2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #38259

Wildfire Detection 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 sci

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

Wildfire Detection Using Wireless Sensor Networks and Internet of Things Technologies

Abstract

The purpose of capstone courses is to provide graduating senior students with the opportunity to demonstrate understanding of the concepts they have learned during their studies. As with many computer science and engineering programs, students of the electrical and computer engineering programs at Utah Valley University (UVU) conclude their degree programs with a two-semester and one-semester capstone design experience respectively. The intent is for students to utilize competencies developed in the first three years of the curriculum in the solution of a complex design problem.

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 Internet of Things (IoT) and Wireless Sensor Networks (WSN) 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 and electrical engineering students have done in their senior capstone course in wildfire detection.

Introduction

As mankind has evolved, technology has grown and expanded with it. One of the largest marks of this evolution is the development of the IoT. 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. 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.

A wildfire is a spontaneous fire that cannot be controlled. Wildfires are caused by various reasons such as droughts, volcanic ignitions, thunderstorms, and human factors. In the last few years, the number, frequency, intensity, and severity of wildfires have increased worldwide. Forests are drier because of the global temperature rises caused by climate change. "Today's flames are larger, more ferocious, and linger longer than they used to be in many regions of the world. [1]". Wildfires release huge amounts of carbon dioxide into the environment and significantly impact the local and global climate. Thirty percent of carbon dioxide in the atmosphere comes from forest fire [2]. The increase in the number, frequency, and severity of wildfires is severely affecting countries economics, ecosystem, and people.

Wildfires destroy thousands of hectares every year all over the globe. There are more than 340 million hectares of forest that are destroyed by fire on the earth. Australia and African countries have the largest areas of burning. Prolonged fires cause harm to human health, to respiratory and circulatory systems. In 2010 American Heart Association published a scientific statement stating that there is a link between air pollution from tiny particles that appear in the air because of wildfires and cardiovascular diseases. Consequently, millions of people will suffer serious long-term health issues.

Every year, wildfires devastate communities across the globe. In 2017, the cost of battling blazes was over $2.4 billion dollars in US [4]. Those that live in fire-prone areas like California, Colorado, and Oregon need to actively watch for warnings and alerts during wildfire season. For some families' wildfires represent the loss of their property, savings, and even life. For example, the number of people killed in 2018 in California Wildfires was 80 and total cost of California Wildfires was 24 billion [3]. In China, there are more than 70,000 wildfires every year [4]. An average of 2.5 million hectares are burned in Canadian forests which costs about $370 million to 470 million per year [6, 7]. The most damaging wildfires happened in the years 2019 – 2021 around the world.

The management of wildfires is a significant challenge and early detection is the key to reduce the intensity and spread of the fire. Wildfires are time-sensitive and can result in significant loss of life and property if not dealt with immediately. It is essential that effective detection and monitoring techniques need to be designed so that wildfires are detected immediately, and measures are taken to avoid spreading it to larger areas. Over the years, many detection and monitoring techniques have been developed which are:

- "Observation from specially equipped fire observation towers and other structures" [8]
- "Ground observation on foot or by vehicles" [8]
- "Air surveillance using special instruments on aircrafts and helicopters" [8]
- Satellite imaging
- Infrared cameras
- Use of Internet of Things (IoT) networks (Cheap IoT sensors)
- Unmanned aerial vehicle -aided Internet-of-Things (UAV-IoT) [9]
- Combining Satellite imaging and UAV-IoT [9]
- Use of Robots

Like any other western states, Utah is one of the most wildfire prone states in the U.S. There are 800 to 1,000 wildfires in Utah annually. In 2018, there were 1,327 wildfires in Utah with estimated damages of $13.4 million. Of those wildfires, 688 were human caused either accidental or incendiary and the remainder were naturally occurring [10]. "Between 1992 and 2012 the length of the fire season across the west increased by nearly six weeks and megafires burning more than 100,000 acres have tripled with 25 to 30 occurring annually in the U.S" [10]. Wildfires damage the natural habitats of animal species and change the native vegetation to more fire-resistant plants and grasses. They also destroy man-made structures, communication, and electrical infrastructure, and destroy recreation and open spaces while increasing mudslides, erosion and downstream sedimentation that can impact fish habitats and water chemistry.

Wireless Sensor Networks

A WSN consists of many wireless-capable sensor devices working collaboratively to achieve a shared goal [14]. 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 [12]. 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 [12]. The potential advantage of networked sensing over the conventional approach can be summarized as greater coverage, accuracy, and reliability at a possibly lower cost [12, 14]. 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 [11, 14]. 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 [13, 14]. 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 [15]. 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 [16]. 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 [17, 18].

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 and Electrical Engineering Program's Capstone Courses

Our computer and electrical engineering capstone courses serve as project-oriented courses. These required courses emphasize major hardware and software co-design. These courses satisfy the ABET requirements for providing students with significant hands-on design experience [18]. Our capstone courses are structured as a collection of open-ended independent student projects which are mutually selected by the faculty supervisors 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. The typical design process experience includes problem definition and constraints, gathering information, concept generation, preliminary design, detail design, communication of results, and improvements [19]. Our computer and electrical engineering capstone courses are based on the Engineering Design Process which is outlined in Table 1[20].

Engineering Design	
Requirement Analysis	**Identify the problem and constraints** **Define goals and criteria**
Functional Analysis	**Research and gather data**
Design Synthesis	**Brainstorm: Develop Possible Solutions** **Analyze potential solutions** **Model and test candidates** **Select a promising solution** **Build a Prototype** **Test and evaluate prototype** **Implement** **Communication of Results**

Table 1: Engineering Design Process [20]

Our computer engineering students are required to take a semester long capstone course which 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.

On the other hand, our electrical engineering students are required to take two-semester long capstone courses. The intention of these courses is to apply competencies gained during their first three years toward the solution of a design problem. Our electrical engineering senior design courses are structured as a collection of independent student projects. As our students are required to design, build, and troubleshoot a fully functional project, they find these courses both challenging and rewarding.

The purpose of senior projects is to provide students with realistic project development experience like what may be expected in industry. The senior project experience is divided into building skills in four major areas which is the most important skill areas to the success of an engineer:

- Teamwork
- Project Management
- Research & Development
- Communication

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 each semester, students turn in a final written report and a final presentation which is evaluated by several faculty members from the department.

Integration of Wildfire-Detection and Monitoring Research in Computer and Electrical Engineering Programs at UVU

The management of wildfires is a significant challenge and early detection is the key to reduce the intensity and spread of the fire. Wildfires are time-sensitive and can result in significant loss of life and property if not dealt with immediately. It is essential that effective detection and monitoring techniques need to be designed so that wildfires are detected immediately, and measures are taken to avoid spreading it to larger areas. Recently, some of our computer and electrical engineering students have shown interest in conducting research in wildfire detection and monitoring. The following sections present the details of two projects that our computer and electrical engineering students have done in the wildfire detection and monitoring area.

First Project: Design and Implementation of Autonomous Rovers for Early Wildfire Response

A team of three electrical engineering students worked on this project for two semesters. The objective of this project was to design and build a prototype for a wildfire detection system that uses a wireless sensor network to detect the fire and alerts an autonomous rover to investigate the area and assess the situation. After the possible fire is verified by the rover, the proper authorities will be notified. A customed android app was developed to manually control the autonomous rover, monitor the data from the sensors, and notify the authorities. Figure 1 depicts the Block Diagram of their System [21].

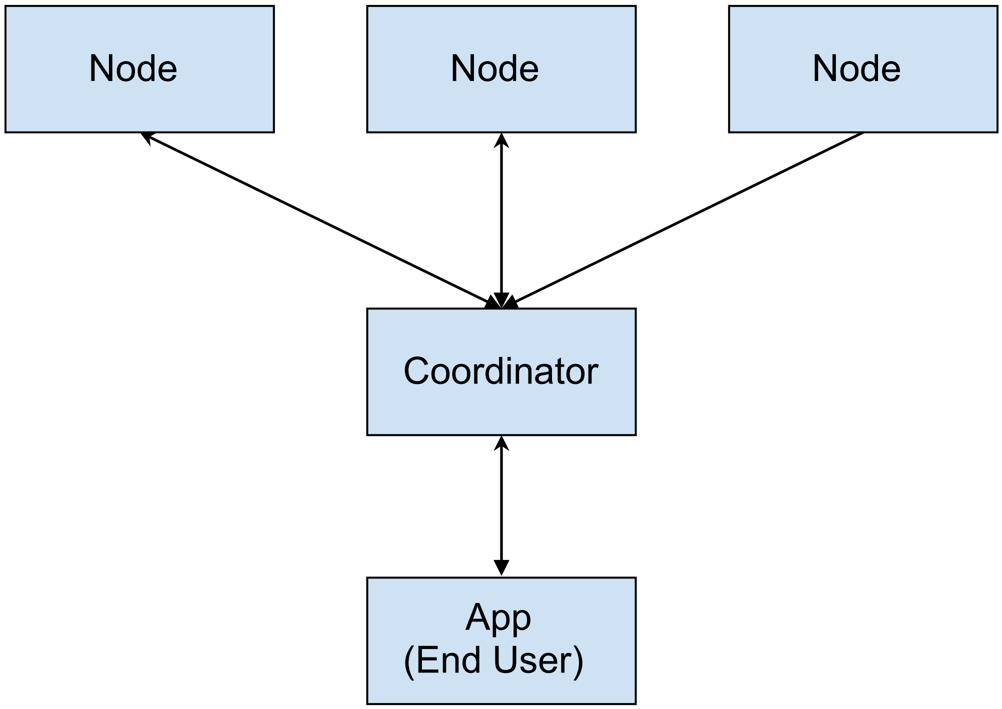

Figure 1: System Block Diagram [21]

Their early fire detection system has three nodes. Each node has temperature, smoke, and humidity sensors as well as a GPS. Nodes can communicate with each other as well as the coordinator. Each node uses a TI CC2650 Launchpad which has a powerful ARM Cortex – M3 processor. Figure 2 depicts a node and its circuit diagram. The system has one coordinator which is on the rover and is equipped with the same sensors as the nodes, as well as an IR camera. Figure 3 shows the circuit diagram for the coordinator which is on the rover [21].

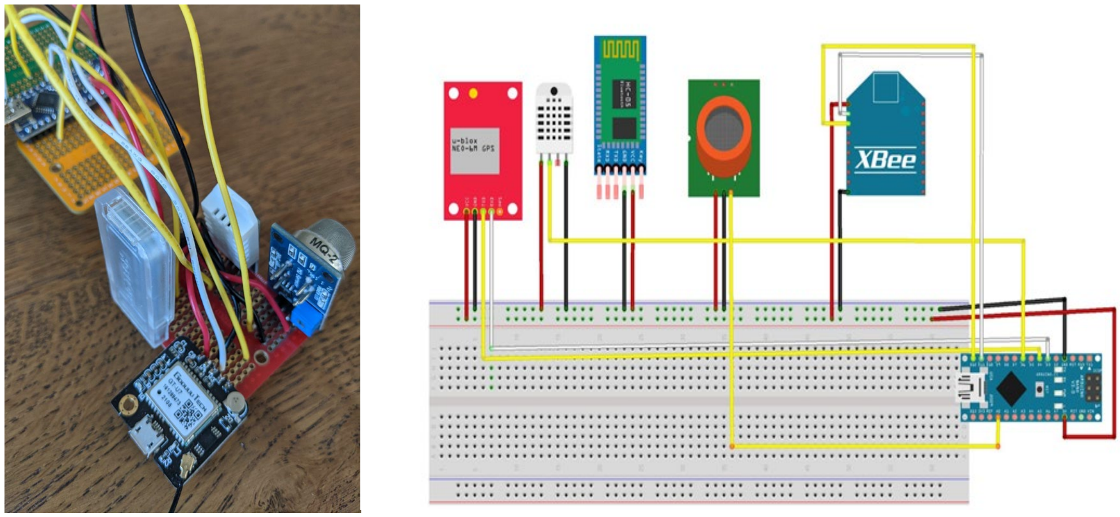

Figure 2: A Node and its Circuit Diagram [21]

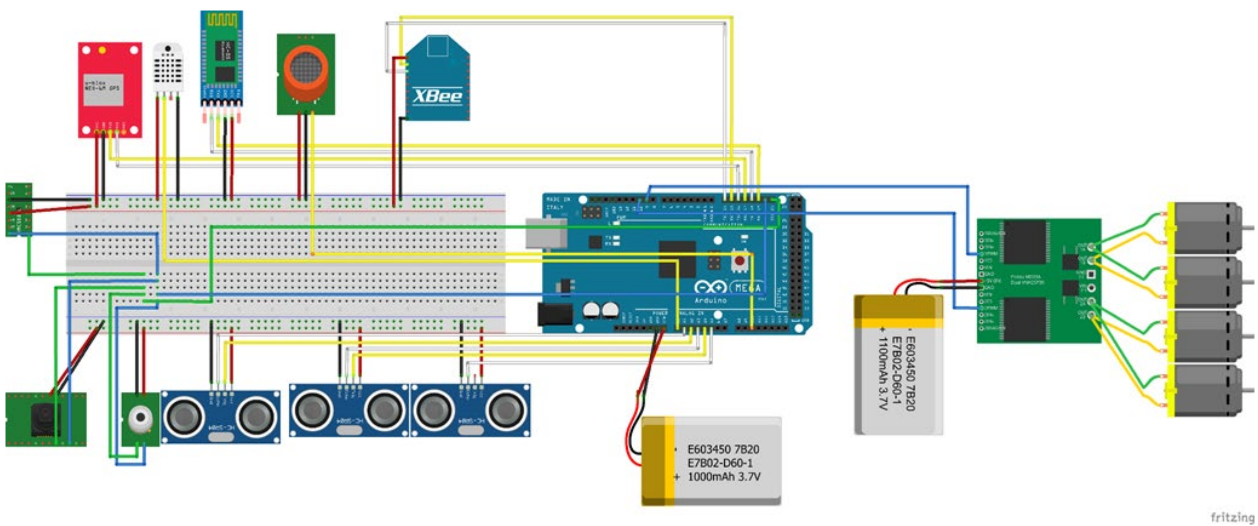

Figure 3: Circuit Diagram for the Coordinator which is on the Rover [21]

The Lynxmotion rover (Figure 4) travels to the location of the fire using the GPS coordinates that received from the nodes. This design adds a second level of verification using the rover.

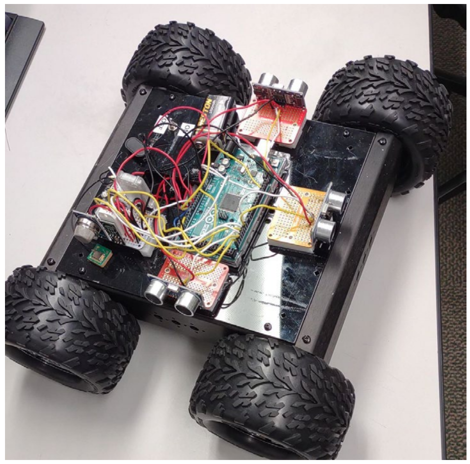

Figure 4: Lynxmotion Rover [21]

The rover carries the coordinator as well as three HC-SR04 ultrasonic sensors, one HC-05 Bluetooth module, one HMC5883L Magnetometer, and one Neo-6m GPS module. Once a node detects a fire the rover is automatically deployed. It uses the two GPS locations from the rover and the node that sent the ping as start and endpoints. The magnetometer gives the UGV heading and allows it to plot a direct path to the node. The ultrasonic sensors can override the current path to avoid obstacles [21].

An Android app is used by the end user to view the real-time information from the nodes and the rover. It is used to receive notifications when the warnings are detected and the pictures from rover can be viewed on the app to verify wildfire. The rover also can be controlled from the app. The app also allows the user to take control of the rover for better readings via the manual override [21].

The app was developed and programmed using the MIT App Inventor. The MIT App Inventor is a web application that allows for easy development and implementation of Android and iOS apps. This tool was used because of its ease of use and its high flexibility and customizability. Figure 5 shows the main app screen. There are three buttons on this page which are bluetooth, control rover, and select. Bluetooth button allows the user to connect to the microcontroller on the rover via bluetooth. Control rover button takes one to Figure 6 which is app's rover control screen. The select button allows the user to select which node information to display [21].

Figure 5: Main App Screen [21]

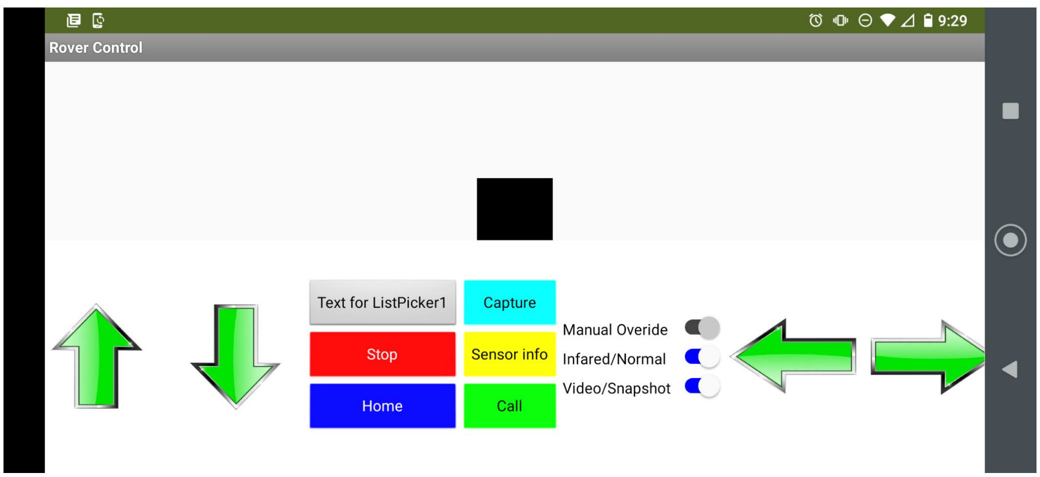

Figure 6: Rover Control Screen (App)[21]

"The rover control screen has lots of buttons that are designed to be user friendly. To make the rover go forward the Manual Override must be enabled. The switch will light up below like the other switches below it. The arrow buttons give directions for the rover, up goes forward, back goes reverse, the stop stops the rover, the left has the rover turn left, the right has the rover turn right. The red stop button stops the rover, and the blue home button calls the rover back to the user by sending the rover to the phone's GPS location. These buttons are designed to give the end user an easy way to manually control the rover outside of autonomous movement. This would allow the user to travel to and monitor a location, even if no warning is sent from the nodes. An additional level of safety and verification is provided by manual control [21].

The green call button is set up to quickly call emergency services and respond to a detected wildfire. An additional button provides the ability to connect the bluetooth in case it gets disconnected. The light blue Capture button is set up for the Arducam to take a picture from the rover and save it to the phone. The yellow sensor info button takes us to another screen within the app that displays the node sensor information. The other two switches would allow us to switch between the infrared and the normal camera and between the video and snapshot modes." [21]

Overall, this project was successful, and the students commented that "we learned a lot by researching and designing the functionality and implementing it through the hardware and software. We completed the core functionality of the project and designed around any limitations, and this can be developed further with future research".

Second Project: Wildfire Fire Detection using Wireless Sensor Networks

The objective of this project was to design a WSN to monitor and detect wildfires. To prototype the design two nodes and one coordinator were built. For the coordinator and nodes, a TI CC2650 Launchpads were used because of their powerful ARM Cortex- M3processor which is depicted in Figure 7.   This ARM processor has a 2.4 GHz transceiver that is compatible with the IEEE 802.16.4, ZigBee, and Bluetooth Low Energy (BLE) protocols [22].

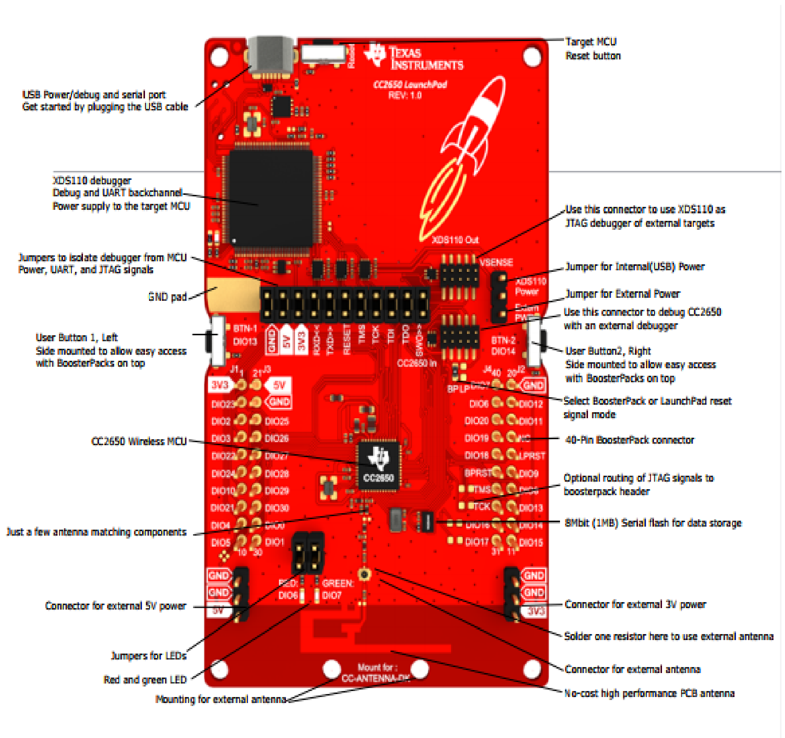

Figure 7: Texas Instruments (TI) CC2650 Launchpad [22]

Each node has a HTU21D-F Humidity Temperature sensor and an Adafruit Ultimate GPS board. A GPS module was used to locate the nodes and sensors in a mesh network to detect anomalies in temperature and humidity. The connection of the temperature and humidity sensor to the launchpad is shown in Figure 8 and the connection of the GPS board is shown in Figure 9 [22].

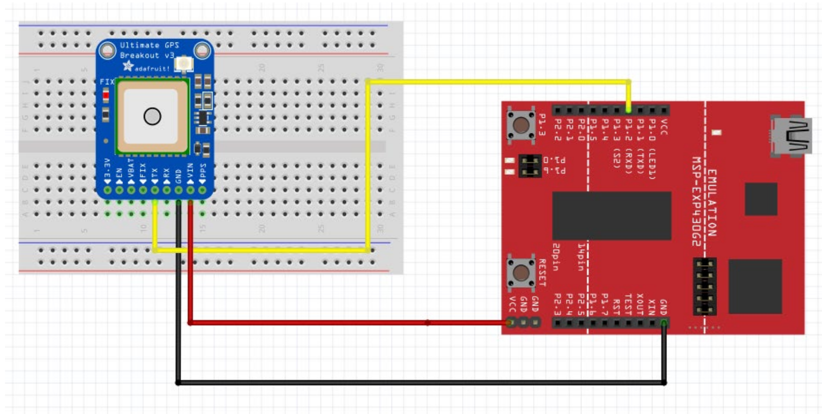

Figure 8: Launchpad Connection to GPS Module [22]

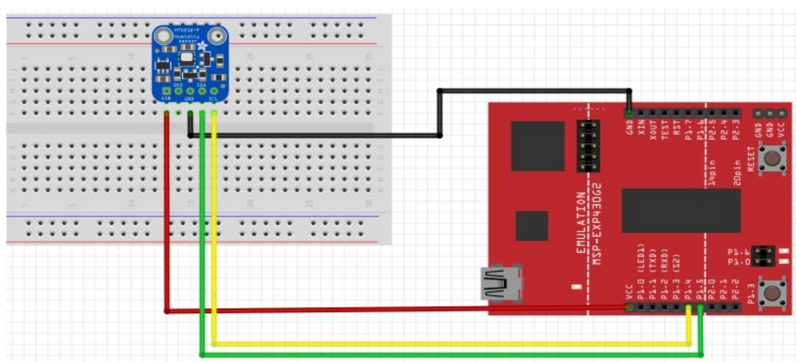

Figure 9: Launchpad Connection to Humidity and Temperature Module [22]

This project focused on building a WSN that demonstrated GPS positioning, and temperature/humidity monitoring. Only one computer engineering student worked on this project for one semester. This project was programmed in C. The following loop creates the packet to be sent and sends it to the base station. Figure 10 shows the code for the said loop [22].

```
while (1)
{
    Task_sleep(10000000/ Clock_tickPeriod);
    /* Wait for an event */
    uint32_t events = Event_pend(radioOperationEventHandle, 0, RADIO_EVENT_ALL, BIOS_WAIT_FOREVER);

    /* If we should send ADC data */
    if (events & RADIO_EVENT_SEND_ADC_DATA)
    {
        uint32_t currentTicks;

        currentTicks = Clock_getTicks();
        //check for wrap around
        if (currentTicks > prevTicks)
        {
            //calculate time since last reading in 0.1s units
            dmSensorPacket.time100MiliSec += ((currentTicks - prevTicks) * Clock_tickPeriod) / 100000;
        }
        else
        {
            //calculate time since last reading in 0.1s units
            dmSensorPacket.time100MiliSec += ((prevTicks - currentTicks) * Clock_tickPeriod) / 100000;
        }
        prevTicks = currentTicks;

        dmSensorPacket.batt = AONBatMonBatteryVoltageGet();
        dmSensorPacket.adcValue = adcData;
        dmSensorPacket.button = !PIN_getInputValue(Board_BUTTON0);
        dmSensorPacket.Temp = *test.t;
        dmSensorPacket.Hum = *test.h;


        sendDmPacket(dmSensorPacket, NODERADIO_MAX_RETRIES, NORERADIO_ACK_TIMEOUT_TIME_MS);
    }
```

Figure 10: NodeRadioTask loop [22]

This project was successful and the student's comment after finishing his project was as follows: "This project has proven to be challenging, but also very rewarding. Learning MCU peripherals, and how to use the RF core is a useful skill in WSNs because of the need to interface sensors and nodes. "

Conclusion

This paper presented recent computer and electrical engineering senior design projects in wildfire detection 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 and electrical engineering education and fulfill many requirements set forth by the Accreditation Board for Engineering Education and Technology (ABET).

References

1. Tahir, Hoor UI Ain, et. Al., “Wildfire Detection in Aerial Images Using Deep Learning”, 2022 2nd International Conference on Digital Futures and Transformative Technologies, 2022.
2. A.A. Alkhatib, “A Review on Forest Fire Detection Techniques”, International Journal of Distributed Sensor Networks, vol. 2014, 2014.
3. California Wildfire Statistics and Facts, https://expandedramblings.com/index.php/california-wildfire-facts-and-statistics/ , accessed on 1/9/2022.
4. Times Editorial Board, “Wildfires are Natural Disasters, but Congress refuses to Budget for them”, Los Angeles Times, Jan. 2018.
5. Wenqing Feng, et. al., “Transmission Line Wildfire Detection Using Landsat-8 Imagery and Multi-scale U^2 – Net”, the 10th China International Conference on Electricity Distribution, 2022.
6. Canadian Forest Service, “The State of Canada’s Forests: Annual Report 2018”, National Resource Canada, Calgary, Canada, 2018.
7. Hope, E., et. Al., “Wildfire Suppression Costs for Canada under a Changing Climate”, PloSone, vol. 11, no. 8, 2016.
8. Khryashchev, Vladimir, et. Al., “Wildfire Segmentation on Satellite Images Using Deep Learning”, 2020 Moscow Workshop on Electronic and Networking Technologies, 2020.
9. Bushnaq, Osama, et. Al., “The Role of UAV-IOT Networks in Future Wildfire Detection”, IEEE Internet of Things Journal, vol. 8, no. 23, 2021.
10. Utah Department of Public Safety, https://hazards.utah.gov/wildfire/, accessed on 1/11/2023.
11. Akyildiz, Ian and Mehmet Can Vuran, “Wireless Sensor Networks”, Wiley, 2010.
12. Li, Yingshu, My Thai, and Weili Wu, “Wireless Sensor Networks and Applications”, Springer, 2008.
13. Dargie, Waltenegus, and Christian Poellabauer, “Fundamentals of Wireless Sensor Networks: Theory and Practice”, Wiley, 2010.
14. Minaie, Afsaneh, et al., “Integration of Wireless Sensor Networks in the Computer Science and Engineering Curricula”, Proceedings of the ASEE Annual Conference, June 2012.
15. Annual Report on the State Poverty in Utah, 2012, Community action partnership of Utah.
16. Information and Statistics provided by the UVU Office of Institutional Research and Information – IRI.
17. NSF Proposal document, “Strengthening Outcomes for Students in Computer Science and Engineering through Leadership, Engagement, Academic Mentoring, and Preparation (LEAP), August 2013.
18. ABET, Inc. Criteria for Accreditation Engineering Programs, http://abet.org , 2013.
19. Dieter, George, and Linda Schmidt, “Engineering Design”, 4th edition, McGraw Hill, 2009.
20. Prairie, Michael, et. al., “Introducing Systems Engineering Concepts in a Senior Capstone Design Course”, Proceedings of American Society for Engineering Education, 2012.
21. Chamberlain, Blake, Quintin Jepsen, and Ryan Semadeni, “Design and Implementation of Autonomous Rovers for Early Wildfire Response”, ECE 4950, Final Report, Spring 2022.
22. Olson, Erik L., “Wildland fire detection using wireless sensor networks”, ECE 4800, Final Report, Summer 2017.