**Abstracts of Capstone Projects**

**April 2021**

**The Crop Doctor: A Fruit and Crop Monitoring System: B1**

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**Advisor:** Professor Bahram Shafai and Professor Taskin Padir

**Abstract**

The Crop Doctor system was built and designed to reduce the risk that farmers, especially small farmers, experience in their everyday job activities. This system provides a cost efficient and effective way for farmers to analyze the health and ripeness of their plants. There are many industries that would benefit from cheap, autonomous laborers, reducing the risk of human injury. This system has a broad range of different use cases allowing it to be tailored to different environments based on the users end goal. From aiding conservationists, who monitor forest fires, to small farmers who make up the largest percentage of American farming operations, the Crop Doctor is crucial in ensuring an overall safer work experience.

The Crop Doctor was designed with ease of use in mind. A GUI was designed to allow for easy visual control over the system. This GUI provides the option for manual and automated control of the Crop Doctor. The manual setting allows the user to control the movement of the Crop Doctor using a traditional directional pad setup with a stop button. Furthermore, manual measurements allow for the type of fruit that is being analyzed to be selected from a dropdown bar and a button also allows for control over when measurements should be taken. The automatic side of the GUI requires the user to select which fruit or crop is being tested or analyzed. This is achieved by providing the user with buttons that correspond with easy to customize pre-determined paths throughout various crops on a farm. The paths also have preset stop points along the path that the Crop Doctor will pause at to take the measurements needed to determine the health of the fruit or crop. The GUI also displays a table providing the user with real-time feedback and health reports on the plants that are being sampled. The Crop Doctor utilizes a color sensor to determine the ripeness of crops. An enormous range of fruits can be categorized into underripe, ripe and overripe based on the color of their skin, in using the color sensor we are able to categorize the fruit. A camera module is also implemented onto the Crop Doctor to allow for further analysis of crops. The images taken are processed using the deep learning library in MATLAB to also categorize the fruit into underripe, ripe and overripe. A Bluetooth module is also implemented to allow for wireless control over the Crop Doctor.

To ensure that it provided accurate reports of the ripeness of fruit, The Crop Doctor was subjected to an extensive amount of testing. The Bluetooth module underwent the most testing as it is the key connection between the control GUI and the Crop Doctor. It was tested by sending and receiving control commands and RGB data from the color sensor. The color sensor also underwent individual tested along with integrated system testing. A variety of different colored objects were used to help fine tune the sensor to ensure it was accurately picking up the intended colors. The camera module’s testing helped to accurately generate clear images. Originally, the captured images were grey scale, however, we were able to manipulate the data transmitted to also include color data for each image.

**Myolink: Arm Control Brain-Computer Interface: B2**

**Team Members:** James Lee, Kathleen Martin, Yi Zhao, Shane Walsh, Erin Raftery, Andy Kim

**Advisor:** Professor Bahram Shafai

**Abstract**

The Myolink team designed and constructed an arm-controlled brain-computer interface (BCI) device which stimulates muscle contraction in the test subject. This system measures electromyographic (EMG) signals, translates these analog inputs into digital control signals through filtering and amplification, and then triggers transcutaneous electrical nerve stimulation (TENS) to induce muscle contraction in another person. *The Myolink features completely wireless communication between the “controller” and the “controlled” person, as well as multiple muscle targets*. BCI techniques have been explored for neuromuscular rehabilitation and therapy because they allow for reinforced learning through simultaneous motion control and motor imagery. The Myolink device could be used as a simpler approach to this concept with applications in physical therapy, disease recovery tracking, and body movement instruction. Further iteration on such a device could lead to functional electrical stimulation to help paralysis patients exercise or use sign language.

To use the Myolink device, the user must first select a muscle stimulation target and locate the corresponding nerve needed to produce the desired action. The Myolink device can accommodate up to two separate nerve stimulation targets. Two measurement electrodes are placed on the forearm of the “controller” and a third ground electrode is placed on the back of the hand. The controller flexes his or her forearm to generate a potential difference at the muscle of interest. Gel on the electrode pads mitigates the effects of skin impedance, and an instrumentation amplifier uses common-mode rejection to filter and amplify the EMG signal. A bandpass filter removes high-frequency noise while amplifying the millivolt-order signal with a high gain. This higher SNR signal is received by the Arduino serial port, which maps the signal amplitude to a range of digital values. A MATLAB script then sends the amplitude data over Bluetooth Low Energy (BLE) to a secondary Arduino Nano microcontroller. The microcontroller then manipulates the resistance of the potentiometers, scaling the applied voltage to the controlled person. This scaling factor is calibrated per test subject via a GUI based on his or her physical reaction to the initial applied signal. The electrical signal is finally passed to the second person through a corresponding pair of electrodes, inducing local muscle contraction. When the controller flexes his or her muscle, the corresponding muscle in the controlled person flexes on command.

Testing of the Myolink system was conducted in the ECE Capstone laboratory at Northeastern University. An initial experiment was run to observe and record a library of output movements at various electrode placements. The completed system was tested by placing electrodes on the forearm based on a reference photo. Electrode placement was critical to avoid crosstalk. The upper bound of the TENS output voltage was carefully chosen based on user feedback such that the highest intensity allowed was still comfortable. These voltages and their corresponding digital identifications were recorded and set as the testing range in software. The controlled subject was blinded to ensure he or she could not predict the motions of the controller.

**Multi-Effects Smart Pedal System: B3**

**Team Members:** Ethan Axelowitz, Caleb Fields, Liam Moynihan, Zachary Stern, Haley Weinstein, Jeff Zhou

**Advisor:** Professor Bahram Shafai

**Abstract**

We have created a low cost, modularized pedal board system for string instruments that can dynamically load and combine analog and digital musical effects. For decades, guitarists have used pedal boards to change their sound as they play, but pedal technology has been stuck in the past. Guitarists could choose between using either a single effect or being forced to buy multi-effect setups that are expensive, heavy, and hard to navigate. Furthermore, current pedal systems require users to completely rewire their pedal connections if they want to schedule their effects differently. Our team has modernized pedal design by creating an advanced effect switching framework that allows effects to be easily rearranged and applied through a lightweight and intuitive mobile application. By combining analog and digital effects in one platform we designed a system that has the flexibility of digital effects without sacrificing the low latency of analog effects.

A Raspberry Pi controls the effect switching architecture while also hosting an API server written in Python with Flask that the mobile app communicates with. The mobile app is written in React Native so that it is compatible with both iOS and Android. The user can use the application to load effects onto any of their connected pedals, and optionally chain together multiple effects to be played together on a single pedal. When they are happy with their setup, the user can simply press apply changes and they’ve got a new pedal setup in seconds without any of the hassle of rearranging and rewiring by hand.

We designed 2 analog effects, overdrive and fuzz, with a custom-made 4-layer PCB. The PCB provides inputs to the guitar amp and outputs to a speaker via aux cord. Control signals are sent from the Raspberry Pi to our PCB via GPIO for our switching architecture implementation and via I2C for our digital potentiometer implementation. The PCB was fabricated overseas and assembled using a variety of SMT and through-hole components in the Capstone lab.

The digital effects were implemented on a Texas Instruments Digital Signal Processing Development Kit. This kit has a high rate AIC23 codec and a large IRAM partition allowing our group to perform fast calculations with long buffers. We developed modularized control systems for families of effects, simulated the effects in python, and then coded the effects in C to test on the development board using the Spectrum Digital USB Emulator. In total, we wrote code for over 14 effects, and the platform has the ability to add more effects with no additional hardware.

With our Raspberry Pi, PCB, and DSP connected together, the user can then select an effect by pressing one of 3 pedals. With an array of multiplexers and control input from the Pi the pedals easily select and activate the correct effects for the users in a simple and seamless system.

**Self-Sustaining Sound Harvester (SSSH): B4**

**Team Members:** Madisyn Dudley, Seamus Egan, Hamaad Hafeez, Olivia Hagedorn, Joshua Toby, Derrin Wang

**Advisor:** Professor Bahram Shafai

**Abstract**

The SSSH team designed and assembled a system to convert sound energy to electrical energy. This system has many practical applications due to the excess sounds generated from everyday sources such as trains, heavy machinery, traffic, and music just to name a few scenarios. As the world shifts in a more environmentally conscious direction, the reliance on green energies will increase thus raising the demand for new ways to harness energy without damaging the environment. The SSSH team proposes using a bending piezo transducer to convert vibrational kinetic energy, in the form of low frequency sounds, to electrical energy that can be both stored and used instantly much like existing photovoltaic cell technology.

To implement the SSSH system, the piezo transducers are wired in series and mounted to a protective enclosure forming a flat array of varying dimensionality depending on the available space. This panel of transducers can then be securely mounted to a surface near a source of loud low frequency sounds. The piezo transducers series circuit is connected to a Greinacher voltage doubling circuit that both rectifies the AC voltage provided by the transducer and doubles the positive voltage. The output of this circuit is a DC voltage that can be used to charge batteries as well as power electronic devices.

To validate the SSSH system, the team performed tests and experiments in the lab and in simulation. Due to the prohibitive costs of high quality bending piezo transducers, only one was purchased. The SSSH team characterized this transducer in the lab to accurately model it in simulations. From there, the team took their experiments in two directions: physical simulations and computer simulations.

The physical simulations were performed in the lab to model the behavior of multiple piezo transducers, the output of the single transducer was connected to an amplifier before being plugged into the voltage doubling circuit. The team proceeded with several tests using a subwoofer, a type of loudspeaker designed to excel at producing low frequency sounds, in order to evaluate the feasibility of this system. These tests included charging a NiMH AA battery as well as powering an LED. Adjustments were made to determine the optimum environment and the results indicate that the SSSH system works most efficiently in an enclosed space where sound is better contained. The computer simulations used multiple AC voltage sources modeled with the transducer’s characteristics to simulate the behavior of a multi-transducer circuit. This simulation was used to test different impedance loads and more complex circuits such as a robust battery charging circuit, as opposed to a simple one made in the lab. The SSSH team believes that further testing in practical environments with more transducers will be required to truly prove the reliability of the SSSH system, but the team’s conclusion is that there is a lot of potential in harnessing sound to produce electricity.

**Visual Hearing Aid: B5**

**Team Members:** [Josie Rowean](mailto:rowean.j@husky.neu.edu), Noel Prince, Brandon Zhang, Gus Pearl

**Advisor:** Professor Bahram Shafai

**Abstract**

The Visual Hearing Aid team has designed and built a system to amplify sound that originates from the user’s gaze. In the last 20 years, there has been a lot of work on sound source localization and eye tracking, but they have largely not been used together for real-world applications. Wearable technology has become more popular in recent years and this technology has a wide range of applications from recreational activities like hunting or birdwatching to accessibility aides or even security and defense where the user needs to identify the location of a sound quickly.

To use the visual hearing aid, the user needs to wear the headset and adjust the camera accordingly. From there the user just needs to start looking in different directions and begin focusing on a designated position. The computer/raspberry pi running the algorithm will output the amplified sound, that is originating from the user’s gaze direction to the headset. The camera that is being used in the pupil tracking is a basic raspberry pi camera with the IR filter removed. Removing the IR filter allows the image captured to be infrared which allows the algorithm to track the pupil better. Using PyGaze and pupil labs, the visual hearing aid makes it possible to track the pupil and calculate an eye vector. There is a microphone array attached to the top of the headset which will capture sound around the user and help determine the direction of the sound’s origin. This integrates perfectly with the ODAS software which allows the visual hearing aid to compute a sound vector. The eye vector and the sound vector are then combined to amplify sound where amplification is tied to a decrease in radian distance between the vectors.

For testing and validation for eye tracking options, we did a minimum feasibility test for different cameras where we tried to get them outputting video and then tried feeding the camera stream into Pupil Labs. This worked for our first piece the Microsoft HD 6000, but that process then failed when we tried to remove the IR filter. Next, we tried the NoIR camera from raspberry pi and were able to feed the stream directly to pupil labs over a local network connection, which means that we do not have to physically connect the x64 processor and the raspberry pi. For testing and validation for ODAS, we used the ODAS web framework. The web framework provided a visual representation of the data we received from the ODAS algorithm where targets are tracked with lines connecting localization data points, which we used to verify that the correct amount of sound sources were being detected from the expected direction.

**Autonomous Pollen Harvesting Drone** (**APHiD): J1**

**Team Members:** Carolina Binns, William Hughes, Jacob Kaplan, ArDelia MacPhail, Alena Porter, Shane Powers

**Advisor:** Professor John Kimani

**Abstract**

APHiD is a drone that implements autonomous navigation and machine learning to recognize and harvest pollinating flowers. Nearly 75% of crops rely on pollination, but several species of pollinating insects are at risk or endangered. Farmers use harvested pollen to supplement natural pollination by using drones to distribute pollen, adding it to existing beehives, or implementing custom blowers on ATVs. As artificial pollination becomes more common, the demand for harvested pollen will increase. Current pollen companies harvest pollen by hand. APHiD is capable of collecting flowers and delivering them to a centralized location where the pollen can be harvested, processed, and sold to farmers. APHiD offers an efficient and cost-effective alternative to harvesting by hand by combining object detection, image recognition, and autonomous navigation.

As APHiD flies, images from a Raspberry Pi Camera Module mounted on the drone are streamed to a base station for processing. The base station consists primarily of an Nvidia Jetson Nano which is used to perform object detection on the video input. A trained object detection model, optimized for specific blossoms, is loaded onto the Jetson Nano board. This will output information about where flowers are in the drones view and how confident the model is that they are the correct flowers. This information will be sent back to the drone by way of the on-board Raspberry Pi. The Raspberry Pi receives a list of bounding boxes from the Jetson Nano based on the detected flowers. The bounding boxes each have a corresponding confidence rating and pixel coordinates to determine the location. The Raspberry Pi runs a navigation script that translates this information into the appropriate movement for the drone, and sends the necessary commands to the APM2.8 flight controller.

In order to focus on retrofitting the drone with components for environmental manipulation and programming navigation and image recognition, a frame kit was purchased and assembled. The kit came with a APM2.8 flight controller, four 30A speed controllers, a GPS, motors, and propellers. An RC transmitter and a LiPo battery were purchased and installed separately. After fully calibrating the drone and connecting the RC transmitter and receiver, the drone was observed to flip and crash on multiple occasions. After consulting with an expert on control systems, it was decided that this was due to a malfunction of the flight controller. It is the belief of the APHiD engineers that had a new flight controller been available, APHiD would have functioned as planned.

**Urban Acoustic Device (UAD): J2**

**Team Members:** Fan Fei, Fernando Nunez Santos, Diandian Yuan, Dillon Johnstone, Sam Baumgartel

**Advisor:** Professor John Kimani

**Abstract**

The UAD team has designed and built a system for counting the number of vehicles that pass in a single direction on a road, as well as taking ambient noise readings in that area. This can be used in cities around the world to modernize the way cities collect traffic data, as well as give urban planning committees insight into the noise affecting the cities’ citizens. Boston, for example, still hires human beings to manually estimate street traffic in the city based off of video feeds. These devices would save money for cities and towns that implemented them and would collect more valuable and accurate data. Built into this value proposition is the ability for cities to simultaneously collect ambient noise data. This data has been used in cities in Europe to build structures that could reduce overall noise levels or reduce the presence of specific frequency spectrums for the sake of their citizens' hearing and emotional health.

A single unit consists of three microphones, a Raspberry Pi, and a solar power block with a battery backup supply. Two microphones are pointed at the street from above, generally aiming for the tires of the cars passing by. The data from these microphones are taken in the Pi, filtered to zero in on the exact frequencies we expect from passing cars, and analyzed for peaks using RMS analysis. A spike is generalized as a passing car, and results of the two microphones are compared in order to tell whether a vehicle is passing from left to right, or right to left based on thresholds. The third microphone is used to simply take in ambient noise data, which is later used to analyze noise levels, as well as the frequency spectrum of the noise in that location. An interface has been created to show how someone could look at noise data in any city around the world that uses these devices. A solar panel is used to recharge a battery which powers the pi, which then in turn powers all the microphones.

Our prototype was tested and utilized around campus. This allowed us to test busier, noisier locations like Huntington Avenue, as well as quieter one-way streets such as St. Stephens, by Stetson East. We used data from each environment in order to optimize our filtering and algorithm to detect vehicles in various situations with various levels and types of background noise. Testing around campus also allowed us to acquire actionable noise data, showing us which parts of campus near roads are louder, quieter, or experience different kinds of frequency spectra. This testing was done with a single unit, but in the future, we would have liked to create more units to enable simultaneous analysis of different locations, as well as test options for wirelessly communicating data from unit to unit, or to a central terminal.

**Camera-Based Identification of Objects for Dementia Patients - Third Eye: J3**

**Team Members:** Harmony Chen, Seamus Maxwell, Kelly Ostrom & Jason H. Sauntry

**Advisor:** Professor John Kimani

**Abstract**

Over 5 percent of adults over 60 years of age are afflicted with Dementia ([WHO](https://www.who.int/news-room/fact-sheets/detail/dementia#:~:text=Worldwide%2C around 50 million people,dependency among older people worldwide.)), an umbrella term for a range of symptoms associated with cognitive impairment. Many early-stage dementia patients are capable of living unassisted, but certain symptoms, such as inability to recognize objects, can make this more challenging. Assistive devices can mitigate these challenges. Our device, Third Eye, is a tablet-like assistive device designed to assist Dementia patients in recognizing everyday objects.

The core of our device is an artificial neural net used for image processing. It takes input from the device’s camera and identifies objects such as bowls or spoons in its field of view. The neural net uses a series of interconnected hidden layers of nodes to pick out objects, then uses a final output layer to classify them.

Machine learning, such as an artificial neural net, is computationally expensive, so Third Eye requires hardware with significant computational power. However, the device is handheld, so small size and low mass are also important. To balance these needs, Third Eye’s microcontroller is an NVidia Jetson Nano, a small but relatively powerful system on a chip with an ARM64 processor running Ubuntu Linux. Third Eye also uses a Raspberry Pi Camera V2 for input, a small WaveShare touchscreen for output, and a 92.5 Wh battery for power. This hardware is contained within a custom 3d-printed case.

Third Eye’s target demographic — elderly dementia patients — often struggle with learning new skills and with technology. For easy adoption, Third Eye’s user interface (UI) must be simple and intuitive. It achieves this using a “want: touch” paradigm, where the user simply touches what they want. The UI opens to a fullscreen camera feed, allowing the user to see the camera’s field of view. When the neural net identifies one or more objects, it is highlighted and labelled over the camera feed. Tapping one of these objects opens a video that demonstrates the use of the object. The user can return to the camera feed using a large “back” button, or by pressing a physical button located on Third Eye’s case. This is a simple UI that should pose minimal difficulty to learn.

Third Eye uses an artificial neural net to identify objects. It is presented in an easy-to-use user interface and packaged in a handheld form factor. It is our hope that its identification of everyday objects will help dementia patients live independently.

**DeepLift Workout Assistant: J4**

**Team Members:** Christopher Bunn, Nicholas Fresneda, Matthew Hoffman, Samuel Horstman, Alexander Tapley, Yajing Wang

**Advisor:** Professor John Kimani

**Abstract**

The COVID-19 pandemic greatly increased demand for home accessible fitness devices. The barrier of entry for these devices is their cost, typically exceeding $1,000, in addition to subscriptions for premium training services. With specialized hardware and utilization of open-sourced software, the cost of these products can be greatly reduced.

DeepLift is a home-fitness solution that provides a standalone mobile app and a smart mirror equipped with a camera, allowing users to workout with whatever tools they have available. By displaying a QR code generated via the mobile app to the smart mirror, users can activate various workouts. The smart mirror and app communicate session info through our custom FastAPI service, which interfaces with a MySQL database hosted on Amazon’s RDS (Relational Database Service). The mirror uses its camera and a pre-trained, open source, pose estimation computer vision model called trt\_pose to detect keypoints on the user’s body. Trt\_pose uses the torchvision module of PyTorch along with NVIDIA’s TensorRT SDK to enable real-time pose estimation to produce keypoints for a user. These keypoints are overlayed onto the camera’s image in order to provide the user with detailed analytics of their workout, such as reps completed in the instance of squatting, and whether proper squat depth has been achieved.

The workout assistant counts reps and determines squat depth by analyzing the position of the hips and knee keypoints. If the hip keypoint is close to the same vertical position as the knee keypoint (roughly parallel), this is considered proper squat depth. Reps are counted based on how many times a user goes from a proper squatting position to a standing position, which is determined by calculating the knee angle (if it is close to 180 degrees, the user is standing). Keypoints are highlighted as different colors based on which state (red for standing, yellow for mid-squat, or green for squat) that the user is currently in. These states help the user determine when they reach the proper depth.

Upon ending their workout, users can review a recording of their workout and the various analytics, which are uploaded via FastAPI to an Amazon S3 Bucket, through the mobile app. The mobile app includes user profiles where they can view their workout summaries, a history of workouts they’ve completed, along with the difficulty and reps completed for each session. The start and finish of a workout is also controlled through the mobile app. With FastAPI endpoints, the mobile app updates variables in our MySQL database which the mirror will monitor for when to finish a workout. The mirror also uses additional endpoints to create and update workout data in our database, as well as upload the final video to S3. The mobile app then uses this data and videos to populate the “Past Workouts” screen in which the user can view all of their previous workouts’ data and analytics.

**Robotic Vacuum Platform for Introduction to ROS and Robotics: J5**

**Team Members:** Michael Almonte, John Caldwell, Artur Symonenko, and Edward Burke

**Advisor:** Professor John Kimani

**Abstract**

There are not many resources easily found online that illustrate a complete tutorial for how to get started with ROS with both software and hardware instructions. Existing options start with the assumption that the reader has already either bought a fully functional pre-assembled kit or has the knowledge to have already created a custom robot with the appropriate parts and focuses immediately on the software implementation. This project aims to bridge this gap by providing instructions on how to get started with ROS from scratch. This includes constructing the robot platform itself with a typical sensor suite, then moving on to installing, configuring, and running the software. Finally finishing with a direction for future learning/project ideas.

We realized that with our initial vacuum robot design, we were being too specific with our guide. We decided that a more generic design, highlighting the numerous capabilities of ROS would be the best way to solve our problem statement. Here, we have designed and built an educational, modular, robot kit with mapping and location capabilities, the basis for most common projects and use cases. Through the use of ROS, we are able to create publisher and subscriber nodes to control the robot, while mapping a given space in real time. A user of our guide would then simply modify the publisher script to fit their own needs, whether it be patrolling an area, autonomous navigation as vacuum, or however they see fit.

**Navigation Architecture in Known Environments with Decoding: T1**

**Team Members:**Thomas Campion, Ali Celik, Allen Lee, Patrick Moore, Canon Sawrey, Barry Yung

**Advisor:**Professor Taskin Padir

**Abstract**

This paper discusses the design and implementation of a low-cost, mobile sanitation robot that navigates a known environment using fiducial markers. (Insert Current Relevance of Project) Minimizing human contact and repeatedly sanitizing known environments could prove to aide in combatting the spread of this deadly disease. Furthermore, development of low computational cost robotic navigation using fiducials has many potential applications across multiple industries.

For this project, the team developed NAKED, a small mobile robot that when be placed in known environments sanitizes tasks autonomously. This was accomplished by using a Rosbot equip with an Orbbec Astra RGB-D camera and using QR codes as fiducial markers. When navigating, the Rosbot will scan the known environment and map it in order to calculate a path to the next fiducial marker. Markers will take the form of QR codes strategically placed around areas in need of sanitation and they contain information about the location of other markers and targets. Each time a QR code is read, the Rosbot then uses libraries like Open CV to decode stored information in markers and rely on path finding algorithms to navigate to the next marker. By using an initial marker, the Rosbot would have the ability to fully navigate an environment autonomously and sanitize targets along the way. Sanitation is performed with a spray nozzle outfitted with a pump attached and powered by the Rosbot.

When implemented, this robot will reduce the contact humans need to have with potentially high-risk environments such as public transportation cars, classrooms, and other target locations of similar scale. This paper shall serve as a design document detailing the intended approach to solving the problems presented. This research and development effort is guided by the Electrical and Computer Engineering Department of Northeastern University.

**AVATAR XPRIZE Northeastern:**

**On-Axis Motor Controller System with ROS Integration: T2**

**Team Members:** Anja Derric, Karl Swanson, Peter Downward, Peter Albanese, Spencer Sochin, Shay Blechinger-Slocum

**Advisors**: Taskin Padir, Peter Whitney

**Abstract**

The AVATAR Team has designed a motor control system enabling a human-manipulated exoskeleton arm to direct the motion of a robotic avatar arm. This capstone supports Northeastern University’s effort towards the ANA Avatar XPRIZE Challenge. It is a $10M competition in which teams compete to create an avatar system capable of transporting human presence remotely in real time. This robotic system will allow humans to manipulate environments from a distance and bypass their own physical limitations. Northeastern University has qualified as one of 38 international semi-finalist teams in the challenge. To further this effort, the Spring 2021 AVATAR team enabled synchronous avatar and exoskeleton motion through a custom motor controller network, robust communication protocol, and a simulation created with the Robot Operating System (ROS).

The design approach for this challenge was to use a parallel development effort between the Computer and Electrical Engineers on the team. Iterating on a previous capstone’s existing mechanical avatar system enabled communication and electronics to be the sole focus of this year’s project. The electrical team developed a custom four-layer printed circuit board (PCB) with optimal signal routing and low-latency communication. The motor controller is capable of both RS-485 and CAN communication and contains reliable SPI lines between the STM32 microcontroller unit and absolute magnetic encoder. The layout perfectly aligns the encoder chip with the corresponding motor rotor, leveraging the existing single-axis mechanical design.

The software team developed firmware for the custom motor control boards capable of reading encoder positions of motors. The RS-485 standard was used to create a request/response protocol between PC and firmware where the PC requests motor positions from the PCBs on the exoskeleton. The position information was published to ROS topics where the ros\_control library was leveraged to achieve motion in Gazebo simulations and the real world. Off-the-shelf ODrive motor controllers interfaced with the ROS network to control the avatar arm. Additionally, we attained force feedback between a physical motor and the avatar arm in simulation.

The Spring 2021 AVATAR team created an integrated communication pipeline; the user interfaces with the exoskeleton, motion is tracked and tested in simulation, and physical motion on the avatar arm mimics that of the user. However, the team was unsuccessful at calibration using custom motor controllers, resulting in a dependency on the ODrive boards for avatar arm motion. Due to the eventual public use case of the Avatar System, a breakdown of the system’s safety features and a user guide for future developers is included in the report. For teams that will continue development, the Spring 2021 AVATAR team recommends fully integrating haptic and visual feedback in the physical system with the custom PCBs. We are confident this improvement will ensure an immersive user experience and bring Northeastern even closer to competition goals.

**Food Waste Reduction System: T3**

**Team Members:** Michael Curley, Jared DuPerre, Ethan Dwyer, Jacob Londa, Christopher Magana & Anthony Rizzo

**Advisor:** Professor Taskin Padir

**Abstract**

Food waste is a global issue that has severe economic and environmental impacts. There are a multitude of reasons why people discard food, one of which is that they rely entirely on scent: a subjective and often deluded perception of spoilage. To combat this problem, our group has designed and constructed a full system to track food spoilage and inform the user of its freshness. With this “smart tupperware” system in place, users would be able to monitor the freshness of their meat via a mobile application, thereby reducing the subjective nature of spoilage. Although our module is intended to work as a household product its usefulness could extend to commercial applications, such as bulk meat storage.

The flow of information in our system is simple. It begins with spoilage detection in a tupperware vessel via gas detection. Because decaying meat emits various types of gases, we have developed a sensor module, referred to as the Lid Module, that is capable of quantifying these concentrations. These analog sensor values are read into a microcontroller, which then advertises the data to an external router over Bluetooth Low Energy (BLE). Given the limited budget, we made the decision to simulate data at the microcontroller level, as our sensors were unreliable and inaccurate after several tests. The proof of concept, however, seems to be a valid approach, pending further testing and the use of more accurate sensors.

The router component is a simple concept but acts as the central device in the whole system. In order to extend the battery life and reduce the complexity of the Lid Module, the router software does all the main data transmission for each Lid Module (each router component can track up to eight Lid Modules at a time). The router follows a three-step procedural loop to achieve desired functionality. First, it advertises a unique UUID via BLE that may be scanned by the mobile application so that one, or several, routers can be associated with a single user. Second, the router fetches Lid Module Bluetooth MAC addresses from the backend that have been associated with the router’s UUID. Third, and finally, the router scans for each of these addresses and gathers sensor data from each Lid Module. This data is then sent to the backend via our custom API and a “freshness” value is returned. This freshness value is then written to the Lid Module where it is translated to an LED state for the user to physically see. It represents whether the food is fresh, almost spoiled or completely spoiled; these values are subjective based on the results of backend calculations.

The mobile application is the component that allows the user to create an account, associate a router and lid modules with it, and view real time data related to their modules. Written in Kotlin and developed for Android devices, the application provides a simple interface that allows a user to control their experience and track the status of their lid modules.

**Demeter The Bell Pepper Harvester: T4**

**Team Members:** Amrit Ramesh, Juan Pablo Bernal, Kevin Lewis, Ziyi Yang, Santiago Delgado and Juan Carlos del Pino

**Advisor:** Professor Taskin Padir

Team Demeter has designed a computer vision system surrounding the Kinova Jaco arm to autonomously pick ripe red bell peppers. The basis of this project was an understanding of the deficiencies of current farming practices when it comes to bell peppers. More specifically, mechanical harvesters, while very fast, are not very effective at distinguishing between ripe and unripe peppers. Furthermore, red peppers do not ripen all at once so a harvester must be able to tell between ripe and unripe peppers. At the same time, more modern robotic harvesters, while very effective at distinguishing ripeness and therefore generally more precise in picking peppers, have some limitations when it comes to their high cost and their speed. With that said there currently are not any commercially viable robotic bell pepper pickers. Ultimately, while we don’t aim to improve on the SOA systems algorithms, hardware, communication, and general speed we do think we can create a rivaled system that is lighter weight, cheaper, and potentially commercially viable.

For the actual design of the pepper picker, we decided to use a net and blade apparatus attached to the Kinova robotic arm such that we could grab, cut the stem, and transport the pepper to a basket. In order to actually recognize the pepper, we used a stereo vision camera module that would not only help us detect ripeness but also help us determine the distance so we can actually pick the pepper. More specifically, as the arm moves, we used one of the cameras to scan through the field of peppers. Whenever the camera detects red, we then stop the movement and used computer vision algorithms to move the arm to get that red object fully within the frame. Finally, we create a bounding box around that red object and send that bounding box image to an ML model that predicts the probability that it is a ripe red bell pepper. In this case, we use the pre-trained ImageNet model trained on the VGG16 architecture. If the red object is a pepper, we will then use the depth of the stereo vision to find the correct 3D position of the target with respect to the arm. The recognition system was run in a Raspberry Pi 4 Model B that communicated using ROS services to a computer running the arm driver. Moreover, a third computer was used to run the machine learning model since the Raspberry Pi was not powerful enough.

To test and validate the system we hung three peppers so that two red would appear in the same frame and a third green pepper would exist to show how the system would handle seeing an unripe pepper. This proved the recognition system can handle seeing two peppers and picking one first, and then the other. This also proved that the stereo vision gives accurate depth, and the hardware can handle cutting through a pepper stem. Results showed that Demeter was able to do everything successfully except cut the stem because the fingers of the Jaco arm did not have enough strength.

**Eyeris: W1**

**Design Team:** Celine Estrada, Muhammad Ghafoor, Jemin Park, Sashank Srinivasan, Kevin Yu, Vincent Zhao

**Advisor:** Waleed Meleis

**Abstract**

285 million human beings currently suffer from low or no vision, 85% of which are elderly. Every year, this number grows by about 2 million people. Since WWI, the white cane has been the primary source of sensory assistance that provides much needed independence to the visually impaired community. By tapping or sweeping the cane from side to side, users trigger their auditory and somatosensory senses and gain a better understanding of their immediate surroundings. However, users can only detect obstacles, cracks, dips, stairs, and terrain at a maximum of 1 meter away and below the waist. This tool, while essential for many, is antiquated, and is in much need of improvement. In fact, a study concluded that over 50% of visually impaired cane users suffer from at least one fall accident per year, with 36% requiring medical intervention.

Our proposed solution, Eyeris, is a modular system that enhances the user’s cane and addresses these shortcomings. It consists of a few primary modules: obstacle detection, audio and haptic feedback, app connectivity, power, and support for external services. Obstacle detection is performed with three time-of-flight sensors oriented to detect obstacles both in front and above the waist between 1-2 meters away. The resulting area of coverage is increased by 3 m2. Data from the sensors is processed by our microcontroller unit (MCU), a Raspberry Pi Zero W, by a high-performance application written in C++17. This data is used to determine the audio and haptic feedback response produced by a speaker and linear actuator respectively based on the user’s orientation and distance from the obstacle. The speaker verbally describes which sensor detected an obstacle and its distance. The linear resonant actuator identifies the active sensor using a distinct number of clicks and provides a repeating pulse at a variable frequency depending on the distance to the obstacle, controlled by a custom userspace driver. The main controller application utilizes multithreading to provide this feedback in real-time.

White canes are unique to the user, so it is important that each user can implement their Eyeris experience as a seamless extension of their current cane. Eyeris accomplishes this by minimizing its footprint; a custom printed circuit board links the MCU with the peripheral sensors, as well as an integrated audio amplifier and team-designed power regulator. The entire system is powered via a lithium-polymer battery which will provide at a minimum 12 hours, and a maximum of 17 hours of use. Eyeris is housed in a compact 3D-printed enclosure, specially designed for a universal mount that attaches to any white cane of the user’s choice.

While capable of operating standalone, the Eyeris system can be further enhanced using a companion iOS app. The speaker voice and number of sensors can be configured via the application. Configuration and sensor data are communicated between the Eyeris system and the companion application, designed in Swift, via Bluetooth Low Energy. The application also leverages the power of the user’s mobile device to add new features; the user can capture their current surroundings using their device’s camera and analyze the footage with Google Vision to determine common landmarks, user orientation, user location, and more. This will help users ensure they have arrived at the correct location or are going in the right direction.

Overall, Eyeris provides long-range obstacle detection, obstacle detection above the waist, feedback control, location identification features, and universality. Similar solutions like the WeWalk replace the user’s current cane rather than supplementing it, have a shorter obstacle detection range, and cost more than five times as much; our system is better equipped to protect the safety of our users.

**Descart: W2**

**Team Members:** Justin Adams, Nicholas Hughes, Julian Perez, John Su, Vlad Vandalovsky, Harrison Wong

**Advisor:** Professor Waleed Meleis

**Abstract**

The retail industry has greatly expanded from just traditional brick-and-mortar stores with the emergence of e-commerce, prompting an exponentially wider selection of products accessible to everyone. Additionally, the COVID-19 pandemic has forced many people to stay at home, prompting increases in online shopping and furthering the divide between the convenience of large online marketplaces and smaller businesses. With this in mind, our team has set out to create a cross-platform and privacy-conscious application, Descart, that centralizes a user’s purchase history across all (online or in-person) vendors to offer personalized recommendations for their next purchase. Through this, we hope to help bridge the gap between large e-commerce businesses and smaller businesses. A user can be connected to both their past purchases with a convenient consolidated purchase history and connected to their next purchase with item recommendations that aren’t limited by the seller. This gives smaller businesses a larger online footprint that can grant them more exposure and patronage from users that would otherwise be overshadowed by larger businesses.

Descart is a mobile application composed of five main components: the frontend UI, the database, the recommendation engine, the backend, and the data adapter. The UI, written in Dart using the Flutter framework, is the application that users see, and allows them to find product recommendations, add them to a shopping list, or see a list of their past purchases. Other functionalities include infinite scroll, searching products/purchases, filtering by categories, and manual input of purchases. The MySQL database stores persistent data like user information, product data, past purchases, and all other data served to the user. The recommendation engine takes individual users’ past purchase data and generates personalized recommendations. The engine is created using AWS’s Amazon Personalize service, which uses their own machine learning algorithms to create and train a customized recommendation engine. The backend is written in TypeScript using the Nest.js framework and developed with a Node.js runtime environment. It connects these three components, the database, UI, and recommendation engine, by sending and receiving data between them. The data adapter is a separate component of the application that is made up of smaller data components that gather, parse, and insert product or purchase data into the database.

Competing companies that our app shares the purchase tracking and recommendation space with are Google Shopping and Amazon’s online marketplace. These services are limited in their offerings due to either a lack of recommendations for brick-and-mortar stores or limited to products within their own company. Our app provides recommendations that can be traced across all vendors and gives users the freedom to choose among a variety of offerings, supporting large and small businesses alike.

**Kanesthetic Learning  
The power to spontaneously explore new places: W3**

**Design Team:** Joshua Alter, Nicholas Craffery, Daniel Peluso, Nithila Raman, Neil Resnik, Katharine Welch

**Advisor:** Professor Waleed Meleis

**Abstract**

Our capstone project joins Northeastern's Enabling Engineering club and Professor Mona Minkara to help those with visual impairments. Our goal is to create alternative infrastructure to communicate medium range navigation and geographic information. Through this collaboration we aim to simplify navigation and landmark identification for those with trouble and have designed a cane attachment to facilitate.

Through extensive research we have concluded that a combination of ultra high frequency radio-frequency identification (RFID) and bluetooth will allow this to come to fruition. The design incorporates an RFID reader and bluetooth receiver to act as the main ‘identifiers’ and RFID tags and bluetooth beacons to act as methods of information dissemination. By leveraging the advancements made in these respective radio wave fields we will be able to handle the retrieval of both static and dynamic information with your cane from a range up to 50 feet. Using the same bluetooth chip, we will be able to output the information auditorily via a paired bluetooth device or the built in audio-jack. Extra functionality will be available with a companion application such as history or setting modification.

The goal of the project is to encourage large entities such as a university, hospital, or city to purchase and set up a number of tags and beacons to make their environment accessible to the visually impaired. The tags will display information such as an office number and professor’s name whereas the beacons will hold longer information like a restaurant’s menu and hours.

Our product exceeds other similar products on the market because of its price, adaptability, and reusability. Smart canes currently on the market cost upwards of $500 while the Kanesthetic attachment can be sold for $300. As it is an attachment, it can be added to any existing cane and does not need to be replaced. While there is a companion application with added features, the product can be used without a smartphone or data.

**Αthelαs: An Autonomous Vitals Measuring Robot for Nursing Homes: W4**

**Design Team:** John Allen, Akhil Bagul, Kaylin Devchand, Christian Hardy, Unnas Hussain

**Advisor:** Waleed Meleis

**Abstract**

In the era of COVID-19, nursing homes and assisted living facilities have fallen under greater strain to keep their patients and caregivers safe. Nursing staff are given more responsibilities without increased resources. Among these responsibilities are health check-ups. Vital sign testing is a crucial first line of detection for many underlying problems or health risks. Nurses/caregivers are trained to perform these vital checks in an accurate way. With a heightened frequency for these tests, these trained caregivers are overwhelmed. The increase in close contact with patients while doing these checkups can also increase risk for both parties. Automation can help reduce the repetitive nature of these tasks, thereby alleviating the burdens on caregivers.

Current solutions to the problem of automated vital testing include accessories, wearables, and industrial robots. Accessories and wearable devices tend to be easier to use, but are limited in the reliability and variety of their medical sensors. Industrial robotic systems can be versatile and help hospitals alleviate repetitive tasks. However, they are very expensive (starting at ~$30,000). Assisted Living facilities do not have the resources to spend on larger scale industrial products.

Athelαs is a vitals-checking robot that can perform medical assessments on the lungs, heart, body temperature, and blood oxidation level. Athelαs consist of five different subsystems: the Robotic Arm, the Patient Tracking algorithm, the Biosensors, Safety, and the User Interface (UI). Using the patient tracking, the robotic arm will safely move towards a patient’s “key point” based on the biosensor that is active (e.g., if the stethoscope is active the arm will be guided to the “chest key point”); all while maintaining as little contact as possible. Once the arm is aligned to the user, the biosensor will read vitals data, and display it on a GUI for the patient or nurses to view. The biosensor suite will include an IR thermometer, a combined heart rate and pulse oximeter sensor, and a digital stethoscope. This will allow the arm to perform all the basic vital sign measurements that are typically needed in nursing homes.

The robotic arm and biosensor subsystems will operate on separate microcontrollers. A Jetson Nano will coordinate communication between the subsystems, while also providing the processing required to run the computer vision algorithms necessary for patient tracking. Data will be displayed on a monitor running on a Javascript based web GUI.

The Athelαs system is a more reliable and complete vital collection than the existing wearable devices, and much more affordable than industrial grade robots. Combined with the autonomous nature of the testing, patient and caregiver contact is greatly reduced and the entire vitals checking process is automated to allow nurses and caregivers to spend more valuable time with their patients, rather than doing repetitive and tedious tasks.

**Band Buddy: W5**

**Design Team:** Ryan Heminway, Sam Paniccia, Walter Galdamez, Rubens Lacouture, Brickman Malham

**Advisor:** Professor Waleed Meleis

**Abstract**

Music is part of almost everyone’s day to day lives. For guitarists, music goes beyond just a listening experience to a hobby or even a profession. For any guitar player, but especially new players, practice is of utmost importance. It is where the player finds their sound, grows their skillset, and ultimately defines their facility on the instrument and in a band. We propose a guitar looper pedal which can enhance a guitarist’s practice routine and help grow this crucial skill set by letting them play in time with uniquely generated drumlines.

Band Buddy is a guitar pedal which can loop a user’s input and provide intelligent accompaniment to the musician in the form of a drum backing track that fits the groove of the user’s input. The user can select a tempo, a desired genre, a sound profile, and how many bars of music (two or four) they wish to play. When the user presses a button on the pedal, it will start recording what the user is playing for the chosen number of bars, looping it back to them in the meanwhile so they can hear themselves. The recorded segment of music is used as input to a generative machine learning model which constructs a drum track that suits the rhythmic elements of what the user played. The pedal then combines these tracks, the drum track and user track, and outputs it to the user as a repetitive loop.

Our design consists of three main software stages that take place on two main pieces of hardware. A Raspberry Pi 4 runs stages one and three of the software pipeline as well a local web server which hosts a web application for parameter configuration. Stage one is responsible for playing the metronome, listening to user input, looping it back to them, recording it, and writing it to WAV format. Stage three is responsible for synchronizing the drum backing track with the user input and playing it back to them. Alongside this, a Jetson Nano is used to run stage two of the software pipeline. Stage two is the heart of the generation pipeline and uses a machine learning model to generate the drum backing track. The model uses a GrooVAE architecture based on work by Google’s Magenta team. Stage 2 has multiple models, each trained to generate a specific genre of music, which the user can pick from to experiment with different genres and styles. Additional overarching software modules handle data transmission between stages and state management among processes.

There are examples of similar products available on the market such as OneManBand and Spark Amp, but they have some disadvantages compared to our design. Both products have a higher cost and require the user to purchase types of equipment they likely already have. Spark Amp is a specialized amplifier which can provide musical accompaniment with bass and drum backing tracks. OneManBand is a fully customized guitar that provides musical accompaniment to what the user is actively playing. Band Buddy works as just another pedal in a guitarist’s already existing arsenal, allowing them to continue using the guitar and amplifier they are already comfortable with. Additionally, Band Buddy would be available for 350$ which is on par with or cheaper than both other products described.