The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41836

Smart System Projects in Computer Engineering Program

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

Smart System Projects in Computer Engineering Program

Abstract

The purpose of capstone design project courses is to provide graduating senior students with the opportunity to demonstrate understanding of the concepts they have learned during their studies and to apply their professional skills and knowledge in a single experience and prepare them for work in industry. As with many computer science and engineering programs, students of the computer engineering program at Utah Valley University (UVU) conclude their degree programs with a semester 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 complex design problem. This paper presents the details of sample projects in smart systems that the students have done in this capstone course.

Introduction

Smart systems are systems that combine data processing with multi-modal sensing, actuation, control, and communication functions to perform smart actions. These systems make decisions based on the data that is gathered by the sensors in a predictive or adaptive manner. The concept of smartness and smart systems are used in different domains such as manufacturing, energy, education, business and management, health care, infrastructure, chemistry, electronics, etc. However, there is a lack of consensus regarding the conceptualization of smart systems [1]. In a systematic literature review done by Romero and others to characterize smart systems, they reviewed papers that contained definition of smart systems and smartness [1]. They summarized the characteristics of smart systems as follows [1]:

- Communication Capability
- Embedded Knowledge
- Learning Capability
- Reasoning Capability
- Perception Capability
- Control Capability
- Self-Organization
- Context Awareness

In the engineering domain, smart systems typically consist of diverse components such as:

- "Sensors for signal acquisition.
- Elements transmitting the information to the command-and-control unit.
- Command-and-control units that take decisions and give instructions based on the available information.
- Components transmitting decisions and instructions.
- Actuators that perform or trigger the required action" [2]

The focus of the smart systems is to design and manufacture new marketable products or services for specialized applications and for mass market applications. Wireless Sensor Network (WSN) and Internet of Things (IoT) technologies can be used to implement efficient and smart systems.

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. "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 [3-7]." 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 IoT 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 [8]. The number of devices that are connected to internet is constantly growing [9]. 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 [10]. 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 [11]. Today, IoT based smart systems [12] that are capable of effective data analysis approaches are used in homes, cars, and other infrastructure systems.

The interesting thing about IoT might be its limitless possibilities. Rapid growth in related technologies continues to fuel more and more use cases.

Wireless Sensor Networks

Recent advances in wireless networks, sensors, 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.

A WSN consists of many wireless-capable sensor devices working collaboratively to achieve a shared goal [13]. 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 [14]. 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 [14]. The potential advantage of networked sensing over the conventional approach can be summarized as greater coverage, accuracy, and reliability at a possibly lower cost [13, 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 [13, 16]. 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 [15, 16]. The use of WSNs has improved the functionality and smartness of many existing applications.

Smart systems provide smart functionality to everyday objects. With the help of wireless sensors, real-time sense and response capability, energy efficiency, as well as networking functionality, objects will become smart objects. These smart objects could support the elderly and disabled. In the healthcare sector, smart systems technology leads to better diagnostic tools, to better treatment and quality of life for the patients by simultaneously reducing costs of public healthcare systems [2].

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 smart systems, internet of things, and wireless sensor networks is growing rapidly, and there is increasing interest in providing undergraduate students with a foundation in these areas. It is crucial that these fields be integrated into the undergraduate computer engineering curricula. This paper presents the details of sample projects that our undergraduate computer engineering students have done in their senior capstone course in smart systems.

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 [17]. 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 [18]. 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 [19, 20].

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 900 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 of Science (BS) in Computer Science, Software Engineering, and Computational Data Science. It also offers a Bachelor of Applied Science in Software Development and a Master of Computer Science. The Bachelor of Science in Computer Science program was one of the first Bachelor of Science programs implemented at UVU in 1993. The program's goal has been to provide a quality program that meets accreditation standards while providing the students with a skill set that allows them to succeed in computing careers. The Computer Science degree at UVU is accredited by Computing Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET) [22]. Currently, the Computer Science Department has more than 1300 students.

Computer Engineering Program's Senior Design Project Course

Our Senior Design Project Course serves as a project-oriented capstone course for computer engineering majors. 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 [22]. The course learning outcomes are as follows:

Upon successful completion, students should be able to . . .

1. Identify relevant topics from previous courses and then apply them to their project.
2. Identify and specify design requirements from general problem descriptions.
3. Communicate design ideas and information.
4. Demonstrate creative thinking.
5. Display information gathering skills.
6. Demonstrate oral and written communication skills.

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 flexibility and deep familiarity with available components. 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 [23].

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 advisor 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 Smart Systems in Computer Engineering Program at UVU

To prepare our computer engineering students for the embedded systems design experience, which serves as a critical element of their education, we offer two courses on embedded system design. Embedded Systems I is a junior level course and Embedded Systems II is a senior level course. However, these two courses on embedded systems design are not enough to teach the students the skills that they need. The focus of our computer engineering capstone design class has been the design of embedded systems. By requiring an embedded design project in our capstone course, our students receive hands-on training in embedded systems that will enable them after graduation. Smart system design is a complex embedded systems design. This paper presents the details of three projects that our computer engineering students have done in smart systems in their capstone course.

First Project: A Smarter Wireless Sprinkler System

This senior design project was sponsored by faculty advisor through an NSF S-STEM grant. Two computer engineering students worked on this project for one semester. The objective of this project was to design a smart wireless sprinkler system to be used in residential and small businesses. A wireless sensor network was designed and used throughout a lawn that took periodic moisture measurements and sent the data to the sprinkler control system, so that the unit can make informed decision about what areas of a lawn need to be watered. The system that was designed can be easily retrofitted into any existing sprinkler system. The top-level view of the system for their design is shown in Figure 1.

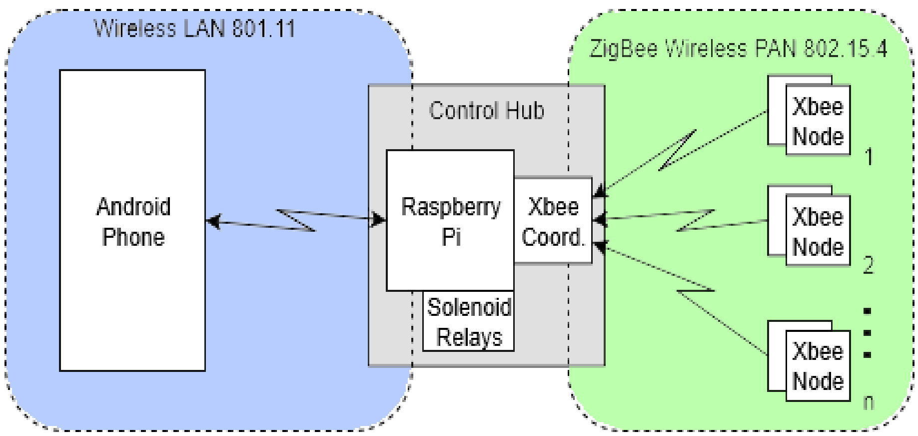

Figure 1: Top Level View of the System [24]

To design the smart wireless sprinkler system, students developed a wireless sensor network where the nodes used solar energy to power the Xbee router and provided charge to a super capacitor for the case that there were periods of low-to-no light. Each node employed a custom-built capacitive moisture sensor, which was used to gather and perform edge computing. Figure 2 shows a picture of the Sensor Probe Prototype.

Figure 2: Picture of the Sensor Probe Prototype [24]

A coordinator was connected to the Raspberry Pi and the Xbee end nodes. The Raspberry Pi served as the brain of the system. It functioned as the sprinkler timer: triggering the required zones when needed for irrigation. It provided an HTTP based server that interfaced with a smart phone application for data inquiry and configuration. It was also connected to the Xbee3 Coordinator node via UART, for aggregation from the wireless nodes in the system. A relay control board was designed to provide a digital interface into a preexisting sprinkler system's solenoid valve. An Android app that was written in Java was developed. This Android app provided a user with information about the state of the system and configuration options for setting or modifying the system's behavior. Figure 3 shows the system diagram for this design.

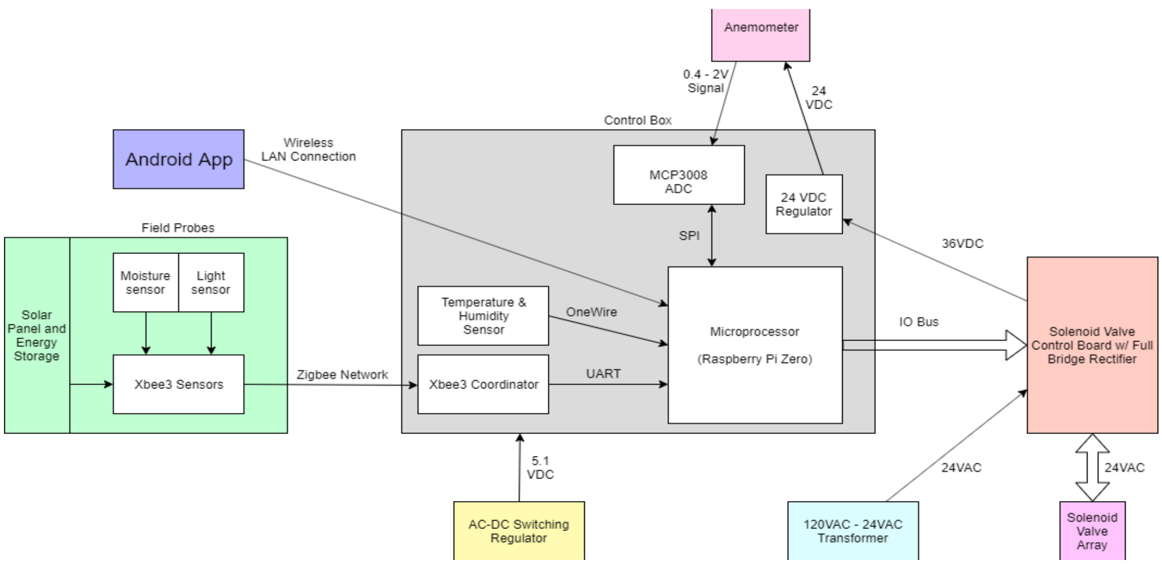

Figure 3: System Diagram [24]

Figure 4 shows the smart wireless sprinkler system's code hierarchy (Android Application, Main controller, and Xbee nodes).

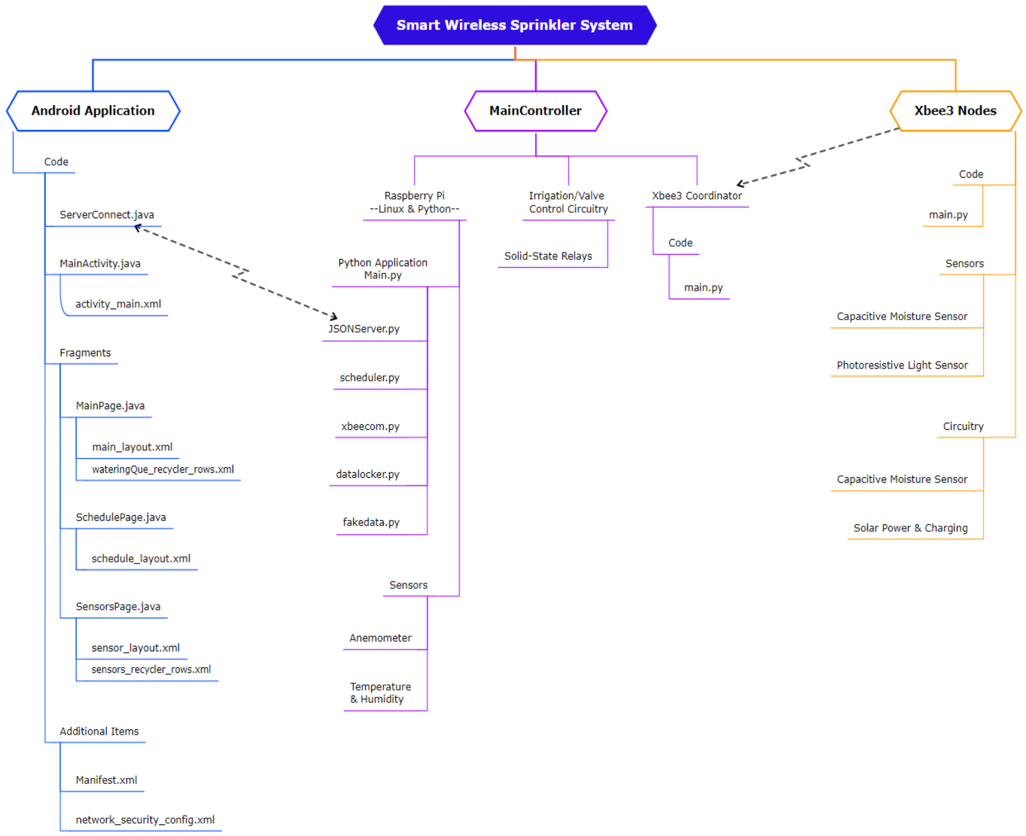

Figure 4: Sprinkler System Code Hierarchy [23]

A typical home or business's sprinkler system has a routine watering schedule which does not take into consideration the weather changes and the water concentration in the soil. However, the smart wireless sprinkler system that has been designed by two of our computer engineering students takes into consideration the above and saves water in a dry environment that we live in. This project was completed successfully. The students were satisfied with their capstone project, one of the students wrote "all in all, the project was a blast to work on. The hardware for the system also provided sufficient complexity for analysis and improvement of knowledge gained from university studies in electronic circuits. Not only was this project a learning opportunity, but it also provided the opportunity to contribute to society by creating a system that can be used to benefit the environment." [23] The other team member wrote, "I learned a lot about teamwork in this project and how to be a better collaborator with someone else. I also learned the importance of fully planning out ideas with collaborators to make sure that everything is cohesive and will function when put together." [23]

Second Project: Smart Intersection

One computer engineering student worked on this project for one semester. The goal of this project was to optimize the flow of traffic and allow traffic to proceed through the intersection with little to no idling and detecting vehicles that illegally ran a red light. Worldwide, millions of people allow their vehicles to sit idle for minutes at a time for different reasons. According to

Sustainable America, the average American spends more than 16 minutes a day idling their vehicles [28]. For every ten minutes a vehicle off prevents one pound of carbon dioxide from being released to the environment. An EDF report shows that in New York City alone, idling vehicles produce 130,000 tons of carbon dioxide each year [27]. One of the ways to reduce the amount of emissions at an intersection is to design a smart intersection. A prototype of a smart intersection was built by the student and is shown in Figure 5. The prototype intersection used a 4-way traffic intersection and introduced a traffic flow controller to adjust the on- time of green lights to correlate with the amount of traffic. Using ultrasonic sensors, the vehicles are detected, and the information is sent to an Arduino to keep track of the number of vehicles and adjust the LED lights depending on the amount of traffic going North/South versus East/West.

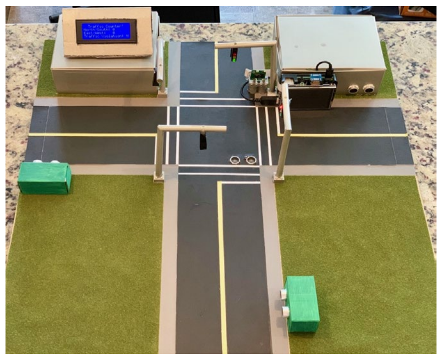

Figure 5: Prototype of a Smart Intersection [25]

Another ultrasonic sensor was used to detect if a vehicle ran a red light. If a vehicle was detected, a high bit was sent from the Arduino to the Raspberry Pi. Using the Raspberry Pi camera, the image of the vehicle was captured. Once the image was captured, license plate detection took place through image processing. Plate detection went through the process of capture, pre-processing, localization, and segmentation to find the location of the license plate. Once the plate was detected, plate recognition sent the characters to an Optical Character Recognition (OCR) engine. The OCR engine determined the characters on the license plate, converted the characters to an ASCII representation, and stored the characters in a database. The image processing program for the License Plate Detection System was created on the Raspberry PI using the Python language and OpenCV as the main library for the license plate extraction. When the Raspberry Pi received confirmation that a vehicle had run a red light, the Pi-camera took a picture of the vehicle and stored the image on an SD card. The captured image of the car is depicted in Figure 6. The captured image went through image processing algorithms to detect the license plate number.

Figure 6: Captured Image [25]

The Cropped License Plate is shown in Figure 7.

Figure 7: Cropped License Plate [25]

This project was a success and a prototype for a smart intersection was designed.

Third Project: Universal Smart Car Kit

The purpose of this project was to design a universal smart car kit to give older cars the features such as the backup camera, digital cockpit, and blindspot monitoring system of the newer cars. Two Computer Engineering students worked on this project for one semester. According to a survey conducted by the National Highway Traffic Safety Administration (NHTSA), 94% of the serious vehicle accidents (2018) were due to human error [29]. They believed that autonomous car features such as back up camera, blind-spot monitoring system, and brake assist can save lives. This kit included a backup camera, blind-spot monitoring system, and a live engine monitoring system. The kit was prototyped using a 2002 Lexus Is300, which has very limited technology for its time. The kit was designed using a Raspberry Pi 4, Raspberry Pi Pico, Elm327 Microcontroller, USB camera, and HC-SR04 ultrasonic sensors. Figure 8 shows the system's wiring diagram.

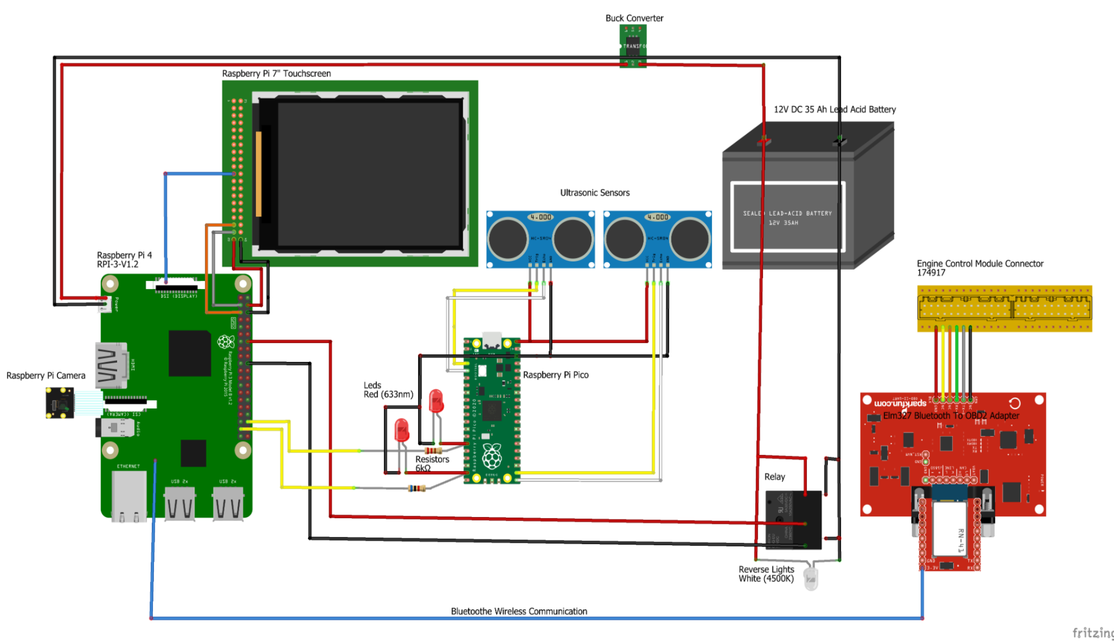

Figure 8: System Wiring Diagram [30]

To install the kit the user plugs in the ELM327 microcontroller into the cars OBDII port. Then, mount the screen to the dash using the provided Velcro strips. Supply power to the system by plugging it into the cars cigarettes lighter. Plug in the fuse for the reverse lights. Mount the backup camera to the rear of the vehicle as well as the 2 ultrasonic sensors. To set up the system the user simply starts the car, and the device will automatically connect and initialize all the systems. Figure 9 shows how the ELM327 microcontroller is plugged into the vehicle.

Figure 9: ELM327 Plugin Point near Drivers Feet [30]

The cost of the kit is under $200.00. These new features are accessible to the driver through an interactive touchscreen which is shown in Figure 10. The kit is easy to install and will take under 20 minutes for the average consumer to install. It does not require vehicle modifications.

Figure 10: Touchscreen Connected to the Car [30]

This project was successful, and students were able to design a kit to upgrade the old cars with new features of the newer cars. One of the students used his own car and installed this kit on his own 2002 car and he was very happy with this upgrade for his car.

Conclusion

Interest in smart systems is growing among tech giants, carmakers, and emerging startup companies. Companies are realizing the shortage of well-trained workforce that is equipped with knowledge to do research and development in this area. Undergraduate students are realizing the benefits of having knowledge in this area which opens a lot of opportunities for them.

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). This paper presented three sample senior design projects recently conducted in smart systems. Our senior design course is structured as a collection of independent student projects. Our students are required to design, build, and troubleshoot a fully functional system. They find this course both challenging and rewarding. 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.

References

1. Romero, Marcelo, et al.," Towards a Characterization of Smart Systems: A Systematic Literature Review, Computers in Industry, 2020.
2. Wikipedia, Smart System, https://en.wikipedia.org/wiki/Smart_system, Accessed on 1/3/2024.
3. Gillis, Alexander, "What is internet of things (IoT)?", IoT Agenda. Retrieved 17 August 2021.
4. Brown, Eric, "21 Open-Source Projects for IoT", Linux.com, Retrieved 23 October 2016.
5. "Internet of Things Global Standards Initiative", ITU, Retrieved 26 June 2015.
6. Hendricks, Drew. "The Trouble with the Internet of Things", London Datastore. Greater London Authority, Retrieved 10 August 2015.
7. 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.
8. Report, "The Internet of Things: An Overview", released October 2015, Internet Society.
9. F. Xhafa, D. Zaragoza, and S. Caballé, "Supporting Online/Offline Collaborative Work with WebRTC Application Migration," in Ubiquitous Computing, 2019, pp. 96–104.
10. "2019 manufacturing trends report", Microsoft, Redmond, WA, USA, Rep. Microsoft Dynamics 365, 2018.
11. Ahn, Jungmo, et. al., "Convolutional Neural Network-based Classification System Design with Compressed Wireless Sensor Network Images", PIOS one, 13(5), P.e0196251.
12. E. G. M. Petrakis, S. Sotiriadis, T. Soultanopoulos, P. T. Renta, R. Buyya, and N. Bessis, "Internet of Things as a Service (iTaaS): Challenges and solutions for management of sensor data on the cloud and the fog," Internet of Things, vol. 3–4, pp. 156–174, Oct. 2018.
13. Minaie, Afsaneh, et al., "Integration of Wireless Sensor Networks in the Computer Science and Engineering Curricula", Proceedings of the ASEE Annual Conference, June 2012.
14. Li, Yingshu, My Thai, and Weili Wu, "Wireless Sensor Networks and Applications", Springer, 2008.
15. Dargie, Waltenegus, and Christian Poellabauer, "Fundamentals of Wireless Sensor Networks: Theory and Practice", Wiley, 2010.
16. Akyildiz, Ian and Mehmet Can Vuran, "Wireless Sensor Networks", Wiley, 2010.
17. Innovative Mobile and Internet Services in Ubiquitous Computing, 2019, pp. 96–104.
18. Annual Report on the State of Poverty in Utah, 2014, Community Action Partnership of Utah, http://caputah.org/images/poverty-reports-full/2014_Annual_Report_on_Poverty_.compressed_1.pdf , access on 1-2-2020.
19. Annual Report on the State of Poverty in Utah, 2012, Community Action Partnership of Utah.
20. Information and statistics provided by the UVU Office of Institutional Research and Information – IRI.
21. NSF Proposal document, "Strengthening Outcomes for Students in Computer Science and Engineering through Leadership, Engagement, Academic Mentoring, and Preparation (LEAP)", August 2013.
22. ABET, Inc. Criteria for Accrediting Engineering Programs, http://abet.org, 2024.
23. Dieter, George, and Linda Schmidt, "Engineering Design", 4th edition, McGraw-Hill, 2009.
24. Martin, Bryce, and David Carlson, "A Smart Sprinkler System", ECE 4800, Utah Valley University, Final Report, Fall 2019.
25. Yates, Doug, "Smart Intersection", ECE 4800, Utah Valley University, Final Report, Spring 2019.
26. Prairie, Michael, et al., "Introducing Systems Engineering Concepts in a Senior Capstone Design Course", Proceedings of American Society for Engineering Education, 2012.
27. "Attention drivers! Turn off your idling engines", *Environmental Defense Fund*, 2016. [Online]. Available: https://www.edf.org/climate/reports/idling. [Accessed: 15- Sep- 2016]. Smart intersection ref 13

28. "Sustainable America", *Sustainable America*, 2016. [Online]. Available: http://www.sustainableamerica.org/. [Accessed: 15- Sep- 2016]. Smart intersection ref 15
29. NHTSA 2019, National Highway Transportation Safety Administration, accessed on 30th January 2024, https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety. Smart kit – ref 1
30. Miles, Bridger and Chance Cochrance, "Universal Smart Car Kit", ECE 4800, Utah Valley University, Final Report, Spring 2021.