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Human-Centered Capstone Design in Electrical and Computer Engineering: Developing Technologies for Patients and Individuals with Disabilities

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Abstract

Capstone design courses are a cornerstone of Electrical and Computer Engineering (ECE) curricula, providing a culminating educational experience for graduating seniors. The primary objective of the capstone project is to offer students a summative opportunity to integrate and apply the technical knowledge, professional skills, and engineering practices developed throughout their undergraduate education in preparation for professional practice. At Utah Valley University (UVU), as in many ECE programs, students complete a two-semester capstone design sequence that emphasizes the application of competencies acquired during the first three years of the curriculum to the solution of open-ended design problems. These courses are structured around independent, student-led projects that require teams to design, build, and troubleshoot fully functional systems, making the experience both challenging and highly rewarding.

In recent years, a growing number of ECE students have elected to pursue capstone projects centered on developing innovative solutions to support patients and individuals with disabilities. These projects engage students in the full engineering design process, including needs assessment, requirements definition, prototyping, and system evaluation, while encouraging collaboration with stakeholders to ensure human-centered outcomes. Representative projects include assistive technologies, adaptive control systems, and health-monitoring platforms designed to enhance accessibility, autonomy, and quality of life. Through participation in these projects, students strengthen their technical and professional competencies while gaining an appreciation for the broader societal impact and ethical responsibilities of engineering practice.

This paper presents representative examples of recent human-centered capstone projects completed by undergraduate electrical and computer engineering students. The projects illustrate how human-centered design principles can be effectively integrated into ECE capstone courses while maintaining technical rigor and preparing students to develop socially responsive and inclusive engineering solutions.

Introduction

Capstone design courses are a cornerstone of undergraduate Electrical and Computer Engineering programs, serving as a culminating experience in which students synthesize technical knowledge, professional skills, and real-world constraints to solve open-ended engineering problems. Traditionally, ECE capstone projects have emphasized technical rigor, system performance, and compliance with engineering specifications. While these objectives remain essential, growing evidence suggests that technically sound solutions alone are insufficient to address the complex, sociotechnical challenges faced by modern engineers [1].

Human-centered design (HCD) is an approach to engineering and design that prioritizes a deep understanding of users, stakeholders, and contextual factors throughout the entire design process, with the goal of creating solutions that are usable, effective, and responsive to human needs. HCD emphasizes early and continuous user engagement, iterative prototyping, and the integration of human, technical, and societal considerations in design decision making [2] – [4].

Human-Centered Design has gained attention in engineering education as a framework that emphasizes stakeholder needs, contextual understanding, and iterative engagement with end users throughout the design process. Rooted in design thinking and participatory design traditions, HCD encourages students to move beyond solution-driven approaches by prioritizing empathy, problem framing, and continuous validation with users [4]. Prior educational research has shown that human-centered approaches can deepen students' understanding of design and support more reflective and need-based engineering practices [5].

Human-centered design relies on an iterative balance between divergent and convergent thinking throughout the design process. Divergent thinking involves the deliberate expansion of the problem and solution space through activities such as stakeholder identification, user research, and ideation, with the goal of generating multiple perspectives and alternatives without premature judgment [6], [2]. Convergent thinking, in contrast, focuses on evaluating, refining, and selecting among these alternatives using defined criteria, constraints, and performance metrics [5]. Effective capstone design instruction intentionally alternates between these modes, enabling students to move from broad exploration of user needs to well-justified technical design decisions. Engineering education research has shown that making these design phases explicit in capstone instruction supports students' professional formation and better prepares them for authentic engineering practice [5] – [7].

Within ECE programs specifically, the integration of human-centered approaches into capstone design presents both opportunities and challenges. Electrical and computer engineering projects often involve abstract systems, embedded technologies, and complex hardware–software interactions that may obscure the role of end users in early design stages. As a result, students may default to solution-driven approaches rather than need-driven problem formulation [5]. Embedding HCD principles into ECE capstone courses can help counteract this tendency by encouraging students to engage in stakeholder analysis, user research, and iterative validation alongside traditional engineering analysis and implementation.

Moreover, the incorporation of human-centered design aligns closely with evolving accreditation and industry expectations. ABET student outcomes emphasize not only technical competence but also the ability to consider public welfare, societal impacts, ethical responsibilities, and stakeholder needs in engineering solutions [1]. Industry partners similarly report increasing demand for engineers who can collaborate across disciplines, communicate with non-technical stakeholders, and design systems that account for usability, accessibility, and real-world constraints [8].

Over the past decade, engineering education has undergone significant changes, shifting toward critical thinking, active learning, and hands-on problem-solving. Despite this progress, a growing skills gap persists in the engineering workforce due to the fast pace of technological advancement. Traditional education methods remain heavily theory-based and task-oriented, which limits students' ability to develop practical, transferable skills [9].

This paper examines the role of human-centered design (HCD) in electrical and computer engineering (ECE) capstone courses, focusing on how HCD frameworks can be systematically integrated into capstone pedagogy while maintaining strong technical rigor. By situating HCD within the context of ECE education, the paper highlights instructional strategies, learning outcomes, and best practices that support the development of engineers capable of designing solutions that are both technically robust and genuinely responsive to human needs. In addition, the paper presents detailed descriptions of three representative undergraduate senior capstone projects that demonstrate the application of HCD principles in practice.

Background Information

UVU is a large regional institution serving over 46,000 students in Utah County, the state's second-largest county. Utah County has been one of the fastest growing regions in the country with more than 96% growth between 1990 and 2010-time period [10]. Because of this huge growth, UVU has undergone multiple transitions since its origin in 1941 and has expanded its mission and role within the region. In 1987, it was a community college. The institution became a state college in 1993 and a regional university in 2008. In fall 1993, the enrollment was 10,500 and tripled in fall 2012 to 31,500. The demand for education has been met by an increase in baccalaureate degrees offered from three in 1995 to 91in 2020 in addition to eleven master programs as well as 65 associate degrees. This required institutional transition has strained state and community resources and created several challenges, particularly in the availability of scholarship funds. UVU is regionally accredited by the Northwest Commission on Colleges and Universities. The university has a dual mission: it offers 110 bachelor's degrees and 20 master's degrees as a comprehensive university, and it also provides 65 associate degrees and 96 certificate programs as a community college. To fulfill its community college mission, UVU maintains an open-enrollment policy. The university serves a diverse student body, with 38% of students being low-income and 41% being first-generation. Additionally, UVU has a significant population of non-traditional students, including 29% who are older than the typical college age, 35% with spouses [11], and 19% with children under age twelve [12]. Despite relatively low tuition, 36% of degree-seeking students attend part-time. These factors contribute to the university's overall graduation rate of 33% (as measured by the national IPEDS standard for completions in 150% of normal time) and a 70% one-year retention rate for baccalaureate degree-seeking students. About 80% of UVU's students will remain in their communities and pursue employment in this region [13, 14].

Computer Science and Engineering 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. 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). Currently, the Computer Science Department has 988 students.

In Fall 2024, the engineering department was reorganized into two: Mechanical and Civil Engineering (MCE), and Electrical and Computer Engineering (ECE). The ECE Department now serves about 300 students and offers ABET-accredited programs in Electrical and Computer Engineering.

Electrical Engineering Capstone I and II Courses

Capstone design project courses serve as a culminating experience for graduating senior students, providing them the opportunity to apply and demonstrate the knowledge and skills acquired throughout their studies. At UVU, electrical engineering students complete a two-semester capstone design sequence as part of their graduation requirements. These courses are structured around independent student projects that challenge students to design, build, and troubleshoot fully functional systems. The primary goal is to engage students in solving complex, real-world problems by utilizing the technical competencies developed during the first three years of the curriculum. Capstone projects not only reinforce professional skills but also help prepare students for careers in industry, making them a vital component of the electrical engineering curriculum.

The primary objectives of senior projects are to simulate industry-relevant project development and to build expertise in four key areas:

- Teamwork
- Project Management
- Research & Development
- Communication

These are the most important skill areas to the success of an engineer.

Capstone I Course (ECE 4900)

The course description for ECE 4900 is as follows:

This course focuses on team-oriented design projects and technical writing by incorporating group projects, oral presentations and written reports. Incorporates engineering standards and realistic constraints including economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political. Emulates the problems encountered by engineers working in commercial, industrial, and governmental entities.

The Course Objectives for this course is as follows:

- Plan an engineering project involving multiple tasks
- Design electrical systems that meet defined constraints
- Communicate technical information on writing
- Identify business issues related to technology
- Explain the impact of engineering on societal issues
- Analyze the economics of designing and manufacturing the engineering artifact

Capstone I is the first course in the two-part senior design sequence. In this course, students complete several key milestones:

- Team formation
- Project proposal and approval
- Project planning
- Procurement of hardware components
- Proof of concept for critical circuits
- Preliminary Design Review (PDR)

The topics covered in this course are as follows:

- Engineering design methodology
- Project selection and need Identification
- Requirement specification development
- Concept generation and evaluation
- Team dynamics and collaboration
- Ethics and legal considerations in engineering
- Basics of Engineering Economics

Each team meets weekly with a faculty advisor to review progress, troubleshoot challenges, and provide regular status updates. Students are expected to commit approximately 10 hours per week, totaling 150 hours over the semester. A final letter grade is awarded based on project performance, participation, presentation, weekly and final reports, and milestone completion.

This course is offered every fall semester. The prerequisite for this course is Embedded Systems I and University Advanced Standing.

Capstone II Cours (ECE 4950)

The course objectives for this course are as follows:

- Design an electrical system or process to meet given specifications with realistic engineering constraints

- Use effective team processes, communication, and conflict resolution skills
- Implement an electrical system
- Troubleshoot an electric system
- Present the design project results orally and in writing format

Capstone II is the second course in the senior design sequence required for graduation. The course requires the completion of the following major milestones:

- Fulfillment of proposal commitments
- Functional project demonstration
- Completion of documentation and poster
- Final Design Review
- Submission of an abstract to a conference (if accepted poster presentation)
- Developing a poster for presentation at a college wide design expo (CET Expo)

Capstone I (ECE 4900) is a prerequisite for this course. Capstone II does not have a scheduled lecture component. Instead, students meet weekly with their faculty advisor to review progress and receive guidance.

The primary outcome of Capstone II is a comprehensive written project report. This document must thoroughly describe the project, providing sufficient detail and clarity so that someone with a general background in electrical engineering—but no prior knowledge of the specific project—can fully understand the work.

In addition to the written report, students will deliver a formal oral presentation to an audience that may include faculty, students, industry professionals, and members of the public. This 30-minute session (which includes time for setup and teardown) will require students to:

- Present their project at a level suitable for a general engineering audience.
- Demonstrate any functional systems or components.
- Answer questions regarding their design, implementation, and results. [15]

Integration of Human-Centered Design in the Computer and Electrical Engineering Program at UVU

Engineering students are educated in an environment of rapid technological change, requiring preparation that extends beyond technical content to include problem solving, teamwork, and adaptability. To meet these demands, Electrical and Computer Engineering (ECE) programs must provide learning experiences that integrate technical expertise with professional skills relevant to contemporary engineering practice.

Within the ECE program at UVU, capstone design courses serve as a primary mechanism for developing and assessing these competencies. The capstone experience is structured to provide students with flexibility in selecting project domains aligned with their technical interests and career goals. This flexibility has enabled the incorporation of emerging design approaches, including human-centered design, into the capstone curriculum. With guidance and encouragement from faculty advisors, a growing number of students have elected to pursue capstone projects that explicitly apply human-centered design principles.

The integration of human-centered design into ECE capstone projects allows students to engage more deeply with stakeholder needs and contextual constraints while maintaining rigorous technical requirements. By working on projects grounded in real-world human needs, students are encouraged to consider usability, accessibility, and societal impact alongside system performance and technical feasibility. The following section presents representative capstone projects completed by UVU's ECE students that exemplify the application of human-centered design within a technically robust engineering framework. These examples illustrate how HCD can be effectively integrated into ECE education and highlight its potential to enhance student engagement and professional preparedness.

Autonomous Medical Delivery/Emergency Notification Rover Project

The growing aging population has led to an increasing number of older adults living independently, many of whom lack immediate access to assistance during emergencies. In the United States, more than 14 million seniors live alone, and falls remain one of the most significant risks associated with independent living. Approximately one in four adults over the age of 65 experiences a fall each year, making falls the leading cause of both fatal and non-fatal injuries among older adults [16]. In 2020, emergency medical services (EMS) responded to more than three million fall-related incidents nationwide, with response times typically ranging from 7 to 10 minutes in urban areas and often longer in rural settings [16], [17]. This delay creates a critical window during which timely assistance may be unavailable.

This capstone project focused on the design and development of an autonomous medical and emergency notification system intended to support elderly individuals who live independently. Motivated by the need to improve safety while preserving personal autonomy, the project adopted a human-centered design approach that emphasized real-world user needs, particularly for individuals who may be injured, disoriented, or unable to actively seek help during an emergency. Rather than limiting the system to emergency alerts alone, the project explored how autonomous technology could provide immediate, on-site assistance during the critical period before emergency medical services arrive [18]. Figure 1 shows a system block diagram of their design.

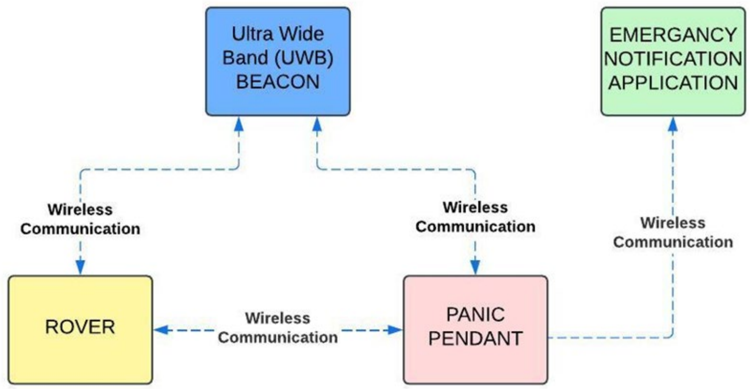
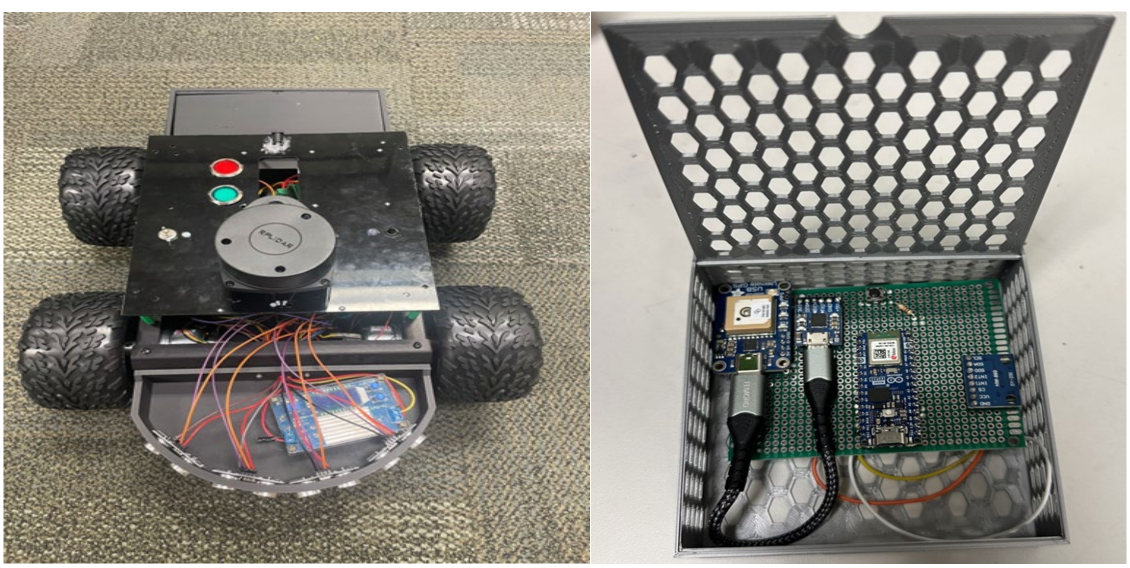


Figure 1: System Block Diagram [18]

The resulting system integrates a wearable panic pendant with an autonomous rover capable of delivering medication and basic first-aid supplies. The pendant can be manually activated by the user or automatically triggered through accelerometer-based fall detection, ensuring reliable operation across a range of physical and cognitive conditions. Once an emergency signal is received, the rover autonomously navigates the user's home using lidar and ultrasonic sensors in conjunction with an Extended Kalman Filter–based Simultaneous Localization and Mapping (SLAM) algorithm. This enables accurate localization, obstacle avoidance, and safe navigation in complex indoor environments. By delivering supplies directly to the user, the system provides immediate assistance rather than relying solely on notification, distinguishing it from traditional medical alert devices. Figure 2 shows the rover and its wiring diagram and the panic pendant and its wiring diagram.



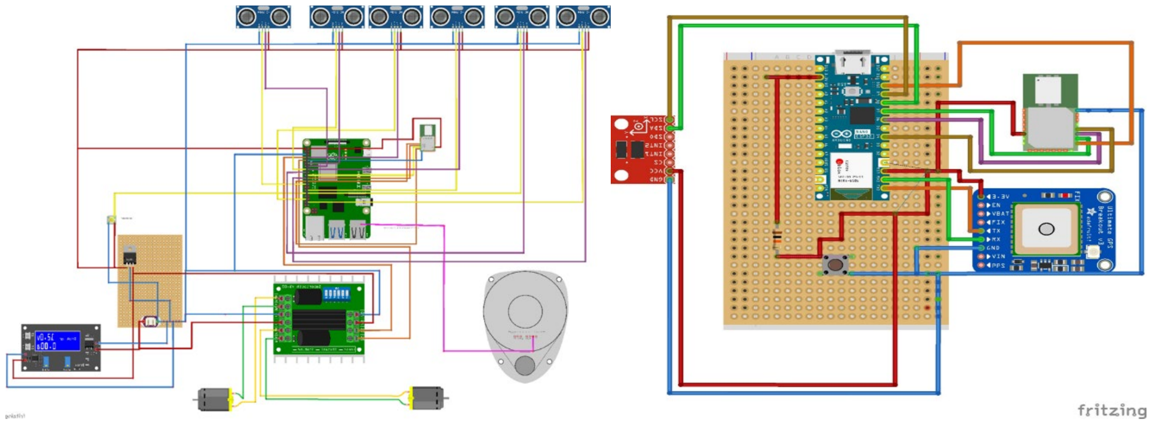


Figure 2: Rover and Wiring Diagram and the Panic Pendant and Wiring Diagram [18]

The autonomous platform is built around a four-wheeled, four-wheel-drive (4WD) vehicle that supports independent wheel control and differential steering. This configuration was selected to ensure stable traction and robust maneuverability across a variety of indoor surfaces, which is essential for reliable operation in residential settings. The integration of sensing, control, and navigation subsystems allowed the students to address both technical rigor and user-centered functionality within a single cohesive design.

The project was completed over two semesters by a team of two electrical engineering students, under the guidance of a faculty mentor. The initial concept emerged collaboratively between the students and mentor, and project funding was provided by the Smith College of Engineering and Technology. The students conducted a review of existing literature on medical alert systems and autonomous navigation before developing and implementing their own design. Through this process, the project served as both a technical capstone experience and an example of how human-centered design principles can be effectively incorporated into electrical and computer engineering education.

This project was successful and the students' comment after finishing their project was positive and they said that "uultimately, this project taught us the importance of hardware separation, modularity, power isolation, and prototyping under real-world constraints".

EEG Smart Clothing Project

A significant portion of individuals diagnosed with epilepsy—up to 40%—do not achieve adequate seizure control through antiepileptic drugs, which remain the primary noninvasive treatment option [19]. For these patients, alternatives are limited and often involve invasive procedures such as surgical removal of epileptic foci. This gap highlights the need for accessible, noninvasive technologies that can improve safety and support clinical management. The EEG Smart Clothing system was developed by one electrical engineering student and one computer engineering student to address this need by providing continuous, real-time seizure monitoring through a wearable electroencephalography (EEG) platform.

Their system is a wearable solution designed by the students to detect seizure activity and provide early warnings by continuously monitoring EEG signals. Brainwave data are collected using gold cup electrodes to ensure high signal quality, then filtered and analyzed across relevant frequency bands to establish baseline power and amplitude levels. Seizure detection is achieved through developer-defined voltage thresholds, and when abnormal activity is detected, a haptic alert system notifies the user to enable timely intervention. Signal acquisition, processing, and analysis are performed on a Raspberry Pi, while a Raspberry Pi Pico microcontroller controls the haptic feedback system. The system diagram is shown in Figure 3 [20].

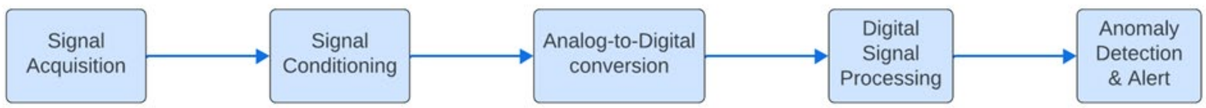


Figure 3. EEG System Diagram [20]

To support long-term, comfortable use, the Pico microcontroller and vibration motors are integrated into a wearable bracelet. Wireless communication between the Raspberry Pi and Pico is implemented via Bluetooth, enabling real-time alert transmission. Future enhancements will focus on improving system portability, user comfort, and advancing the seizure detection algorithm beyond fixed thresholds. Overall, the EEG Smart Clothing system represents a step toward practical, real-time health monitoring for individuals with epilepsy, offering both immediate safety benefits and long-term EEG data collection to support medical diagnosis and treatment. By combining EEG monitoring and a portable, user-friendly design, the system provides early warnings for seizures, reducing risks and improving outcomes. This project demonstrates the potential of wearable technology to enhance health monitoring and save lives.

This project was successful and the students' comment after finishing their project was positive and they said that "The EEG Smart Clothing system demonstrates a significant step toward accessible, real time health monitoring for individuals who suffer from epilepsy; offering life saving features and long-term data storage that will be used for medical monitoring and diagnosis".

Smart Communication Device for the Hard of Hearing: Sign Language Gloves Project

Sign language serves as a primary mode of communication for individuals who are deaf or hard of hearing, yet it remains unfamiliar to much of the general population. In the United States, approximately 11 million people—about 3.6% of the population—are deaf or experience significant hearing loss, which can create substantial communication barriers when interacting with individuals who rely on spoken language [21]. These challenges often result in frustration and reduced accessibility in everyday interactions.

In this project, students designed a smart communication system to help bridge the communication gap between individuals who are deaf or hard of hearing and those who are not familiar with sign language. Their design centers on a pair of gloves equipped with flex sensors and accelerometers to capture American Sign Language (ASL) hand gestures. Sensor data are processed in real time using onboard microcontrollers, allowing the system to translate gestures into spoken output. The right-hand glove uses a Teensy 4.1 microcontroller to interpret the sensor data and generate speech through a speaker, while the left-hand glove, powered by an Arduino Nano, collects sensor data and transmits it wirelessly to the right glove using NRF24L01+ modules. Figure 4 shows the System Block Diagram for their design.

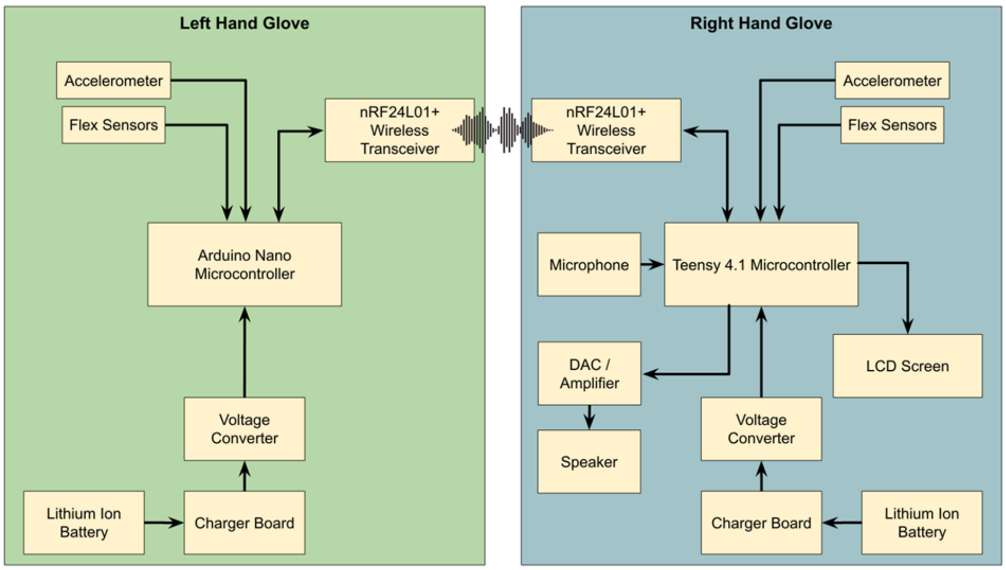


Figure 4: System Block Diagram [22]

Portability and ease of use were key considerations throughout their design process. Unlike earlier versions that required a computer for processing, their system operates independently using embedded microcontrollers, making it more practical for everyday use. The gloves are powered by lightweight, rechargeable lithium-ion batteries with integrated voltage regulation and charging circuitry. This design minimizes weight and power consumption, ensuring that the system does not restrict natural hand movement during use. The breadboard Prototype of the design is shown in Figure 5.

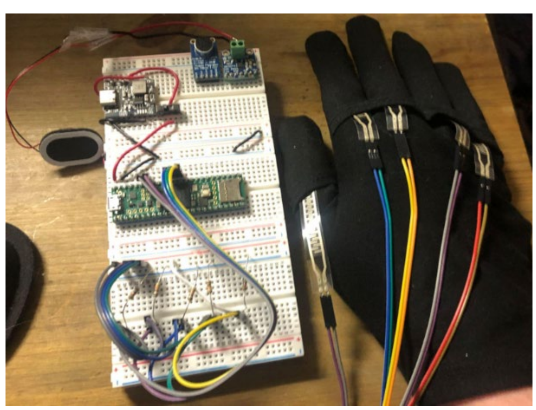


Figure 5: Breadboard Prototype [22]

This project was successful and the students' comment after finishing their project was positive and they said that "this project illustrates the powerful role technology can play in making communication more accessible and equitable for all individuals".

Conclusion and Concluding Remarks

This paper presented representative senior capstone projects that incorporate human-centered design within undergraduate electrical and computer engineering programs. The capstone experience is structured around student-led, open-ended projects that require students to design, build, and validate fully functional systems while applying the technical knowledge and skills developed throughout their academic programs. Through these projects, students engage in self-directed learning, develop advanced problem-solving and troubleshooting abilities, and gain experience researching and interpreting incomplete or poorly documented technical information. Student feedback and final project presentations consistently reflect a strong sense of accomplishment, increased confidence in engineering practice, and pride in their completed work. As such, the senior capstone experience remains a critical component of electrical and computer engineering education and continues to align with the outcomes and expectations established by the Accreditation Board for Engineering and Technology (ABET).

The three human-centered capstone projects discussed in this paper demonstrate that human-centered design principles can be effectively integrated into ECE capstone courses without diminishing technical rigor or disciplinary depth. By grounding engineering design in authentic user needs, stakeholder engagement, and iterative validation, these projects illustrate how human-centered approaches can be naturally embedded within traditional ECE activities, including system modeling, hardware–software integration, and performance evaluation. Collectively, these examples highlight the value of human-centered capstone experiences in preparing graduates who are not only technically proficient but also equipped to design engineering solutions that are responsive to real-world human needs.

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