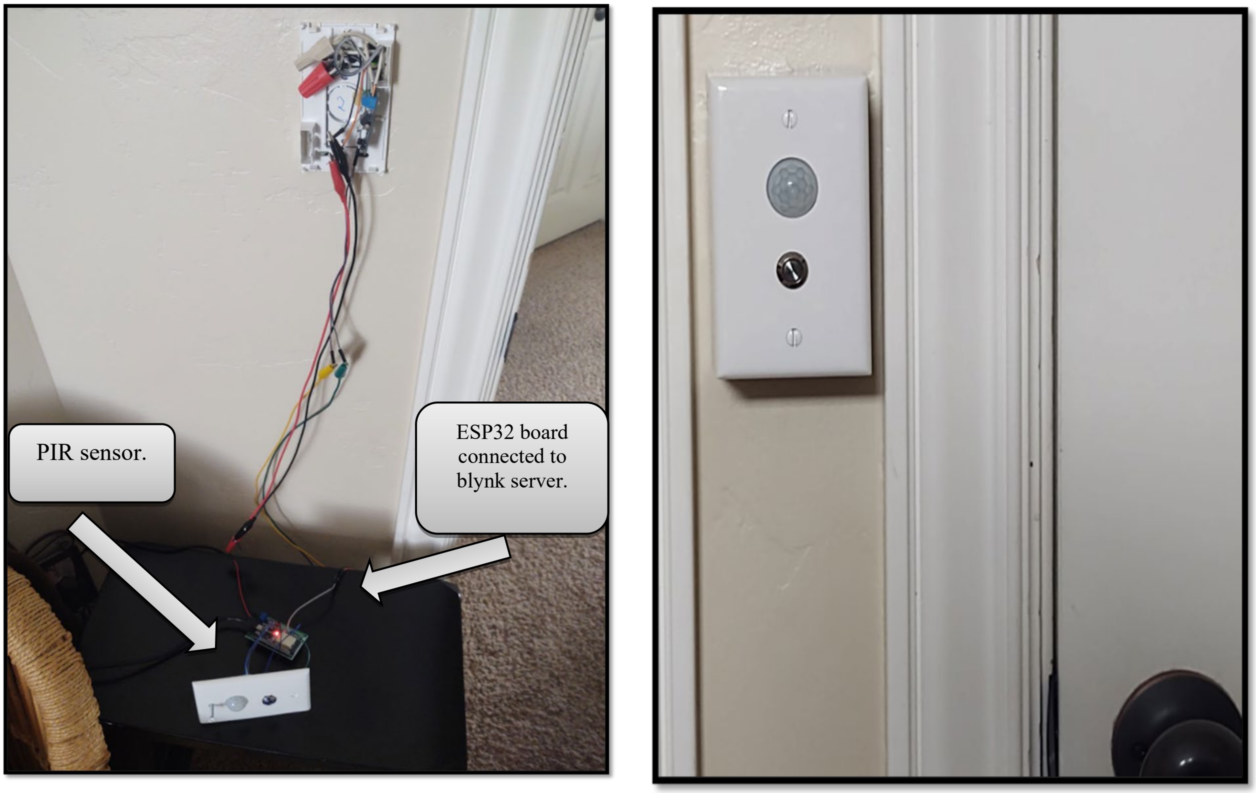


**Figure1: Node in the Bedroom – One ESP32 Wirelessly Connected to the Sensor Network [16]**

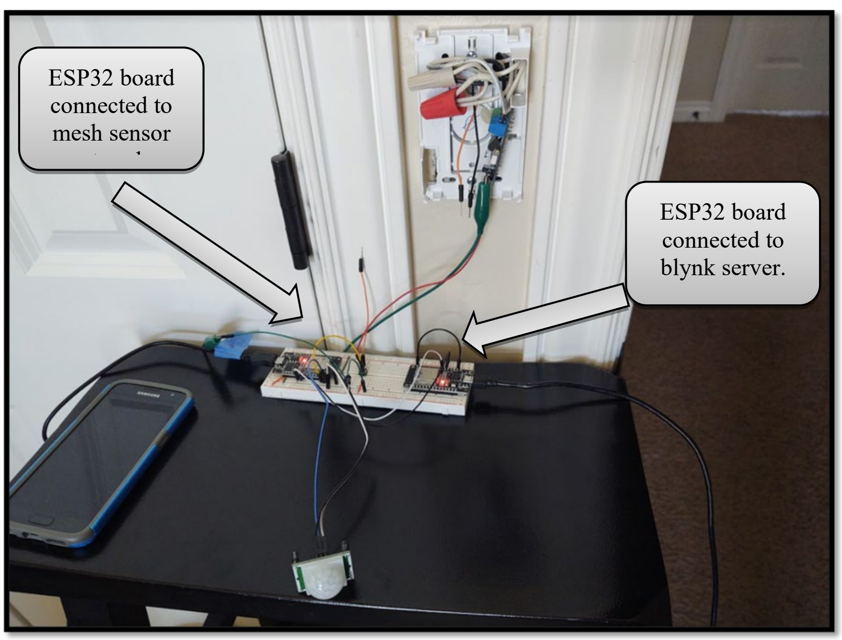


**Figure 2: Node in the Office [16]**

Figure 2 shows the node in the office. This node contains two ESP32 boards one which is connected to the blynk server via Wi-Fi and the second one that serves as a coordinator node to communicate with the other nodes in the mesh network. This node also has a PIR sensor. There is another node in the hall way. This node contains one ESP32 board and a PIR sensor for motion detection. The system diagram is shown in Figure 3.

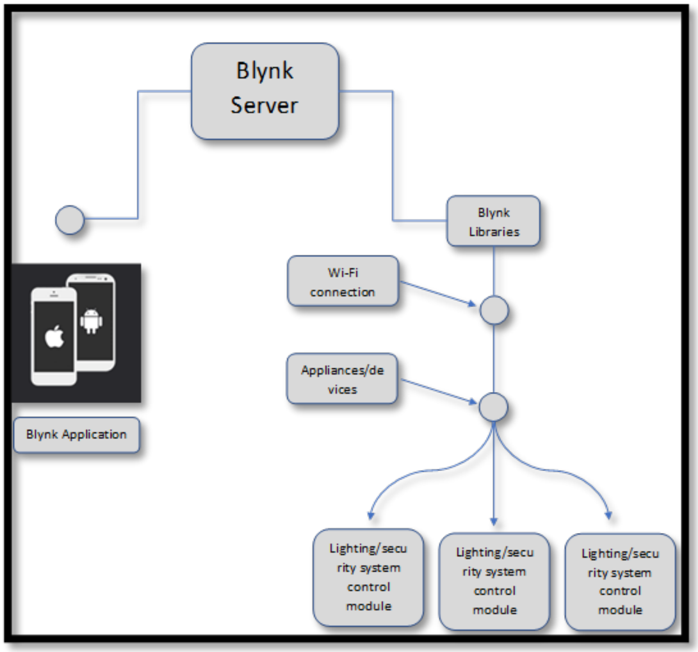


**Figure 3 – System Diagram [16]**

The sytems communication is shown in Figure 4.

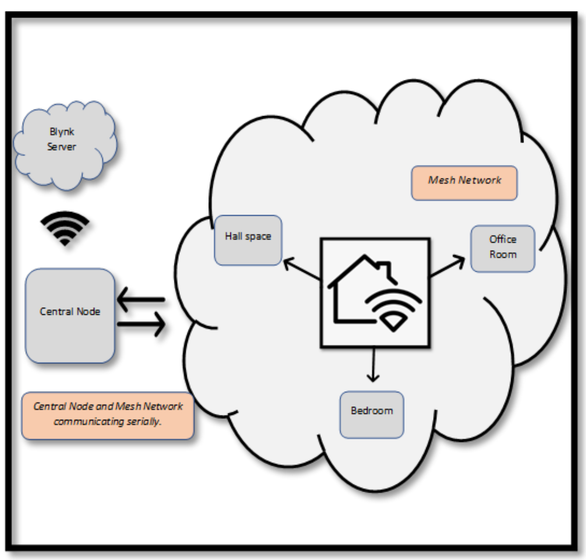


**Figure 4 - System Communication [16]**

Figure 5 shows how office node communicates with the Blynk server.

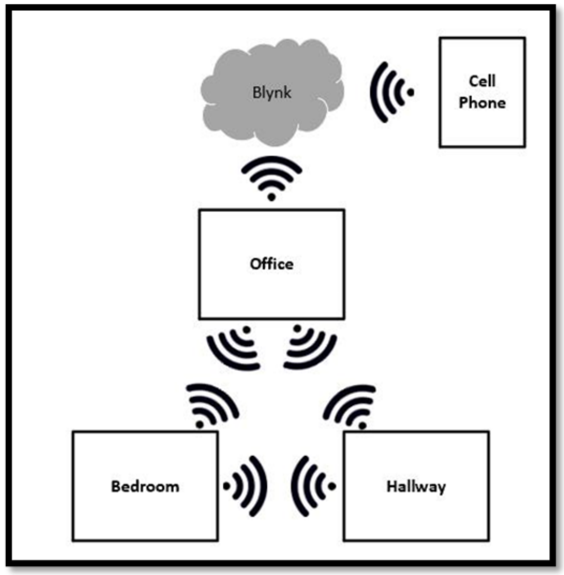


**Figure 5 – Office Node Communicates with the Blynk Server [16]**

Figure 6 shows the system schematic of the three nodes. The office was chosen as the "central" node and holds the additional board for the Blynk connectivity.

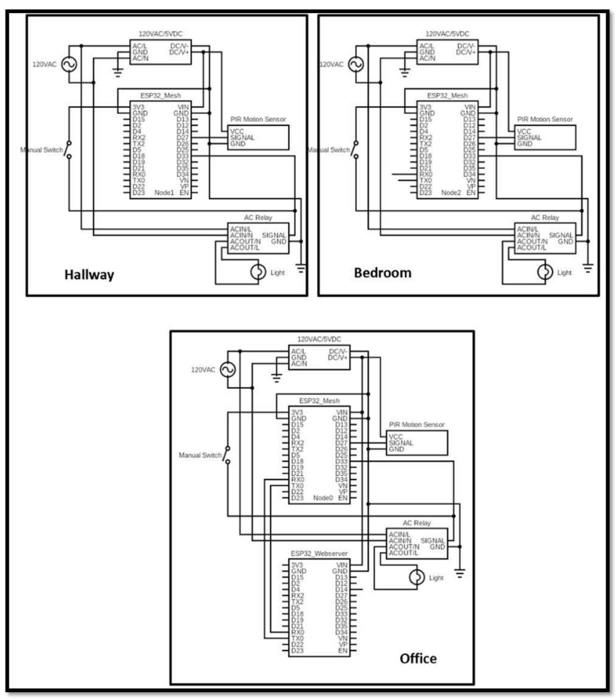


**Figure 6 – System Schematic of Three Nodes [16]**

In this design, all the decision making was done inside the central node using an adjacency matrix algorithm. This algorithm used an n-dimensional adjacency matrix which listed all nodes (rooms) that were adjacent to a reference node. As a user moved from one adjacent room to another, the system turned off the light in previously occupied room and turned on the light in the newly occupied one. Motion sensor data and light signals throughout the home along with the state machine shown in Figure 7 were used to track the location of a user and control the lights as they moved through the house [16].

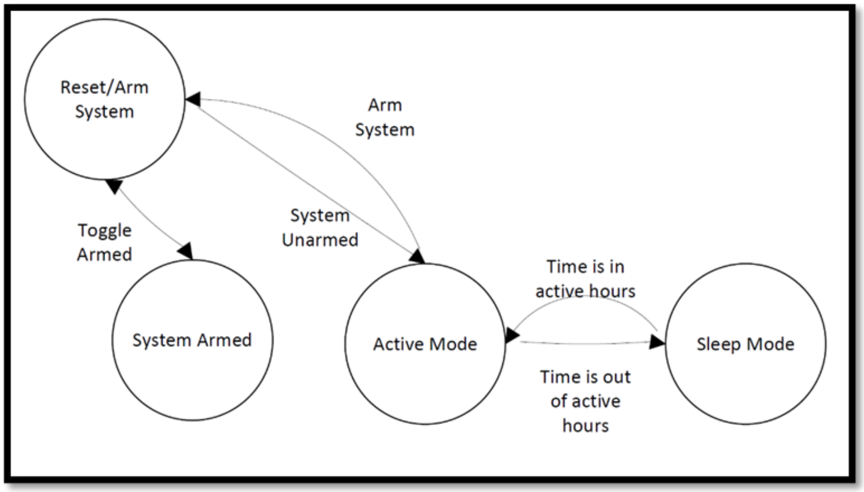


**Figure 7 – State Machine Implimentation in the Adjacency Matrix Algorithm [16]**

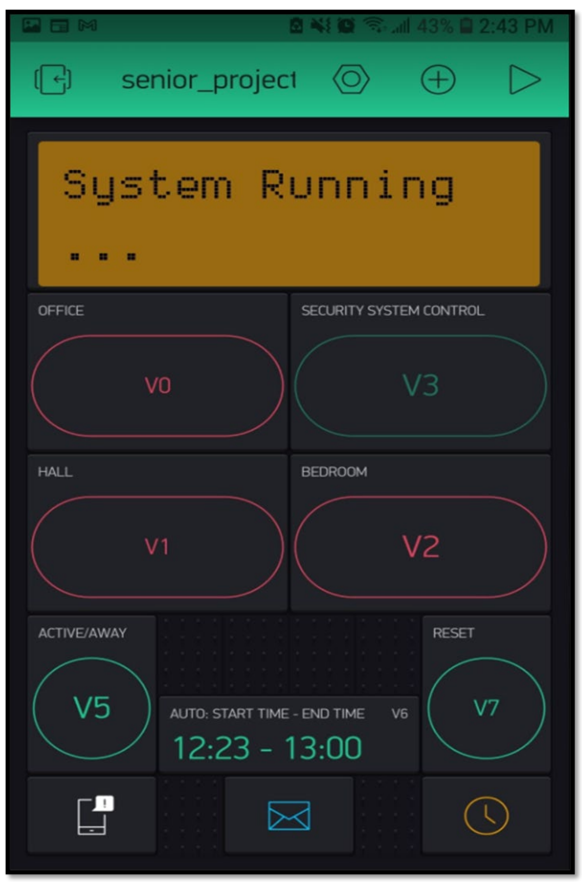

**Figure 8 – Graphical User Interface [16]**

Figure 8 depicts the graphical user interface containing a display, buttons to control lighting in the office, hall, and bedroom. The security system button activates the motion detection capabilities. Also, the system contains a reset and active/away buttons and a time input slot that allows user to input time for setting active and away hours [16]. This capstone project was successful and the students' comment after finishing their project was positive.

### Second Project: Smart Homes of the Future

The purpose of this computer engineering capstone project was to design a smart home that used efficient WSN nodes and ran completely on DC solar power. A team of two computer engineering students worked on this project for one semester. This project was given to the students by the faculty advisor. The smart home was constructed using a small shed unit to simulate a house which is shown in Figure 9.

**Figure 9: Smart Home Prototype and Coordinator Node [17]**

For this smart home three node was created. The first node (the entryway) has an IR-array which monitored both motion and temperatures of approaching objects. Behind the entryway, the temperature and humidity sensor was also mounted and connected directly to the Raspberry Pi. Along the back side of that same room a remote motion sensor and gas sensor were connected to an XBee, which wirelessly monitored the room and reported to the Pi. Finally, the third node had a motion detection sensor, to also wirelessly monitored motion in the room and reported back to the Raspberry Pi [17].

On the exterior, the two solar panels were mounted, which pulled energy from the exterior and stored in the green battery unit mounted to the inside of the unit. All of the sensors and Raspberry Pi were powered by the power generated by the solar panels, which were mounted to the top, and the power delivery cord was routed along the roof and lies tucked next to the battery. The system diagram is shown in Figure 10 [17].

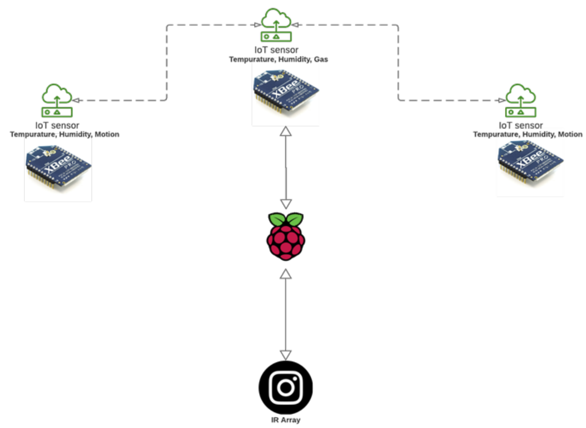


**Figure 10: System Diagram [17]**

At the entry way the IR-array which is a collection of IR sensors was connected to the Raspberry PI to detect heat in a distance. This MLX90640 IR-array is used to detect if a person at the door is running a fever. Figure 11 shows the IR array push notification flow chart and Figure 12 depicts the Raspberry Pi and IR array pinout. Figure 13 shows the home layout [17].

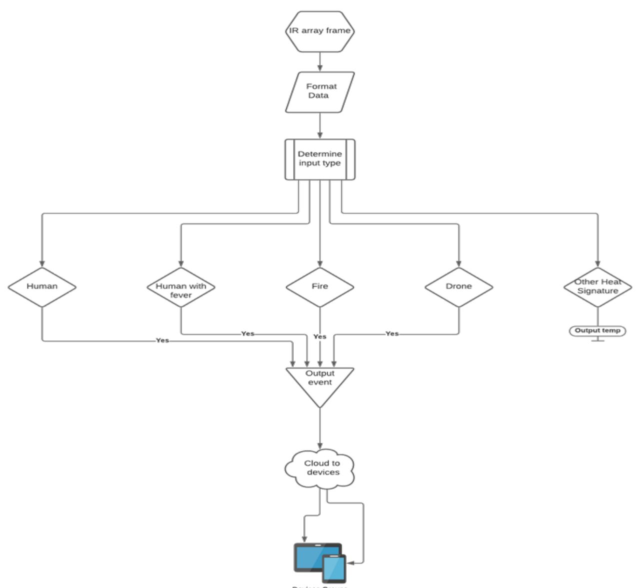


**Figure 11: IR Array Push Notification Flow Chart [17]**

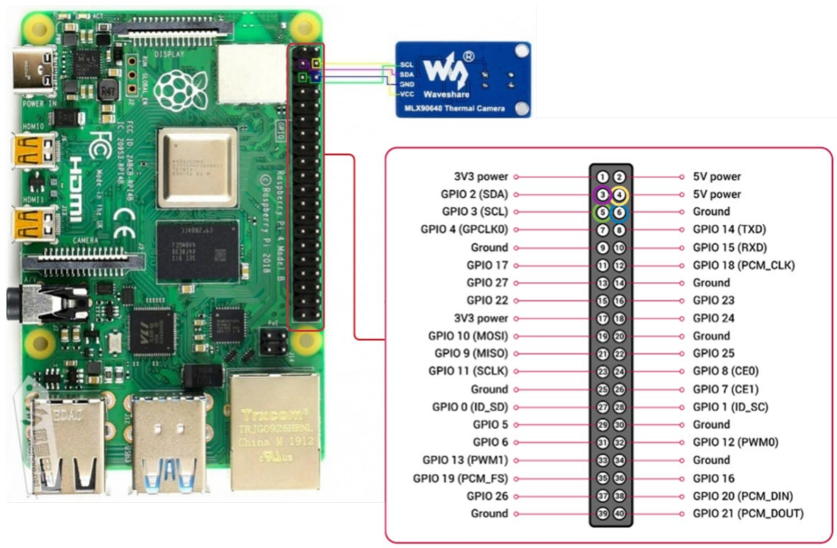


**Fig. 12: Raspberry Pi and IR Array Pinout [17]**

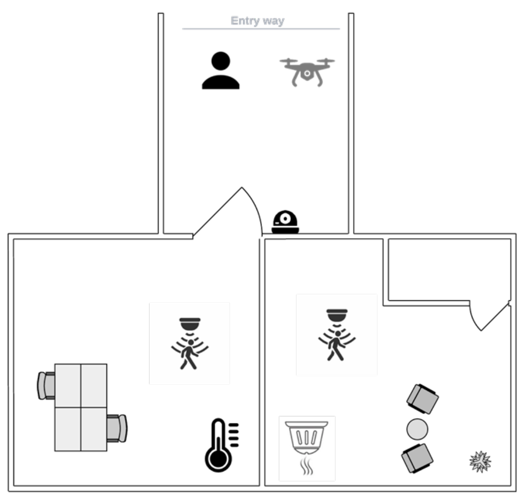


**Figure 13: Home Layout [17]**

This project was successful and the students' comment after finishing their project was positive and they said that "much was learned in this project."

## Conclusion

This paper presented recent computer engineering senior design projects in efficient and smart homes where WSN and IoT concepts and technologies have been utilized. Our undergraduate 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. Senior capstone design courses remain an engaging aspect of undergraduate computer engineering education and fulfill many requirements set forth by the Accreditation Board for Engineering Education and Technology (ABET).

## References


1. Alam, M. Raisul, et. al., "A Review of Smart Homes – Past, Present, and Future", IEEE Transactions on Systems Man and Cybernetics Part C, 2012.
2. Gillis, Alexander, "What is internet of things (IoT)?", IoT Agenda. Retrieved 17 August 2021.
3. Brown, Eric, "21 Open-Source Projects for IoT", Linux.com, Retrieved 23 October 2016.
4. "Internet of Things Global Standards Initiative", ITU, Retrieved 26 June 2015.
5. Hendricks, Drew. "The Trouble with the Internet of Things", London Datastore. Greater London Authority, Retrieved 10 August 2015.
6. Shafiq, Muhammad; Gu, Zhaoquan; Cheikhrouhou, Omar; Alhakami, Wajdi; Hamam, Habib, "The Rise of "Internet of Things": Review and Open Research Issues Related to Detection and Prevention of IoT-Based Security Attacks", Wireless Communications and Mobile Computing. 2022. ISSN 1530-8669.
7. Report, "The Internet of Things: An Overview", released October 2015, Internet Society.
8. "2019 manufacturing trends report", Microsoft, Redmond, WA, USA, Rep. Microsoft Dynamics 365, 2018.
9. Ahn, Jungmo, et. al., "Convolutional Neural Network-based Classification System Design with Compressed Wireless Sensor Network Images", PIOS one, 13(5), P.e0196251.
10. Minaie, Afsaneh, et al., "Integration of Wireless Sensor Networks in the Computer Science and Engineering Curricula", Proceedings of the ASEE Annual Conference, June 2012.
11. 2. Li, Yingshu, My Thai, and Weili Wu, "Wireless Sensor Networks and Applications", Springer, 2008.
12. 3. Dargie, Waltenegus, and Christian Poellabauer, "Fundamentals of Wireless Sensor Networks: Theory and Practice", Wiley, 2010.
13. Akyildiz, Ian and Mehmet Can Vuran, "Wireless Sensor Networks", Wiley, 2010.
14. Utah Code and Board of Regent's Policy Statements Regarding UVU's Mission and Role: Planning, Budget, and Human Resources, UVU Planning, Budget, and Human Resources, September 21, 2018.
15. 2. Information and statistics provided by the UVU Office of Institutional Research and Information – IRI.
16. Estrada, Kevin, and Devan Hone, "Efficient and Smarter Homes Through Presence-Based Control", ECE 4800, Capstone Final Report, Spring 2021.
17. Froelich, Jason and Talmage Shumway, "Smart Homes of the Future", ECE 4800, Capstone Final Report, Fall 2021.