ELECOMP CAPSTONE **SUMMIT** THURSDAY, MAY 8, 2025

THE UNIVERSITY OF RHODE ISLAND

ENGINEERING **SHOWCASE** FRIDAY, APRIL 25th, 2025

THINK BIG WE DO™

Safety Critical Applications for RISC-V Platforms

DRAPER®

Team Members: Jeshua Benzant (CPE), Adam Lubinsky (CPE), Nathan Kaye (ELE)

Technical Director(s): Steve Lawrence, Jesse Sullivan, Evan Kelly, Rick Wang, Mike Smith

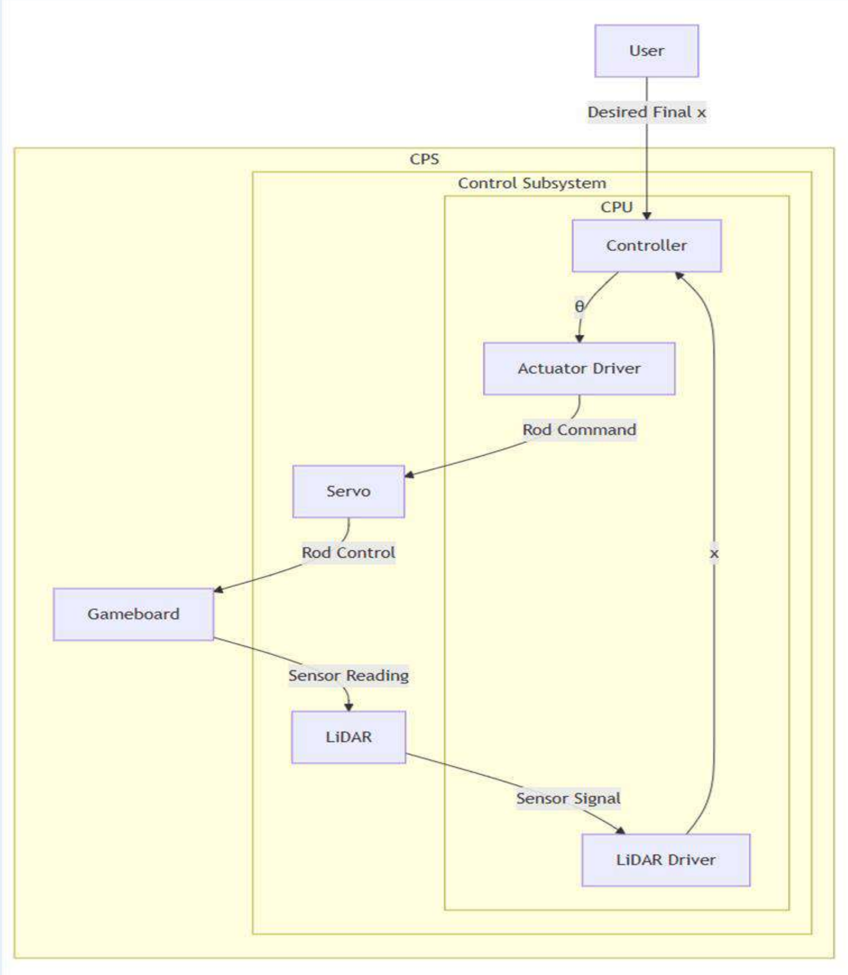
Project Motivation

The race for space is real and happening now, and Draper is on a mission to lead. Safety critical applications and computer platforms are a part of Draper's DNA that go back to the Apollo era guidance computer. Developing the next generation of this technology is critical to our national defense. We are looking for a motivated student team to support development of a safety critical application using the Rust programming language on a RISC-V platform.

Key Accomplishments

Key Features and Their Relation to the Project

- **PID Control System:** Refined into a PD controller for responsive actuation, enabling reliable ball manipulation across varied game scenarios. The system adapts in real-time to ball movement, ensuring high repeatability in performance.
- **LiDAR Integration:** Fully implemented for accurate velocity and distance tracking. Its data stream was synchronized with the servo, allowing deterministic feedback control.
- **Servo Control Mechanisms:** Enhanced with a precision screw-drive linkage that converts rotational motion into vertical rail movement, crucial for controlling the pole's theta angles.
- **Rust-Based Real-Time Programming:** Core functionality including LiDAR parsing, servo command handling, and feedback logic was implemented in Rust. The language's memory safety model minimized concurrency and timing errors.
- **Hardware-Software Integration:** Achieved full system integration on the VisionFive 2 board, which replaced the BeagleV-Ahead due to better documentation and peripheral stability. Rust modules interfaced cleanly with GPIO and PWM hardware.
- **Platform Transition and Validation:** A major project pivot occurred with the adoption of the VisionFive 2 board. This enabled more reliable I2C communication and facilitated a smoother testing process.



Breakdown of Block Diagram

The finalized system includes:

- **LiDAR Sensor:** Captures position and velocity data of the rolling ball.
- **VisionFive 2 CPU:** Processes sensor input, executes the PD control loop, and drives servo commands through GPIO.
- **Servo Motor with Lead Screw:** Converts control signals into precise vertical rail movements, modulating the opening of the poles.
- **Closed-Loop Feedback:** The servo's output affects the ball's behavior, which is measured again by LiDAR—completing the loop for continuous dynamic control.

GPU acceleration and camera vision are planned for future expansion but not implemented in this phase.

Development Timeline

- **Phase 1:** Conduct research on control strategies, sensor placement, and system parameters. Validate control equations via MATLAB simulations.
- **Phase 2:** Select servo motors, LIDAR, design mounts, and create preliminary CAD models.
- **Phase 3**: Implement Rust programming, simulate PID control, and develop ball trajectory models.
- **Phase 4**: Integrate hardware with the Vision FIve 2 and begin testing servos and sensors.
- **Phase 5**: Optimize control algorithms and hardware-software integration. Conduct system-level testing.
- **Phase 6**: Finalize assembly, validate performance, and prepare documentation for submission.

This structured approach ensures cohesive development of a robust and efficient control system for the 'Shoot to the Moon' game, meeting both technical and project goals.

Anticipated Best Outcome

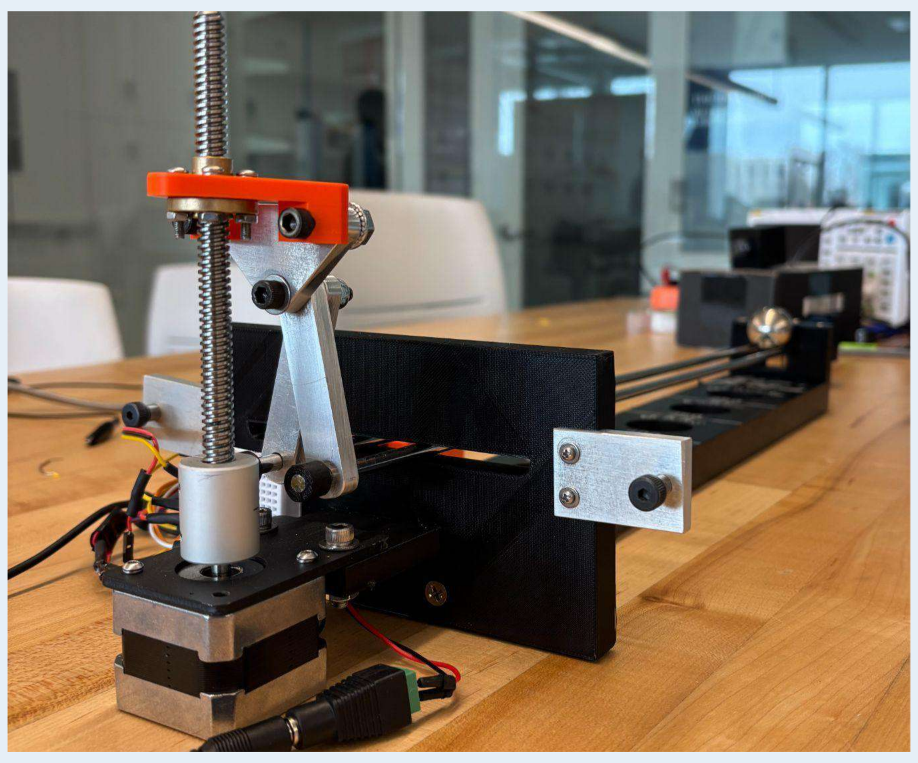
The goal is to create a Rust application on a RISC-V platform and identify security features of Rust used to increase robustness of the application.

1. Detailed system level design document including system ICD
2. Detailed hardware design of system & Detailed software design document
3. Software test plan & Integration test plan
4. Source code
5. Compiled binaries
6. A working prototype system
7. Technology assessment report including
   a. Security assessment of Rust
   b. Benchmark of RISC-V architecture performance
   c. Benchmark of GPU performance

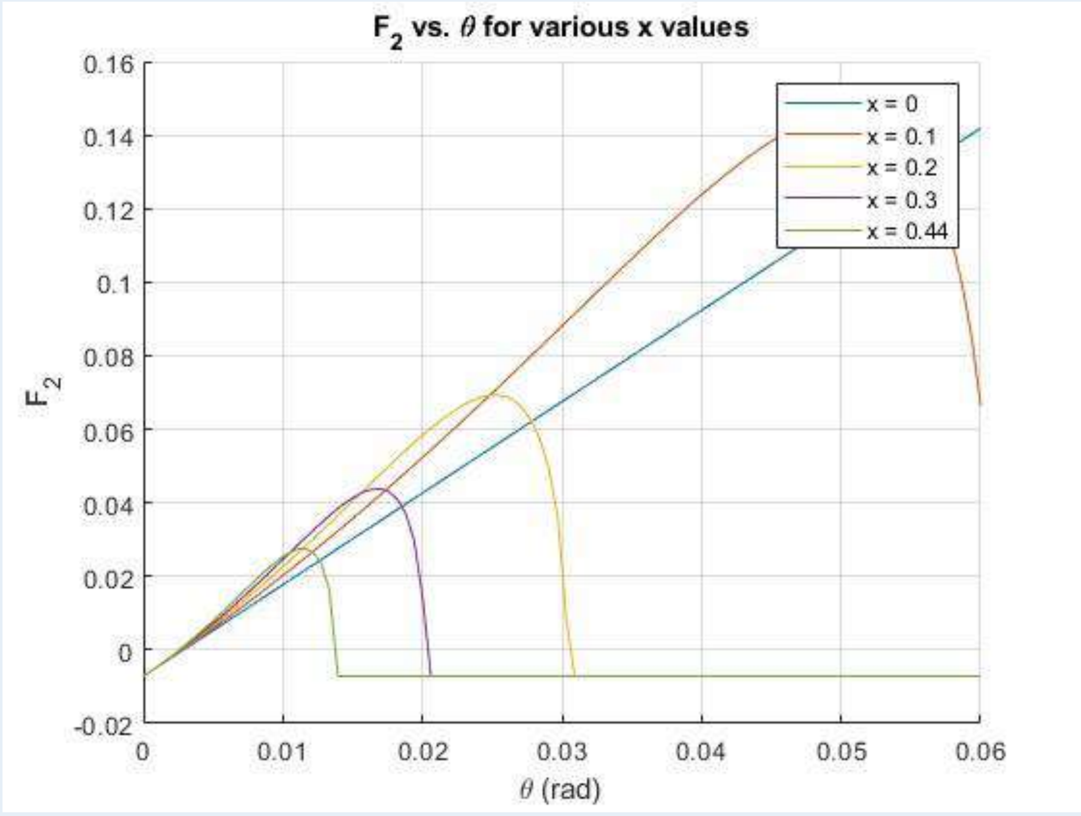
Project Outcome

The system successfully automated the "Shoot the Moon" game using Rust on a RISC-V platform, demonstrating reliable, real-time control. This confirms the platform's potential for future safety-critical and AI-integrated applications.(ABO Achieved)

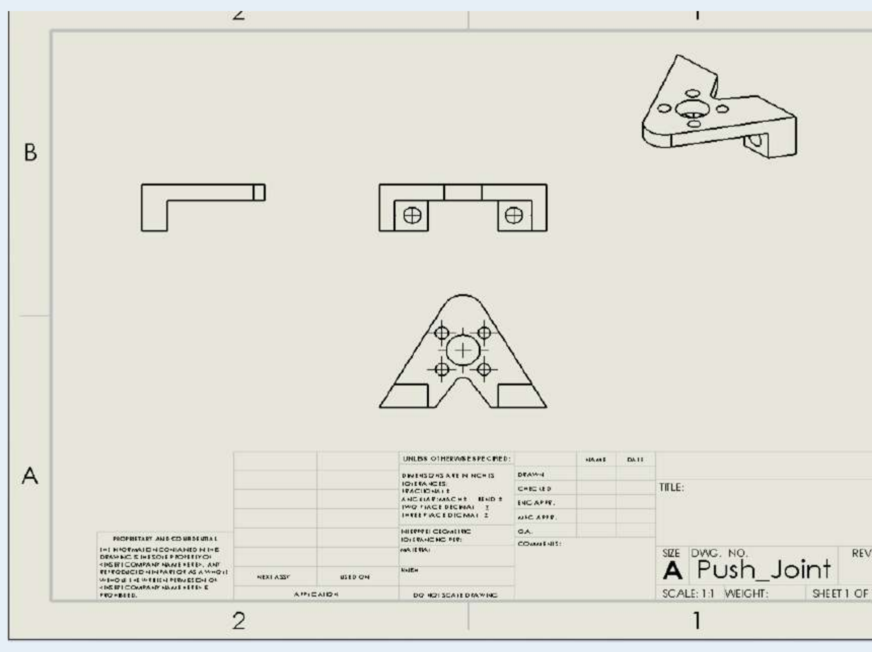
Figures



Full Hardware of Project



MATLAB Plotting tool



Solidworks Model for Push Joint

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Market Gap Assessment Tool

Using Artificial Intelligence to predict and recommend actions

Boston Scientific

Team Members: Zachary Notarianni (CPE), Samuel Raheb (CPE)

Technical Director(s): Kevin Bagley, Demetrios Petrou, Dennis Hubbard, Prashanth Somu

Project Motivation

The bioengineering field is advancing rapidly, making it difficult for companies to stay ahead of emerging technologies and trends. Traditional research methods struggle to keep pace with the growing volume of scientific publications, patents, and regulatory data. This project aims to bridge that gap by developing an AI-driven platform that provides real-time, predictive insights into technological developments. By automating the collection and analysis of public data, the system identifies under-the-radar innovations, uncovers unmet market needs, and enhances competitive intelligence. For Boston Scientific, this tool will offer strategic foresight—informing R&D decisions, identifying promising startups, and highlighting areas for product improvement. Leveraging a multi-agent AI system, the platform delivers structured, customizable reports tailored to user preferences. The goal is to empower decision-makers to act on opportunities before they become mainstream, ensuring a sustained competitive edge in a rapidly evolving industry. Ultimately, this project contributes to accelerating innovation and advancing healthcare solutions in bioengineering.

Key Accomplishments

- **Development of a Modular Multi-Agent AI Architecture:** Designed and implemented a modular, multi-agent system where each agent is dedicated to a specific task in the research and report generation pipeline. Roles include browsing, researching, editing, reviewing, writing, revising, and publishing. By breaking down the workflow into smaller, well-defined units, the system enables specialized agents to operate more efficiently, reducing redundancy and increasing accuracy. This modularity allows for easier debugging, feature upgrades, and improved task focus. Agents are deployed to operate in parallel, enabling asynchronous task execution. For example, multiple researcher agents can simultaneously investigate different topics or subtopics, dramatically improving processing time and scalability. The modular structure also supports future expansion, where new agents with unique specialties can be easily integrated without disrupting the core pipeline. **(Fig. 1)**
- **Automated Web Scraping and Intelligent Data Collection:** Built robust scraping agents capable of retrieving structured and unstructured data from a range of reputable sources, including PubMed, the FDA MAUDE database, Google Scholar, Bing, and hand-picked domain-specific websites. These agents intelligently navigate dynamic HTML structures using XPath and CSS selectors, with built-in error handling for page changes or network timeouts. The architecture supports parallelized scraping—different agents can scrape various sources simultaneously, speeding up the data collection process and increasing throughput. Additionally, scraping activity is rate-limited to ensure source compliance and avoid service disruption.
- **API Integration for Structured Data Retrieval:** Integrated several APIs including PubMed, FDA, Tavily, and arXiv to retrieve clean, structured, and high-value data with greater consistency than web scraping alone. Custom connectors were developed to parse JSON and XML responses, translating them into a standardized internal format for processing. This dual-source model—scraping and API access—ensures redundancy, completeness, and higher-quality research inputs.
- **NLP-Powered Semantic Analysis and Content Summarization:** Leveraged advanced natural language processing tools through OpenAI's GPT-4 API to analyze large sets of research papers, regulatory filings, and patents. These LLM-based systems perform semantic clustering, keyword extraction, and summarization to identify trends and distill complex content into digestible insights. Semantic comparison allows the platform to detect novel research patterns, underexplored themes, and emerging technology clusters across time. **(Fig. 3)**
- **Report Generation Engine with Customization Controls:** Developed a report generation engine that transforms raw findings into professional, human-readable documents. Reports can be customized into various formats such as Summary Reports, Advanced Reports, and In-Depth Analyses. Users can set preferences for content detail, section depth, tone, and citation formatting. The engine is built to be extensible for future templates and report types, ensuring long-term flexibility. **(Fig. 2)**
- **Web-Based Front-End with Real-Time Feedback Loop:** Designed a user-friendly dashboard where Boston Scientific researchers can enter queries, monitor agent activity, and adjust output parameters. The interface includes a built-in human feedback loop, where users can clarify ambiguous queries, rate the usefulness of generated reports, and guide the system toward more relevant insights in future sessions. This tight feedback cycle helps improve personalization and report quality over time. **(Fig. 1, Fig. 4)**
- **Intelligent Source Filtering and Trust Scoring:** Implemented a source scoring system that evaluates content based on domain authority, recency, citation metrics, and technical specificity. This allows the system to prioritize higher-quality sources in both API and scraped data, improving the trustworthiness of results while filtering out outdated or irrelevant content. **(Fig. 4)**
- **Dynamic Outline Construction and Research Prioritization:** The editor agent dynamically generates a research outline based on early-stage data analysis. Sections are automatically prioritized by relevance, keyword density, and data availability, allowing the researcher agents to focus their efforts efficiently. This structure ensures that the final report covers the most impactful insights while maintaining logical coherence. **(Fig. 1)**
- **Multi-Format Report Export and Cloud Collaboration:** Final reports are exportable in PDF, DOCX, and Markdown formats. Integration with AWS WorkDocs provides a secure environment for collaboration, version control, and real-time feedback across teams. This makes the tool more adaptable for use in cross-functional R&D and strategic planning workflows.
- **Custom Source Whitelisting and Blacklisting:** Users have control over which sources are included or excluded in the research process. Through whitelisting and blacklisting, the system can be fine-tuned to reflect Boston Scientific's internal policies or to exclude low-value domains. This improves precision and relevance of findings.

Anticipated Best Outcome

The best outcome of this project is a fully functional AI-powered research assistant that enables Boston Scientific to identify emerging technologies, market gaps, and competitive insights with unmatched speed and accuracy. The system will generate high-quality, customizable reports that inform strategic decisions in R&D, partnerships, and innovation planning. By leveraging real-time data and predictive analytics, the platform will uncover hidden opportunities and enable early action on breakthrough technologies. Success will be measured by improved decision-making efficiency, enhanced innovation pipeline visibility, and the system's ability to adapt to evolving user needs across multiple domains in bioengineering.

Project Outcome

The Project ABO has shifted its initial focus and has been achieved.

Figures

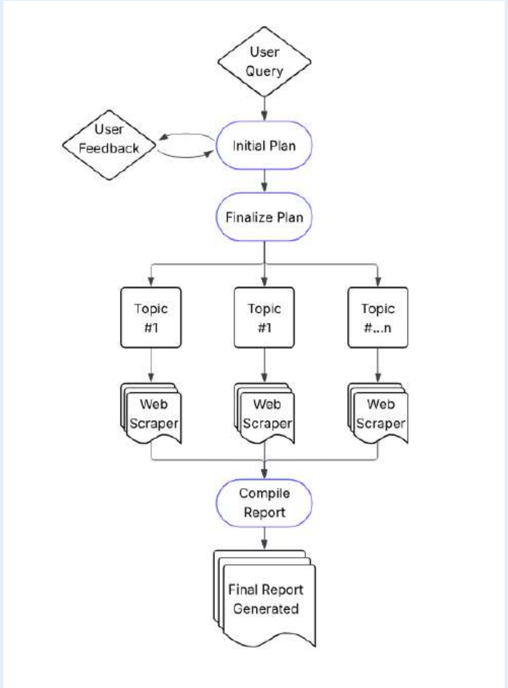


Fig. 1 : Flowchart illustrating the AI's report generation process, detailing the progression from initial user query through iterative planning with user feedback, culminating in automated topic-specific research, web scraping, content aggregation, and final report compilation.

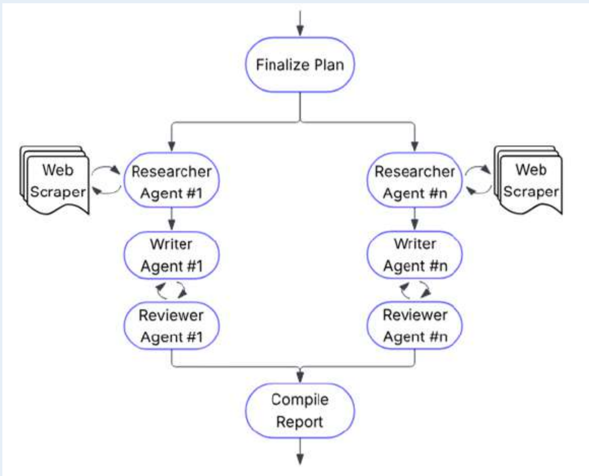
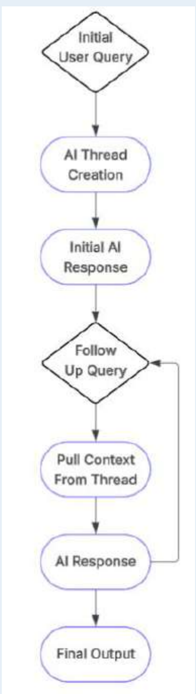


Fig. 2 : Branching diagram depicting interactions among specialized AI agents—researcher, writer, and reviewer—highlighting the iterative exchange with web scraping processes, ultimately leading to a systematically compiled, user-ready market gap analysis report.



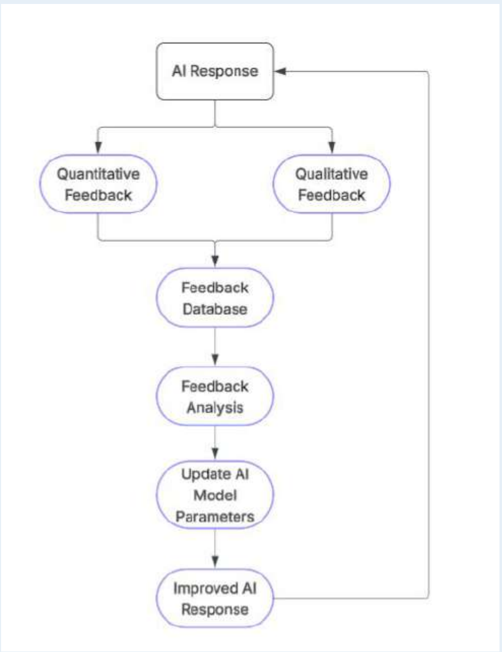


Fig. 3 (Left): Map illustrating the conversational threading mechanism used to maintain context in ongoing AI-user interactions, powered by OpenAI's Thread API

Fig. 4 (Right) : Visual representation of the user feedback integration cycle, detailing how both quantitative and qualitative feedback from users directly inform and improve the AI's performance over iterative cycles.

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Underwater Camera

Underwater monitoring and inspection camera

DBV TECHNOLOGY
CUSTOM OCEAN INSTRUMENTATION

Team Members: Ishan Chadha (ELE/CPE), Jake Javier (CPE), Noah Sarji (ELE)

Technical Director(s): Dr. "Bud" Harold Vincent, Connor Vincent, Zachary Lindo, Colin Vincent, and Nathaniel Brown

Project Motivation

DBV Technology specializes in designing, manufacturing, and operating underwater instruments. These include underwater acoustics, recovery systems, and custom instruments. With this comes a need to monitor and observe equipment that is being tested, or is in use. Oftentimes, an underwater camera system is used. Market options for these systems do exist, but they are often expensive, proprietary, and fully tethered. They usually don't attach to poles. Thus arises the need for a custom-built system. This system will have to be cheaper than market options, while still being capable of the same functionality. An important feature of the system will be the wireless connection from the transmitter to the display. Commercial options are directly connected to the display, which hampers flexibility in setup and use. A wireless system allows for a stable display while maneuvering the camera. This custom built system will assist in product deployment/testing, as well as inspections.

Key Accomplishments

Market Research: The team began the project with market research, analyzing available commercial options for underwater camera systems and how they work. It was observed that all of the systems utilized a physical tether design to transmit the camera feed to the topside display due to the difficulty of transmitting any signal underwater. They tended to be very expensive and marketed towards divers as diving cameras.

Block Diagrams: 5 block diagrams were created to model potential design solutions. A Raspberry Pi was used as the "brains", taking in a video feed and transmitting it to the display. The topside display was a cellular device that connected to the Raspberry Pi via a wireless hotspot hosted by the Pi. The device would have a custom-made app that displayed the video data and some buttons for pan-tilt-zoom control. The main difference between the block diagrams was the transmission method between the camera and the Pi. The ones the team looked at were Analog, Power over Ethernet (PoE), HDMI, and Gigabit Multimedia Serial Link (GMSL2). Design variations were included. The HDMI design ended up being chosen.

Raspberry Pi Configuration: A Raspberry Pi 4 model B was chosen as our computer. It was configured to host a 5G hotspot. A Flask web application would run on the Pi, allowing connected users to view the video feed, take pictures, and record video. A systemd. service was used to launch this on startup. On shutdown, the Pi will save all relevant data, safely close all running programs, and shut down. These are done through Python scripts on the Pi, and ran on startup as a systemd.service.

Power Management PCB: The PCB consists of two functional stages. One is to convert the higher voltage input from two 18650 batteries in series down to 5V. This step-down voltage converter is accomplished by using a buck converter chip, which was selected to meet the power requirements of the system. The second stage functions as an external on/off switch for the system. The switching circuit uses a dual MOSFET IC and connects to the Raspberry Pi GPIO pins directly, enabling controlled power on and off of the system through a physical button.

HDMI End Termination: An HDMI cable was terminated and threaded through the waterproof housing at the bottom of the pole. On the submerged end of the pole, the waterproof housing holds the camera and the CSI cable to HDMI converter module, secured in the housing with screws (design developed by DBV employee Nathan Brown), and connected to the unterminated end of the HDMI cable. The team attempted to use the COVID brand HDMI termination kit, but after 2 failed attempts, a backup solution was implemented. Using a solderless screw terminal, the stripped wires were attached and tested to be successfully functional.

Flask Web Application: Developed a web-based application using Python's flask framework to stream live video feed from the camera module in real time. Integrated fully functional buttons to capture both still images and record videos. Users may also view the photos taken and the videos that were recorded on the website.

Working Prototype: By using a portable battery pack in place of the power management PCB, we were able to create a prototype of the pole mounted camera for testing. The system functioned as needed, providing a high quality, low latency live video feed to a wireless display topside. The battery pack was used in place of the PCB before arrival. After arrival, it was replaced with the functional PCB.

Anticipated Best Outcome

The team will design, build, test, and demonstrate an Underwater Inspection and Monitoring Camera. The pole-mounted version will transmit live video data from the camera to a transmitter at the top of the pole. This transmitter will connect wirelessly to a topside display, and allow for remote control options. These options will allow for recording and taking pictures. The topside display will be separated from the pole. A stretch goal is to create a suspended version, which will be lowered into the water via a tether, and will accomplish all of the above as well.

Project Outcome

The anticipated best outcome of the project was achieved.

Figures

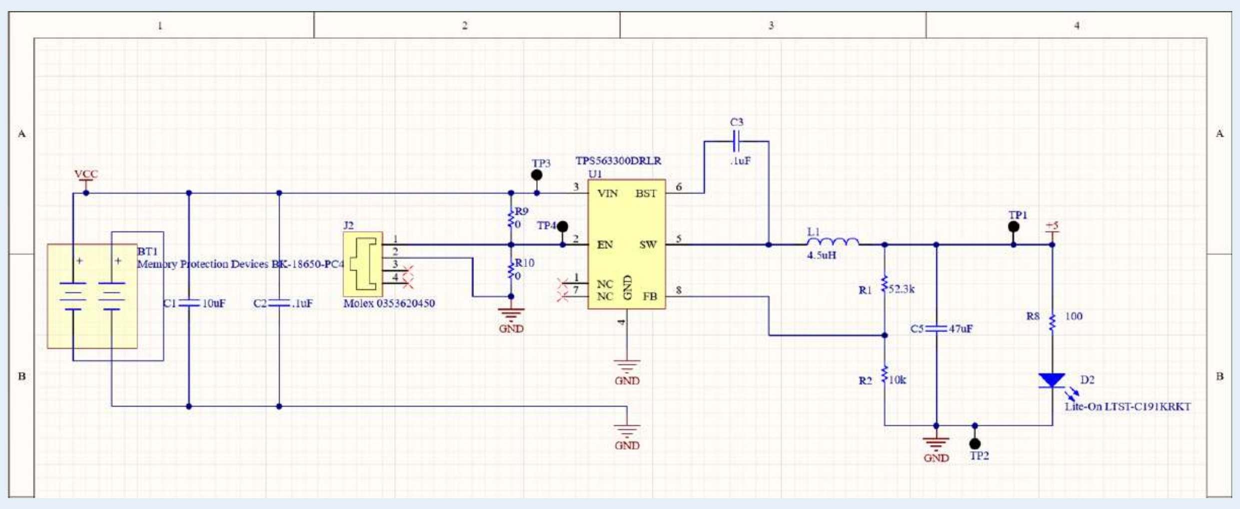

Figure 1: Voltage Regulator Schematic

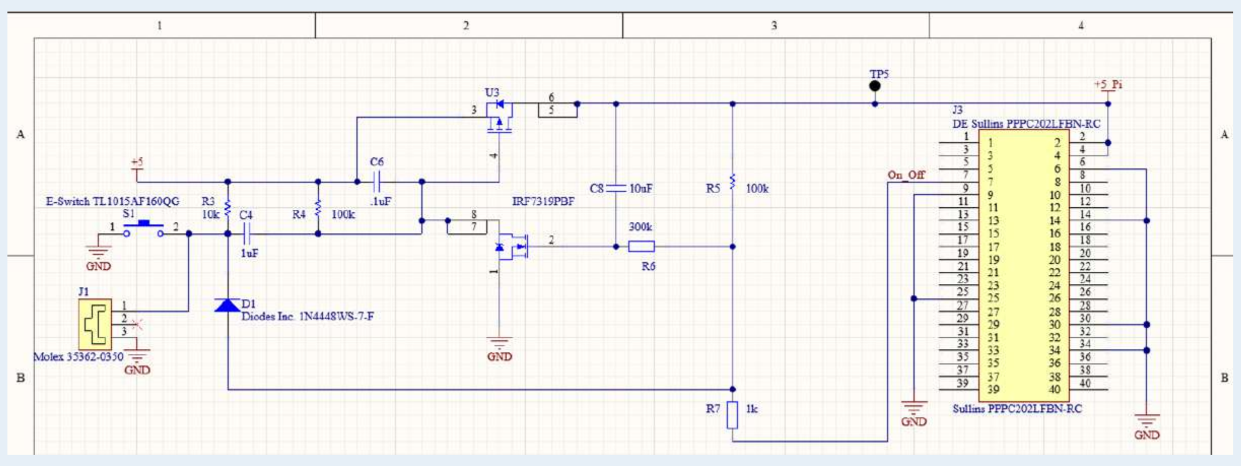

Figure 2: On/Off Switch Schematic

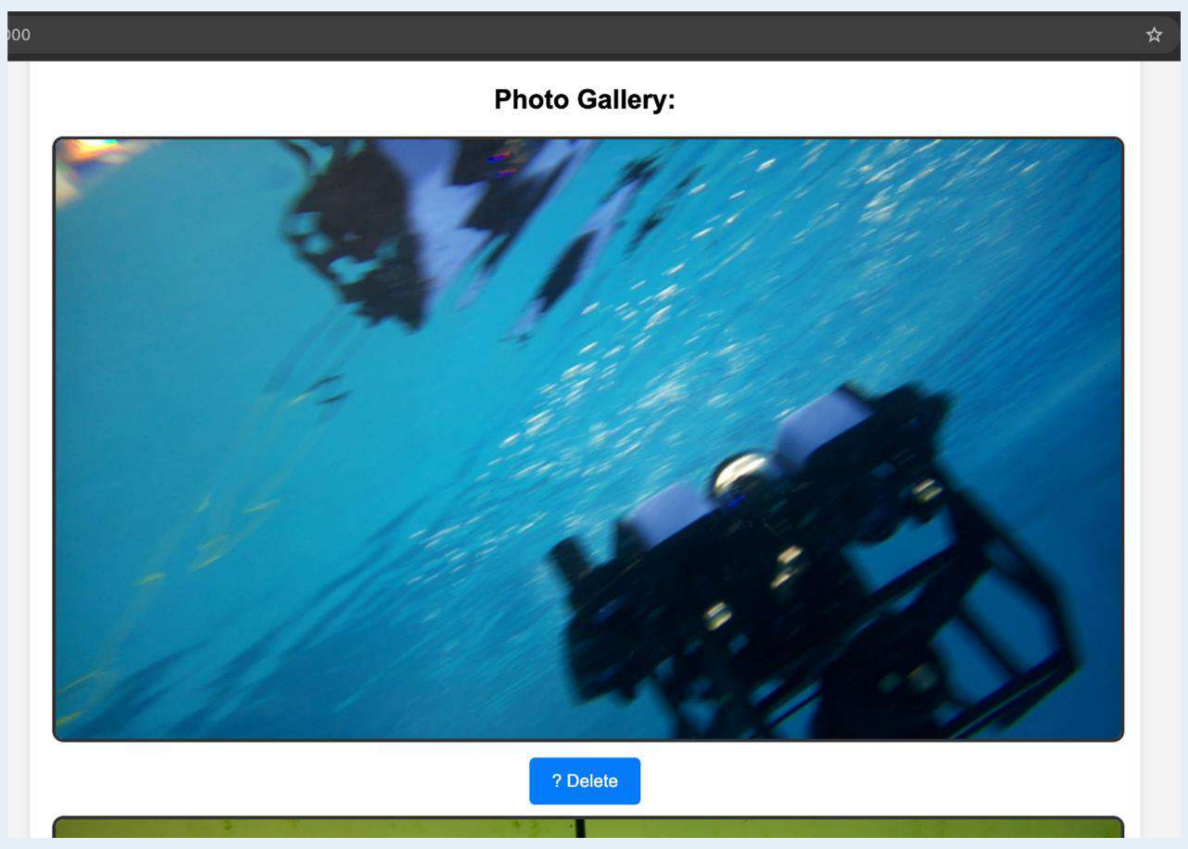

Figure 3: Flask Web App Displaying a Photo

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Using ML to Monitor Remote Connection Sessions

DISPEL

Team Members: Noah Samuel Markus (CPE), Tyler Distefano (CPE)

Technical Director: Dean Macris

Project Motivation

Dispel provides secure remote access for customers to various critical infrastructure networks. The Dispel Zero Trust Engine for Remote Access (DZTE-RA) instantiates a compostable workstation (Virtual Desktop) for engineers to maintain or service programmable logic controllers (PLCs) or access other engineering workstations inside the environment. The DZTE-RA provides a feature of screen recording that enables an administrator to review or even watch the actions any engineer is accomplishing in the environment. For larger systems, administrators can't watch or even review all screen recordings unless there is some event that triggers review (an incident or mistake was made). Dispel is interested in designing a system that can categorize different types of user actions through screen recordings. These actions are classified based on administrator-designed rules. The end goal is to enable an anomaly in the engineer's action (using the wrong program or running unauthorized commands) to trigger an alert and disconnect the system from the network.

Key Accomplishments

Dataset Scripts: Noah created a dataset initialization python script that takes a list input variable and then creates a new CSV based dataset and uses the list input to create features. Next Noah created an add features script allowing a user to add new features to an existing dataset via a list variable.Finally, Noah created a data addition script that takes scraped text and then counts the number of features it finds. **(Fig 4)**

Model Research: Noah has also begun testing different AI models with a test dataset he created with the dataset creator. These models include K-NN, Random forest, and logistic regression. Ultimately Noah chose the Isolation forests model as the way to go, because its main use is detecting anomalies within an unclassified dataset

Model Testing: Noah tested the isolation forests model with datasets created using the dataset creation and addition scripts from last semester. Noah also tested by building a function that allows the user to input data directly into the model and the model would tell you if the data entered is anomalous or not.

Fine Tuning Detection system: Using the POC infrastructure that Tyler created, Noah set up the live anomaly detection system, and fine tuned it by changing the contamination levels using the created videos to test this system.

"Tug of war" Alert system: Finally, Noah added a "tug of war" system that would determine when to pause the connection and send an alert to the Administrator. This system adds 1 to a running count every time there is an anomaly, but will then subtract one every time there is no anomaly. While testing this system, the "tug of war" algorithm was actually able to stop a malicious action before it happened as shown in the figure below and in the demo.**(FIG. 2)**

OCR Research and Testing: Tyler researched and tested different OCR modules to find the most accurate, efficient library to be used with our design. The best option that was found is easyOCR. Tyler also worked with Noah to improve the OCR speed.

Text scraping: Tyler created a script to take a video stream frame by frame, convert the frames to grayscale and then feed these images into the OCR the OCR will then return all the text found in that specific frame.

Dataset Builder: Tyler made a script to take a large folder of videos and cut them down into a user defined interval these videos are then ran through the OCR and a data set is then created from this and stored as a CSV **(Fig 4)**

Live data collection: Tyler has also created a script similar to the previous "Dataset Builder" however this script is for live video where the data is repeatedly checked with the model to determine if the data found on that specific frame of the video is anomalous. After this the script will then add all collected data from the session to the existing dataset to allow for the model to be trained on this new data.

Blacklist text/commands: Tyler has added a feature to the Live data collection script that allows for the user to put in text that they specifically know that none of their users should be seeing; this could be used for exact commands or different types of programs.**(Fig 2)**

Anticipated Best Outcome

The Anticipated best outcome for this project is a proof of concept for a remote connection anomaly detection system that does not need to be installed on the host system, therefore using live streamed video instead. This includes developing a model that can analyze scraped text and use that to detect anomalies. If a certain number of anomalies are detected during a session, there will be a placeholder where the connection can be halted and alert the administrator. In addition there will be a "blacklist" function where customers can manually specify commands, words, and applications that would be malicious and would cause the system to halt the connection.

Project Outcome

We are proud to report that on April 11th we were able to meet the Anticipated Best outcome and deliver the proof of concept to Dispel.

Figures

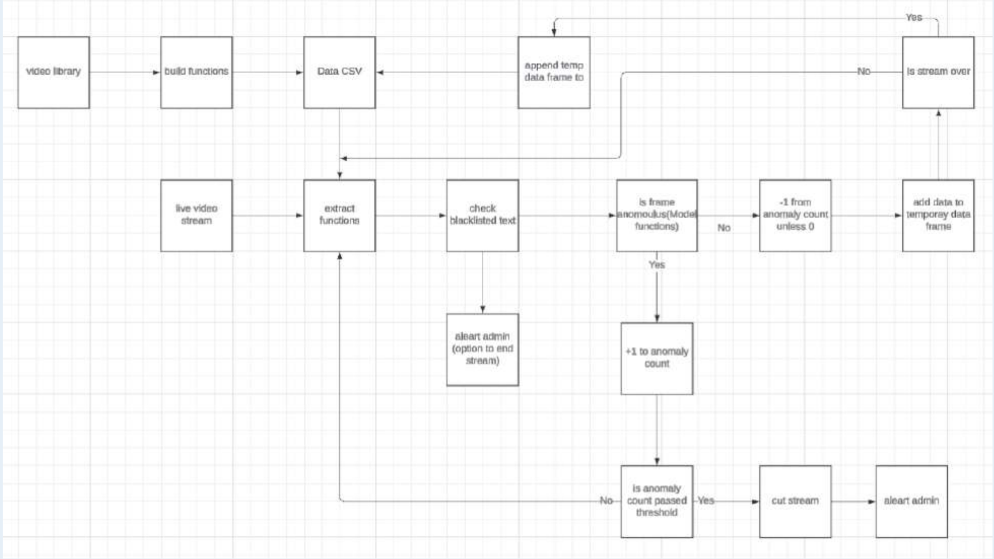

Fig 1. Block diagram

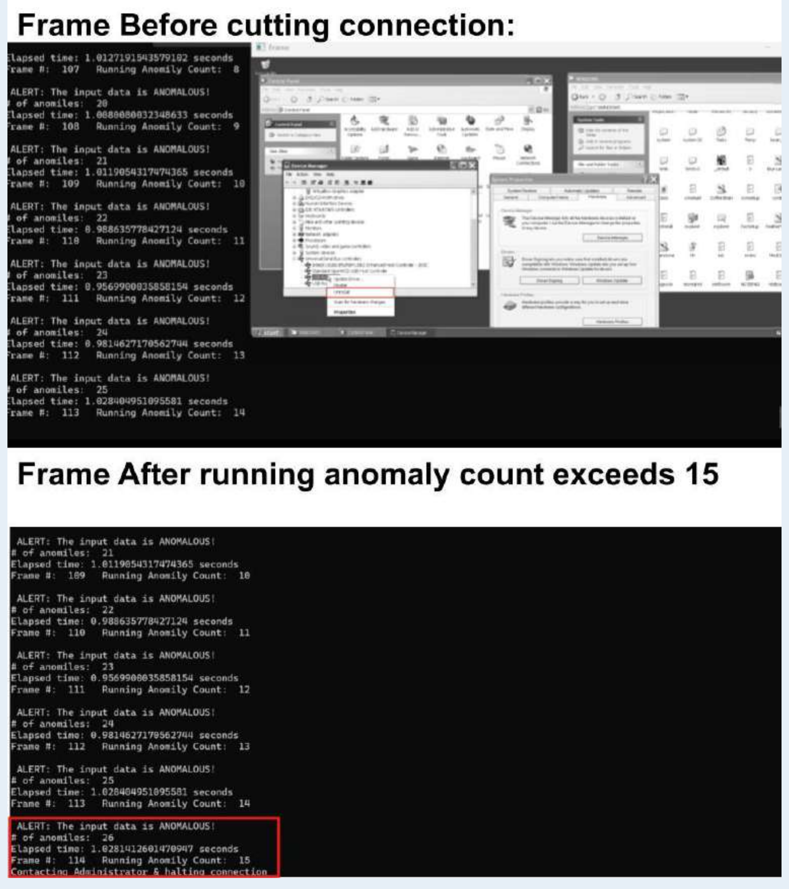

Fig 2. Anomaly detection "Tug of war" system working and stopping action before it happens.

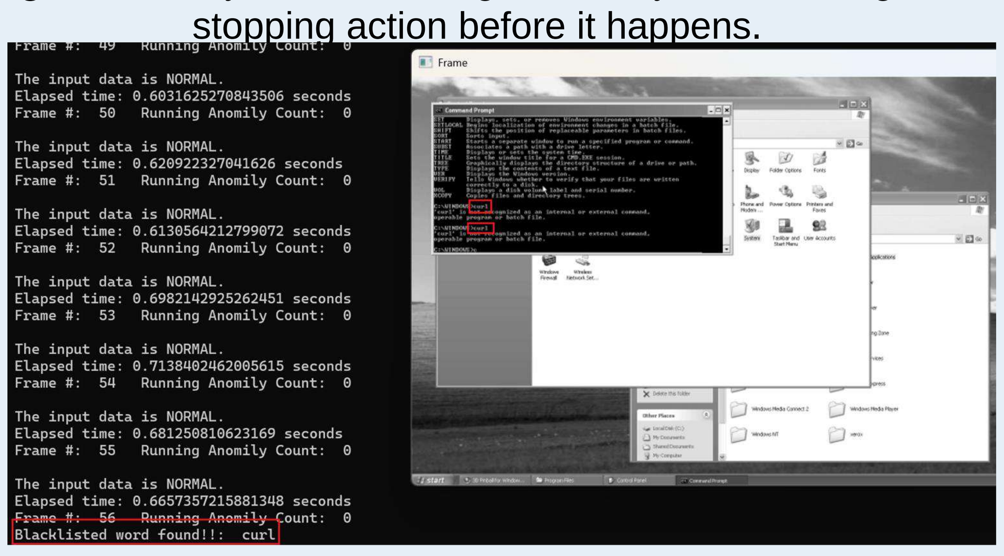

Fig. 3: Catching blacklisted command "curl" and ending connection.

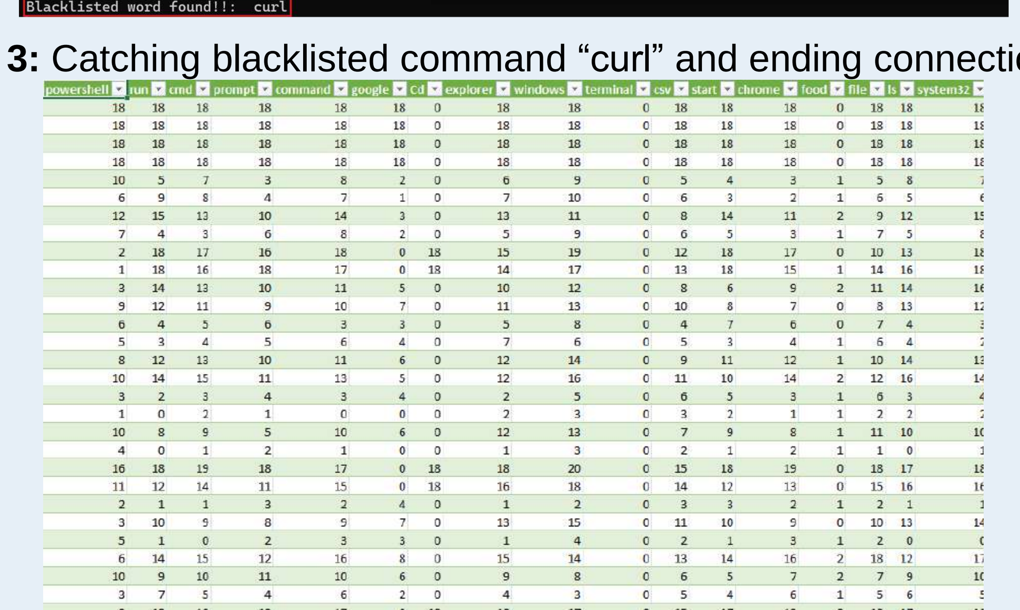

Fig. 4: Example of what our dataset could look like.

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High Reliability Dynamically Reconfigurable Optical Networks

GENERAL DYNAMICS
Electric Boat

Team Members: Kylie Pasternak (ELE), Austin Noon (CPE), Alexander Gill (ELE)

Technical Directors: Michael Brawner, Joshua Malaro | Consulting Technical Director: Mike Smith

Project Motivation

The motivation behind this project is to incorporate next generation add-drop networking technology into a fiber optic network. The goal is to investigate and assess technology options and develop simulation model(s) of a scalable on-demand, dynamically reconfigurable network that can enable high reliability system flexibility. This will enable a new approach to providing a flexible, robust, and highly reliable interface boundary between system providers and the vehicle networks, known as “Tactical Middleware”. Achieving this would reduce platform integration costs and improve the ability to integrate next generation networking systems into current networking infrastructures.

Key Accomplishments

- **Technology Investigation & Assessment:** Capstone designers have researched a broad range of fundamental concepts and technologies applicable to this project. A “trade space area” has been defined which identifies the technologies and hardware that will be investigated and assessed. Evaluation criteria for each trade space area was defined and Pugh matrices were used to finalize technology down selection.
- **Hybrid Network Topology Design:** The project requires three total subnets, five channels between each subnet, 10 nodes, and two spare nodes. A hybrid network topology including two star topologies and one full-mesh topology was chosen, as this option best represented the required characteristics of our network. There was an emphasis on redundancy, fault tolerance, protocol compatibility, reconfigurability, and scalability. Both of these topologies represent each of these key characteristics. Full-mesh networks are excellent in terms of redundancy and fault tolerance, as there are multiple pathways to each node available in the network. Star topologies offer great benefits in terms of scalability and reconfigurability, as they are known for their ease to expand upon. The topology is shown in **Figure 3.**
- **ROADM Simulation:** A ROADM simulation was conducted in Simulink. This simulation was built from scratch in Simulink through the use of multiple subsystems and Simulink blocks. The ROADM Simulink model features multiple key components, such as: wavelength division multiplexing input, a dynamic wavelength selective switch, dynamic add and drop ports, an optical channel monitor, and an optical amplifier. Each component was carefully researched and implemented to resemble a real-world ROADM device as closely as possible. Simulations were then conducted to conclude whether or not the provided frequencies from our technical directors could pass through the system. These frequencies were successfully multiplexed in the same time domain, and were successfully passed through the ROADM node while maintaining signal integrity. The ROADM model can be seen in **Figure 1.**
- **Scaled ROADM Simulation:** A scaled simulation of the 30-ROADM node network was conducted in Matlab to visualize how data moves through the network. This was achieved by creating a ROADM structure in Matlab, and creating thirty instances of the struct. Data was passed through the network, entering at a random node and finishing at a random node. Metrics such as bit-error-rate (BER) were tested for, and variables such as latency and noise were introduced to model real-world impairments. The output of this simulation can be seen in **Figure 2.**
- **Media Converter Simulations:** Three versions of media conversion were modeled: Serial-to-Fiber, HDMI-to-Fiber, and Ethernet/Copper-to-Fiber. The purpose of these simulations are to represent input signals (serial, video, ethernet) through the processes of encoding/compression, transmission (adding Gaussian noise), and decoding/decompression. The Bit-Error-Rate (BER) and Signal-to-Noise Ratio (SNR)/Peak Signal-to-Noise Ratio (PSNR) are calculated to quantify the degradation of the signal through the media conversion process. These signals are used as inputs for the ROADM Simulation.
- **Transport Layer 4 Simulation:** A simulation to model layer 4 of the OSI model was conducted to test the network’s behavior during the transfer of packets. This simulation had to be built from scratch using C++, after the conclusion was made that using outside software was ineffective. The simulation tests the TCP protocol, specifically how the packets are transmitted throughout the network. In this simulation, the 30-ROADM node network is created and tested, as well as implementing variables such as packet delay and packet loss to closely model impairments found in real-world networks. If the packets fail to reach their destination, they will be properly resent and said losses will be recorded.

Anticipated Best Outcome

The best outcome will be achieved when capstone designers gain hands-on engineering experience in the areas of:

- Technology Investigation & Assessment
- System design
- Prototype Simulation & Modeling
- Software development

Capstone designers are expected to successfully design and simulate and model a prototype of a dynamically reconfigurable data network.

Project Outcome

We were able to meet the anticipated best outcome. General Dynamics Electric Boat was provided with a full report outlining the testing process, test results, and top two contenders for the final design.

Figures

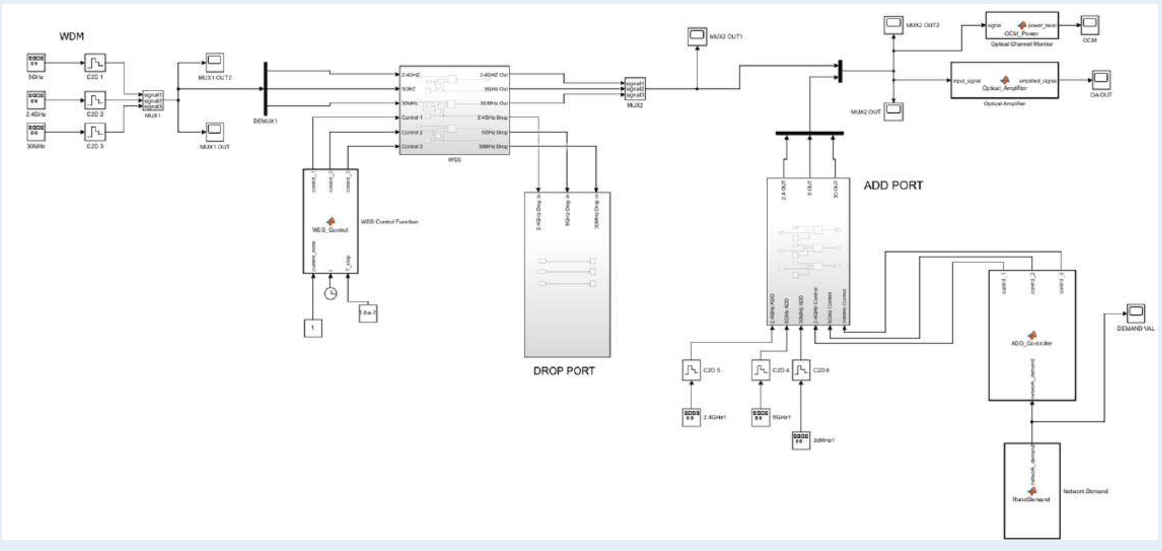

Fig. 1: The completed ROADM model in Simulink. This functional model features wavelength division multiplexing input, a dynamic wavelength selective switch, dynamic add and drop ports, an optical channel monitor, and an optical amplifier.

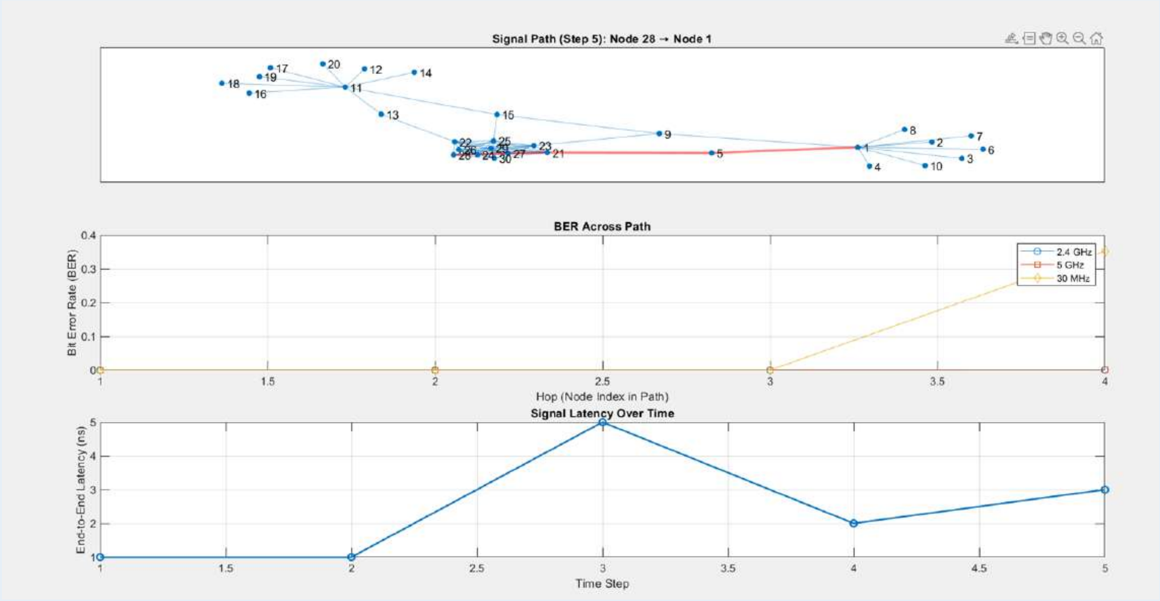

Fig. 2: The results of testing the scaled network of 30 ROADM nodes in Matlab. Bit-error-rate (BER) and latency were used to test the network’s behavior. Shown above is a simulated time step with the corresponding latency and BER.

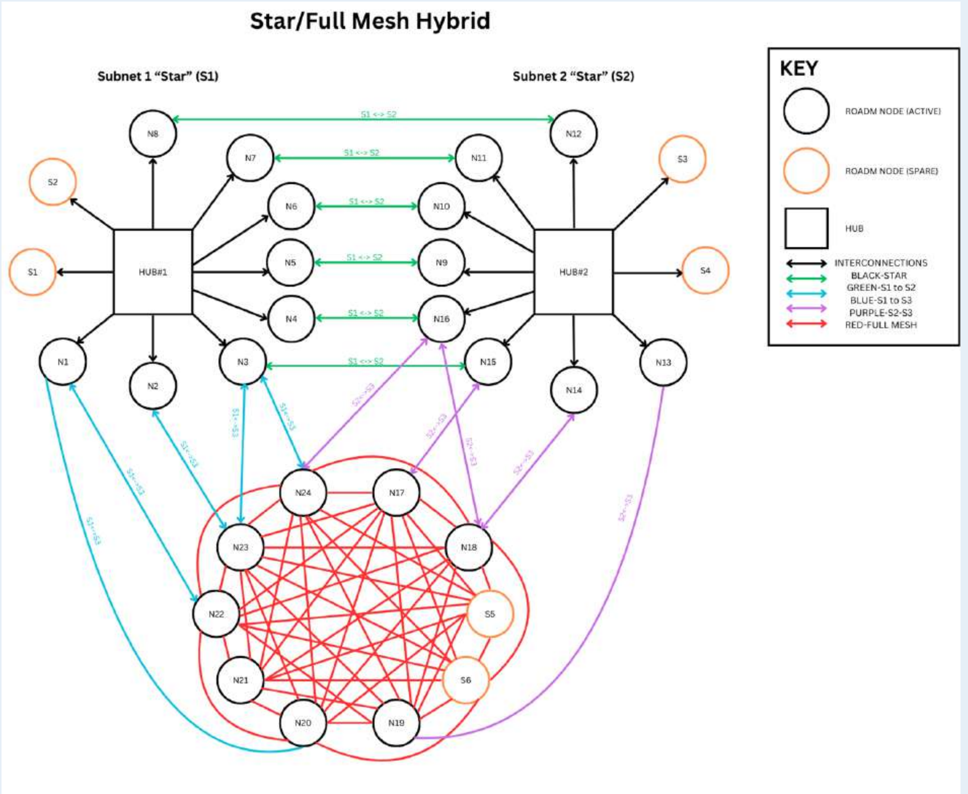

Fig. 3: A two-star/fush-mesh hybrid topology network. This network topology was designed to emphasize redundancy and fault tolerance. Each subnet features multiple interconnections to ensure multiple paths to each node are available at all times.

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Robotic Assembly, Inspection & Test Automation

Team Members: Benjamin Maguire (CPE), Jack DeMarinis (CPE)

Technical Director: Russell Buckley | Consulting Technical Director: Mike Smith

Project Motivation

Hayward Industries' Rhode Island facility manufactures over 100 printed circuit board assemblies (PCBAs) but relies on manual processes for through-hole assembly. These methods are time-consuming, labor-intensive, and prone to errors such as mislabeling and assembly mistakes. Faulty PCBAs often require labor-intensive rework or are discarded, leading to significant operational costs. This highlights the need for a more efficient, accurate, and streamlined approach to through-hole assembly and inspection.

This project aims to automate the through-hole assembly process to address these challenges. The proposed automated workstation will populate PCBs with through-hole components, conduct real-time visual inspections, and log production data to enhance efficiency and quality control. Its flexible and scalable design will allow for easy adaptation across various factory configurations, providing long-term value. By automating these processes, Hayward can reduce errors, improve production speed, and maintain higher quality standards while meeting future manufacturing demands effectively.

Key Accomplishments

- **Robotic Feeder and PCB Handling System:**
  Capstone designers developed a robotic feeder system that serves as the foundation of a fully automated through-hole PCB assembly line. Utilizing a UR3 robotic arm fitted with a custom-designed end effector, the system leverages a dual-suction and lever-switch mechanism to reliably detect, grip, and transport bare PCBs with alignment accuracy of ±0.5 mm. The team engineered a versatile PCB holder in Fusion 360, printed in-house, that accommodates a wide range of board sizes. This holder includes a modular screw-in mount system adaptable to different surface geometries, enabling rapid prototyping and support for future board variations. Through careful CAD modeling and iterative prototyping, the handling system was refined to ensure both mechanical reliability and repeatable precision throughout the pick-and-place sequence.
- **Custom Vibratory Feeder, Chute System, and Component Orientation Infrastructure:**
  To automate the delivery of through-hole components, the team designed and built a complete vibratory feeding system with 3D-printed hoppers, tapered plates, and ERM motor-driven chutes. These chutes were customized to accommodate components of varying pin counts and sizes (2–5 pins), ensuring consistent orientation and alignment within a constrained form factor. The feeder modules were integrated onto a standardized layout plate with modular mounts and wire management features, enabling straightforward adjustments and scaling. Onboard OpenMV cameras, mounted to a dedicated AOI fixture fabricated from aluminum extrusions and 3D-printed brackets, captured real-time grayscale images of components. These images were processed using custom Python algorithms that identified part position, rotation, and flip orientation. The extracted data—consisting of pixel coordinates and alignment metrics—was formatted and transmitted over UART to the control PC.

  To enable seamless coordination with robotic systems, the team developed custom driver boards and signal conditioning circuits for motor and sensor control across multiple subsystems. This included powering the ERM motors, vacuum pumps, and lever-switch sensors while maintaining stable, noise-resistant feedback loops. The entire vision-guided orientation and placement pipeline was synchronized with UR3 commands, forming a unified closed-loop system. This infrastructure not only replaced expensive commercial feeding systems but also enabled tight integration with robotic motion planning, setting a foundation for future GUI control and real-time production monitoring.
- **Dual-Robot Pick-and-Place Integration:**
  A two-robot architecture was implemented, pairing the UR3 and Meca500 arms to divide PCB handling and component insertion tasks. The UR3 robot, already tasked with board loading and alignment, was programmed to receive coordinate data from the vision system and convert pixel values to real-world X–Y–Z coordinates with precision using a Python-based kinematic transformation layer. Concurrently, the Meca500 robot utilized this coordinate stream to execute high-speed, accurate vacuum pickup and rotational alignment of components before inserting them into board locations with a placement tolerance of ±0.3 mm. Both robots were programmed through custom Python interfaces and simulated in RoboDK to ensure reachability, collision avoidance, and optimal cycle timing. Z-axis rotational alignment algorithms were employed to guarantee pin orientation matched hole orientation, reducing insertion errors and rework.
- **Simplified Conveyor Architecture Through Robotic Substitution:**
  Rather than designing a dedicated conveyor subsystem, the team consolidated material handling by re-tasking the UR3 arm to function as both feeder and transporter. This decision eliminated the need for a separate conveyor mechanism, reducing mechanical complexity and failure points. The robotic arm was able to handle both populated and blank boards between stations, with dynamically programmed waypoints enabling adaptable transfers based on real-time feedback. This substitution simplified the system architecture, reduced part count, and enhanced overall maintainability while preserving flexibility for future expansion or reconfiguration.

Anticipated Best Outcome

The best outcome will be achieved when capstone designers gain hands-on experience in:

- Robotic system design and integration
- Vibratory component feeding and optical part detection
- Custom motor control hardware and sensor interfacing
- Software control and system coordination

Capstone designers are expected to prototype an automated, vision-guided robotic cell for through-hole PCB assembly.

Project Outcome

We partially met the anticipated best outcome. Hayward Industries was provided with a fully functional prototype featuring automated PCB handling, part feeding, and dual-robot pick-and-place. A comprehensive report outlines system performance, integration results, and recommendations for future AOI and GUI development.

Figures

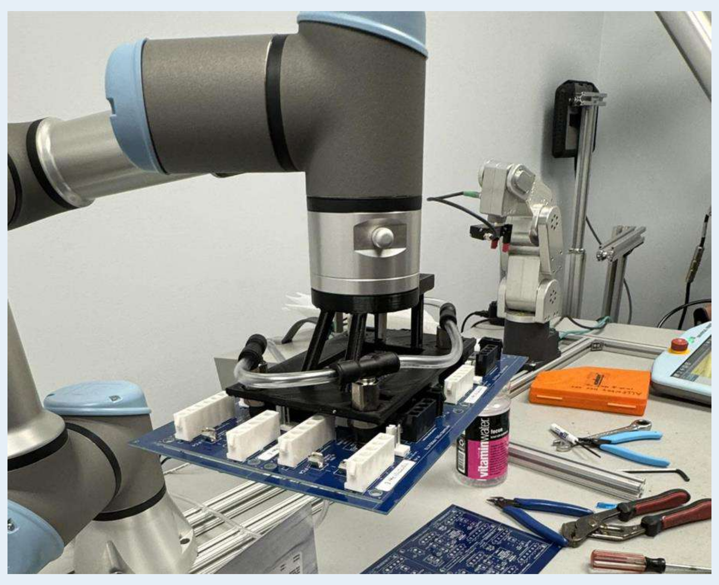

Fig. 1: PCB being picked up by UR3 Robot: This figure illustrates the UR3 robot utilizing a custom suction end effector with lever switches to accurately pick up a bare PCB from the holder, ensuring precise alignment for subsequent assembly steps.

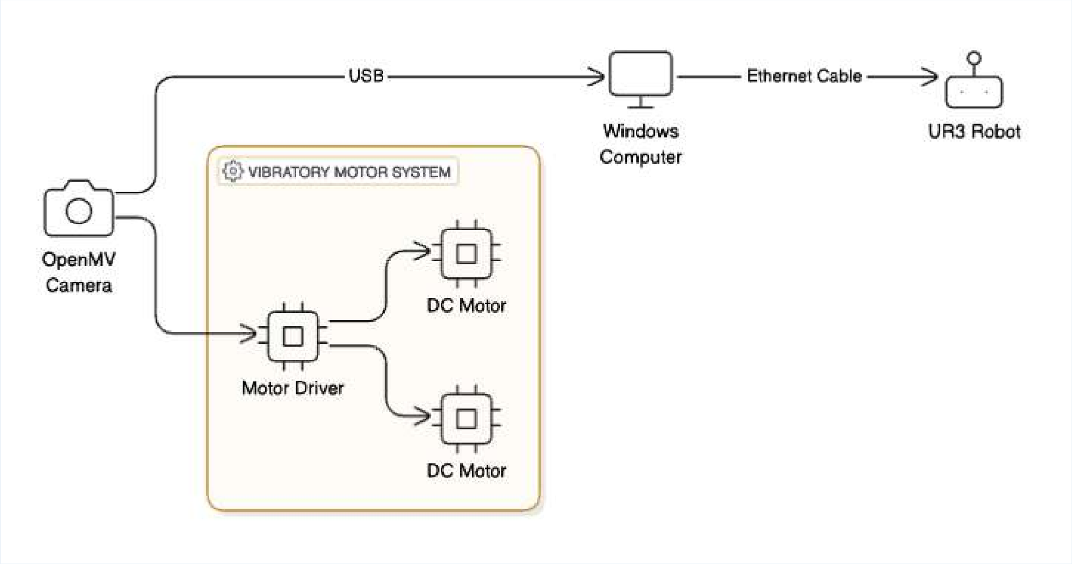

Fig. 2: Vibratory Feeder Communications Flow Chart: This diagram depicts the data communication flow between the vibratory feeder's AOI system, Python-based detection scripts, and the UR3 robot, enabling real-time control and synchronization for accurate component placement.

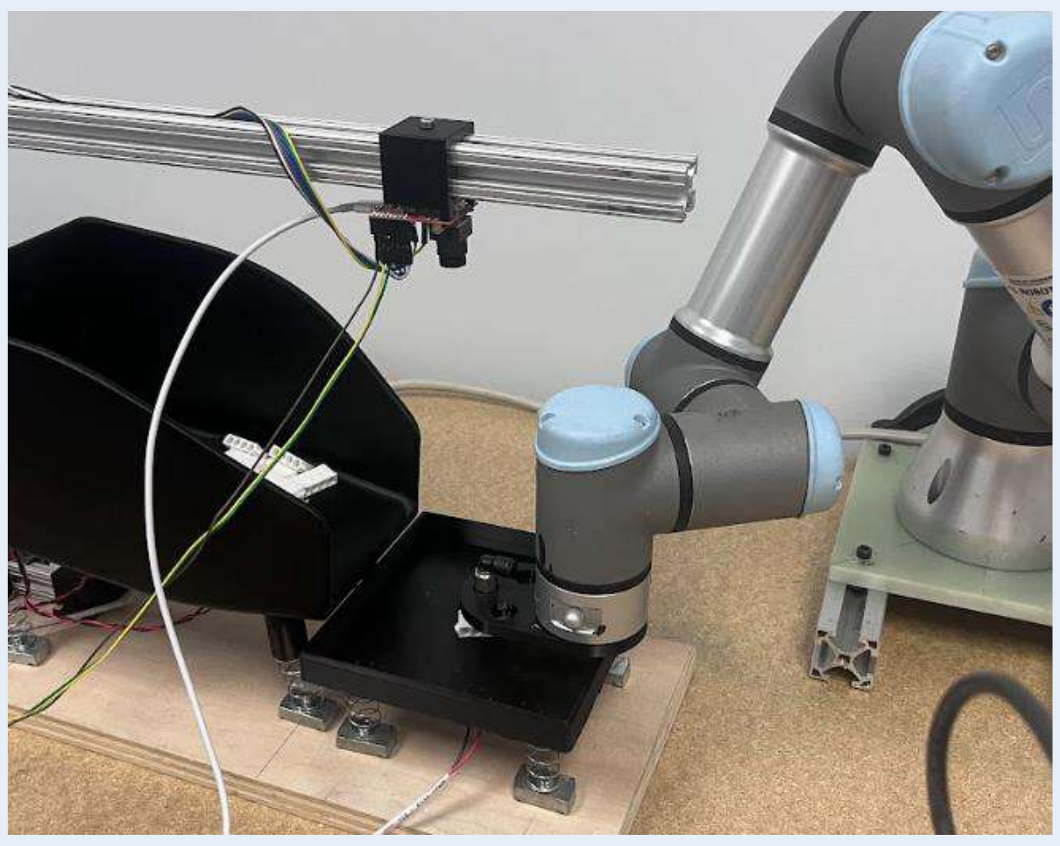

Fig. 3: UR3 Robot Using Custom Fine-Tip End Effector for Part Pickup: This figure shows the UR3 robot deploying a custom-designed fine-tip suction end effector to retrieve a through-hole component from the vibratory feeder plate. The slim-profile design ensures precise alignment and secure vacuum pickup, enabling reliable handling of small components in high-accuracy assembly workflows.

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Developing The Hydroelectric Water Purification System (HWPS)

Remedion

Team Members: Aaron Phare (EE), Michael Marsella (CPE)

Technical Director: Alexander Tompkins

Project Motivation

Our project tackles two global challenges—water pollution and energy efficiency—through Remedion's innovative Hydroelectric Water Purification System (HWPS), now adapted for residential use. Originally designed for municipalities, the HWPS delivers ultra-pure water directly to homes, protecting families from contaminants linked to aging infrastructure and inadequate municipal filtration. What sets it apart is its built-in hydroelectric generator, which produces clean, renewable energy while purifying water—helping reduce household energy costs. This dual-function system offers both environmental and economic benefits, enhancing health, sustainability, and quality of life. Remedion's broader mission is to combat pollution in water and food systems using sustainable technologies. By advancing accessible solutions for clean water and energy, we aim to support individual well-being and drive global progress in public health and environmental responsibility.

Key Accomplishments

- **Simplified System Design:** The HWPS design was streamlined to enhance manufacturability, reduce complexity, and improve overall system performance. This simplified approach ensures easier assembly and more efficient operation, laying the foundation for a scalable and production-ready prototype. **Fig. 1** provides a block diagram illustrating the optimized flow and layout of the revised design.

- **CAD Model Development and Visualization:** To support mass manufacturing efforts, the team developed a comprehensive CAD model of the HWPS. This included detailed labeling of each component to ensure clarity in assembly and manufacturing processes. **Fig. 2** *(For NDA purposes, labeling has been removed)* highlights the proposed CAD designs, representing a crucial step in visualizing the physical implementation of the system. The finalized model was submitted to company advisors to begin the mass manufacturing process.

- **2D Design Prints for Manufacturer Handoff:** Supporting the CAD model, the team created detailed 2D technical drawings to accompany the design submission. These prints serve as essential documentation for manufacturer handoff, providing precise component representations to support accurate fabrication and assembly.

- **3D Design Alignment with Project Requirements:** Through close collaboration with the technical director, the design direction for the 3D model was refined to meet all project constraints and functional specifications. This ensured the design would be feasible for real-world application while aligning with Remedion's goals for sustainability, performance, and efficiency.

- **User Interface (UI) Layout Redesign:** Significant improvements were made to the UI layout of the HWPS companion app, particularly the water quality page, to enhance clarity and ease of use. These changes were informed by user experience best practices and are aimed at delivering clear, real-time information on system performance and water quality. **Fig. 3** showcases the updated homepage, designed to offer intuitive navigation and instant access to critical metrics for end-users.

- **Webpage Integration for Customer Support and Brand Awareness:** To elevate the user experience, the Remedion team strategically integrated direct access to the existing Remedion company webpage within the HWPS companion app. This enhancement allows users to effortlessly navigate to customer support, submit inquiries, and explore in-depth information about the HWPS system and Remedion's broader mission. By embedding these resources directly into the app interface, the team ensured a seamless, intuitive experience that empowers users with quick access to essential tools and assistance. **Fig. 4** illustrates how this integration supports fluid navigation and strengthens user engagement across both platforms.

Anticipated Best Outcome

The ideal outcome of this project is the successful development of a whole-home Hydroelectric Water Purification System (HWPS) market model that transforms household access to clean, safe water. By removing harmful contaminants from tap water, the HWPS enhances water quality and ensures families have reliable, purified water at all times. This advanced system directly addresses the urgent need for clean water access, promoting better health and peace of mind. Focused on both innovation and impact, the HWPS aims to improve water safety and overall well-being, creating a sustainable solution for long-term household and health benefits.

Project Outcome

While the Anticipated Best Outcome (ABO) has not yet been fully realized, Team Remedion has made significant strides toward its achievement. The team is actively engaged in ongoing development efforts and is currently in consultation with manufacturers to bring the whole-home Hydroelectric Water Purification System (HWPS) to life. With continued dedication and steady progress, **Team Remedion has paved the way for the company to move forward in manufacturing the whole-home systems.**

Figures

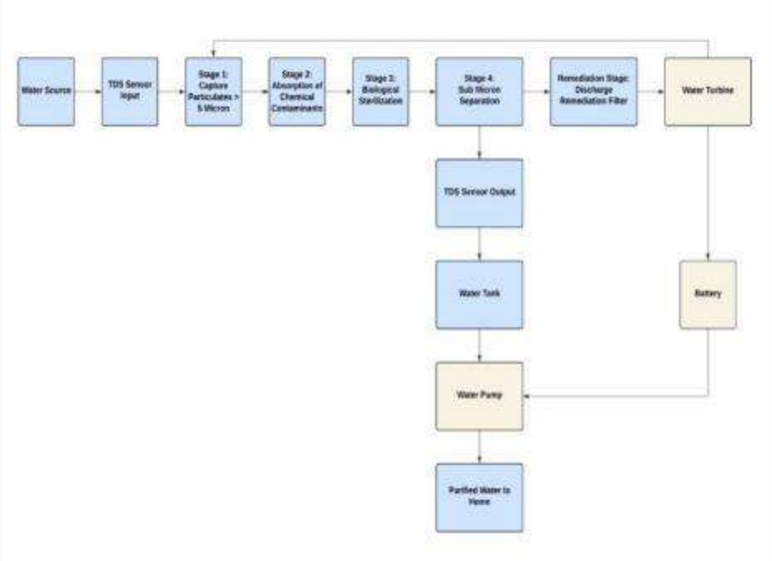

Fig. 1: The block diagram illustrates the streamlined design of the HWPS, incorporating all filter stages for optimal efficiency. It features an TDS sensor located at the sub-micron separation stage that monitors the water quality output, detecting any deviations exceeding 50 ppm to ensure consistent, high-quality performance

Fig. 2: The developed CAD model served as the blueprint for the HWPS market model, featuring a streamlined and optimized design that incorporated all filter stages. This comprehensive structure facilitated the creation of detailed implementation plans by manufacturers, ensuring a smooth transition from design to production will take place.

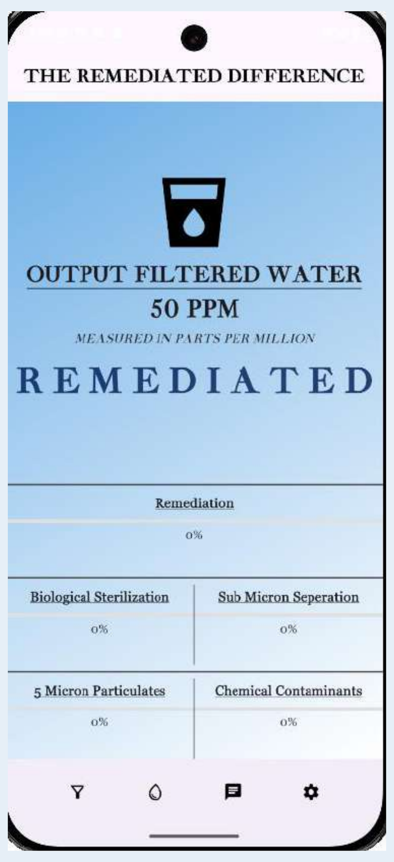

Figure 3: The redesigned UI offers seamless access to essential resources, optimizing the user experience. It enables users to effortlessly monitor water quality and quickly detect any deviations from the standard, ensuring consistent performance and reliability.

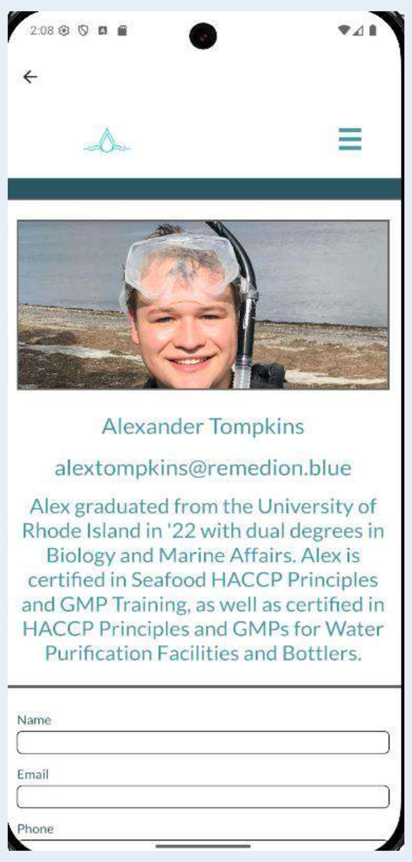

Figure 4: Integrating the dedicated Remedion webpage enhances the user experience by providing quick and easy access to customer support. This integration allows users to promptly contact the team, ensuring that any concerns or issues with their unit are addressed without delay.

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On-Premises LLMs

Using Local Large Language Models (LLMs) to aid Java and Rust Software Development, Automated Testing, and Software Reviews

Team Members: Logan Richards (CPE), Damien Lee (CPE)

Technical Director(s): John Sullivan, Alexander Moulton, and Thomas Santos

Project Motivation

Rite-Solutions is continually improving its software development processes, practices, and tools to increase individual and team productivity while improving product quality, decreasing time to market at lower cost. Of particular interest to Rite-Solutions is the use of open source, Large Language Models (LLMs) that support the automated generation of software design, interfaces, code development, testing, and documentation. Rite-Solutions develops and maintains a significant body of Java software used in legacy and on-going projects. Looking forward, Rite-Solutions envisions the use of more modern languages such as Rust to address software safety challenges associated with safety critical systems. A key impediment to the automated generation of software and related digital artifacts in our environment is security. Our desired solution will need to host LLMs on premise where our security policies and controls can protect proprietary and/or other sensitive software and digital assets.

Key Accomplishments

Dataset Creation

In order to create our dataset we decided to use synthetic data. Synthetic data is data generated artificially which is used to test and train large language models. In order to use synthetic data, we had to make some important decisions. We had a number of different possibilities with the model we were going to be training; Codestral Mamba being one of our choices. We decided that using Codestral Mamba could lead to the same shortfalls that we were supposed to be training out of the model. ChatGPT has models specifically trained for specific needs so we planned to choose a model which was trained for code generation and which was trained on both C++ and Rust. We ended up with 850 data pairs. The data was then turned into JSON format for use with the model.

Hyperparameter Initialization and Optimization

The first step to creating our initial hyperparameters was by understanding what hyperparameters for training a large language model were and what each one could change within the training process. These parameters range in importance and some were not changed for optimization purposes. Hyperparameters are necessary as configuration for each run of our training. By changing the hyperparameters, we change the way that the model will intake and learn from the data we are giving to it. With this in mind, finding a starting point for these hyperparameters was important to understanding them and getting the most out of our training data. Once we saw the loss outputs of the training, we were able to find a best version of our hyperparameters. The following was our values which we used to train our model.

Hyperparameter	Value	Reason
Batch Size	4-16	Low to prevent overfitting with smaller dataset
Learning Rate	5e-5 to 1e-4	Only a subset of parameters are being trained (PEFT)
Optimizer	AdamW	Works well with hugging face's transformer library; efficient for limited data
Max Sequence Length	256-1024	Adjust based on function sizes in dataset
Epochs	10-30	Dataset is small; more epochs may be necessary for training to be impactful
LoRA Rank	4-16	Lower rank keeps adaptation lightweight
LoRA Alpha	16-32	Higher values improve expressiveness
LoRA Dropout	0.1-0.2	Prevents overfitting

Python Code for Training

Run.py: Entrypoint for executing the fine-tuning pipeline. Loads user-specific configurations via YAML, sets up console and file logging, dynamically creates output directories to organize logs, training results, and the saved models after fine-tuning. Utilizes the different modules to initialize the model/tokenizer, preprocess the dataset, and begin fine-tuning. Optionally supports Weights & Biases for metric tracking and visualization.

Config files: Defines all parameters needed for fine-tuning, including the model to be trained, the dataset path and max sequence length, training hyperparameters, and the LoRA configuration to enable Parameter-Efficient Fine-Tuning (PEFT). LoRA includes parameters such as dropout, rank, alpha, and the target modules significantly influence the fine-tuning results.

Train.py: This script is for orchestrating the fine-tuning process to ensure stable and reproducible training. Some features include full logging of metrics, loss, and resource utilization, evaluation and checkpoint saves at configured intervals, optimizer customization and warmup scheduling, and training and validation datasets. Logs a sample batch before training to catch format/tokenization issues.

Data_utils.py: Validates the dataset (e.g. required columns exist, no empty rows), shuffles the dataset for randomness (the same seed is used for reproducibility), tokenizes the C++ and Rust code pairs using the provided tokenizer from the YAML file, and masks the padding tokens in the labels with -100 to ensure loss is only computed using valid tokens.

Anticipated Best Outcome

The best outcome is :

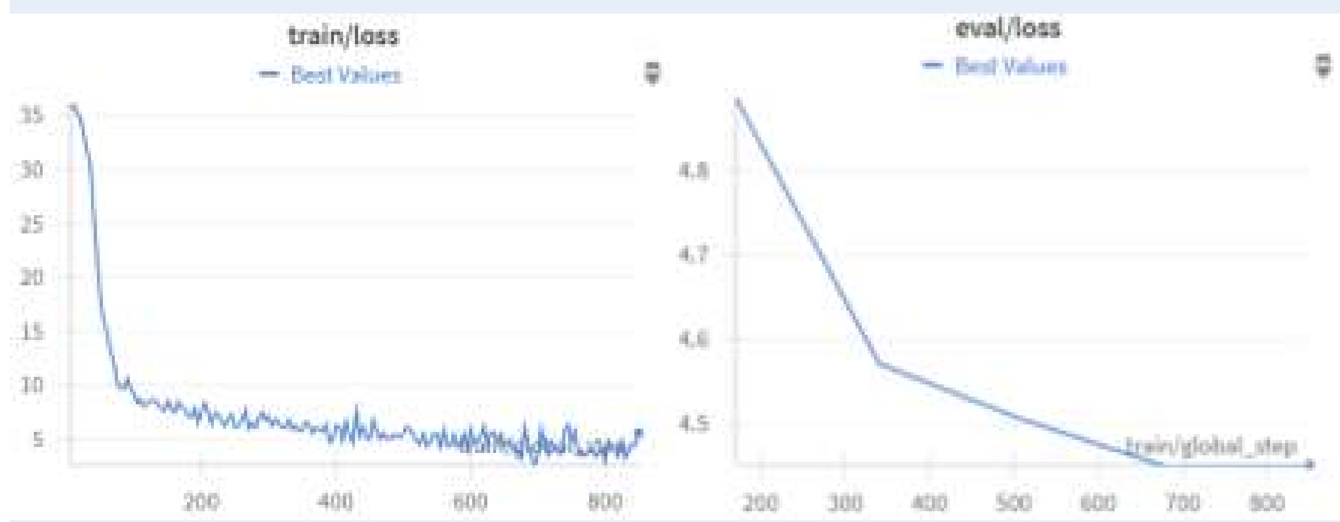
- Deliver a containerized large language model which can be used to translate legacy C++ code into Rust
- Be proficient in code generation based on a prompt or block of code
- Be able to generate in Rust and Java
- Be able to run on a regular laptop
- Not use any outside sources or packages.
- Be based on an open source model and will be fine tuned to meet these requirements

Project Outcome

We were able to achieve the ABO requirements. We have a working model which can translate the company's legacy code to Rust and gained valuable understanding of machine learning and fine tuning

Figures

This figure shows the LLM system and how it goes from data creation to fine tuning to outputting LLM response.



These losses are based on the best outcomes of our hyperparameter search. Evaluation and training losses are important in understanding the validity of the current hyperparameter configuration

This shows our Streamlit app using a fine-tuned version of Codestral Mamba to take in a user prompt and generate a response

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SANCTUARI ECHO MIKE 2

Post-Release Tacking Device For Small Mammalian Species

SANCTUARI

Team Members: Jack Russo (ELE), Ismail Muhammad (ELE), Barry Huang (ELE), Amani Hameed (CPE)

Technical Director(s): Joe Moreira, Chris Rothwell

Project Motivation

Historically, wildlife rehabilitators accept that contact will be lost when releasing animals back into their natural habitats after providing care throughout the animal's youth or critical recovery period. However, the ability to track and monitor released animals can increase their chances of their survival. Monitoring in aggregate also provides valuable biological and ecological data capable of fundamentally advancing various core conservation efforts. Wildlife tracking technology is evolving, but the most reliable and available systems still involve radio and satellite telemetry. Microchips and PIT (passive integrated transponder) tags can be useful in recognizing a given individual, but they typically provide no location data.

Key Accomplishments

Main PCB V1: Designed the first version of the main board following two detailed design review sessions. Integrated correct impedance control and differential pairs for USB signals through the usage of Saturn PCB . The board includes the Quectel BG77, a low-power LTE Cat M1/NB2 and GNSS module used for cellular connectivity and GPS tracking, and the Silicon Labs EFR32BG24, a Bluetooth Low Energy (BLE) system-on-chip used for wireless communication. Also included are a GPS antenna and a Bluetooth module. Successfully ordered and assembled the boards for hardware validation and testing Fig. 1 and 2 shows the first version of the main PCB in circuit maker.

Secondary PCB V1: Created the first version of the main PCB focused on environmental sensing. The board houses both a microphone sensor and a temperature sensor, enabling data acquisition for the system's sensing functionality.

JSON document handling: Developed a JSON-based communication system for the BG24 microcontroller to interface with a Flutter-based mobile application. The system allows for structured, parameter-driven control over GPS data collection and cellular upload processes. The JSON document defines fields such as gps_frequency, starting service, and upload_interval to customize operation timing, along with flags like store_gps_data, upload_on_completion, and battery_mode to control power usage and data handling. It also includes tracking system status and errors, such as status and error code. The BG24 parses this JSON structure, executes the corresponding commands (e.g. storing and uploading data), and operates in coordination with the BG77 module for GPS acquisition and cloud transmission.

GPS Capability: Using the Quectel BG77 cellular module the device is able to parse GPS fixes containing longitude coordinates, latitude coordinates, speed, and elevation. This data is then stored on a web based real time database with unique ID's for each entry

Prototyping: In the development of this product development boards for the BG24 microcontroller and BG77 cellular module were integrated together to perform the tasks and accurately test the circuitry of our PCB design. In this process we found the need to use another board designed for bidirectional level shifting as well as direct solder pad connections. See the prototype in Fig. 3.

Cellular service: Configured the BG77 module using the Hologram IoT platform, enabling cellular connectivity. Activated a Hologram global SIM card through the Hologram dashboard, configured the appropriate APN settings, and verified connectivity through AT commands. This setup allows the BG77 to access the cellular network and transmit GPS data to the cloud once it has been collected and processed by the BG24.

Flutter app: Development and integration of a comprehensive Bluetooth communication system in our Flutter app using the Flutter Blue Plus package. Designed and implemented a robust Trap class that interfaces with BG24 devices, enabling reliable Bluetooth discovery, connection, configuration, and data transfer. Engineered a full protocol for reading and writing BLE characteristics and descriptors such as for sensor control, configuration, certificate retrieval, and temperature data while handling retry logic, segment sequencing, and data validation. Also designed data models (Config, Info, Control, etc.) to serialize and parse binary data exchanged with the device. This Bluetooth foundation enabled dynamic trap management, configuration over-the-air, real-time data acquisition, and seamless device interaction within our Flutter UI, forming the core of the smart trap system.

Anticipated Best Outcome

Successful design, prototyping, and testing of a small, lightweight, wearable, long-service-life tracking architecture (electronics and battery power source) suitable for smaller mammalian species such as fox, raccoon, skunk, opossum, rabbit, and more. A "stretch goal" is to include smaller species should the basic architectural design be suitable.

Project Outcome

The Anticipated Best Outcome of the project was not achieved. However, many of our set goals through this project was meet.

Figures

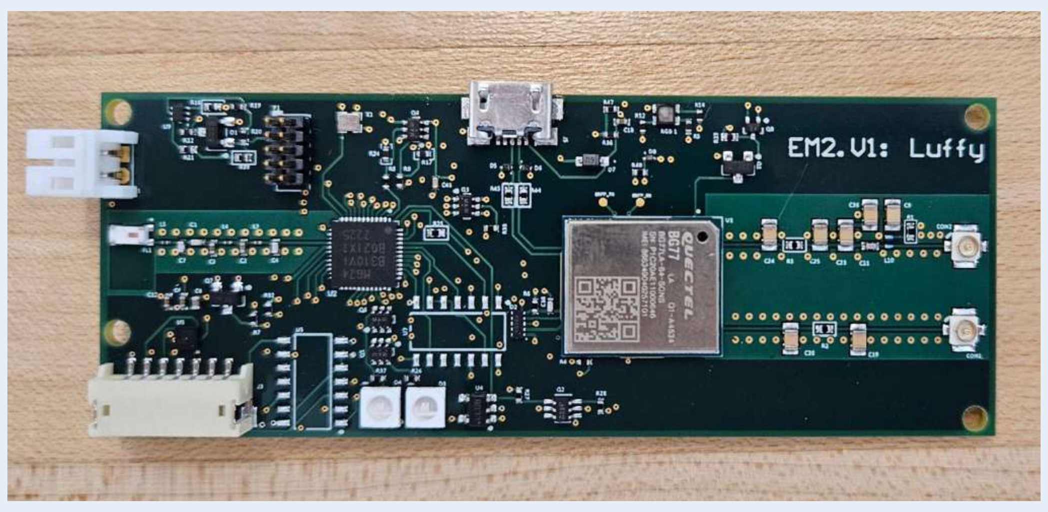

Figure 1: Image of the front of the main PCB. The lighter green rectangle shows the GND polygon pours which are part of the impedance control for the antennas.

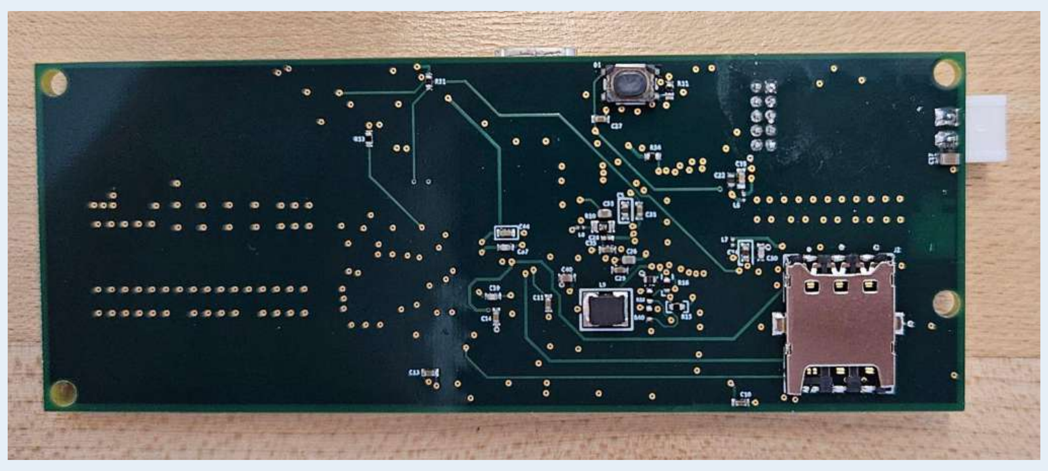

Figure 2: Image of the back of the main PCB.

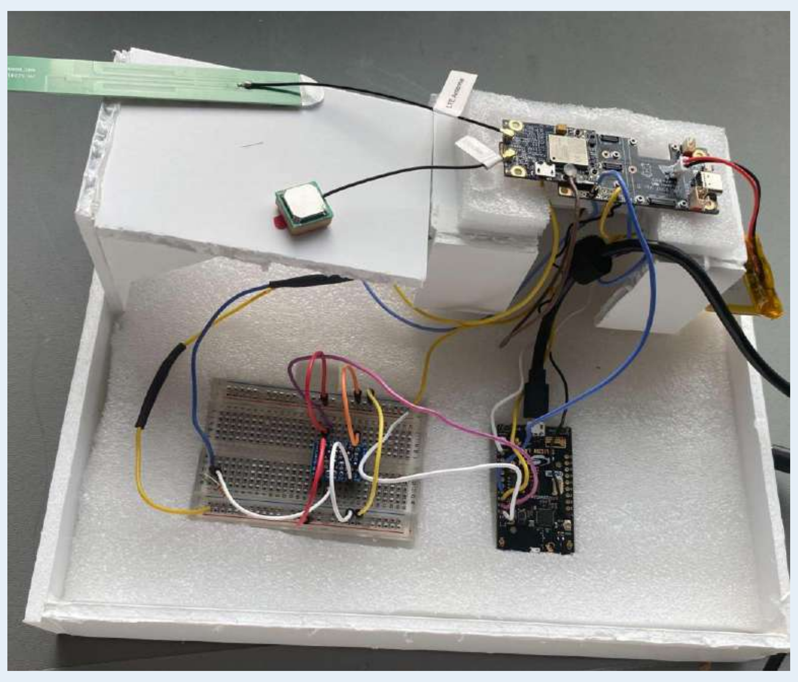

Figure 3: Prototype during development of the system using rak wireless development kit for the BG77, silicon labs microcontroller development kit, voltage translator, and antennas.

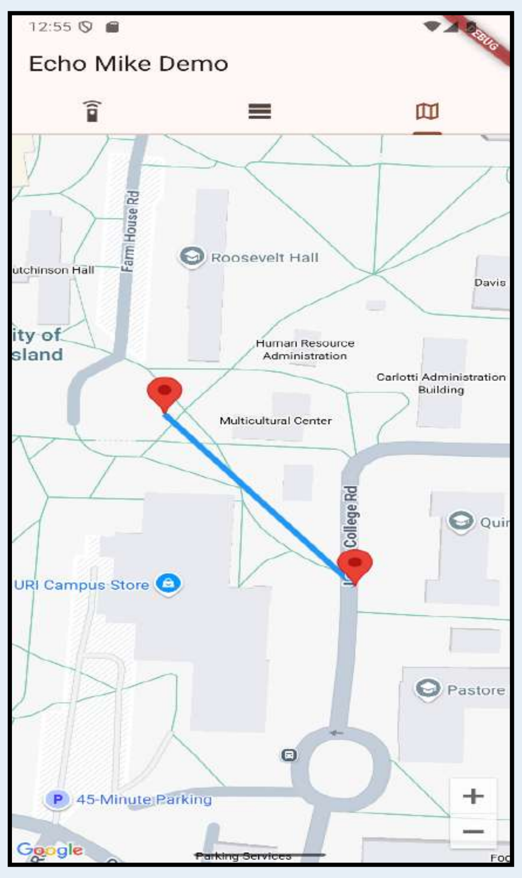

Figure 4: Imagine of the mapping of the GPS data from the Flutter App

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BLAST

Burst Learning Audio Spectrogram Transformer

SEACORP
A KAPCO Defense Company

Team Members: Shuichi Kameda (CPE), Jakob Porto (CPE, CSC)

Technical Director(s): Bill Matuszak , Megan Chiovaro

Project Motivation

For end-to-end audio classification, convolutional neural networks (CNNs) have been a dominant architecture for many models. While CNNs were considered indispensable, they do have their shortcomings, notably in their ability to capture global context in data. By utilizing the Audio Spectrogram Transformer (AST), we can improve on the results of previous CNN-based models in many ways. The first is through performance; based on available research, an AST model has the capacity to produce state-of-the-art predictions, sometimes outperforming CNN-based approaches. Another is through the capturing of long-range dependencies within data, which is done dynamically through the self-attention mechanism. Overall, the AST model displays remarkable promise for the field of audio classification. Even so, SEACORP believes we can improve upon the model through fine-tuning, which if done for a specific task, may produce highly effective results. By utilizing these advantages with transfer learning, we seek to design an audio classification model that can show the potential for application in multiple scenarios, such as anomaly detection and sound event localization.

Key Accomplishments

AST and Spectrogram Background Knowledge: Most of our initial understanding of the AST framework came from the MIT research paper published by Gong et al **(Fig. 1)**. Additionally, we needed to learn raw waveform-to-log-Mel spectrogram conversions, which is the input format required for the AST model. Over the course of this project, we were able to learn the required material to build and train our AST model for our intended task.

Training Environment: To develop our model, we had to prepare a suitable training environment. To accomplish this, we were able to use the Unity Cluster, a collaborative, multi-institutional high-performance computing cluster, to help us with this task. Using the Unity Cluster, we were able to both acquire hardware and be able to schedule programming tasks even when our computers were unavailable for use.

AST Model Prototype: A fully functional prototype of the AST model was developed using the Hugging Face Transformers API **(Fig. 2)**. The pipeline begins by converting the audio samples from our dataset into 16 kHz single-channel audio, after which they are transformed into 128-bin log-Mel spectrogram inputs. The inputs are then processed by the AST architecture (i.e., patch embedding, positional embedding, transformer encoder...), where the model learns the required information for audio classification. The resulting model yields a strong evaluation accuracy, producing a ~95% accuracy metric on the test subset of the dataset.

Data Augmentation: To improve the robustness of our data, we utilized several data augmentation methods, some of which include time-stretching, pitch shifting, and signal-to-noise modulations, among others. These methods fall into several categories: generalized signal distortion, dynamic range adjustments, and random noise addition. Using these techniques helped improve the model's generalizability, allowing for better performance in different settings.

Data Collection: The model was trained on the AudioMNIST dataset, which is comprised of spoken digit (0-9) recordings. As an attempt to improve robustness in noisy environments, we used portions of the DEMAND dataset, which primarily contains background chatter in different settings. These samples were mixed with the original dataset to produce synthetic audio of digits spoken in broader environments.

Hyperparameter Fine-Tuning: To fine-tune our model, we attempted to use several evaluation methods and spectrogram types. As expected, the best spectrogram type was the Mel Spectrogram, which led to the more important hyperparameters being evaluation metrics. To train our model, we used 4 evaluation metrics, accuracy, precision, recall, and f1 score. Along with this, we were able to track loss in order to better train our model over each epoch. Altogether, by using the Hugging Face API, we were able to train our model using these hyperparameters.

Audio Receiver: For live inferencing, we purchased the RØDE NT-USB Mini Microphone. This is a quality microphone which allows us to capture audio from the user with minimal outside noise thanks to its cardioid polar pattern. It also features a frequency response of 20 Hz to 20 kHz, covering the full range of human speech, and connects via USB-C for plug-and-play compatibility.

Output Handler: We explored several output handlers for delivering model predictions, starting with a simple terminal-based interface and later testing frameworks such as Gradio and Streamlit. Ultimately, we chose Streamlit due to its balance of visual clarity, intuitive interface, and ease of deployment, making it the most effective platform for demonstration in a real-time setting.

Demonstration: To demonstrate the inference capabilities of our model, we implemented a real-time digit classification interface **(Fig. 3)**. The script utilizes the sounddevice module to capture a 2-second audio clip of the user speaking a number (0-9) into their microphone. The audio is then passed through our trained model, from which a prediction is output along with class-wise confidence scores. We used a Streamlit-based web application to display the relevant information using a bar chart in an intuitive user interface.

Anticipated Best Outcome

The anticipated best outcome saw us developing an effective model utilizing the Audio Spectrogram Transformer as described in the MIT research paper by Gong et al. The main objective is to leverage transfer learning to tune an AST model to a specific audio classification task, such as Right Whale identification or similar audio analysis. Ultimately, were tasked with creating a demonstration that the technical directors can showcase to other industry leaders in the field at conferences. This demonstration will be intuitive to use with some degree of interactivity.

Project Outcome

We were able to successfully achieve the Anticipated Best Outcome. We have delivered an effective model that can be used as a demonstration for showcasing the potential of transfer learning with the Audio Spectrogram Transformer.

Figures

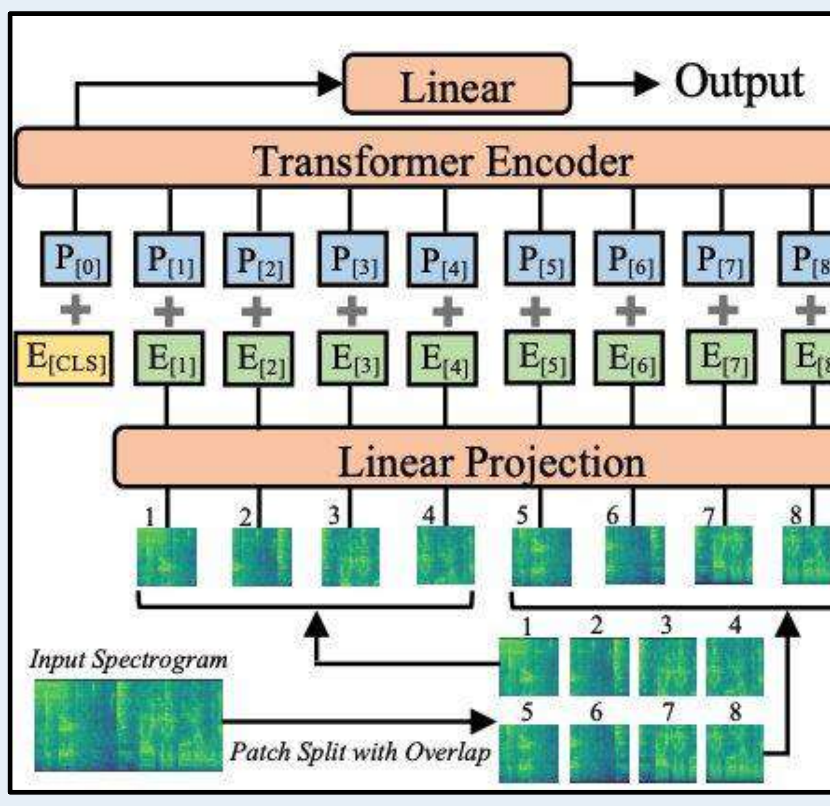

Fig. 1: Audio Spectrogram Transformer architecture

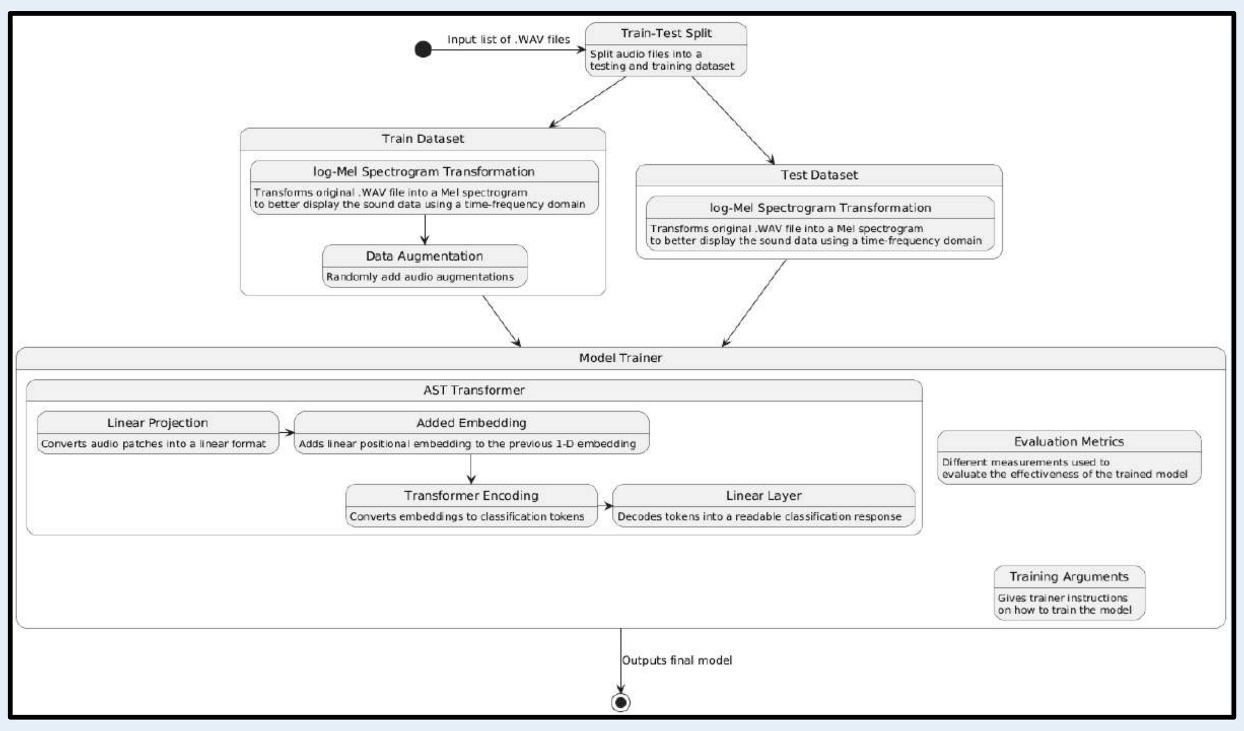

Fig. 2: AST training pipeline including data preparation, feature extraction, and model learning.

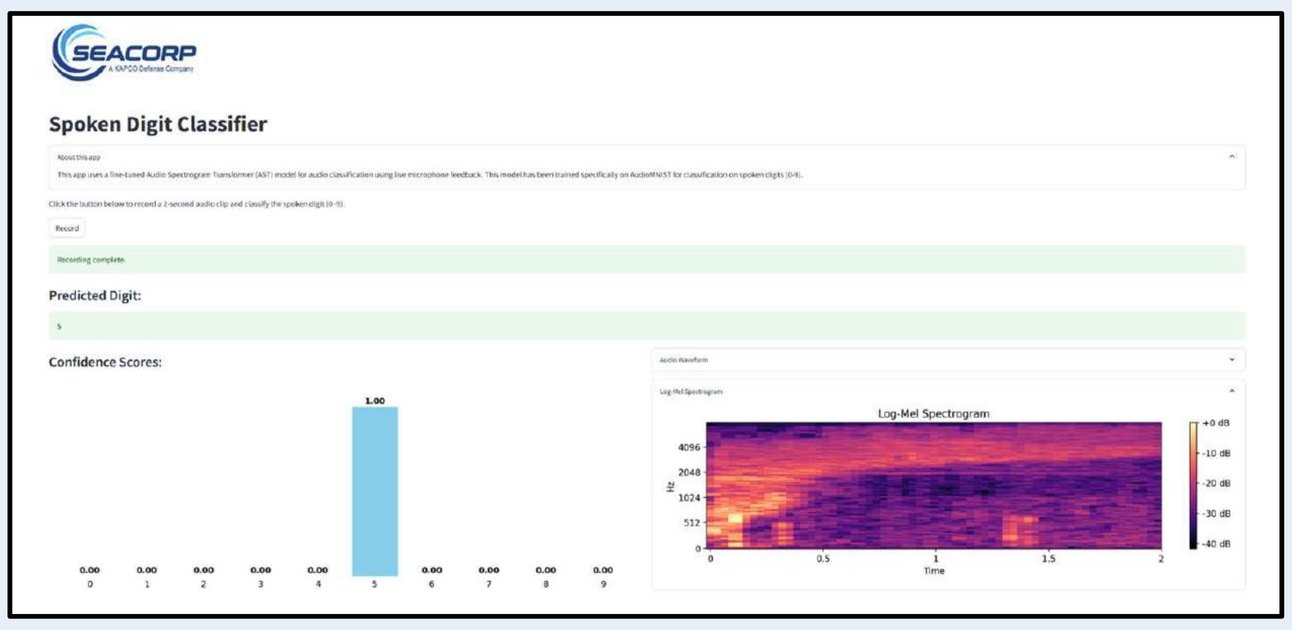

Fig. 3: Locally-hosted web application for interacting with model.

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AI/ML For Wildlife Rehabilitation

SANCTUARI
A 501(C)(3) NONPROFIT ORGANIZATION FOR WILDLIFE

Team Members: James DeMello (CPE), Van Davey (CPE)

Technical Director(s): The name of your Technical Director/Directors

Project Motivation

There is a pressing shortage of wildlife rehabilitators to care for animals in need, leading many to feel overwhelmed and unable to provide optimal care. This project seeks to address this critical issue through the application of Machine Vision and Artificial Intelligence (MV/AI) technologies. Through such advancements, we can significantly enhance wildlife rescue, rehabilitation, and veterinary practices.

SANCTUARI has amassed nearly 0.75+ petabytes of valuable, mission-critical video footage. The goal of this project is to intelligently filter this footage to extract relevant animal content, which will then be used to develop AI systems integrated with video monitoring. These systems will greatly improve the capacity and diagnostic capabilities of wildlife caregivers. Ultimately, the project aims to demonstrate various methods that will enhance care for wild animals, ensuring they receive the attention and treatment necessary for their recovery and well-being. Through these innovations, we hope to reinforce support for wildlife rehabilitation efforts.

Key Accomplishments

File Metadata to Excel

Made an executable program that will take user input and export file directory metadata to a designated excel file.

Ordering Hardware

Designers were given the authority to spec & order an advanced AI dedicated hardware for use toward project goals.

Logger Program

Will take an input directory and process all the mp4 videos contained within and export a .txt file log to an output directory of the user's choosing.

Editor Program

After specifying an input directory containing all previously filtered files, the user can designate editing options to process the videos for specific content.

Parallel Processing Implementation

Implemented parallel processing onto the Logger & Editor to expedite the processes via parallel computing with Nvidia tensor cores.

Video File Segmentation

Using the OpenCV library we learned to break videos into parts based on detections present.

Class Integration

We began the groundwork for implementing more classes into the YOLO model for future teams to expand upon.

Testing of Existing Data

Via the programs developed we have begun testing the existing 800+ Terabytes of footage at Sancutari's disposal

Creation of Sorting Algorithm

Python programming to sort all videos based on only animal, only human, or both human and animal.

Addition of New Classes

New classes that are not included in the basic YOLO architecture have been added/tested for implementation

.

Anticipated Best Outcome

To achieve the ABO, at least 3 of the following 6 objectives must be completed:

- Design a system for filtering the most relevant video records provided.
- Apply the filtering system to all video files.
- Create a separate system to use videos that pass the filtering process.
- Enhance efficiency and effectiveness in wildlife care through improved video analysis and support.
- Train and test an AI system using the filtered videos, designed for monitoring purposes.
- Deploy the trained AI as live video monitoring "virtual helpers" for wildlife caregivers.

Project Outcome

Achieved ABO. Exceeded initial expectations and achieved 4th objective.

Figures

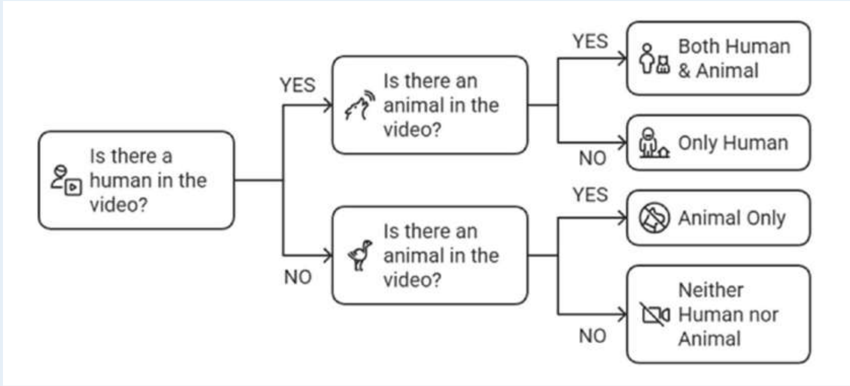


Figure 1 - Classification Diagram

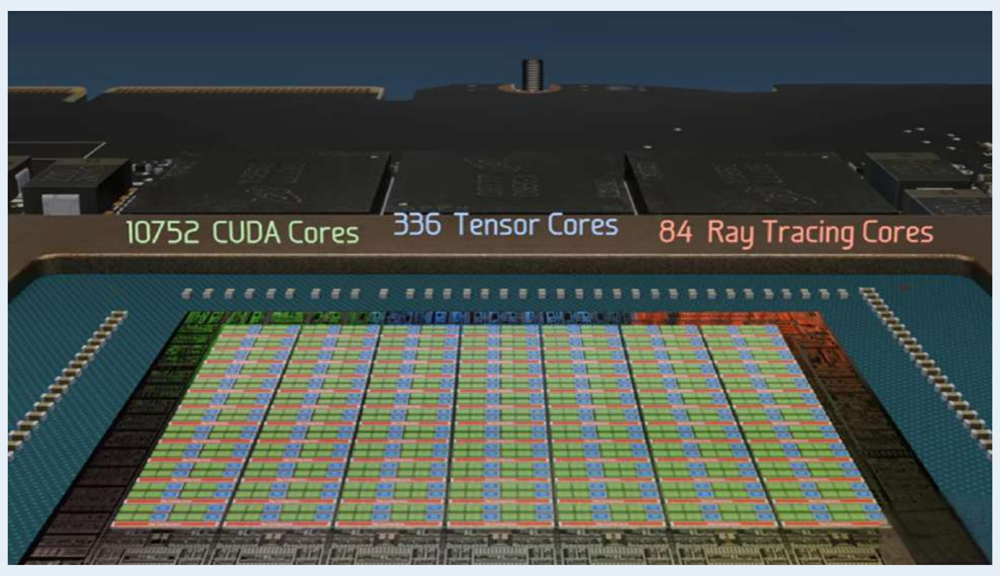
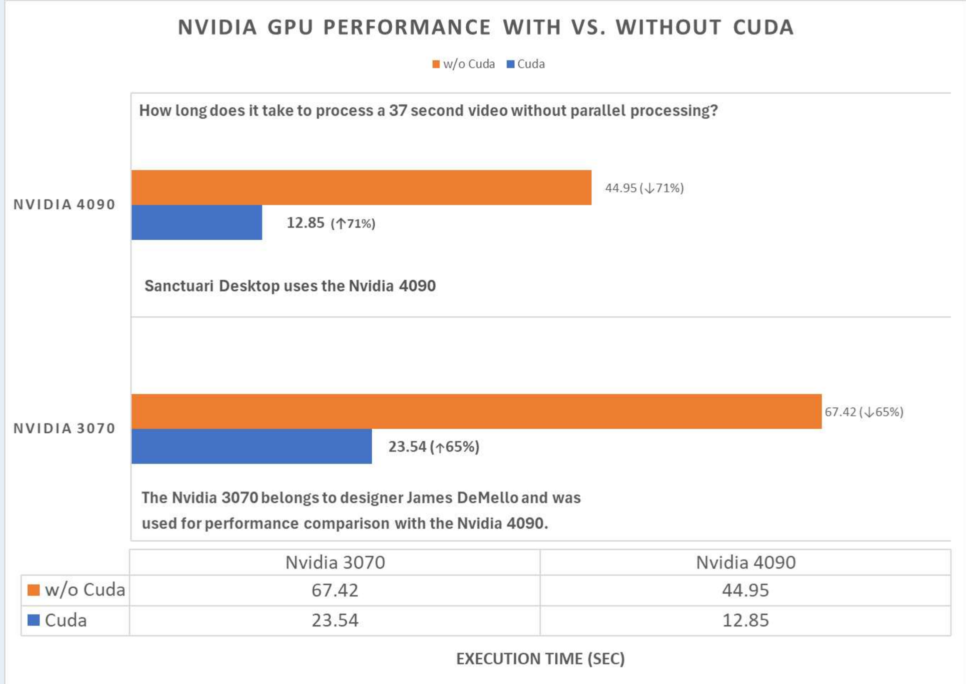


Figure 2 - Nvidia 4090 Core Architecture



	Nvidia 3070	Nvidia 4090
w/o Cuda	67.42	44.95
Cuda	23.54	12.85

Figure 3 - CUDA Performance Comparison

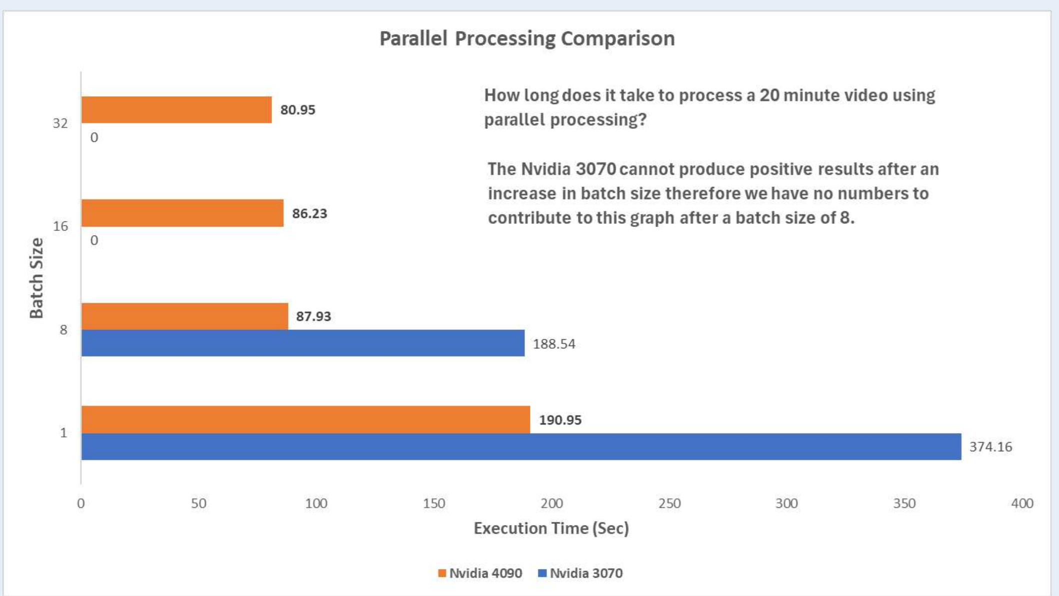


Figure 4 - Parallel Processing Performance Comparison

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URI ICRL Robotoy

A Robotic Toy for K-12 Robotics and Programming Exposure

ICRobots Intelligent Control and Robotics Lab

Team Members: Argha Goswami (CPE), Andrew Rae (CPE), Ryan Bolanos (ELE), Thomas May (ELE)

Technical Directors: Dr Paolo Stegagno & Cameron Amaral

Project Motivation

Exposing young Rhode Islanders to programming and robotics is a way to promote access to well-paying jobs and other opportunities. Additionally, increased participation of people from under-represented groups could also promote diversity in the field, and ultimately result in an increase in the total number of workers. The ICRobots lab is partnering with the URI College of Engineering (COE) to bring STEM programs focused on robotics to schools across Rhode Island from K-12. RoboToy is being especially developed to fill the need for students in early education (K-5). Programming inherently requires basic skills like reading and math that are still being acquired in the early stages of education, which add to the burden of learning new skills. Graphical programming tools have been developed to introduce foundational programming concepts in an easier setup, but they still lack the contact and manipulation experience provided by physical toys, which is fundamental in early childhood.

Key Accomplishments

- **PCB Design:** The PCB consists of six 8-pin connectors, allowing a 12 row by 8 column button array to be created. This button array will take in each row's command arguments and output them to the Arduino. This is all connected by a 20-pin connector to the bottom most pinouts on the Arduino Mega Unit.
- **PCB to Arduino Code Testing:** Two versions of test codes were created in order to support the PCB functionality. The first code tests individual key presses of the button array. The second test takes the entire row as a byte and stores the total value into an array. This second test is what we used in our final version of the robotoy code, and is used to determine which instruction is called. These tests can be seen in **Fig. 1.**
- **Body Design:** The body of the Robotoy was completely redesigned from the ground up. A panda was chosen as the form Robotoy would take in order to be more aesthetically pleasing and more appealing to children. The body is a modular design consisting of a baseplate and panda shell affixed onto it. The baseplate has compartments for the DC motors, the breadboards which contain many of the electronic components, and mounting for the PCB and Arduino Mega/Motorshield. Attached to the baseplate are also the wheels in the rear and a roller ball bearing in the front. The panda shell consists of three separate parts, the head, the center, and the rear. The center portion accepts the command blocks, and the rear portion houses the power switch and start button. All parts of the body fit together with interlocking joints to allow for simple assembly and disassembly. The complete 3D model is shown in **Fig. 2.**
- **Power System:** The power system consists of a power switch and a DC power terminal. We achieved best results using a 12V corded power supply but we were also able to use five AA batteries in a battery carrier wired to a voltage regulator and attached to a DC power jack. Using the batteries provided a portable but underpowered result, a tradeoff that should be examined more in the future. The power system is shown in **Fig. 4.**
- **Command Blocks:** The command blocks are designed to easily snap in and out of the Robotoy. Each block has a set number of “legs” that push the necessary buttons depending on the command that is to be executed. The command blocks have up to a maximum of eight legs for the eight bits of the commands. Additionally, the last four bits of the command (the operand), can be removed and interchanged between blocks. **Fig. 3** shows the command blocks.
- **Accessory Electronics Integration:** The Robotoy utilizes two ultrasonic sensors, one in the front and one in the rear. The sensors are used for obstacle detection and depending on the distance from a detected obstacle, a passive buzzer will make different alarm sounds and jingles. Also integrated is a microphone that can detect claps or loud sounds, and when such a sound is detected the buzzer will make a sound. The complete pinout is shown in **Fig. 4**.

Anticipated Best Outcome

The Anticipated Best Outcome (ABO) of this project is a fully functional and replicable prototype of a single robotic kit with a ground robot and coding blocks to be delivered to K-5 classrooms around Rhode Island. The robot should be powered by regular AA batteries and integrate 2 ultrasonic sensors and one sound sensor. It must be able to read a sequence of up to 12 blocks inserted into a slot on its back, with each block representing commands such as go forward, backwards, right, left, stop, as well as implementing for-loops and if-statements. Each block should also be visually different in a way that can be easily recognized by illiterate users.

Project Outcome

The Anticipated Best Outcome has been achieved with the exception of the for-loop and if-statement features.

Figures

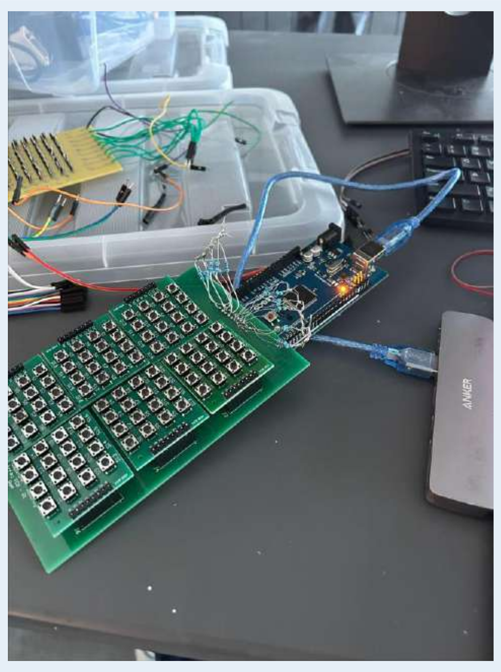

Fig. 1 Testing of complete PCB with push button arrays

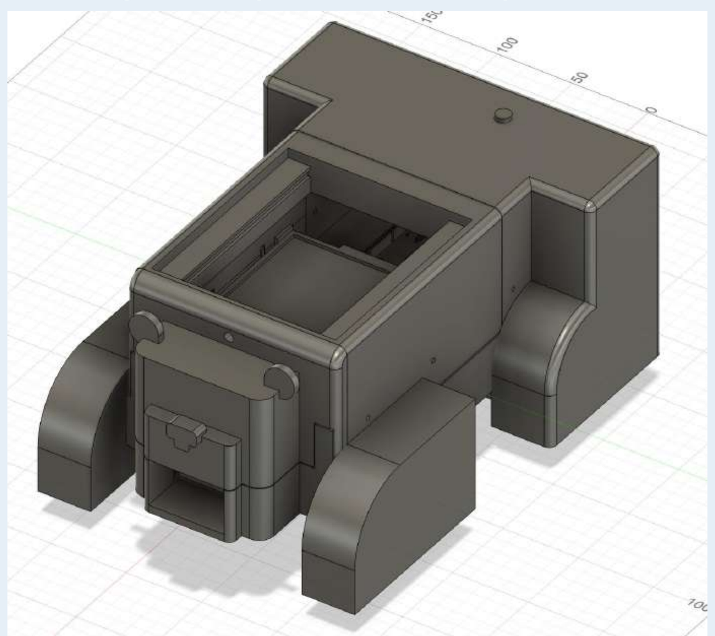

Fig. 2 3D model of complete Robotoy.

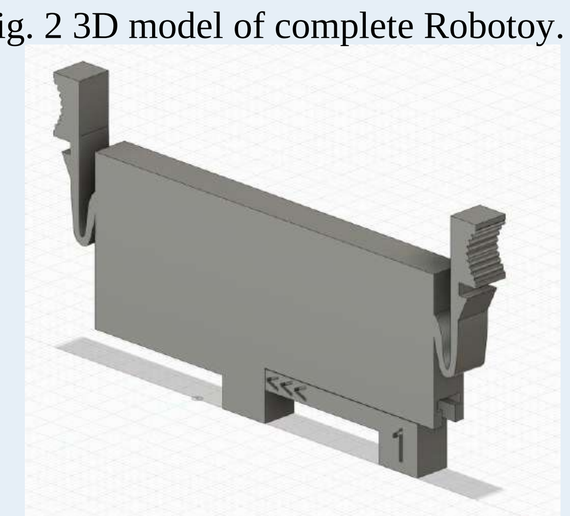

Fig. 3 Command block with opcode 0001 and operand 0001

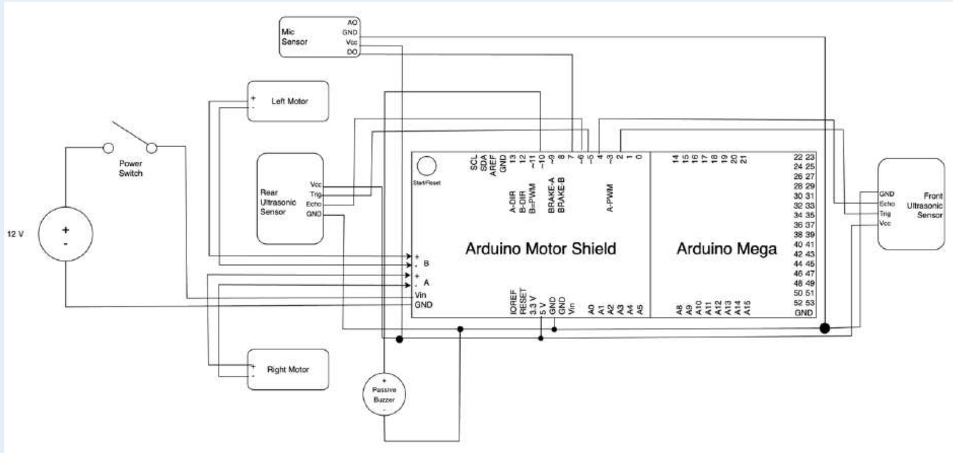

Fig. 4 Complete Robotoy pinout

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iPEBB

integrated Power Electronics Building Block

URI PEL
University of Rhode Island Power Electronics Lab

Team Members: Justin Smith (CPE), Gianni Smith (ELE), Max Bongiovanni (ELE), Patrick Feliz (ELE)

Technical Director(s): Dr. Yeonho Jeong & Xueshen Zhang

Project Motivation

PCS performance heavily depends on the design process, which traditionally relies on expert-driven, time-consuming methods with inconsistent results. Each application presents unique constraints, requiring tailored parameters or new topologies to optimize efficiency and power density. Machine learning offers precise and efficient design optimization but faces challenges like lack of standardization and design complexity. This capstone project aims to develop a design automation framework using ML, modular systems like iPEBBs, and heterogeneous computing to accelerate and streamline PCS design while maintaining strong power electronics fundamentals. The goal is to improve design accuracy, reduce development time, and meet evolving industry demands.

Key Accomplishments

This project is centered on designing and implementing a power conversion system for a UAV platform, combining hardware development with embedded control. The team's efforts included circuit design, simulation, PCB fabrication, firmware development, and system integration. The following key accomplishments highlight the major milestones and technical achievements completed over the course of the project.

- **Synchronous Boost Converter Design and Implementation**: The team successfully designed and built a synchronous boost converter capable of stepping up 6V to 8V at a 15A load. This included calculating component values, designing the magnetics, validating the design through PSIM simulations, and analyzing output stability under dynamic load conditions.
- **Custom PCB Development**: A fully functional PCB was designed in Altium Designer, fabricated, and assembled. Special care was taken to minimize switching noise and thermal issues through layout optimization and component selection.
- **Quadcopter Power Integration**: The converter was integrated into a quadcopter platform, providing stable power to onboard electronics. The system was tested under varying load condition, validating the converter's robustness and reliability.
- **Embedded Firmware Development**: Custom C firmware was written for a TI F28069M microcontroller to implement a closed-loop PI control system. The firmware samples output voltage via ADC, calculates the required duty cycle, and updates ePWM outputs in real-time to regulate voltage.
- **Controller Testing and Simulation**: The PI-based control loop was developed and validated using oscilloscope testing. A software model was also implemented to verify controller behavior without hardware.
- **Systems Understanding**: The team gained hands-on experience in everything power electronics —from simulation and PCB design to firmware development and real-world testing. From this project, we have developed a deep understanding of power regulation, control loops, different converters, and the architecture of quadcopter systems.

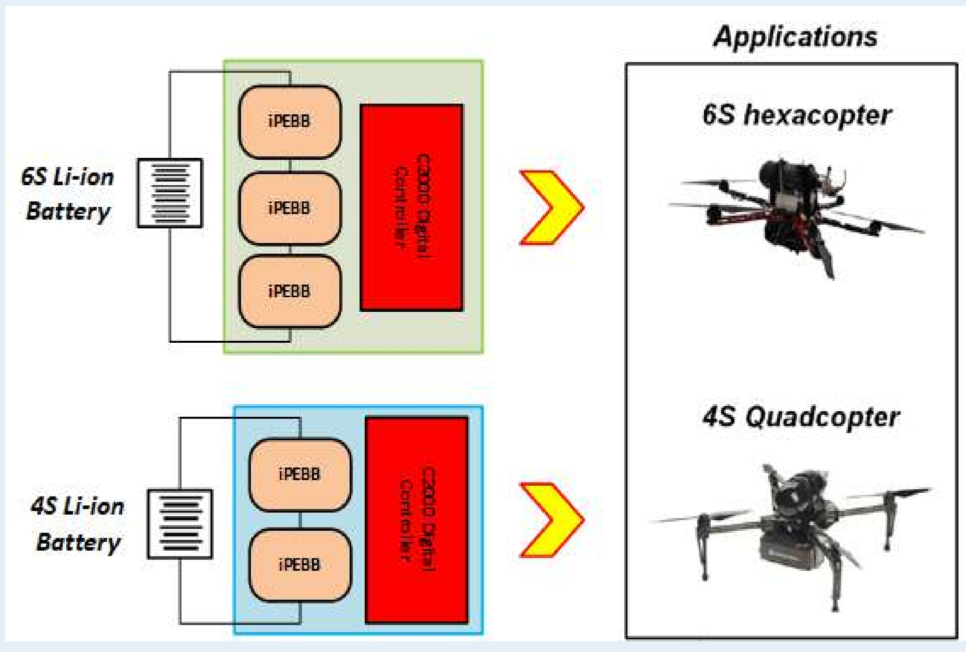
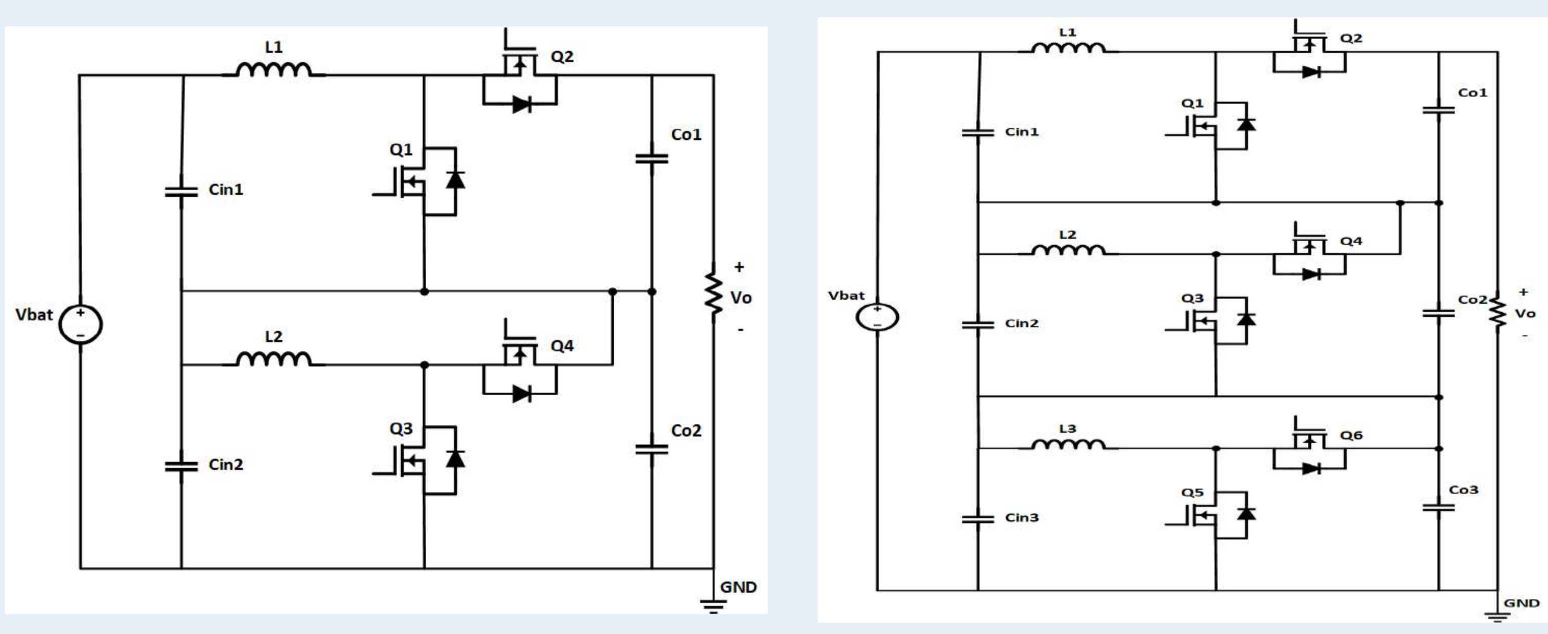


Figure 1: Overview of Capstone Design Project



(a) (b)

Figure 2: Synchronous Boost Converter Stack (a) Quadcopter (b) Hexacopter

Anticipated Best Outcome

This project aims to develop two PCS prototypes for a 6-S hexacopter and a 4-S quadcopter, along with a PEDA tool running on platforms like AWS or OCT-FPGA. Using outputs from the tool and human input, a single iPEBB will be designed, implemented, and tested to meet electrical requirements and compare design strategies. This will be followed by configuring, evaluating, and demonstrating multiple iPEBBs.

Project Outcome

The anticipated best outcome was not met. We were able to design a Power Conversion System with digital control. We were not able to complete the ML portion of the project

Figures

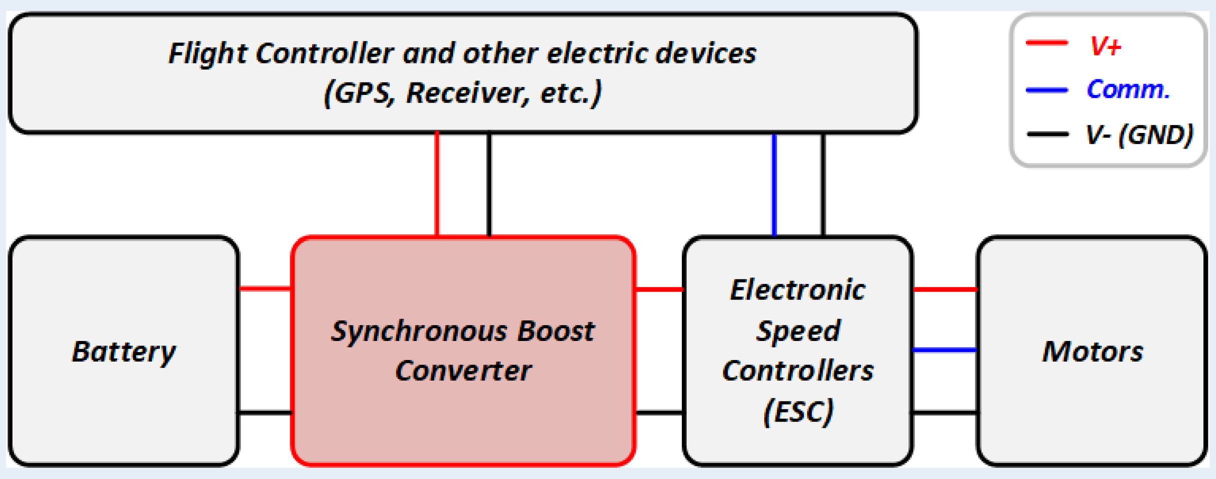


Figure 3: Block diagram of the hardware circuit for PCS in drone applications.

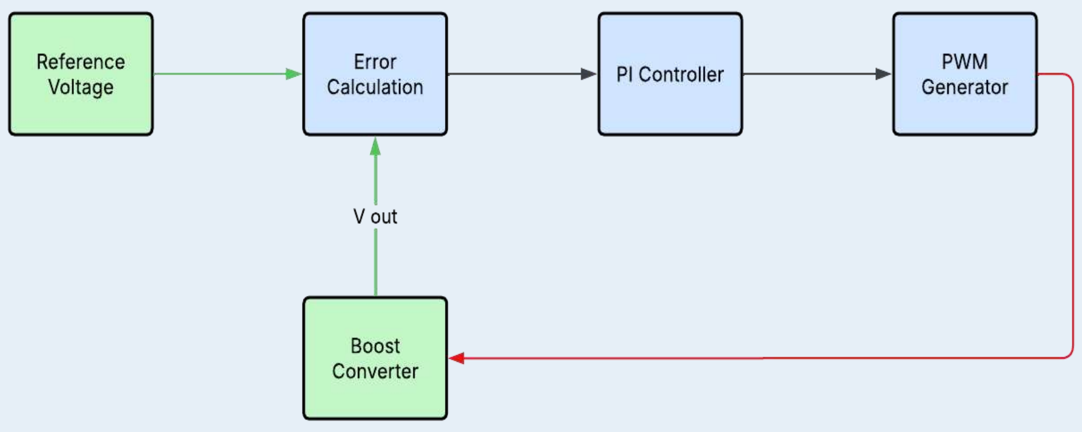


Figure 4: Closed loop control for the PCS

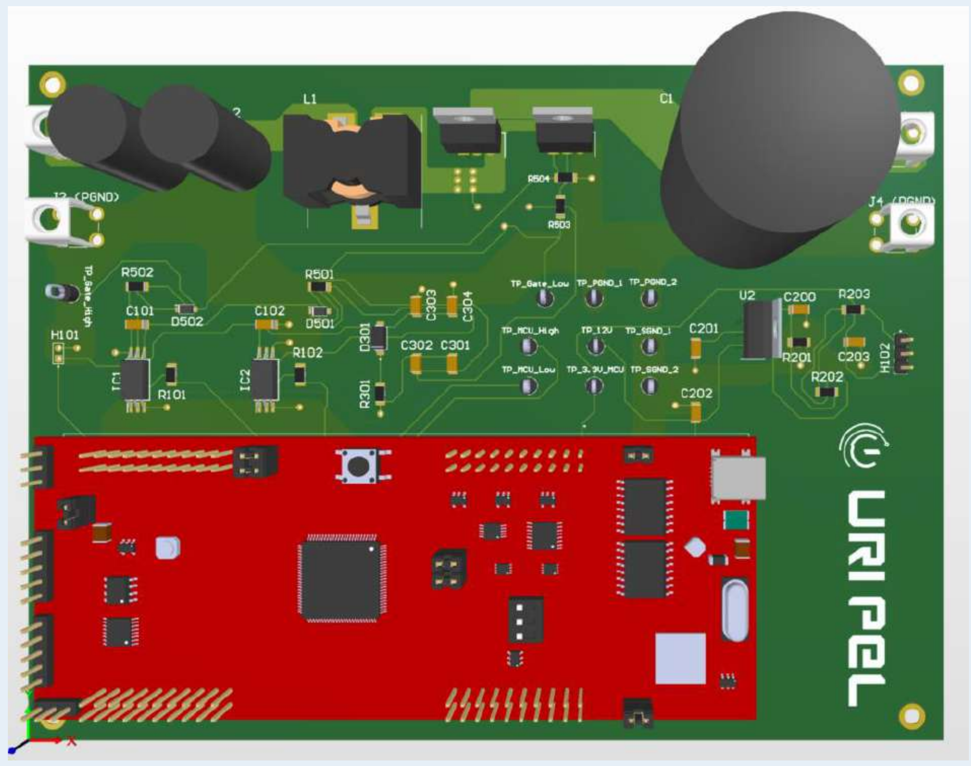


Figure 5: Synchronous Boost Converter PCB Ver. 1

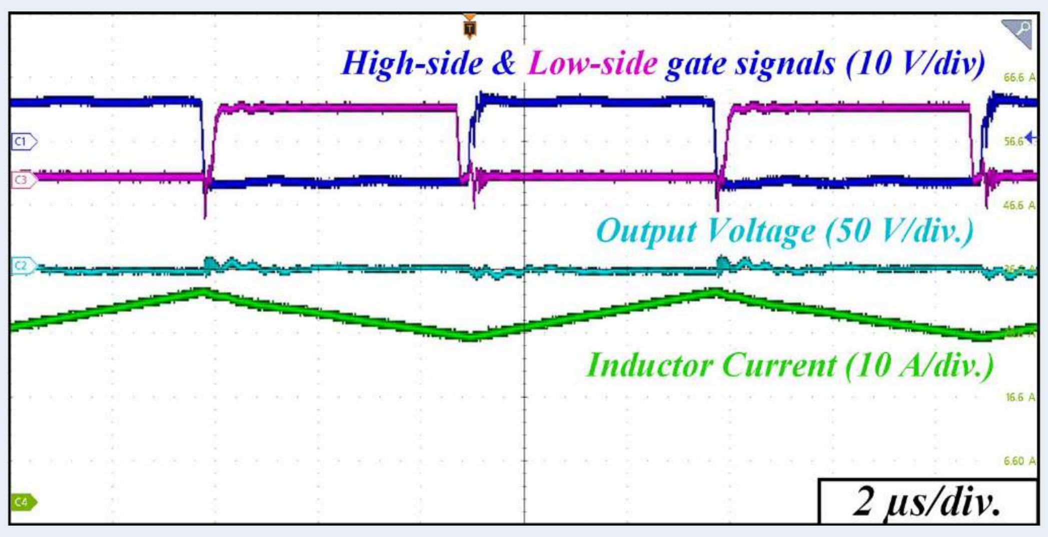


Figure 6: Single - Synchronous Boost waveforms under 100% Load (Open Loop)

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Vicor Corporation

GPIB Command Library and CBIT Expander Card

Team Members: Liam Crisfield (ELE & CPE), Andrew Langille (ELE), Gianni Biondi (ELE)

Technical Director(s): Al Binder, Nathan Shake, Daniel Hartnett, Kristopher Keeble, Joshua Hoyle

Project Motivation

The main motivation for Vicor's projects this year is aiming to make the company's die testing more efficient in its edge testing as well as increase Vicor's current Automated Test Equipment(ATE) accuracy. The GPIB Command Library accomplishes this by automating the testing for these wafers outside of the Automated Equipment with a power supply and multimeter. The command library will be able to fully control and run tests, saving time and allowing for an increased accuracy in the test.

The I2C CBIT Expander Card aims to increase the amount of resources Vicor's ATE can use. Vicor's test equipment uses CBITs to increase their device's test limitations however these relay controllers need to be controlled by the resources from within the ATE which are limited. This causes systems to get more complex and need more resources to be tested. To remedy this issue a card must be made to provide the system with more resources to control CBITs.

Key Accomplishments

Power Supply GPIB Commands: All functions involving controlling a power supply over a GPIB connection have been completed. These functions include setting a desired voltage, current clamp as well as enabling and disabling output. The commands used in this part of the project were based on the SCPI language which utilizes strings of commands to control equipment.

Multimeter GPIB Commands: All functions used to set and take readings on a multimeter through a GPIB connection have been completed. This includes functions to set the type of measurement, such as measure voltage, measure current, measure resistance and measure capacitance. Additionally, functions have been created to take multimeter readings based upon the set measurement type and store the measured values in a set test log. The commands used in this part of the project were based on the SCPI language as well as commands directly from ETS which are used for the logging software.

GPIB Command Test Functions: Test programs have been created using all functions created. These programs were used as proof to display the functionality of our code when implemented into the testing environment which will be used.

GPIB Command Library User Manual: In the GPIB Expander Card user manual there is an in depth description of the SCPI protocol as well as all commands used within the functions. This is then followed by an explanation of how to utilize the commands as well as examples of each command working.

CBIT Expander Card: The CBIT Expander Card has been designed to increase the amount of resources available to Vicor's Automated Testing system. The card will be able to do this by utilizing ICs to control a series of relays which will open or close the circuits the CBIT is on. The board's schematic was provided by the Vicor team and has been implemented into a horizontal and vertical form factor by our Capstone Project team.

Vertical CBIT Expander Card: The Vertical CBIT Expander Card has been completely designed and implemented. The board has been created for use with a vertical connector and has been fully tested ensuring that it completely functions correctly. The main focus on the boards was to ensure a small size on a 2 layer design.

Horizontal CBIT Expander Card: The horizontal CBIT Expander Card has been completely designed and implemented (**Fig. 3**). This board has the same functionality as the vertical card in a different form factor. The card has been completely populated and tested confirming that it is completely functional.

CBIT Expander Daughter Board: To test the functionality of the CBIT Expander Card we have decided to create a daughter board which will connect the load board and the two Expander Cards (**Fig. 2**). The board will use 16 LEDs to test all 16 CBITs on a card. The board has been completely developed and tested, with everything working as intended. (**Fig. 4**)

Adapt CBIT Expander Code: In order to utilize the CBIT Expander Cards the main IC on the boards must be controlled using a program. Our team was able to make edits to some pre existing code which directly controlled the IC. Using I2C commands our team was able to have the MCP23017 chip control a series of 16 output pins altering between high and low. These outputs control the relays which simulate the function of a CBIT in Eagle Tests Systems equipment, by enabling or disabling a 12V input.

CBIT Expander Card User Guide: In the CBIT Expander Card user guide there are very in depth descriptions of how the card functions and is to be used. These descriptions cover both the hardware and software that are used, in particular going over how important ICs function and commands necessary to control the 12V resource output.

Anticipated Best Outcome

In order for Vicor to fully integrate benchtop resources into their ATE setup they will need a library of commands to control them. This includes commands used to force voltage and current as well as measure voltage, current, resistance and capacitance. Vicor will additionally need all supporting header files used in the code, to allow implementation of all functions into their test environment.

The CBIT Expander that utilizes I2C commands will need to be a custom designed PCB with all necessary connections to adapt the PCB to the test hardware. In addition, a test board will be designed to confirm the functionality of the expander card.

Project Outcome

Our team met all ABOs presented to us including, an additional stretch goal. This stretch goal pertained to an excel macro to assist in Vicor's Test Equipment Creation.

Figures

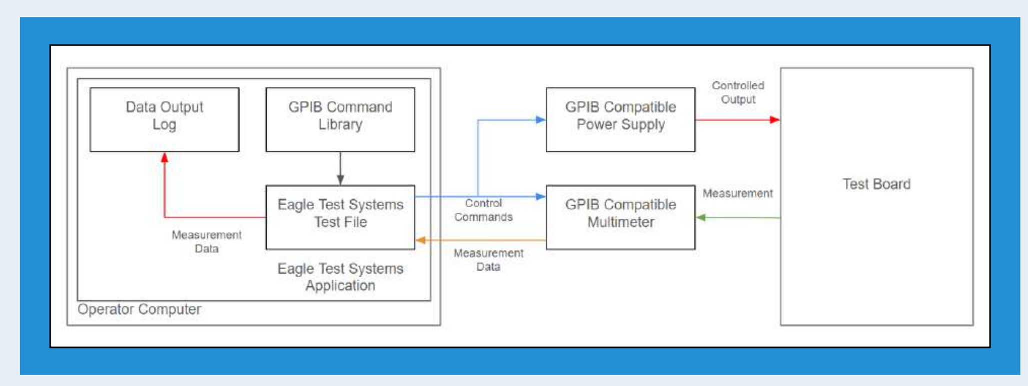

Fig 1: GPIB Command Library Block Diagram

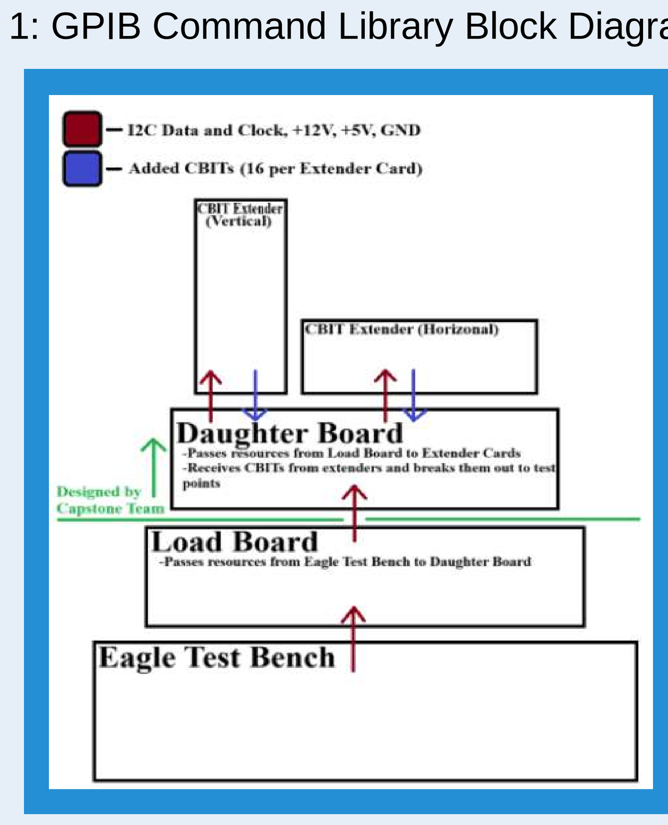

Fig. 2: Diagram depicting test bench setup for using CBIT Extender Card

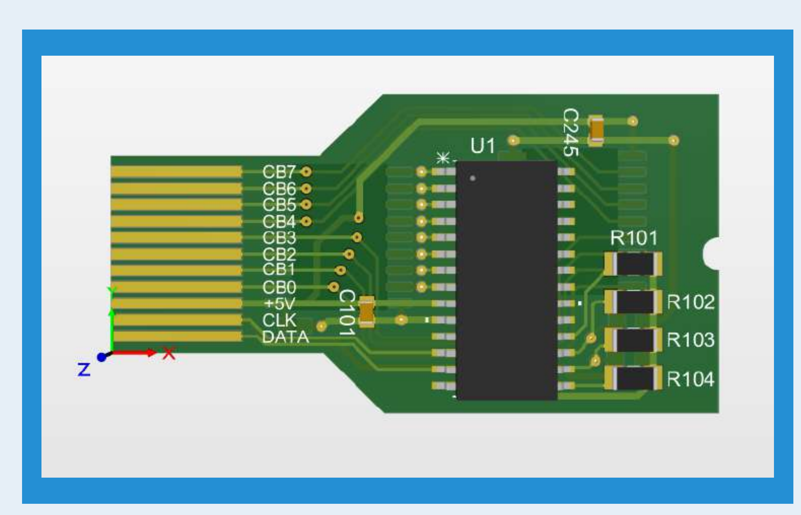

Fig. 3: The horizontal design for the CBIT Expander card

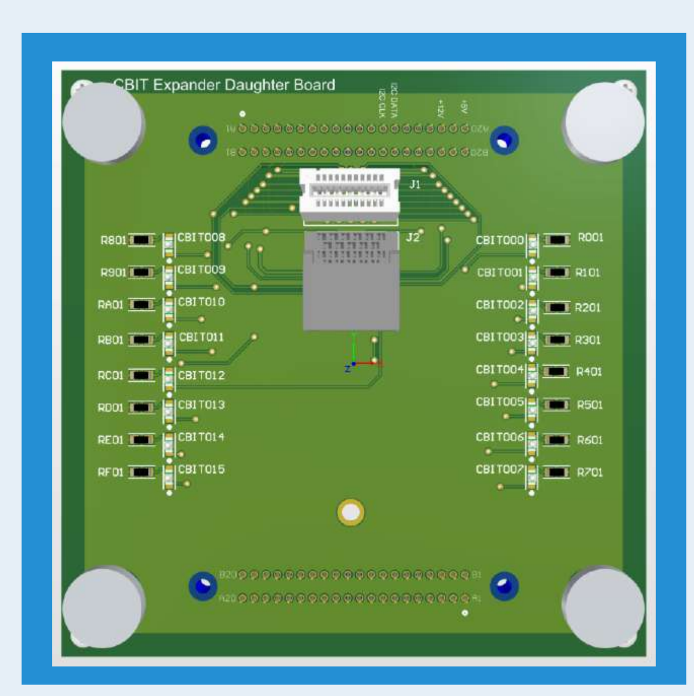

Fig. 4: The vertical design for the CBIT Expander Card

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XBOT

Motor Control on XCORE.ai

XMOS®

Team Members: David Quevedo (CPE), Ean Newman (ELE), Noah Hawkins (ELE)

Technical Director: Andrew Cavanaugh | Consulting Technical Director: Chris Rothwell

Project Motivation

The motivation behind the XBOT project is to leverage and showcase the capabilities of XMOS's xcore.ai chips through the development of a sophisticated robotic arm. The xcore is a highly versatile processor designed to excel in real time control and AI applications. Building upon the work of the previous team, this project seeks to refine and enhance a five-axis robotic arm system that integrates voice commands for control. By demonstrating the flexibility of and computational power of xcore.ai chips, the project aims to create a powerful marketing tool for XMOS. Additionally, it also provides a platform for developing robust motor control algorithms, real-time processing, and predictive maintenance. These advancements have potential implications for industial applications, emphasizing energy-efficient motor control and automation. The ultimate goal is to demonstrate XMOS technological prowess while creating reusable design elements for future deployments.

Key Accomplishments

Motor Control: Motors have been tested and confirmed to all be in working condition meaning we don't need to replace any of them. We have generated a signal using the oscilloscope to show the PWM signal as XBot runs.

PCB Updates: Analyzed our PCB to make the corrections necessary for the ABO. We added a test point to a level shifter (24v to 5v). We have rerouted the Microphones to the correct tile, tile 1, making it possible to program since the SDK is set up like this by default. We have outlined the addition of a second QSPI flash to ensure memory flashing to both XCore.ai chips independently. Plan to add an additional through hole via for ground to ensure smooth probing and testing of the PCB with an apparatus like the oscilloscope. We also generated a BOM that allowed us to categorize and catalog the parts that are available or needed to be reconfigured or ordered from another source.

Kinematic Configuration: Determined the configuration doesn't rely on an external library but an internally defined class for the mathematical operations. This provides significant flexibility as we have full access to all private members of the kinematics class. This allows for fine-tune controlling of the parameters directly. We will adjust and optimize the robotic arm's movements to better align with our project's specifications and goals. David has outlined a plan to create a separate build environment to test different parameter configurations. Experimentation with various tuning strategies will allow us to optimize the arm's responsiveness and stability.

PCB Testing: Performed various tests to see if the updated PCB is working as intended. This included an initial continuity test at many crucial locations on the board, and reading test point voltages when the board was powered on. There were initially issues with the microphones on our board, but after replacing the microphones the voltage reading at the microphones were correct.

PWM Signal Manipulation: Determined the methodology of adjusting the PWM signals required for the precise movements needed on the arm. The source code used for manipulating the PWM signal accesses a library made for our stepper motors, this being the TMCStepper library. The TMCStepper library grants control over many different aspects of the PWM signal, including the amplitude, amplitude offset, amplitude gradient, PWM frequency, and duty cycle. Additionally, these aspects of the PWM signal can be automatically set using the TMCStepper library. Through experimentation, it can be determined whether or not the user should set these values, or if these values should be determined automatically.

Object Detection: David has trained and tested a CNN based object detection model. It was trained using a public dataset that recognizes geometric shapes such as squares, circles,

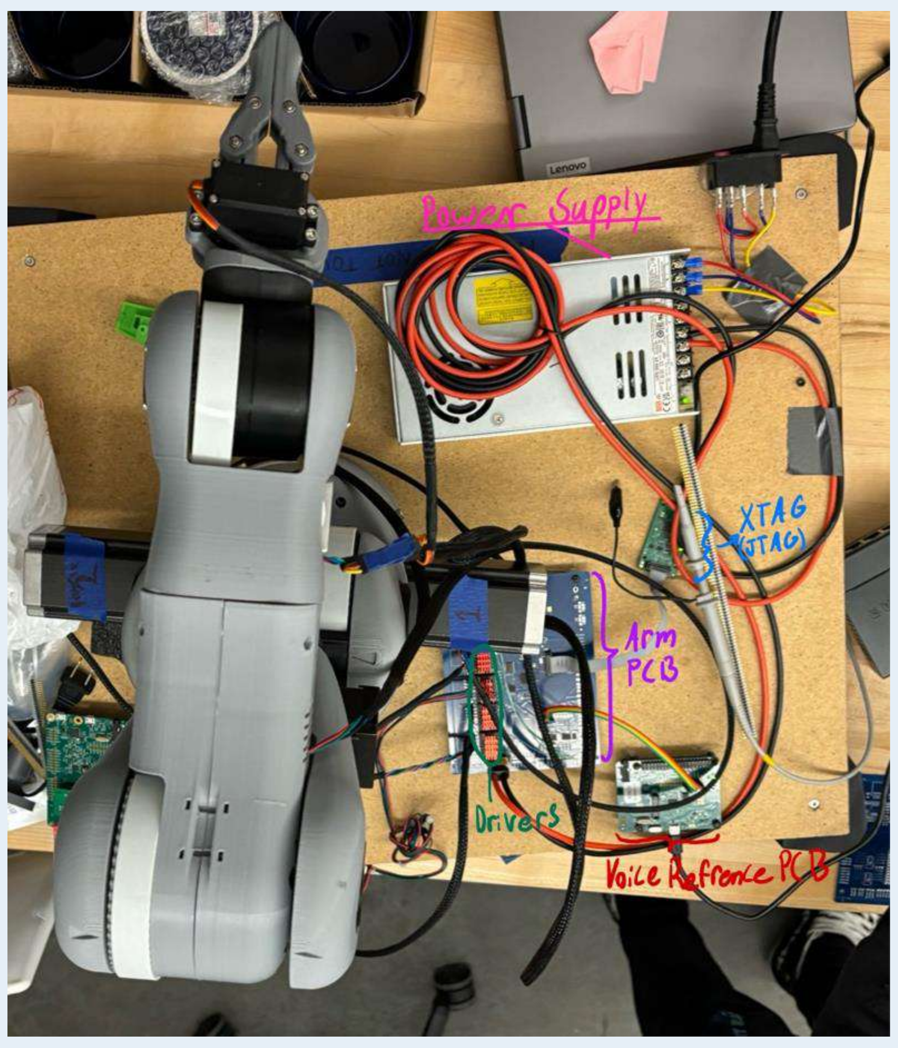
Anticipated Best Outcome

The Anticipated Best Outcome (ABO) for the XBOT project includes successfully replicating the previous year's robotic arm demo while making significant enhancements. Key targets involve creating an updated PCB with no errors, achieving precise motor control of at least axis using low-level algorithms, and demonstrating object manipulation between two points. Additionally, if time permits, implementing machine learning-based predictive maintenance for at least one subsystem is a stretch goal. Achieving these objectives would demonstrate the xcore.ai chip's capabilities, enhancing XMOS's presence in the motor control market and providing a robust hardware-software reference design for potential customers.

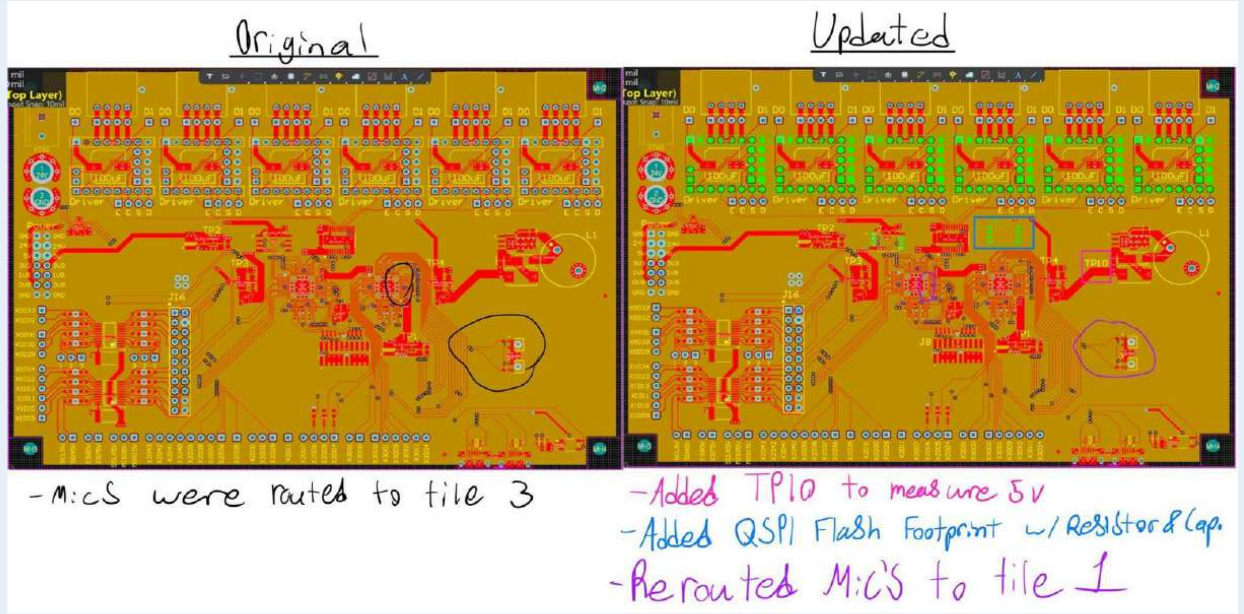
Project Outcome

Our ABO was accomplished, as we were able to successfully update the PCB and perform a demonstration moving an object to a different location.

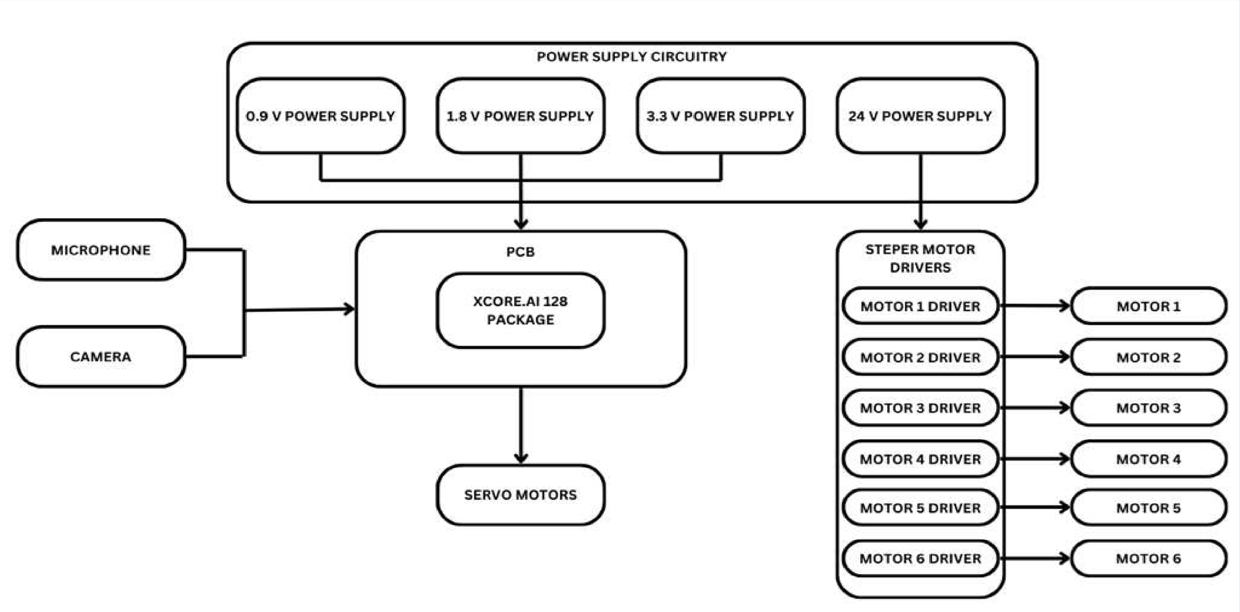
Figures



Arm PCB + XTAG + Voice Reference PCB + Power Supply Set Up



PCB Changes



High Level System Block Diagram

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XMOS: Smart Amp

Audio DSP on XCORE.AI

XMOS®

Team Members: Ahmad Almuhtaseb (CPE), Sahil Chadha (CPE and ELE), Evan Murray (ELE)

Technical Director(s): The name of your Technical Director/Directors

Project Motivation

XMOS processors are well suited for AI, Digital Signal Processing, and control processing, giving the company strong brand recognition in the high-end audio market. Most of its existing applications involve some combination of Analog to Digital/Digital to Analog Converters, USB audio streams, and DSP. That being said, XMOS has not yet created an application which directly acts as a high fidelity audio product like an amplifier or a sound system. With this project, the team wishes to see if the DAC can be removed in order to create a lower cost solution with tighter control over the output sound from the DSP subsystem. This project will also demonstrate the ease of use of Audioweaver from DSP Concepts; if the Anticipated Best Outcome is achieved, then a team of students will have created a prototype audio product (in this case a digital guitar amplifier) in just 7 months.

Key Accomplishments

Output Stage: A half bridge class D amplifier was simulated in LTSpice, effectively recovering an input signal. Within LTSpice a PWM signal generator was made for the input to our gate driver. Using our selected MOSFET the signal was amplified and passed through a LC 27KHz low pass filter. The recovered signal on the load accurately replicates the original input signal.

Input Stage: With our analog signal coming from an electric guitar pickup the signal needs to be amplified. An LTSpice simulation of an Op Amp and a resistor to represent the input impedance of our ADC were created. This simulation showed the effectiveness of our chosen design.

Speaker Cabinet: Both custom made and off the shelf options were explored for the physical housing of our project. Two driver speakers (8 ohm and 16 ohm) were purchased for potential future test benching.

PWM Algorithm: The PWM algorithm was successfully implemented with three different options for depth (128, 256, 512 bits). The algorithm takes an ADC sample, converts it into a series of pulses, and then sends those pulses out in a buffer through a 1 bit port to generate a PWM. This was tested with a 1KHz sine wave, and the corresponding timing diagram is shown in Fig 2.

Integration Into AWE Software: As demonstrated in the flowchart (Fig. 1), the PWM algorithm has been incorporated into the xcore software through the usage of parallel threading to process PCM samples without interrupting the I2S serialization

DSP Programming on XCORE with Audioweaver: Using Audioweaver, different modules for both signal integrity and audio enhancements have been recognized. Currently, the team has developed reverb, phasor, and compression modules to be used as audio effects. Audioweaver was also used to create a dithering upsample enhancement to aid in signal accuracy from digital to analog.

Auto Pitch Algorithm: Using Matlab the team was able to create a proof of concept for a guitar pitch detection and correction algorithm. The algorithm makes use of built-in Matlab functions and modifies input audio to follow standard guitar tuning pitches.

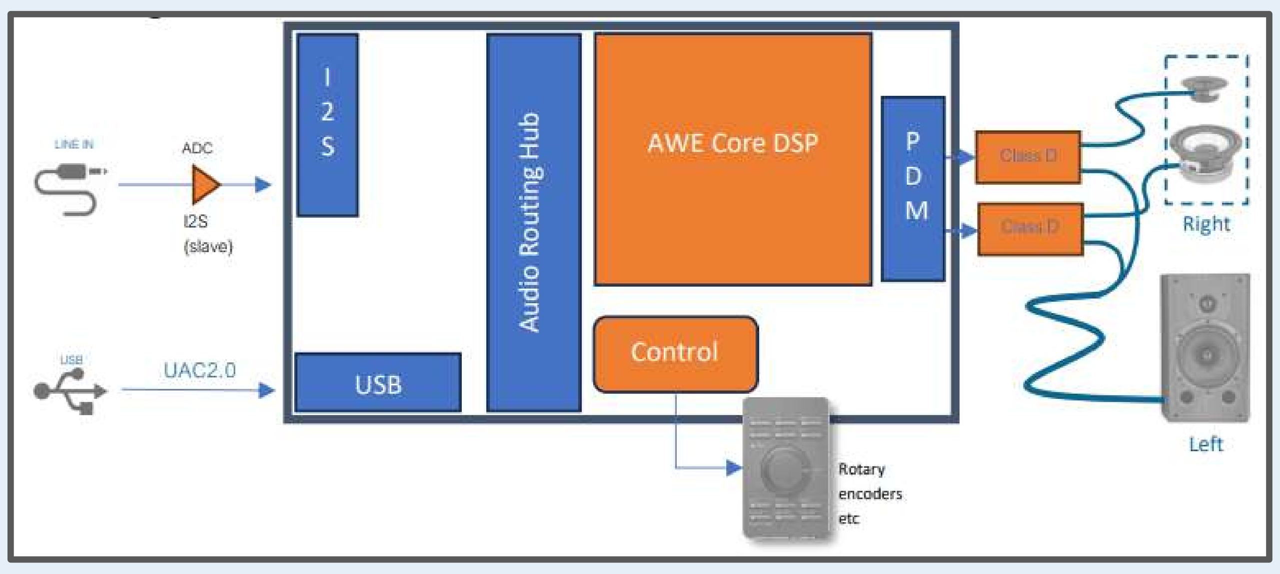

Fig 4. Top-level block diagram

Anticipated Best Outcome

The best outcome is to:

- Implement a Class D amplifier with software control from an xcore
- Accept input from an instrument. In our case, a guitar pickup
- Implement Digital Signal Processing on xcore.ai
- (Bonus) Play sound from a guitar that never needs tuning

Project Outcome

The ABO was partially achieved for this project. While the PCM to PWM software and DSP modules were created, the hardware never arrived due to complications with the manufacturer

Figures

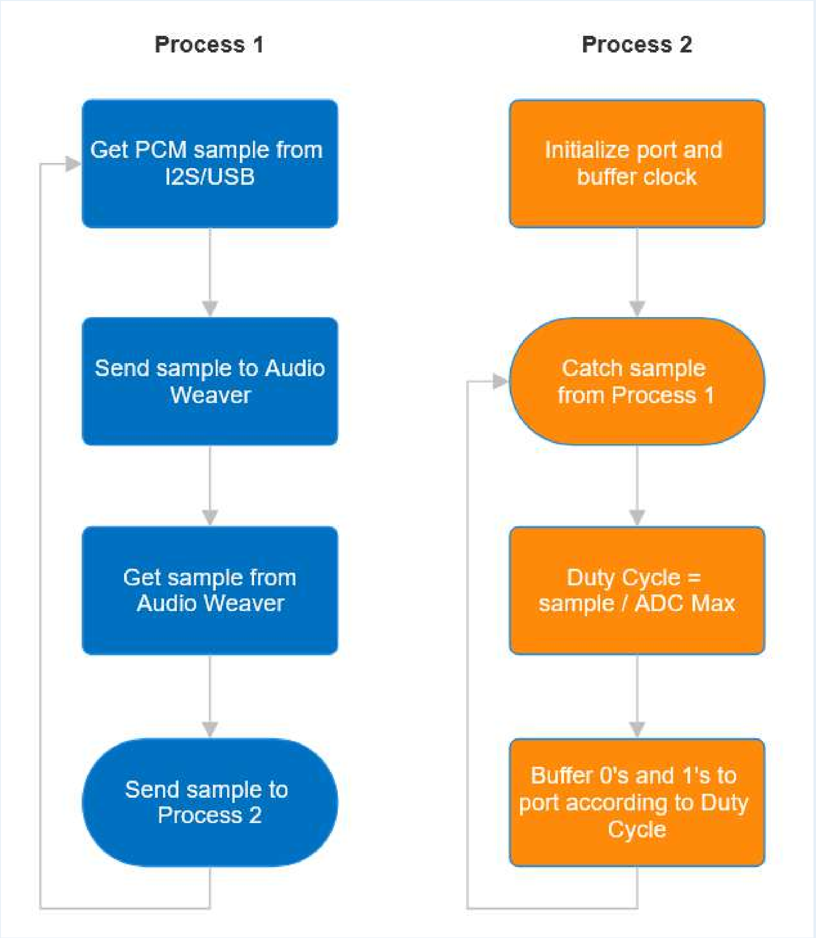

FIg 1. Flowchart for parallel communication between AWE Core DSP and PDM

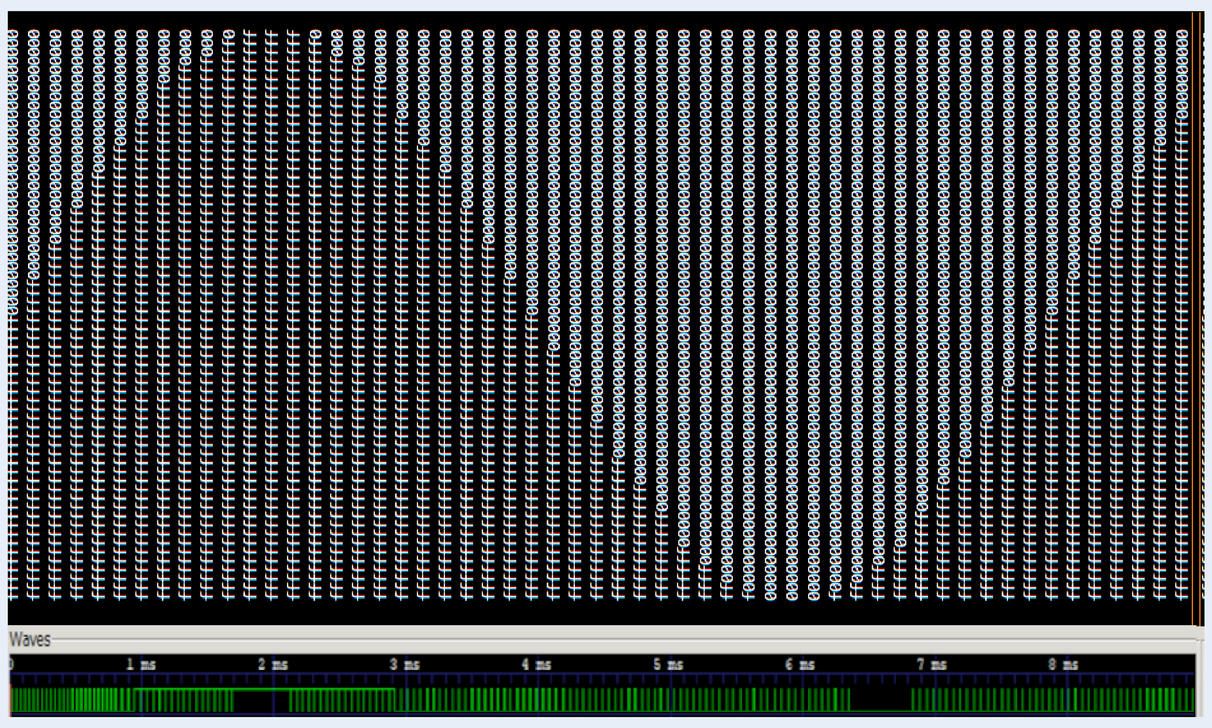

Fig 2. 1KHz sine wave represented by PWM pulses

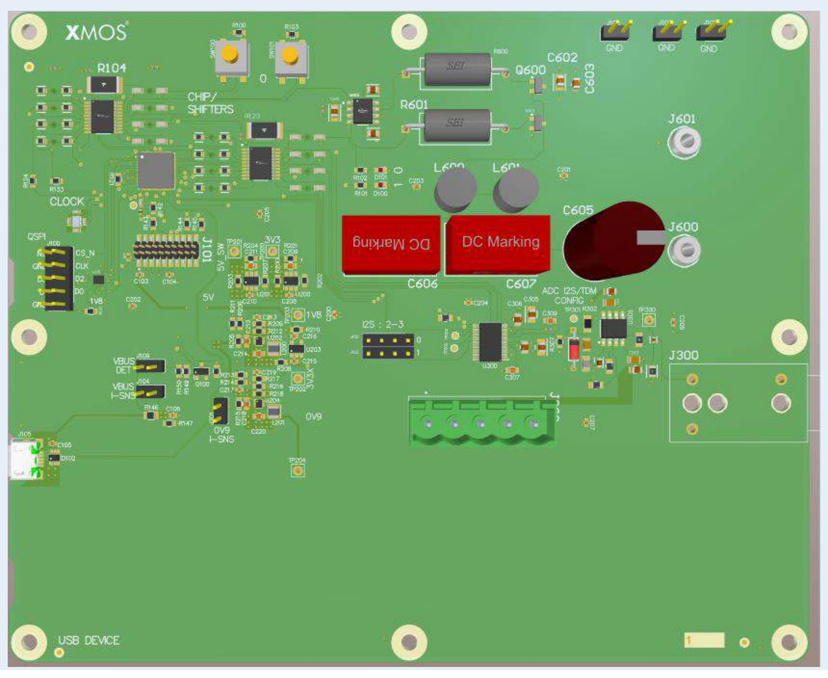

Fig 3. Finalized PCB Layout in 3D Viewing Mode

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Zebra Technologies

Project Greenville - Ultra High Frequency (UHF) Radio Frequency Identification (RFID) Wristband Read Range

ZEBRA

Team Members: Remi Lloyd (ELE), Ryan Hurley (ELE)

Technical Director(s): Joseph Moreira, Gene Hofer

Project Motivation

Ultra High Frequency (UHF) Radio Frequency Identification (RFID) wristbands are used in hospitals and other applications to track patients and supplies. This project aims to increase the effectiveness of the wristbands and to allow further read range and to enable the wristbands to function over a variety of positions and angles on a human arm. The existing technology is a single wearable wristband, however it does not function from all directions and could have increased performance. The team experiments with different designs and methods to find the largest increase in performance possible. Possible improvements include new materials, antenna configurations, secondary supporting wristbands and more. With such improvements made to the wristband it will enable more accurate and reliable patient tracking and identification. More range will also reduce the number of RFID readers and antennas in a given area and will reduce the cost of installation and operation costs.

Key Accomplishments

- **Research:** The testing and prototyping work done for this project required the team to first develop an understanding of the current RFID wristbands and their related equipment including antennas, readers, and thermal printers. This project also required research into the material science concepts related to RFID and how contact with different materials is understood to impact performance.
- **Benchmarking and testing procedures:** The most important testing was accurate and repeatable benchmarking of the original wristbands. The team carefully constructed a measurable procedure for all testing variables to maintain uniformity in testing. Many of the original bands were tested and averaged to find the base performance. All future performances were compared to this average to look for improvements. RFID is very noise sensitive and lots of common devices use frequencies similar to RFID. Monitoring and controlling the environment was critical to keep the testing valid.
- **RFID Prototyping:** Many different prototypes were constructed and tested then compared to the existing performance. Materials such as copper were used in varying thicknesses to compare the results from using more conductive materials than the existing aluminum. The results showed conductivity does not provide significant performance increases. Different thicknesses were tested for antenna design in aluminum and copper. Chip configurations and orientations were compared. A direct thermal printer was used to print aluminum foil onto plastic substrates. This allowed for antenna poles to be printed and tested directly. A brief form was conducted in an antenna design software package to look for potential improvements to be made from simulation versus a lab setting.
- **Rapid Testing:** Rapid testing is a quick way to test the significance of a prototype without committing excessive time into one idea. For example, the maximum range, significance of antenna curvature, and unimportance of antenna overlap were quickly discovered. These quick tests were on the spot ideas that sparked a theory and were tested without the entire lab setup. This way the relevant ideas could be noted and tested extensively later while the ideas that did not perform were not tested as extensively. This allowed the team to focus time onto promising ideas and ultimately narrow down on effective solutions.
- **Spacer Testing:** Spacers are material additions which are placed in between the arm and the RFID wristband, they are intended to improve performance by shielding the RFID wristband from the interference of the human body. The team performed a large number of tests to ascertain the effectiveness of various spacers, with particular focus on their effect on the directionality of the wristband. This testing of spacers included the Comfy Cuff spacer, the Fabrifoam Nimbus spacer, the Fabrifoam X-trend spacer, and a silicone wristband. Additionally a later version of the Fabrifoam Nimbus spacer was tested. This version was identical to the previous one tested except with the addition of a length of Velcro to secure it around the wrist. The addition of Velcro was found to have virtually no impact on the performance of the combination of the Fabrifoam Nimbus spacer and the RFID wristband.
- **Human testing**: Testing was conducted using the wrists of real people in order to better understand the prototypes' real-world performance. This approach is contrasted with the team's typical mode of testing, which usually involved using a fake arm designed specifically to have a dielectric constant similar to that of an average person's wrist.This alteration of the established testing procedure has proven effective in demonstrating the overall efficacy of the prototypes developed by the team. The results have revealed considerable variability, with performance differing from person to person. However, despite these fluctuations, the team's most successful prototype consistently outperformed the original product in nearly all instances, showcasing its superior design and functionality.

Anticipated Best Outcome

The anticipated best outcome for this project is to produce a wristband prototype which provides greater directionality and readability than Zebra's existing wristbands. This prototype should be manufacturable using existing Zebra equipment. Wristband performance is measured by a combination of reads per second at incrementing angles and reads per second in magnitude. Wristband directionality is more significant and creating a perfectly omni-directional wristband without requiring a separate wristband to be worn is the best case scenario. Finally, the wristband should follow existing criteria for size and dimension requirements and be printable in existing Zebra RFID printers.

Project Outcome

The anticipated best outcome was achieved.

Figures

Figure 1: From top to bottom are the following. Ruler for scale, exposed existing RFID wristband with a dipole configuration. Backing of wristband. Thick RFID spacer material. Thin RFID spacer material. Existing RFID spacer material. These spacers are worn under the wristbands to allow space between the RFID antenna and the user's arm.

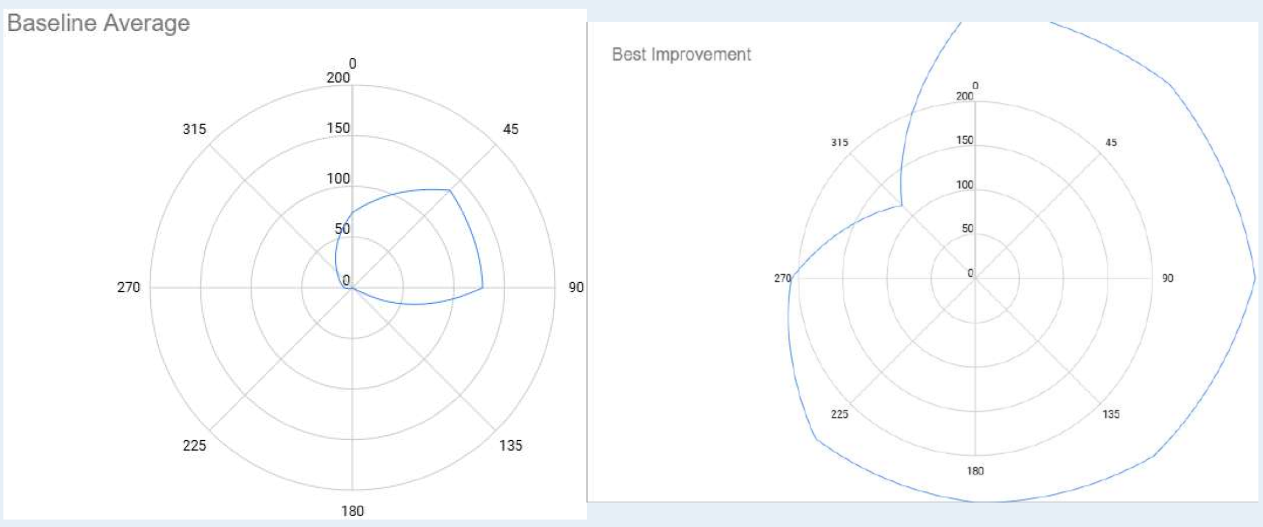

Figure 2: Existing wristband performance average (left). Best measured performance (right). Both graphs have the same scale to demonstrate the improvement in performance. The omni-directionality and magnitude improvements are significant.

Figure 3: Testing of wristband paired with a silicone spacer

Figure 4: Testing of a wristband without spacer

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Project Emilia (Phase 2)

Wireless Enablement of Green Power Technologies for Edge Devices

ZEBRA

Team Members: Ruben Germosen (CPE), Alex Lupo (CPE), Jake Nicynski (CPE), Joseph Kulik (ELE)

Technical Director(s): Joseph Moreira and Bradley Willard **Consulting Technical Director(s): Chris Rothwell and Joseph Daiaa**

Project Motivation

In pursuit of Zebra Technologies' social and environmental goals, this project aims to improve the power efficiency and reduce both the carbon footprint and consumer costs of Zebra's products. Our team is motivated by the opportunity to make a meaningful impact on the world, benefiting both current and future generations. It's extremely important that we aim to reduce carbon emissions due to their harmful effects on the environment and public health, and we are very grateful to have the opportunity to help make a positive contribution towards the global efforts in achieving Net Zero by 2050. Our team is very grateful to be able to collaborate with Zebra Technologies on this innovative project and exciting opportunity as this project has the potential to positively impact millions of devices around the world reducing both carbon footprints and consumer total cost of ownership.

Key Accomplishments

- **Google Cloud MQTT Broker Setup:** The MQTT Broker that we created is being run on Google Cloud Run. Through Google Cloud Run, we used the computer engine to create a virtual instance, which is the MQTT server. Now in the SSH for the virtual instance, I downloaded mosquitto to allow for data flow between devices and the cloud using MQTT protocols. Then we added another firewall rule to allow devices to connect to the MQTT Broker using the cloud's IP address. The Google Cloud MQTT Broker is successfully running and devices can connect to transmit data.
- **Connecting the Google Cloud to the Microcontroller:** To connect the Arduino to the Google Cloud MQTT Broker we used last semester's Arduino code that was able to connect to a device's MQTT Broker. The functionality and messages to turn the pins on can stay the same, but the initial connection needs to be changed to the cloud's IP address. The Arduino then connects to the cloud's MQTT Broker which allows information to be sent and received to the microcontroller. The Arduino was able to successfully send and receive data to turn voltage pins on and off.
- **Bluetooth app/website to connect to the Arduino Uno R4 WiFi:** The bluetooth app/website is able to display real time data and cumulative energy consumption data in watt-hours, as well as show the current status of the charger hardware. From the app the user is able to manually override the green energy software to charge the printer if needed, this including the charge wakeup, charge enable, and power on run signals. Additionally the user is able to schedule printer on and off times throughout a given week to limit wasted energy.
- **External Memory:** A 32 GB SD card module was used to store data and was connected to the Arduino R4 WiFi using the SPI communication protocol. The module was powered with a 5V supply to ensure proper operation. The Chip Select (CS) pin was initialized in the setup. In the code, the SPI library and SD library were included to facilitate communication with the SD card.
- **Reimplementing the existing Arduino Nano ESP32 programs on the Arduino Uno R4 WiFi:** After switching from the existing Arduino Nano ESP32 to the Arduino UNO R4 WiFi due to technical difficulties implementing the external memory on the Arduino Nano EPS32, the current code had to be re-implemented to work with the Arduino Uno R4 WiFi board. This includes the existing MQTT, Bluetooth, and external memory code. Additionally we will be using the Arduino UNO R4 WiFi to connect to the INA233 EVM.
- **INA233 EVM:** The INA233 was used to monitor voltage signals. The INA233 is also able to measure the voltage drop across IN+ and IN- which is then converted to a digital value known as Codes. The correlation between Codes and Current was measured and found to be linear when measured on low and high current values. We then set up a test circuit and derived a formula to convert Codes to Current.
- **Connecting the Arduino R4 WiFi to INA233:** In order to establish a connection between our main board and the INA233, I2C communication protocol was utilized. To power the INA233, 5 volts was being inputted from the Arduino R4 and then SCL and SDA were the two main communication lines. The arduino was programmed to read the address register responsible for measuring voltage and current. The Arduino was also programmed with the formula to convert Codes to Current and displayed so successfully on the Serial monitor along with Voltage and Power readings.

Anticipated Best Outcome

The anticipated best outcome of Project Emilia is to implement its green power charger with dual WiFi/Bluetooth architecture at the test fixture and pre-EVT levels. This hardware and software implementation will detect optimal charging times for edge devices, reducing both the carbon emissions and charging costs for Zebra Technologies' customers. Project Emilia will also use Google Cloud Run to store data captured by the microcontroller to allow users to visualize the reduced carbon footprint and cost savings via an app or website, showcasing the benefits of charging during peak energy outputs from the grid.

Project Outcome

Through the efforts of our team, we successfully met the anticipated best outcome of our capstone project, demonstrating both the effectiveness of our planning and the quality of our execution.

Figures

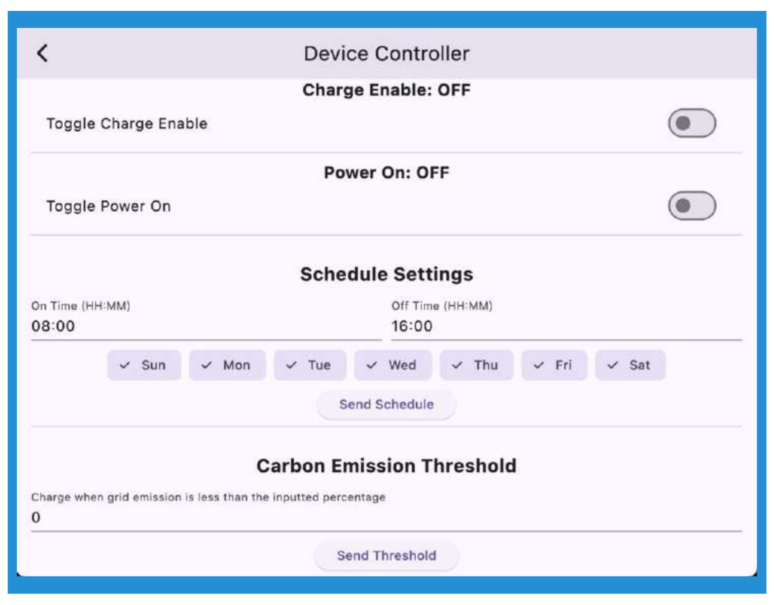

Fig. 1: Bluetooth Application created through Flutter that connects to the Arduino microcontroller and sends data back and forth

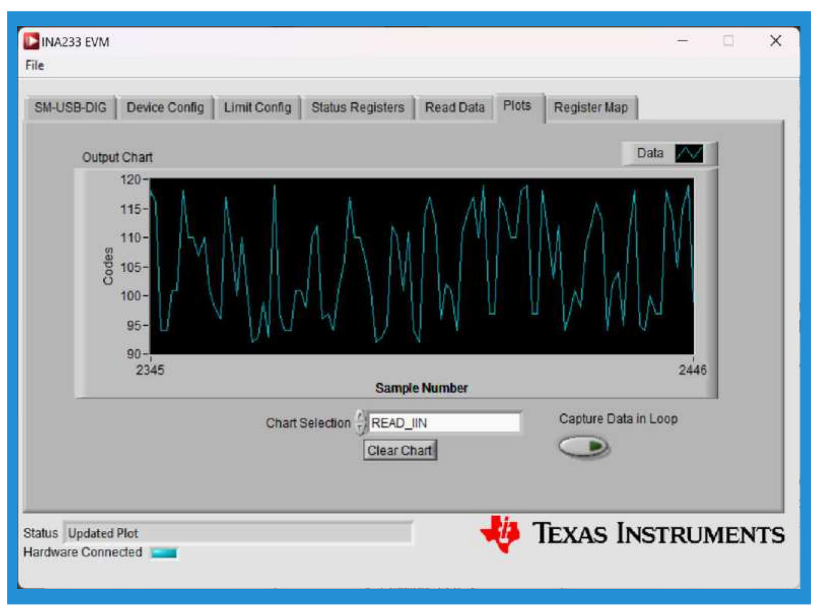

Fig. 2: INA233 EVM takes the voltage drop across the shunt resistor and converts it into a digital value on the GUI plotter

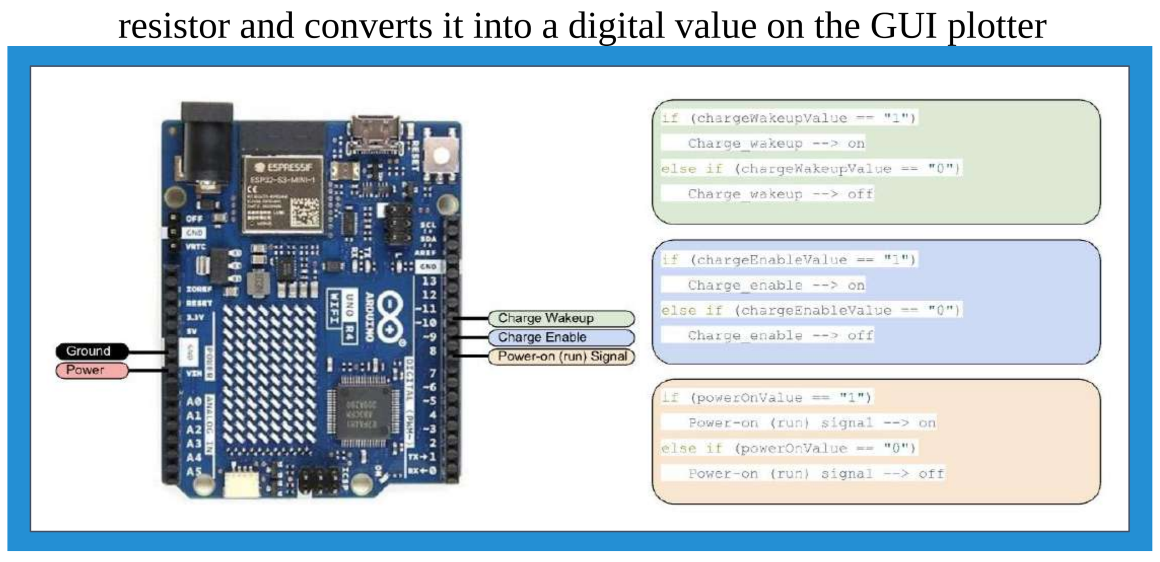

Fig. 3: Arduino Uno R4 WiFi Pin Diagram

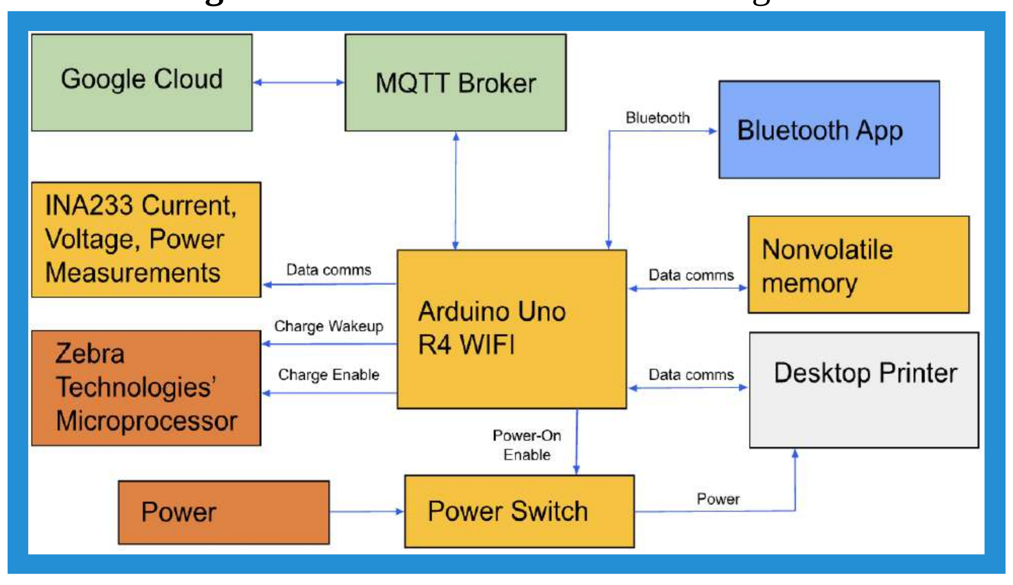

Fig. 4: Arduino Uno R4 WiFi Block Diagram

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AI/ML OBJECT RECOGNITION AND ANALYSIS

ZEBRA

Team Members: James Furtado (CPE), Ryan Steele(CPE), Korali Kouadio (CPE)

Technical Director(s): Matthew Corvese, Patrick Hegarty

Project Motivation

This project aims to optimize the output accuracy of Zebra Technologies' thermal printers. Thermal printers are often at risk of printouts appearing smudged, blurry, or misaligned. This affects the quality and legibility of printed materials like labels and receipts, posing issues for consumers of Zebra Technologies products. These issues stem from the limitations of thermal printing technology, which often require manual adjustments to maintain precision. By leveraging machine learning, the project seeks to develop an automated system to detect and correct these flaws in real-time. This approach will reduce the dependency on human intervention and enhance the reliability and efficiency of Zebra Technologies' printing solutions. This solution has the potential to significantly improve customer satisfaction by delivering consistently high-quality printouts while allocating more company time toward other ventures. This innovation aligns with Zebra Technologies' commitment to advancing technology and maintaining its competitive edge in the industry.

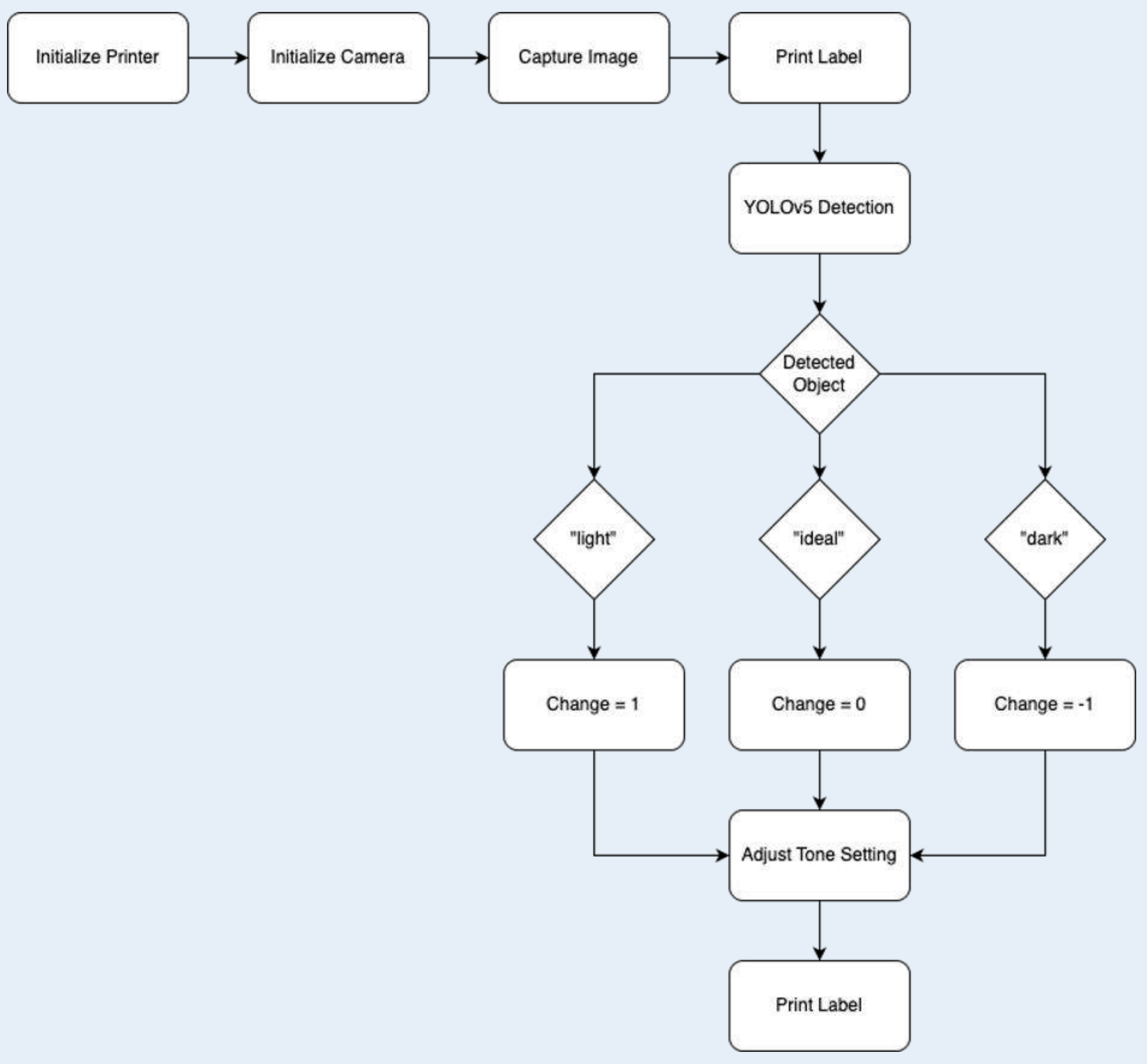
Key Accomplishments

- **Printer communication and control:** The code establishes direct communication with a Zebra printer over a local network using raw socket programming. A dedicated Printer class encapsulates all printer-related operations, including sending commands, receiving responses, and handling connection timeouts. The class implements methods to set printer configuration variables using ZPL (Zebra Programming Language) commands. Label printing or tone-setting updates can also be sent using ZPL commands. Using this code, the printer can produce optimized labels in varying conditions. Lastly, error handling is also included to ensure the system doesn't crash if the printer is offline, for example.

- **Camera Integration:** The application integrates a video input device using OpenCV (cv2.VideoCapture), allowing real-time frame capture from a connected camera or microscope. Once initialized, the application verifies the camera's availability and notifies the user in case of connection failures. A simple dialog box lets the user input how many images should be captured. After that, a folder selection window is presented to choose where the captured images will be stored. A window with a button allows the user to trigger manually each image capture, ensuring precision in the data collection process. Each image is then saved with a timestamp and counter.

- **YOLOv5 Object Detection:** After each image is captured, we use a pre-trained YOLOv5 object detection model to classify the image tone as either "light," "dark," or "ideal." This is done by invoking the detection script with arguments such as the image path, model weights, confidence threshold, and input size. Real-time feedback from the detection process is parsed by reading the output line-by-line. Using regular expressions, the code identifies lines that contain object detection results and extracts the detected label. The program can then take immediate corrective action based on the detection result.

- **Dynamic Tone Adjustment:** Lastly, we have the feedback-driven tone adjustment loop. Once the YOLOv5 model detects whether the image is too dark, too light, or ideal, the tone setting of the printer is adjusted accordingly. This adjustment logic ensures that future labels are printed with improved visibility and contrast. As such, if the detected tone is "light," the tone setting is increased. If it is "dark," the tone value is decreased. And if the tone is "ideal," no change is made. The new tone value is sent to the printer through a ZPL command before the next label is printed. This closed-loop feedback system ensures consistent print quality across a sequence of multiple labels, for example.



Current Model Flowchart

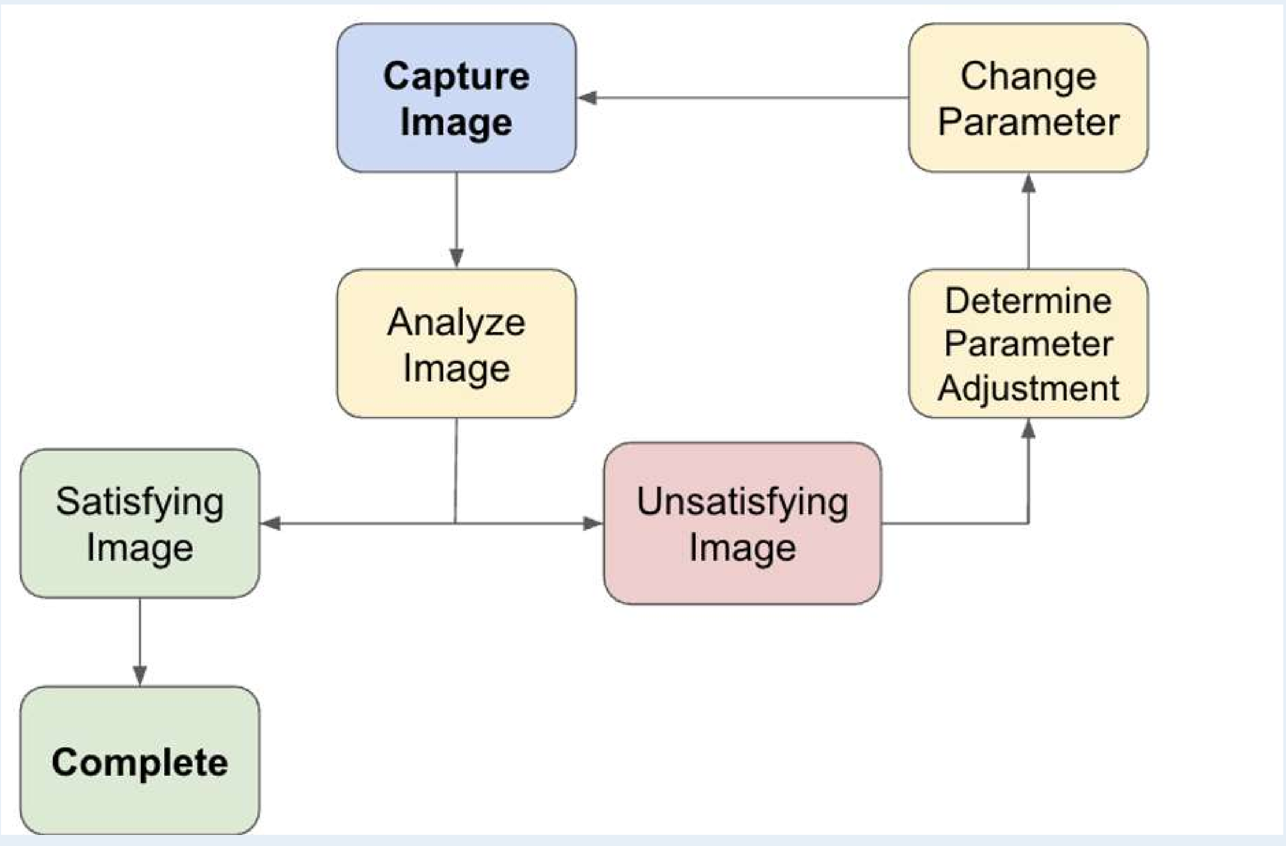
Anticipated Best Outcome

The ABO of this project aims to deliver a fully operational Machine Learning model that enhances Zebra Technologies' commercial printer outputs. The system begins by capturing an image of the initial printout, which the model analyzes before assigning a letter grade from A to F. The grading is based on factors such as blurriness and legibility. It then iteratively adjusts printer settings, reprinting until grade A is achieved. The model also saves adjustments for recurring patterns, such as barcodes and QR codes, to improve future precision. A user-friendly interface will provide real-time tracking of progress and adjustments, ensuring optimal print quality with minimal user effort.

Project Outcome

The main project outcome was to automate the detection, evaluation and improvement of the given picture/label. This outcome was successfully achieved.

Figures



Generic System Overview

Camera/Digital Microscope

Zebra Printer ZQ620 Plus

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