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SYMPOSIUM
TUESDAY, DECEMBER 16, 2025

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Real-time Procedural Visual Aids

Boston Scientific
Advancing science for life™

Team Members: Noah Vargas (CPE), Jarrett DeFreitas (CPE)

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

Project Motivation

Endoluminal surgery is an emerging and rapidly evolving branch of advanced endoscopy, requiring clinical expertise, concentration, refined technical skill, and the use of highly specialized instruments to achieve safe and effective outcomes. As these procedures continue to occur, there is increasing interest in technologies that can support physicians during real-time decision-making. The integration of real-time visual aids represents an important proof of concept step toward demonstrating the feasibility of embedding machine learning–based guidance into existing or future clinical systems. These visual tools are designed to enhance the workflow of advanced endoscopists performing Endoluminal Surgery (ELS) by providing immediate information. The overarching motivation for developing such aids is to reduce the training time required for physicians to gain proficiency, lower cognitive load during demanding procedures, and decrease the likelihood of complications or operational errors. Ultimately, these advancements aim to elevate both safety and performance in endoluminal surgical practice.

Anticipated Best Outcome

The primary goal of the ELS Procedural Visual Aids Project is to develop proof of concept tools that demonstrate the feasibility of implementing real-time visual assistance during endoscopic procedures. Achieving this outcome will validate both the practicality and potential clinical value of integrating machine learning based visual aids into the workflow. In addition, the project aims to generate informed recommendations for future technological improvements, including enhancements in model performance, data processing, and system integration. These insights will guide the next steps toward producing and deploying a fully functional real-time assistance system.

Key Accomplishments

- **Image Classification Research:** A study of image classification machine learning (ML) was conducted to better understand available tools. The results of this research include deep learning frameworks such as PyTorch and TensorFlow, models including convolutional neural networks, and the computer vision task Instance Segmentation.
- **Dataset Creation:** A dataset was created in order to train the convolutional neural network. This was accomplished by taking open-source videos of Endoscopic Submucosal Dissections (ESD) and splitting the video frame by frame. Because of this individual blood vessels can be seen during training.
- **Image Annotation:** The dataset comprising 6,000 images then had to be annotated using image segmentation. With the tool CVAT 1000 instances of blood vessels have been annotated so they can be used in the training of an accurate model. Image segmentation is the process of partitioning particular images into different sections so they can be used in a meaningful analysis.
- **Model Selection:** The convolutional neural network that is most apt for real-time image processing is a You Only Look Once (YOLO) model. YOLO models operate by dividing an image into a grid and predicting bounding boxes, classes, and segmentation masks in a single forward pass through the network, making them significantly faster than other CNN models. **(Fig. 4)**
- **Dataset Interpretation:** To maximize the value of the dataset created, transformations of annotated frames were implemented. This means by rotating, flipping, and changing the hue of each blood vessel annotated, we can increase the size of the dataset multiplicatively.
- **Model Training:** Training for the model is currently occurring. The training is being done using the UNITY cluster provided by the University of Rhode Island that houses GPUs that are able to handle the dataset and model. Currently the model is overfit thus achieving perfect results after only 15 epochs **(Fig. 1) (Fig. 2)**

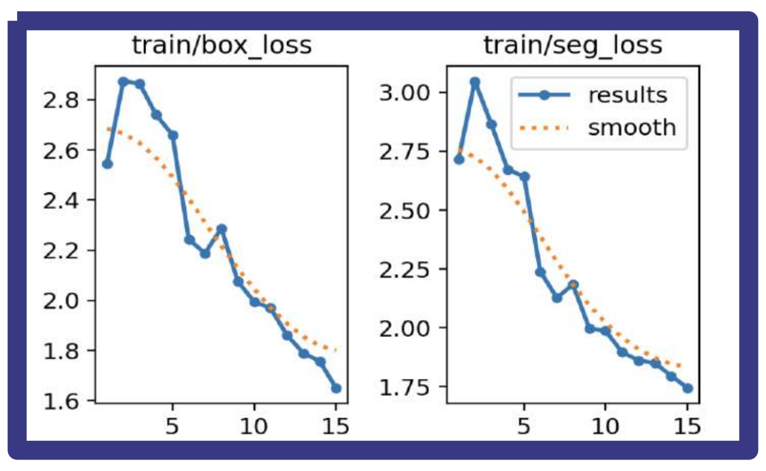

Figure 1: Loss Functions

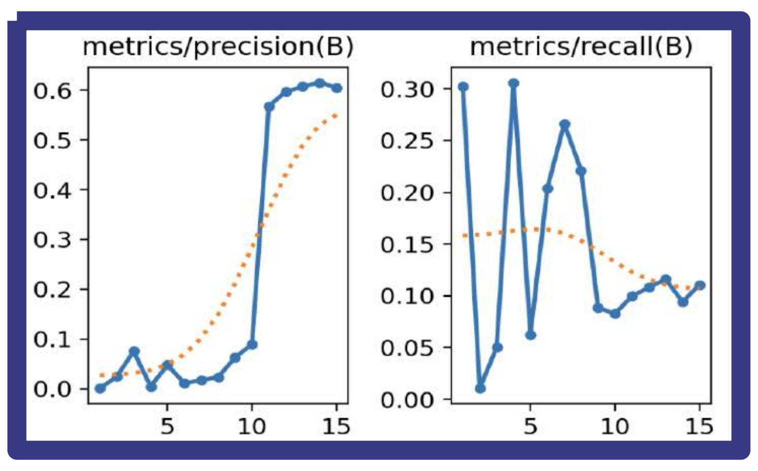

Figure 2: Precision and Recall

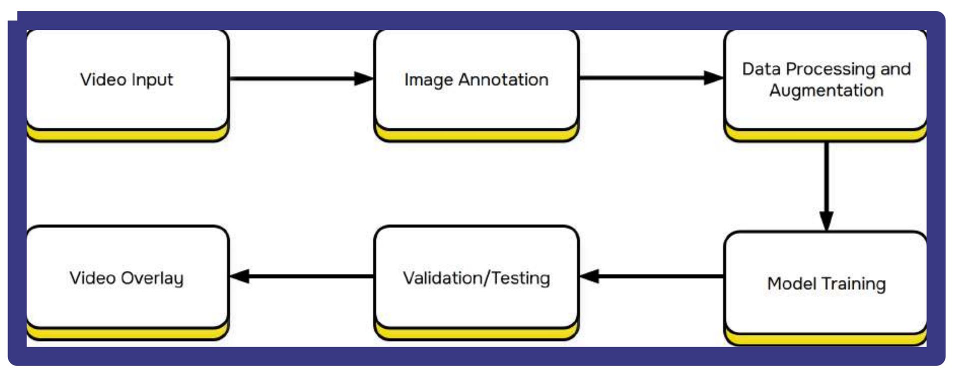

Figure 3: Block Diagram

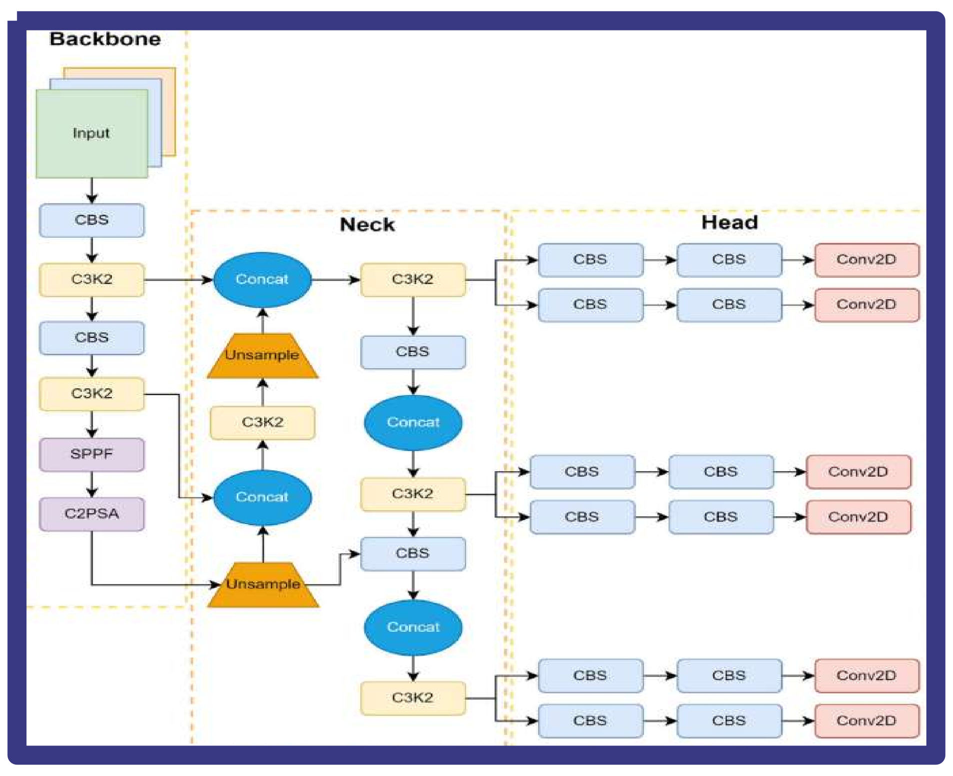

Figure 4: Architecture of YOLO-v11

Remaining Technical Challenges

- **Fine-Tuning:** The current model requires significant fine-tuning, particularly because the confidence threshold is too high for predictions to appear reliably. As a result, the model often detects nothing even when vessels are present, making evaluation difficult. Lowering the threshold alone will not be a long-term solution. Additionally, tuning like IoU thresholds, focal loss, and learning rate will all need to be considered.
- **Annotation Categories:** The current dataset treats all vessels as a single class; however, this leaves out important context. We anticipate separating blood vessels into low, medium, and high-risk categories based on factors such as proximity, visibility, and size. Creating these separate annotations will create several challenges. Some of these challenges include Making sure that the risk levels are clearly defined and that by adding these labels we make sure our class imbalance is handled correctly.
- **Additional Concepts Implementation:** Beyond blood vessel segmentation, the model will be expanded to detect and segment additional targets. Introducing these new targets presents several technical challenges. Some of these challenges include ensuring that each new concept is clearly defined for annotators, managing increased annotation time, and preventing overlapping or conflicting labels. Adding these new targets may also create significant class imbalance, requiring the use of the strategies mentioned in the "Fine-Tuning" section.
- **Video Overlay: (Fig. 3)** The final step required to achieve the anticipated best outcome is implementing the ability to run the trained model on real-time video streams. This will allow the system to process endoscopic footage as it is captured, enabling true live visual assistance. To accomplish this, the project will utilize Ultralytics' real-time tracking and inference tools, which provide built-in support for deploying custom-trained YOLO models in dynamic, high-speed environments.

Implications for Company & Economic Impact

These advancements aim to assist advanced endoscopists performing Endoluminal Surgery (ELS) by reducing cognitive burden, enhancing identification, minimizing clinical complications, ultimately providing greater value to both physicians and patients. As a leading manufacturer of medical devices, Boston Scientific has the ability to leverage this technology by supporting future upgrades and innovative features.

Boston Scientific seeks to establish leadership in this emerging area by delivering solutions that enable clinicians to perform complex procedures more efficiently and effectively. As Endoluminal Surgery continues to expand and increase complexity, the integration of real-time visual aids will facilitate broader adoption, enhance procedural precision, and create new opportunities for innovation and growth within the field.

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DigiTrap

An Intelligent Lobster Trap

DBV TECHNOLOGY
CUSTOM OCEAN INSTRUMENTATION

Team Members: Kevin Vu (CPE), Jacob Phillips (ELE), Anna Civitillo (ELE)

Technical Director(s): Dr. Harold T. Vincent II, Connor Vincent, Colin Vincent, Zach Lindo, Hayden Radke, & Mike Smith (CTD)

Project Motivation

The functionality of underwater traps intended for harvesting marine species is questionable. Additionally, the ropes tied to conventional underwater traps can get caught and harm other aquatic life not meant for harvesting. DBV Technology has created a new, ropeless lobster trap meant for safer and sustainable harvesting, but monitoring the success of the trap falls into the same pitfalls as conventional traps: there is not much available to monitor the success of the trap while it is deployed. In our capstone project, we will design and test a system that can collect data in underwater traps, specifically a lobster trap, to both monitor the success of DBV Technology's new trap as well as provide research data on marine animal behavior and oceanographic conditions. This project will integrate sensors, cameras, and embedded computing to create a reliable data collection platform.

Anticipated Best Outcome

The best outcome is:

- ·Validate system functionality through iterative testing to deliver a field-ready prototype that enhances trap monitoring capabilities.
- ·Select and justify all sensors through research to ensure reliable underwater performance and meaningful data collection.
- ·Integrate acoustic and mechanical sensing to detect lobster activity and trigger recording events.
- ·Utilize a microcontroller and onboard computer to process, timestamp, and store sensor and video data.

Key Accomplishments

In support of the project motivation to improve underwater trap monitoring and enable safer, data-driven ropeless fishing technology, the team has established a strong technical foundation across sensing, power management, system architecture, and embedded development. Extensive sensor research was completed by investigating mechanical, acoustic, and environmental sensors and narrowing the options to specific models that are practical for marine conditions. Through continuous communication with our Technical Directors, the team finalized a sensor suite capable of detecting lobster activity and collecting environmental data that will help assess trap performance. A complete system power consumption budget was also created. This involved calculating current draw for all electronics and developing battery life estimations that support long term deployment planning. Multiple system block diagrams were produced and iteratively refined. Early diagrams helped identify essential components, while later iterations incorporated final hardware selections and clarified system level data flow and power distribution.

Substantial progress has also been made on both the Raspberry Pi 5 and microcontroller. The Raspberry Pi 5 operating system, network access, and development environment were all configured. Dual IMX708 cameras were integrated and verified through libcamera testing, confirming that the Pi can reliably serve as the optical sensing platform for behavioral monitoring inside the trap. On the embedded side, the STM32 microcontroller was configured using STM32CubeIDE and CubeMX. This work included peripheral setup, refinement of STM32 specific C programming, successful UART communication with the Raspberry Pi, and initial sensor interfacing on the Nucleo board. Together, these accomplishments demonstrate that the sensing pipeline, embedded control logic, and onboard data collection are all progressing toward the projec

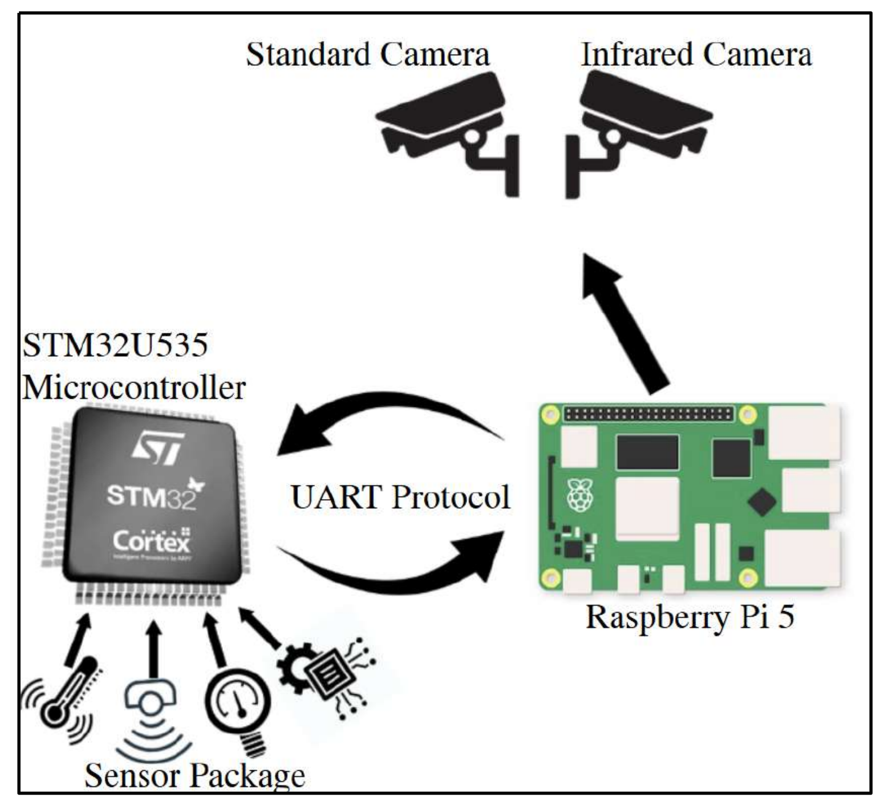

Figure 1: High level intercommunication graphic

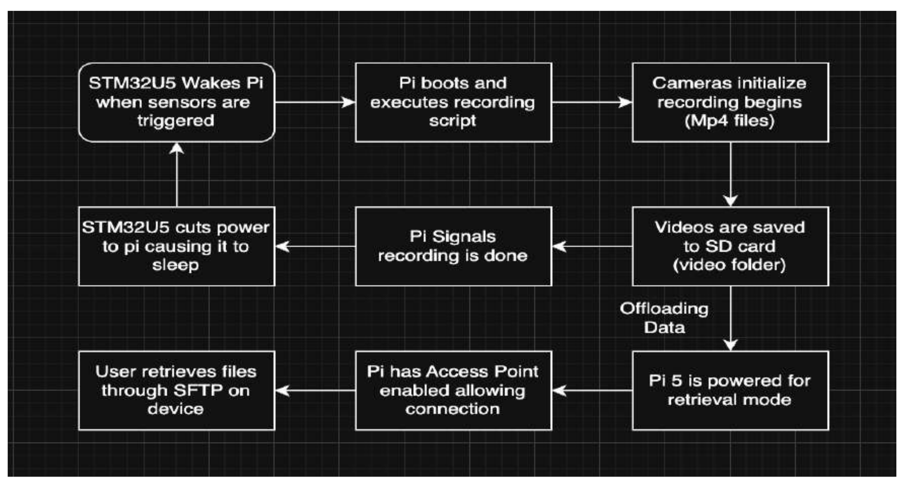

Figure 2: Workflow Diagram of Recording to File Transfer

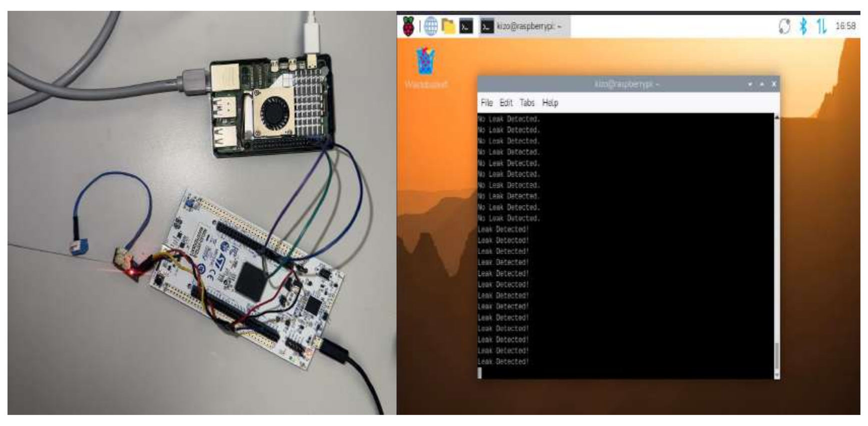

Figure 3: Live Demo of Leak Sensor

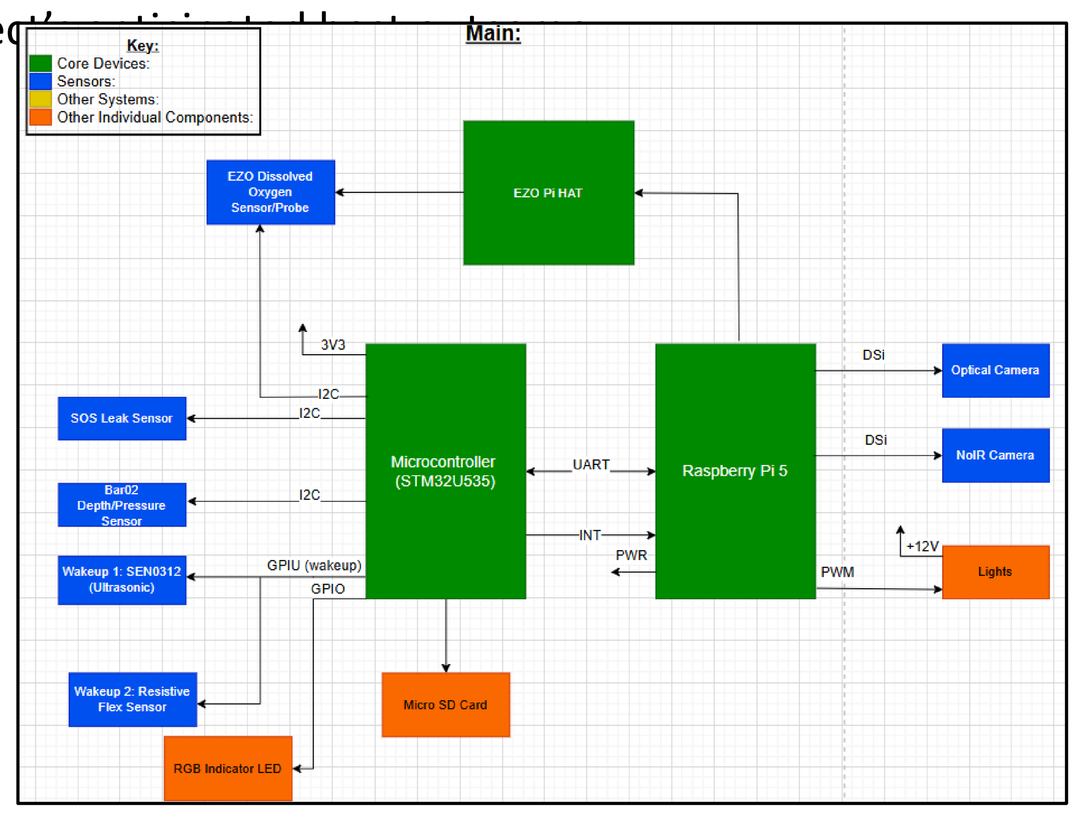

Figure 4: Main System Block Diagram

Remaining Technical Challenges

Schematic and Layout Design:
Our system requires PCB to mount the Raspberry Pi Compute module and STM32U535 once we move past the prototyping phase in our design. This means we need to design a custom schematic and layout for a PCB that will interface our computer and microcontroller with the rest of our components. Our system also requires a custom PCB for stepping down, filtering and distributing power from the battery pack that will be included in our system. All components have been selected and the schematic design process is in progress.

Communication Between MCU and Pi 5:
The project relies on reliable, low power UART communication between the STM32U5 MCU and Pi 5 to coordinate wake/sleep behaviour, logging, and data transfer. This requires designing a compact, well structured message format for commands, status flags, and error codes that both devices can parse consistently. We also need to add acknowledgements and timeouts so neither side hangs on a missed message.The design is in progress, with implementation and validation still to be completed.

Implications for Company & Economic Impact

A functional DigiTrap prototype would enable DBV to offer a sensor package that helps fishermen collect better data to assess trap performance, and to use deployed traps as distributed data-collection platforms for broader sampling of coastal bottom conditions. If we are successful, the system could be refined into a marketable product for DBV to sell or license within the undersea industry. This innovation would not only advance sustainable fishing practices but also provide new economic opportunities through data driven fishing management. In the long term, it could position DBV as a leader in intelligent, environmentally responsible marine technology solutions.

Edge Computing on GPUs for Ground Robotics

DRAPER®

Team Members: Sarah Eisenstein (CPE), Ben Gulezian (ELE)

Technical Director(s): Stephen Lawrence, Rick Wang, & Mike Smith (CTD)

Project Motivation

The project is motivated by Draper's long-standing leadership in autonomy, edge computing, and multi-agent systems. Draper develops algorithms and software that support autonomous missions across underwater, terrestrial, aerial, and space environments, and the need for compact, intelligent, collaborative robotic platforms continues to grow. This project aims to enable a swarm of small ground robots to explore and map cluttered indoor spaces using onboard computation and centralized coordination. By building an edge-compute infrastructure that fuses local sensing with shared mapping, the team advances Draper's goal of demonstrating scalable swarm autonomy. The motivation also reflects broader challenges in robotics, especially operating reliably in GPS-denied, visually cluttered office environments. Creating robots that can interpret their surroundings, share information, and maintain situational awareness is essential for future autonomy architectures. This work lays the foundation for systems that are efficient, resilient, and deployable across diverse operational settings.

Anticipated Best Outcome

The anticipated best outcome is a functional prototype demonstrating edge computing for swarm autonomy across multiple ground robots. At the baseline level, the system will perform 2D SLAM, centralized map fusion, and visual marker detection. Advanced outcomes include coordinated navigation between at least two robots using shared logic. Stretch goals expand into 3D mapping through stereo or monocular cameras and CUDA-accelerated perception tasks. Collectively, this prototype will validate Draper's ability to deploy collaborative indoor exploration systems that combine onboard processing with centralized intelligence, ultimately showcasing a scalable model for future autonomy platforms.

Key Accomplishments

- ROS2 Development & DevOps:
Set up a full ROS2 Humble workflow using Docker, WSL, and VSCode. Implemented Git/GitHub version control and remote SSH development on the Jetson for headless debugging and deployment. (Fig. 4)
- Jetson Orin Nano Bring-Up:
Flashed and configured the Jetson; upgraded to JetPack 6.2; installed ROS2 with ARM64 packages; enabled WiFi and remote development; validated stable system power.
- Robot Assembly & Chassis Engineering:
Built the JetBot prototype with 3D-printed parts, motor drivers, camera mount, and wiring (Fig. 1)(Fig. 2). Designed and adjusted a SolidWorks chassis to fit the stereo camera and power system (Fig. 3).
- Motor Control & IMU Integration:
Validated I^2C communication with the PCA9685 and achieved reliable PWM motor control. Configured the BNO055 IMU and confirmed stable orientation outputs for future sensor fusion.
- Stereo Vision, ML Depth & Obstacle Detection:
Brought up the stereo camera and implemented a RAFT-Stereo depth estimation pipeline. Added object identification and depth based obstacle detection for real-time perception.
- Teleoperation & Early Autonomy:
Implemented keyboard teleoperation and integrated IMU + stereo data pipelines to support early mapping and navigation testing.
- SLAM & Perception Preparation:
Established core components for future SLAM, including IMU validation, stereo-camera testing, ROS2 networking, and perception node groundwork.

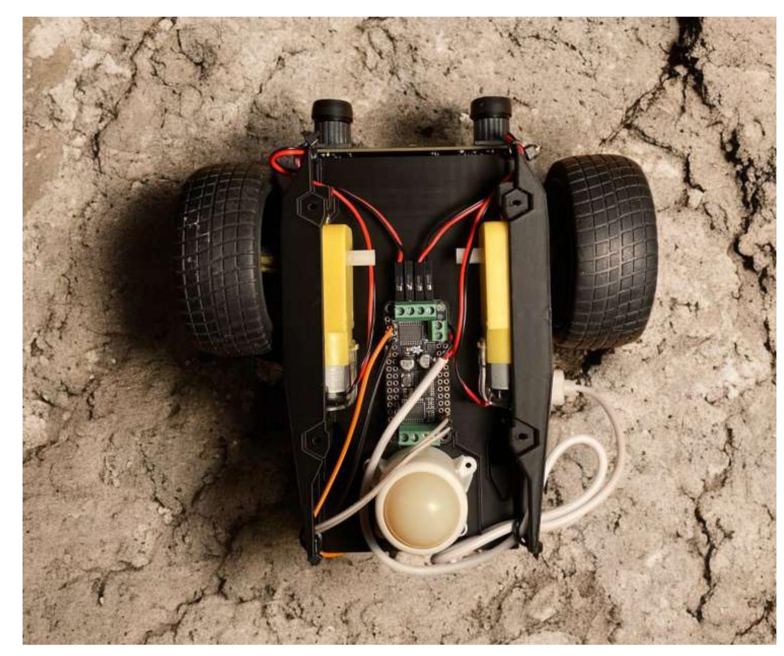

Fig. 2

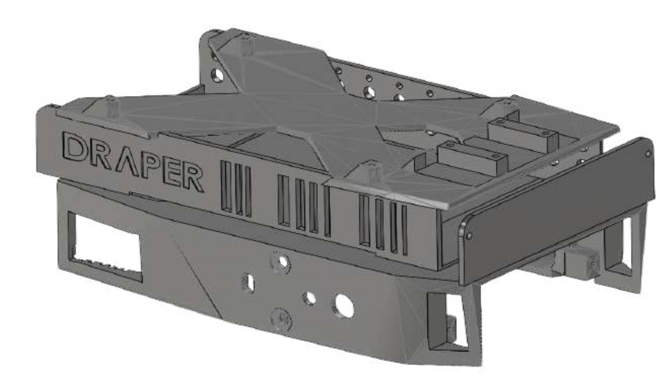

Fig. 3

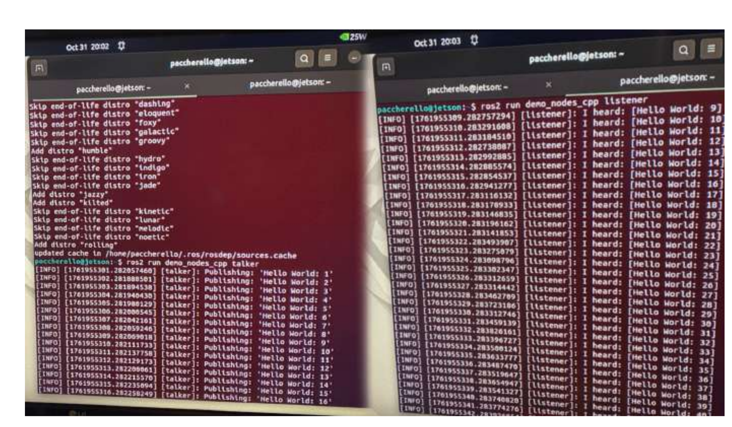

Fig. 4

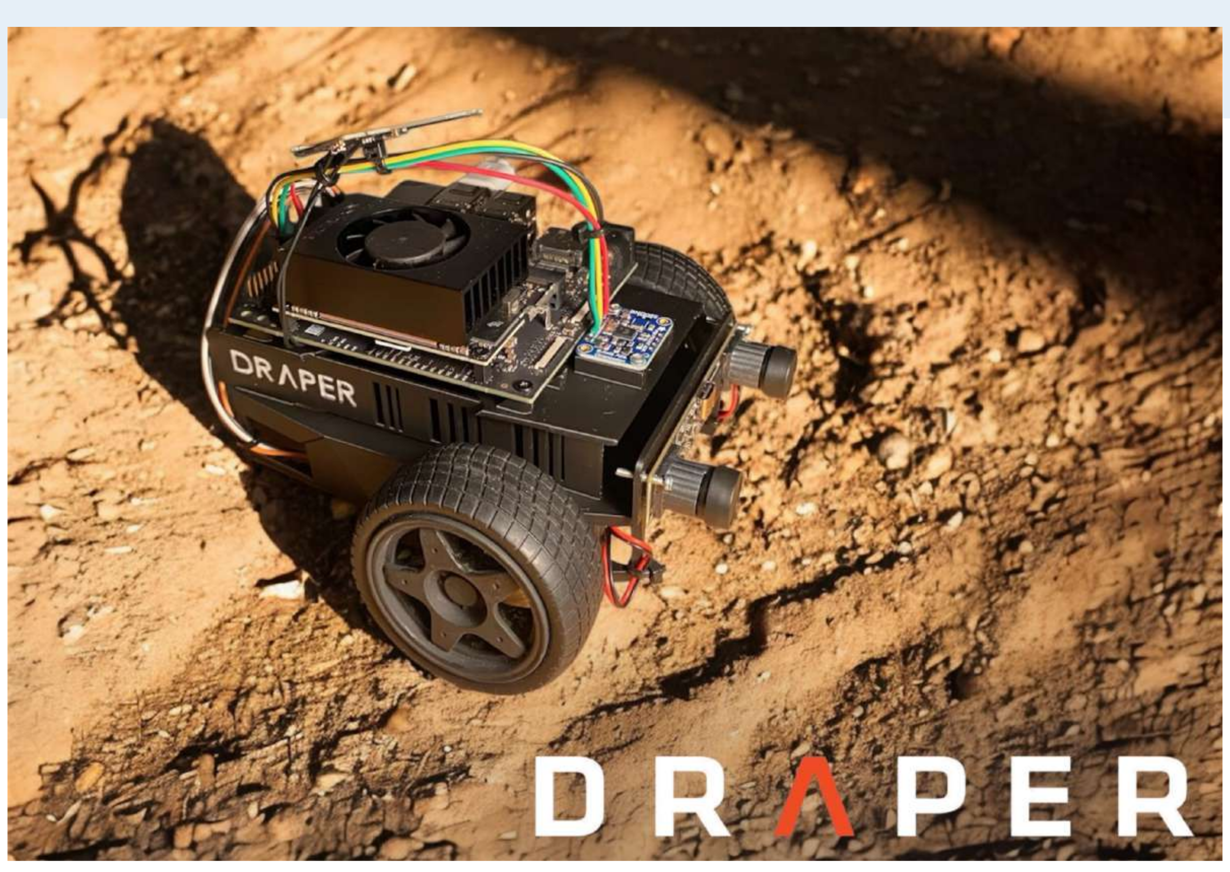

Fig. 1

Details of Results and Discussion

This stage of the project concluded with results that fully met our expectations. All core components of the robot are operating smoothly, allowing us to shift from foundational setup into true autonomy development. Most importantly, we now have a reliable and stable platform that supports the entire software stack we will build on top of it. This reliability gives us the confidence and freedom to move forward into SLAM, map fusion, and multi-robot coordination without needing to revisit earlier stages.

With the platform solidly in place, we are genuinely excited to begin implementing the more advanced behaviors that motivated this project from the start. As we transition from testing individual functions to observing the robot perform full mapping and navigation routines, we expect to see rapid progress.

Looking ahead, this progress also highlights how compelling the technology becomes when we consider miniaturization and scalability. While the current prototype uses modular, development-friendly hardware, the underlying architecture is well suited to a future PCB-integrated design. By consolidating electronics into a compact, purpose-built board and reducing the robot's size, it becomes possible to create a much smaller, faster, and more efficient version of this platform. Such a miniaturized system, especially when produced in quantity, could enable extremely rapid, high-resolution mapping of indoor environments through coordinated swarms of compact robots. The successful foundation established this semester demonstrates that this long-term vision is feasible and provides a strong trajectory for future development.

Implications for Company & Economic Impact

A successful prototype will strengthen Draper's edge computing and autonomy capabilities, directly supporting its mission to deliver advanced solutions for national security. Demonstrating swarm autonomy enhances Draper's competitiveness in future contracts involving collaborative robotics, multi-agent mapping, and indoor navigation. Because autonomous platforms reduce human risk and scale more efficiently than traditional staffing models, the economic benefits extend beyond Draper, lowering operational costs for government and industry partners. Ultimately, this project advances technologies that enable teams of robots to gather richer situational data, operate safely in hazardous environments, and improve mission efficiency at a fraction of the cost of conventional approaches.

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Safety Critical Applications for RISC-V Platforms

DRAPER®

Team Members: Jamie Iglesias (CPE) and Shane Stamp (ELE)

Technical Director(s): Steve Lawrence, Mike Smith, Jeshua Benzant, and Jesse Sullivan

Project Motivation

Safety-critical embedded systems need to be predictable, secure, and easy to verify. Our project focuses on using an open-architecture RISC-V platform combined with Rust to explore how memory-safe software and transparent hardware can improve reliability in real-time applications. Rust removes many of the common issues found in traditional embedded languages, while RISC-V provides full visibility into the hardware without relying on closed toolchains or proprietary features. To test these ideas, we are using the mechanical "Shoot-the-Moon" game as a real-world environment that requires accurate sensing, fast reaction times, and precise servo control. The game provides a simple but technically demanding system where timing, driver design, and hardware behavior directly affect performance. The motivation for the project is to understand how memory-safe software and open hardware behave together in a real-time, sensor-driven application.

Anticipated Best Outcome

The anticipated best outcome is a fully functioning physical system, running on a RISC-V platform, that can reliably play Shoot-the-Moon with at least 80% accuracy from a fixed initial state. This includes robust drivers interfacing with Rust, a clean dependency-injected control architecture, stable and repeatable sensor measurements, and smooth, predictable servo actuation. In parallel, we will provide a QEMU-based RISC-V environment capable of booting the StarFive OS image so early development and testing can occur without immediate access to the hardware. If time permits, we will extend the system with additional capabilities such as camera-based sensing and expanded control logic to improve performance benchmarks on the physical platform.

Key Accomplishments

- **RISC-V QEMU Environment Built**

Configured QEMU to successfully boot the StarFive Linux OS image on a virtualized RISC-V machine. This supports early development and exploration prior to hardware testing.

- **Team-Wide Docker Development Setup**

Built a unified Docker environment bundling Rust, cargo, QEMU tools, and build scripts. This ensures every team member uses the same development environment and avoids version inconsistencies.

- **VisionFive 2 Hardware Bring-Up**

Verified stable board power-up, repaired earlier component damage, and established UART console access. Logged the boot flow and tested GPIO, I2C, and PWM interfaces required for servo control and sensor communication.

- **Servo Driver + Control Path Planning**

Outlined timing and control-loop requirements and began refactoring the servo driver using dependency injection. Confirmed initial PWM functionality on the VisionFive 2 hardware.

- **LiDAR Integration + Mount Design**

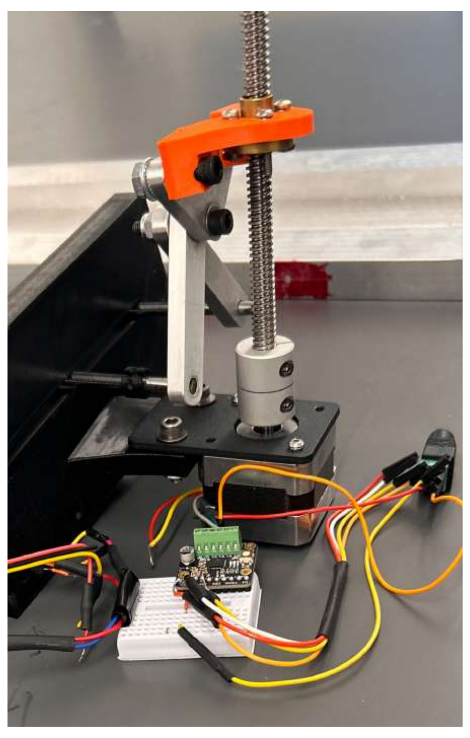
Selected the LiDAR distance sensor and began mechanical design of the 3D-printed backplate and mount for stable readings. Tested mechanical alignment and early sensor behavior.

- **Rust Architecture Layout**

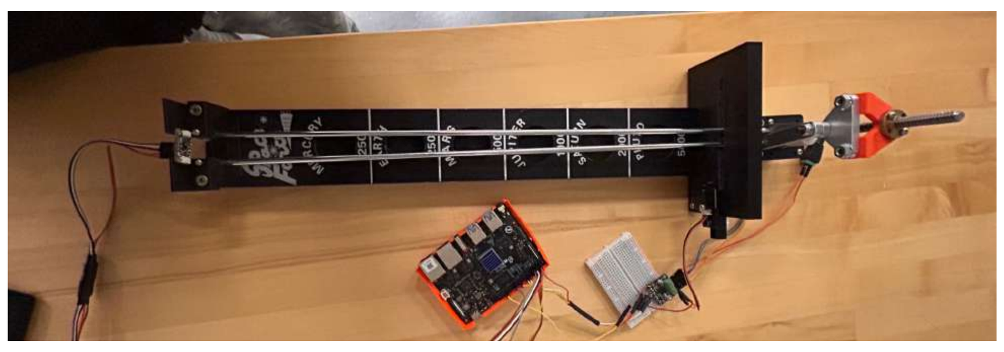
Created module boundaries for sensor sampling, servo control, timing utilities, and error handling. Began reorganizing the driver interfaces so low-level hardware access (including C-based drivers) is isolated from higher-level Rust control logic.

- **Mechanical Layout & First Prototype**

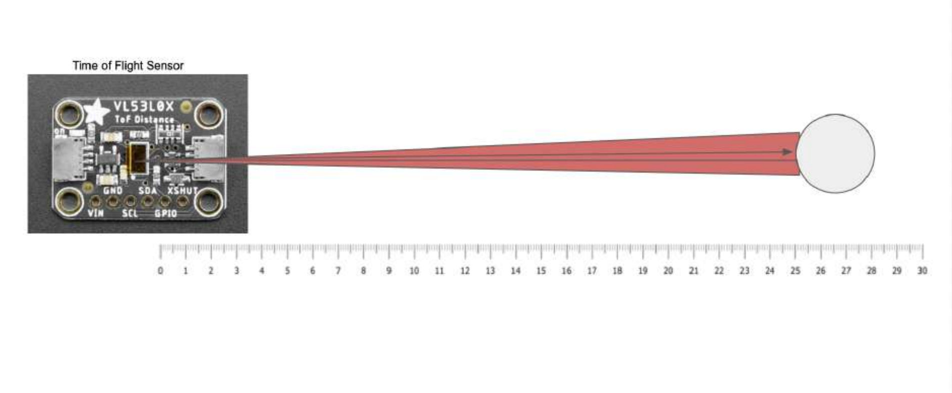
Drafted and printed the first version of the backplate mount. Verified clearances, hole spacing, component placement, and cable routing.



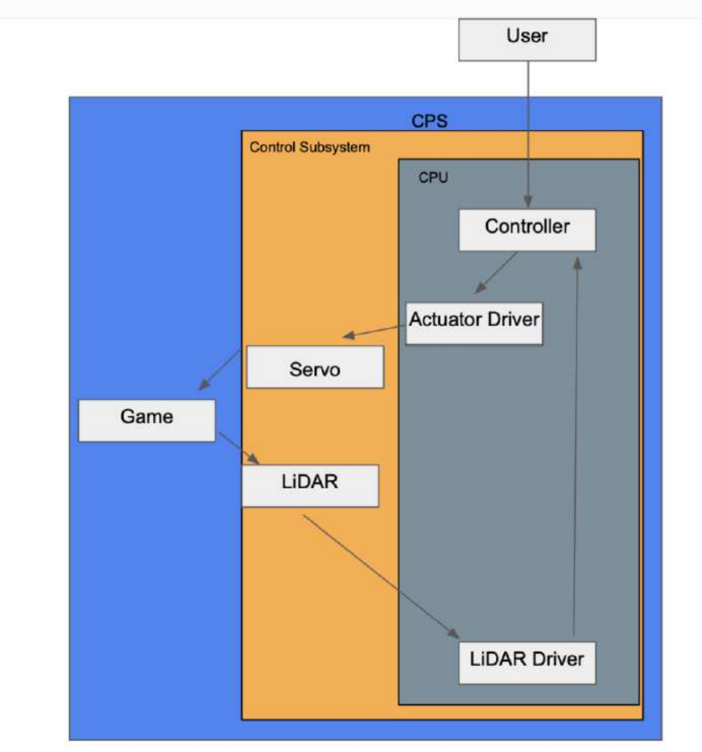
Stepper Motor with Microcontroller Setup



"Shoot The Moon" Game Board



LiDAR Sensor Functionality



Hardware Architecture

Remaining Technical Challenges

- **Driver Refactoring Completion**

  Finish refactoring all sensor and actuator drivers using dependency injection for better safety and testability.

- **Control-Loop Accuracy & Stability**

  Achieve low-jitter, predictable timing necessary to reach the 80% accuracy target.

- **LiDAR Filtering & Noise Management**

  Add filtering, smoothing, and validation logic to reduce jitter in distance measurements.

- **Mechanical Backplate Refinement**

  Iterate on the 3D-printed mount to improve rigidity, alignment, and sensor consistency.

- **Performance Logging Tools**

  Develop tools to record loop timing, servo behavior, and sensor performance to support tuning and optimization.

- **Final Documentation & Safety Analysis**

  Prepare the RISC-V + Rust safety analysis, emulator notes, integration documentation, and final Draper deliverables.

Implications for Company & Economic Impact

This project demonstrates how organizations like Draper can explore the benefits of combining open-architecture hardware with memory-safe software to reduce development risk and improve long-term maintainability. By investigating how Rust and RISC-V operate together in a real-time physical control task, the project provides practical insight for future research in robotics, autonomy, and embedded safety-critical systems. Economically, using open hardware and transparent toolchains can reduce reliance on proprietary ecosystems, shorten testing and iteration cycles, and lower long-term development costs through increased modularity, reusability, and clarity in both hardware and software design.

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Remote Power Control/Monitoring and Solid State Protective Devices for PDUs

Project by: General Dynamics Electric Boat

Team Members: Robert Schmitt (CPE), Danny Haigh (ELE), Rafael Heagney (ELE)

Technical Director(s): Michael Brawner, Matthew Huestis, Mike Smith (CTD)

Project Motivation

This project looks to design a reconfigurable DC power distribution system for servers and electronic racks, with the overall goal of allowing students to assess technology options, build simulations, and fabricate a working prototype. The scope of the project includes rack-level DC distribution, power monitoring, consumption, data communications, and solid-state protection to deliver clean and reliable power distribution.. Students will perform trade studies, evaluate Technology Readiness Levels (TRLs), and identify maturity risks, gaining experience from concept through prototype and test.

Anticipated Best Outcome

The best outcome is :

·Electric Boat reduces the cost and complexity of integrating new systems into its platforms.

·EB gains fresh engineering perspectives by observing how students frame problems and test solutions.

·EB gains a clearer understanding of technical options, system limits, and integration dependencies.

·The effort helps guide how this capability is developed for real operational use.

·Overall, EB can deliver innovative systems faster, at lower cost, with improved quality and reduced time-to-market.

Key Accomplishments

Distribution Architecture Selection: The high-voltage DC (HVDC) distribution stage, which delivers power from the central rectifier/UPS system to the individual rack-level PDUs, will operate at 400 VDC. This stage forms the facility's primary DC distribution bus. The low-voltage DC (LVDC) distribution stage, to deliver power from the rack-level PDUs to the downstream equipment, will operate at 12 VDC. This stage forms the secondary DC distribution bus supplying the IT loads. A visual representation of the conversion stage can be found in **Fig. 2.**

Circuit Protection Strategy: In distribution systems that feed sensitive IT equipment, protection against fault currents is especially important. Fault protection has been assessed for the 400VDC and the 12VDC stage. The HVDC stage protection strategy consists of a combination of HVDC-rated breakers and fuses, and EMI input filtering for clean power delivery. The LVDC stage protection strategy consists of a combination of LVDC-rated branch breakers and fuses, and output control relays.

System Network, Telemetry, & Monitoring Strategy: System network and telemetry targets have been identified. The system shall include network-interface components capable of distributing equipment status, health indicators, and system alerts capable of notifying remote users when certain parameters are met. The system shall be capable of monitoring and reporting input and output power quality and instances of out-of-tolerance conditions. Output load conditions shall have monitoring capabilities. All monitored metrics shall have data recording capabilities for future historical analysis and comply with the Open System Architecture (OSA) model. **Fig. 3** is a representation of our strategy

System Remote Control Strategy: System remote control targets have been identified. The system shall provide remote management and controllability functions necessary for safe and effective operation of a multi-rack DC distribution environment. The system shall support dynamic and prioritized power control, consisting of dynamic power allocation across connected loads and user-definable prioritized power allocations.

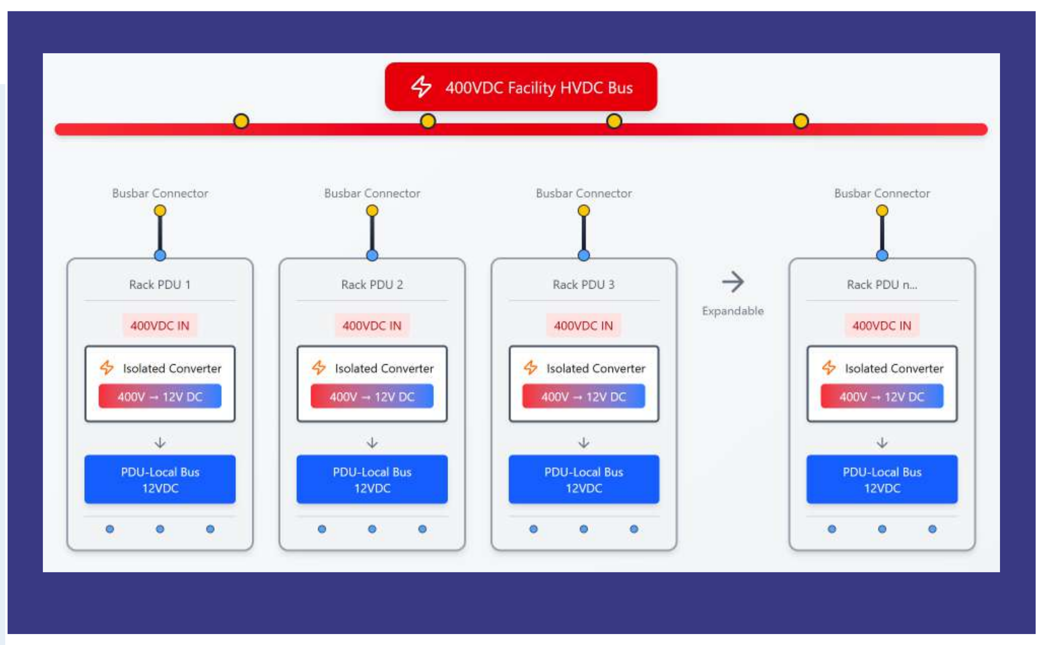


Fig 2: Conversion Stage Architecture

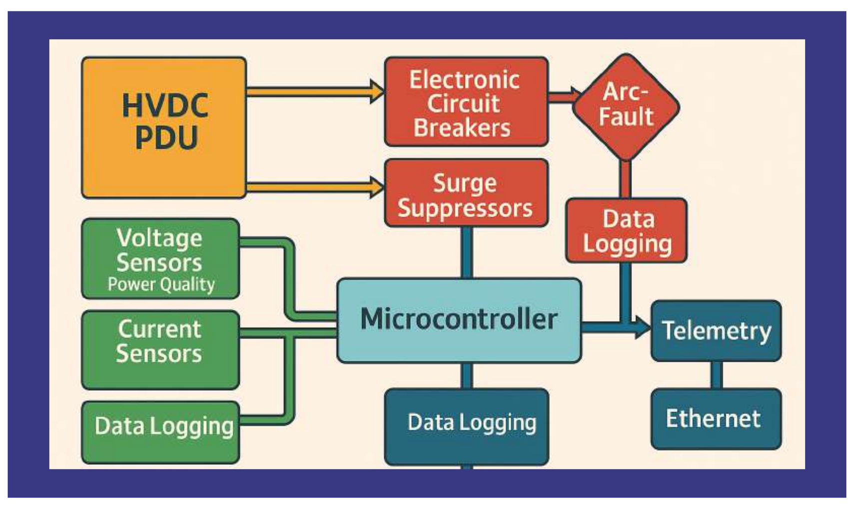


Fig. 3: System Network, Telemetry, & Monitoring Strategy

Fig. 4: Image of a Rack PDU

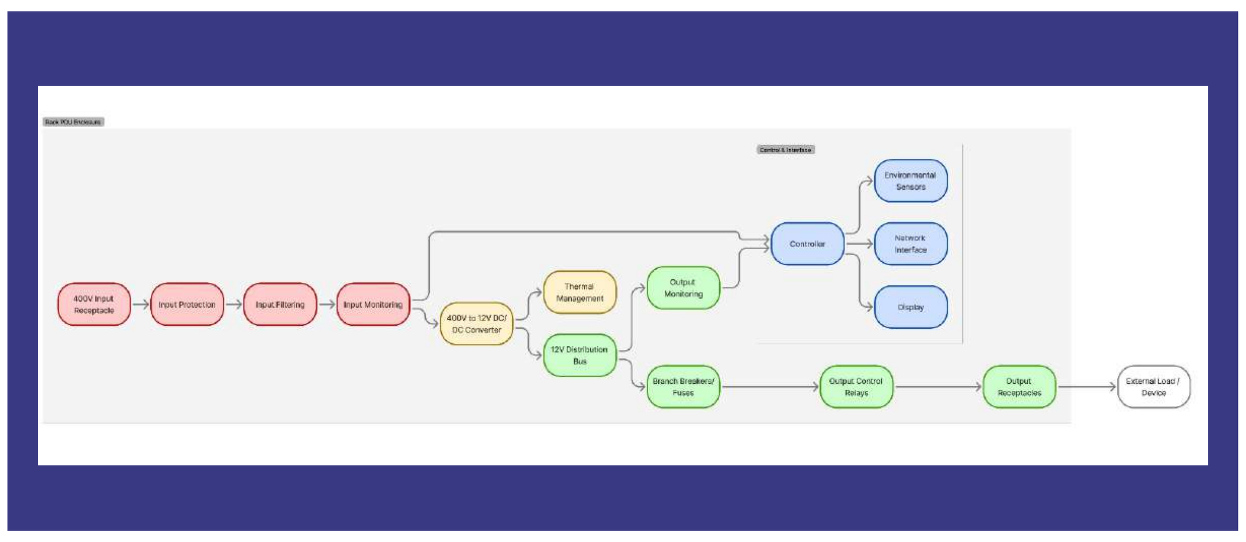


Fig 1: System-Level Functional Block Diagram

Remaining Technical Challenges

High-Voltage DC Isolation, Safety, and Arc-Fault Management: High-voltage is difficult to manage because it can produce arcs with no natural zero crossings. This demands larger clearance distances, reinforced isolation barriers, and arc-fault detection. Switches, relays, and disconnects must be DC-rated to break faults without welding shut. Meeting UL/IEC safety standards, ensuring touch-safe serviceability, and preventing catastrophic HV faults becomes one of the most complex aspects of PDU design.

Efficient, Multi-Stage HVDC-to-Low-Voltage Conversion: Stepping down HVDC to multiple low voltage stages requires high-efficiency isolated converters. Achieving high conversion efficiency from a 400V DC to a 12V DC bus requires sophisticated topologies like LLC resonant or phase-shifted full-bridge converters. Wide-bandgap semiconductors help reduce switching loss but introduce complex gate-drive and EMI challenges. We must minimize switching losses, magnetic core losses, and current ripple while achieving high power density.

Thermal Management in High-Density Rack Environments: Even efficient converters generate significant heat at kilowatt power levels. In a compact PDU, removing hundreds of watts without noisy fans requires optimized airflow, heat spreading, and careful placements of MOSFETs, magnetics, and capacitors. Hot spots must be minimized and maintained for long-term reliability. We must obey derating curves, integrate temperature sensing, and ensure the PDU survives certain inlet temperatures while maintaining stable operation.

Implications for Company & Economic Impact

A successful project outcome will provide Electric Boat with innovative design perspectives and a deeper understanding of emerging DC power distribution and management technologies. By exploring new architectures for intelligent PDU systems, EB can identify opportunities to reduce system integration cost and complexity in future platforms. The project also strengthens EB's workforce pipeline by exposing students to real engineering challenges and enabling EB to observe new approaches to problem-solving. Ultimately, the insights gained will help guide technology development, inform concepts of operation, and support long-term modernization efforts in power distribution systems.

ELECOMP CAPSTONE SYMPOSIUM
TUESDAY, DECEMBER 16, 2025

THE UNIVERSITY OF RHODE ISLAND

THINK BIG WE DO™

Shipyard 4.0

Cyber-Physical Testbed, Digital Twin, and Operator Dashboard for Secure Shipyard Manufacturing

Team Members: Aryana Sadr (ELE), Garrett Kemper (CPE/ELE), Laila Ghazi (ELE)

Technical Directors: Anissa Elias, Stephen Eacuello, Alexander Moulton & Thomas Santos

Project Motivation

The U.S. currently builds less than 1% of the world's commercial ships, which shows how urgently the country needs to improve and modernize its shipbuilding industry. The April 9, 2025 Executive Order directly responds to this problem by pushing for stronger shipyards, a better trained workforce, and major upgrades in technology to help restore America's maritime strength. However, bringing new technology into shipyards also creates bigger security risks that must be addressed. This is where Rite-Solutions is in a strong position, because the company can lead research and development focused on supply-chain security, infrastructure protection, and resilience for future shipyard systems.

Anticipated Best Outcome

By April 10, 2026, our best outcome is a fully integrated platform that improves the security and resiliency of shipyard manufacturing using a physical testbed, digital twin, and operator dashboard. The testbed of robots, conveyors, sensors, laser engraver, and CNC machine will run an automated workflow, while a ROS2/MuJoCo digital twin mirrors it in real time. The dashboard will monitor and control the system, visualize events, and support kill chain–based vulnerability analysis.

Key Accomplishments

- Completed first two Minimal Viable Product (MVP) phases of development and established major components of the physical testbed, digital twin, and dashboard **(Fig. 1)**.
- Assembled and calibrated the physical testbed, including Niryo robotic arms, conveyors, sensors, and a laser engraver functioning together in an automated workflow.

Digital Twin

- Created synchronized digital twin environments using Fusion 360, URDF/Xacro, ROS2, and MuJoCo.
- Built Pre-MVP, MVP 1 and MVP 2 layouts; visualized robot and conveyor behavior in RViz.
- Implemented MuJoCo digital twin with functional conveyor belts, Niryo arms, and an XArm Lite 6 **(Fig. 2)**.
- Developed a ROS2 digital twin node, configuration-based initialization, and a stimulator node for fully testable communication **(Fig. 4)**.

Dashboard

- Selected Python/FastAPI with HTML/CSS/JavaScript as the dashboard stack.
- Developed a responsive UI with topology views, robot metrics, and alert panels **(Fig. 3)**.
- Implemented real-time live data streaming via MQTT and JSON endpoints.
- Added an updated UI and search page for querying historical robot data.

Additional Accomplishments

- Completed an initial cyber kill chain analysis.
- Authored SRS documents for the physical testbed, digital twin, and dashboard.
- Developed a discrete network simulation tool for system performance and vulnerability analysis **(Fig. 5, 6)**.

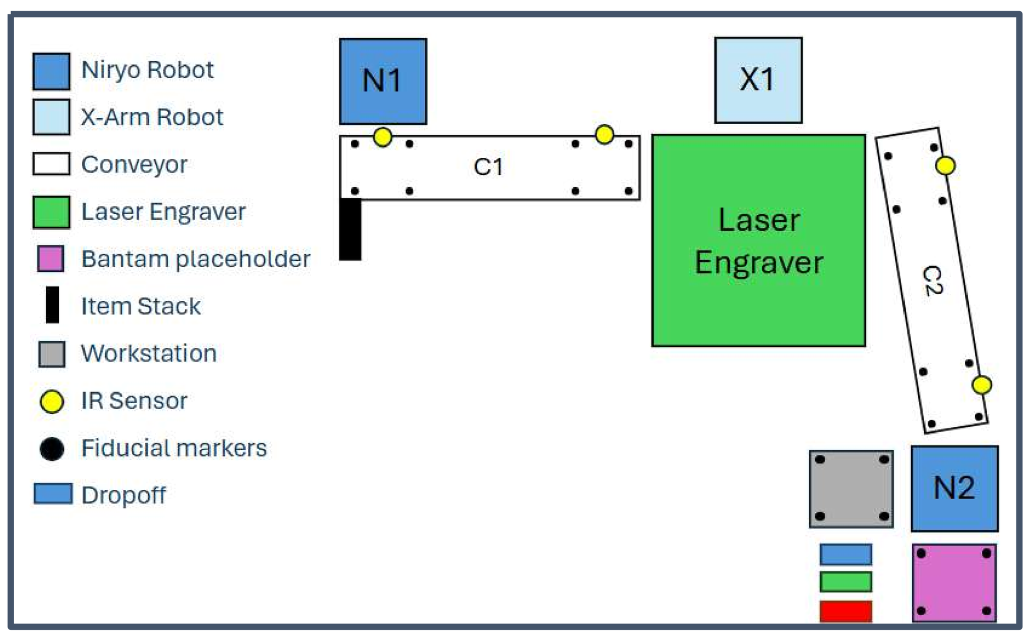


Fig. 1: Layout Diagram of the Physical Testbed

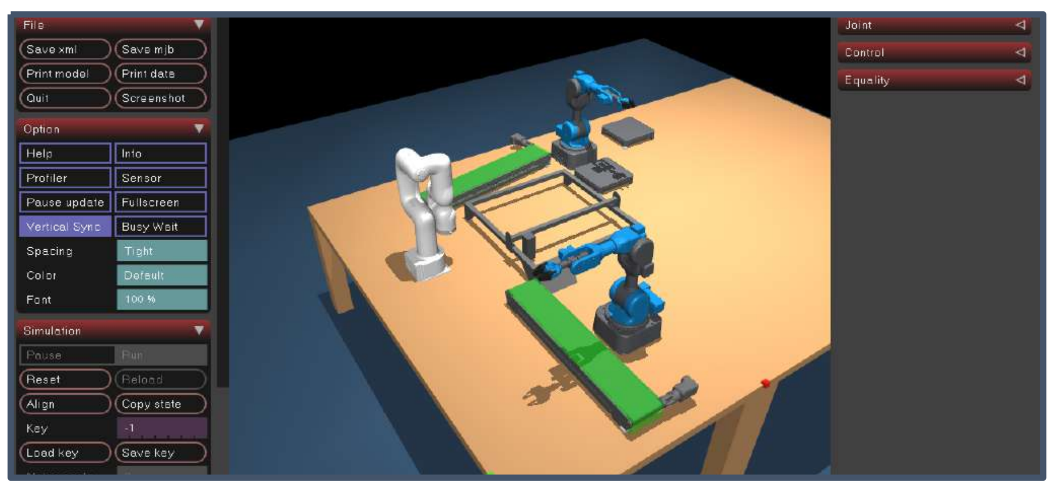


Fig. 2: Rendering of Digital Twin in MuJoCo

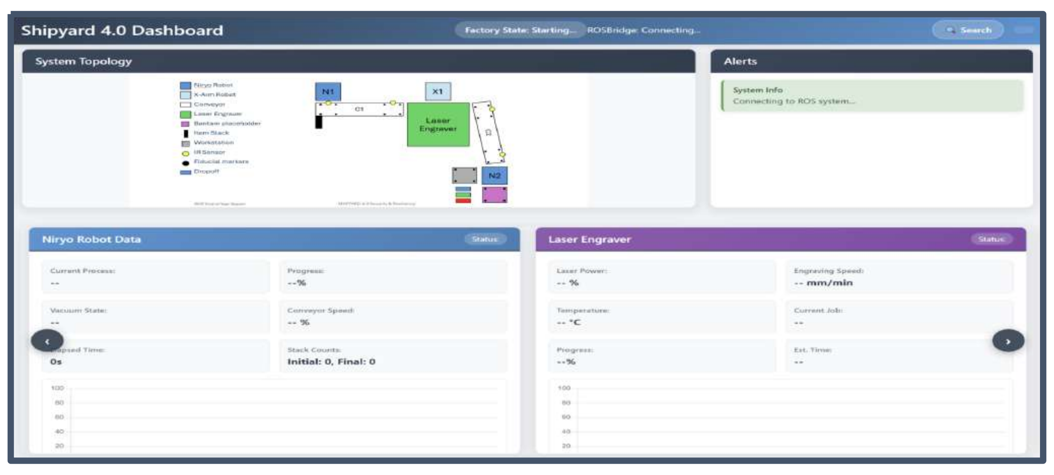


Fig. 3: UI of Dashboard

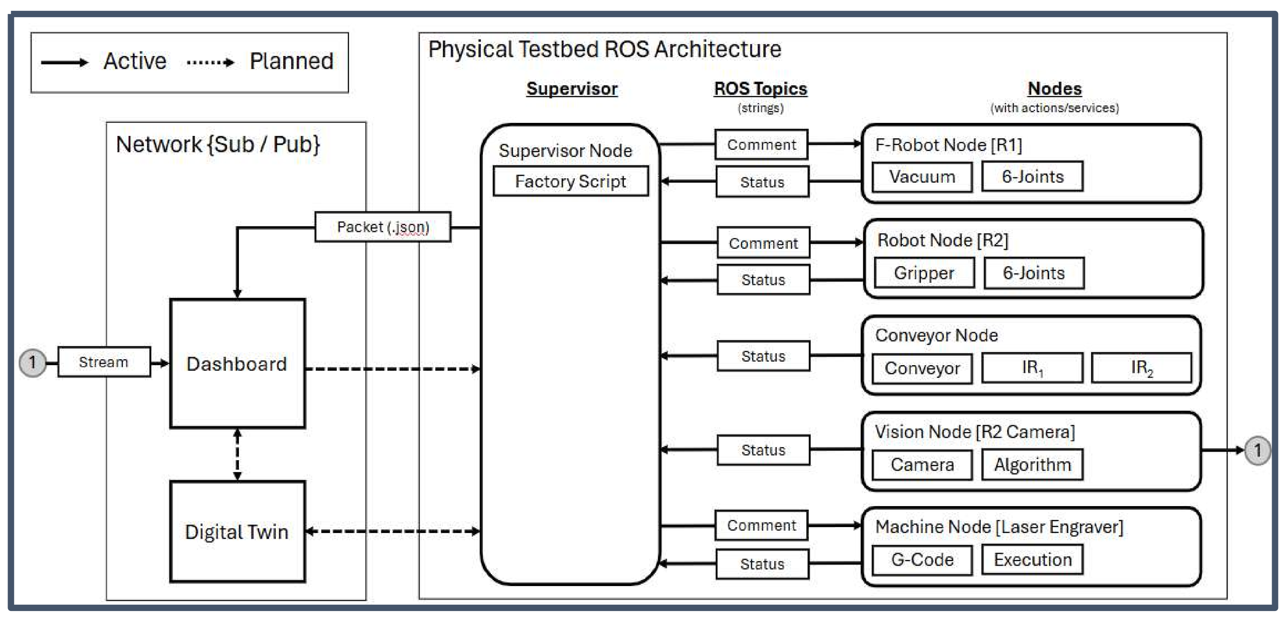


Fig. 4: ROS 2 node diagram showing the communication network between the Supervisor Node and all hardware nodes, Dashboard and Digital Twin.

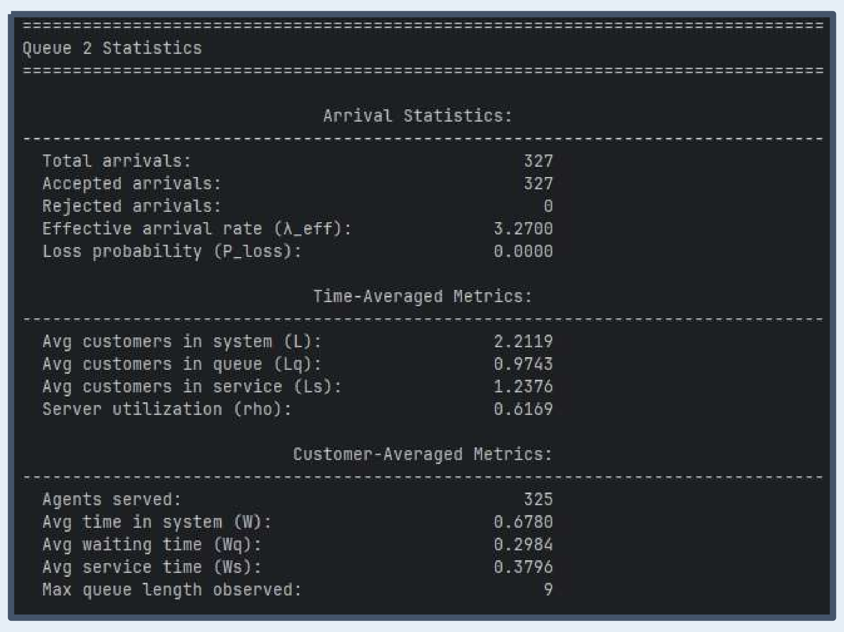
Remaining Technical Challenges

Digital Twin

- Develop killchain analysis metrics
- Improve simulation performance and accuracy
- Integrate outputs and alerts with the dashboard

Dashboard

- Finalize ROS2/Rosbridge integration
- Add Postgres database and secure remote access
- Incorporate testbed and digital twin topic streams



```
Queue 2 Statistics

                    Arrival Statistics:
  Total arrivals:                              327
  Accepted arrivals:                           327
  Rejected arrivals:                             0
  Effective arrival rate (λ_eff):           3.2700
  Loss probability (P_loss):                0.0000

                  Time-Averaged Metrics:
  Avg customers in system (L):              2.2119
  Avg customers in queue (Lq):              0.9743
  Avg customers in service (Ls):            1.2376
  Server utilization (rho):                 0.6169

                Customer-Averaged Metrics:
  Agents served:                               325
  Avg time in system (W):                   0.6780
  Avg waiting time (Wq):                    0.2984
  Avg service time (Ws):                    0.3796
  Max queue length observed:                     9
```

Fig. 5: Discrete Simulation Metrics

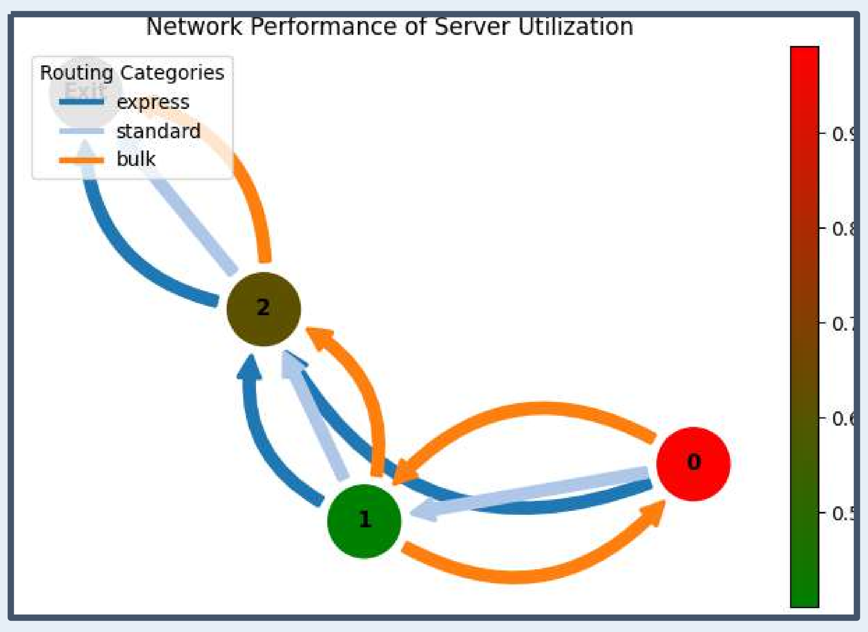


Fig. 6: Discrete Simulation Connectivity Graph

Implications for Company & Economic Impact

The anticipated best outcome will have implications for Rite-Solutions by positioning the company as a leader in new technologies that enhance shipyard security and resiliency. By developing this platform, Rite-Solutions can advance in kill chain modeling, cyber threat analysis, and security testing in manufacturing environments. Economically, this project will strengthen Rite-Solutions in government and commercial markets focused on maritime modernization. This project will also drive internal research and development.

SANCTUARI ALPHA INDIA 2

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

Team Members: Jackson Albro (CPE), Grey Daly-LaBelle (ELE)

Technical Director: Joe Moreira **Consulting Technical Directors: James DeMello, Yashaswini Mandalam**

Project Motivation

Within the field of wildlife rehabilitation, there is a need to monitor the animals that are being rehabilitated, whether that be through traditional means or with new technologies. At the SANCTUARI rehabilitation center, animals are monitored with a multitude of security camera systems that trigger whenever they detect motion. While this feature is helpful for the rehabilitators, there are many occasions of a "false positive" motion or a non-animal being captured on video, taking up unnecessary disk space. Over time, much of the video data captured by the security cameras may be unhelpful for further use. As the team assigned to this project, our task is to implement a system that uses object recognition and AI to filter out the "false positive" video data and create a reliable set of animal data. When this objective is achieved, the refined data can be further processed with AI tools in order to classify animal behaviors and movements that will be useful in conservation and rehabilitation efforts.

Anticipated Best Outcome (ABO)

Within this project, there are seventy-five (75) ABOs, however we only have to complete twenty-five (25) of these ABOs to achieve a successful project. The first third of the ABOs are what we have been focusing on thus far, and they involve implementing a filtering method in order to process large amounts of video data in a timely and reliable manner. The rest of the ABOs deal more with the continued processing of the refined data, namely the use of AI tools to classify animal behaviors and movements.

Key Accomplishments

Object Detection/Classification Selection: Early on within the project, we were fortunate enough to find pretrained AI models that could be used to complete some of our ABOs. The primary model that we have been utilizing thus far, Google's camera trap AI, includes generous amounts of documentation and was straightforward in setting up and testing on our local system. The camera trap AI accepts images as input, and outputs detection and classification files for each batch processed, revealing what was found in the input. There is also an option for annotation, which allows for a visualization of what objects were detected/classified. (**Fig. 1**)

Construction of Processing Pipeline: As the project progressed, there was a need to determine the components that would need to function at each stage of the data processing/filtering pipeline in order to receive a usable output. (**Fig. 4**) Given that the primary detection/classification tool that we are using only accepts images, a component to split videos into frames was necessary to add into the processing pipeline. In a similar vein, the videos must be reconstructed after the frames are processed, so we implemented a way to reconstruct videos.

Development of GUI: Considering the amount of "moving parts" residing under the surface of the pipeline, there was a need to develop a GUI for ease of use, both for us and those who will be using the design. (**Fig. 2**) In its current state, the GUI allows the user to first choose an input directory for the videos they wish to process. From there, the user can choose an output directory where they would like to see their results. After choosing a processing option, the GUI will show a processing status for each stage of the pipeline as well as a total elapsed time at the end. The user is able to view the pipeline output in their selected output directory.

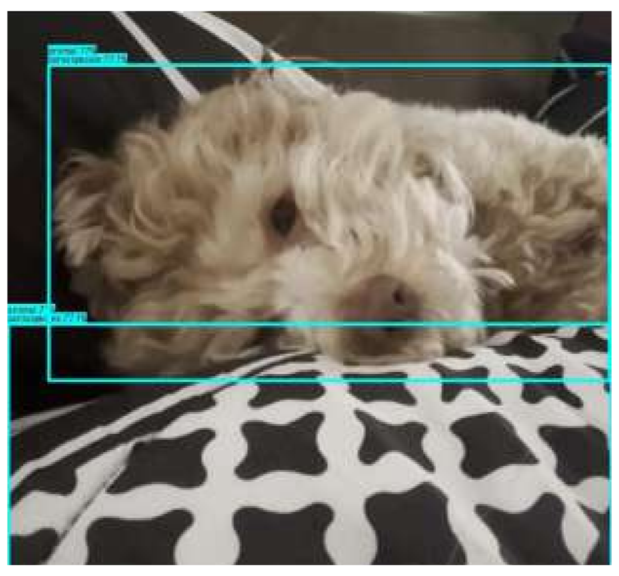


Fig. 1: Frame annotated with camera trap AI results

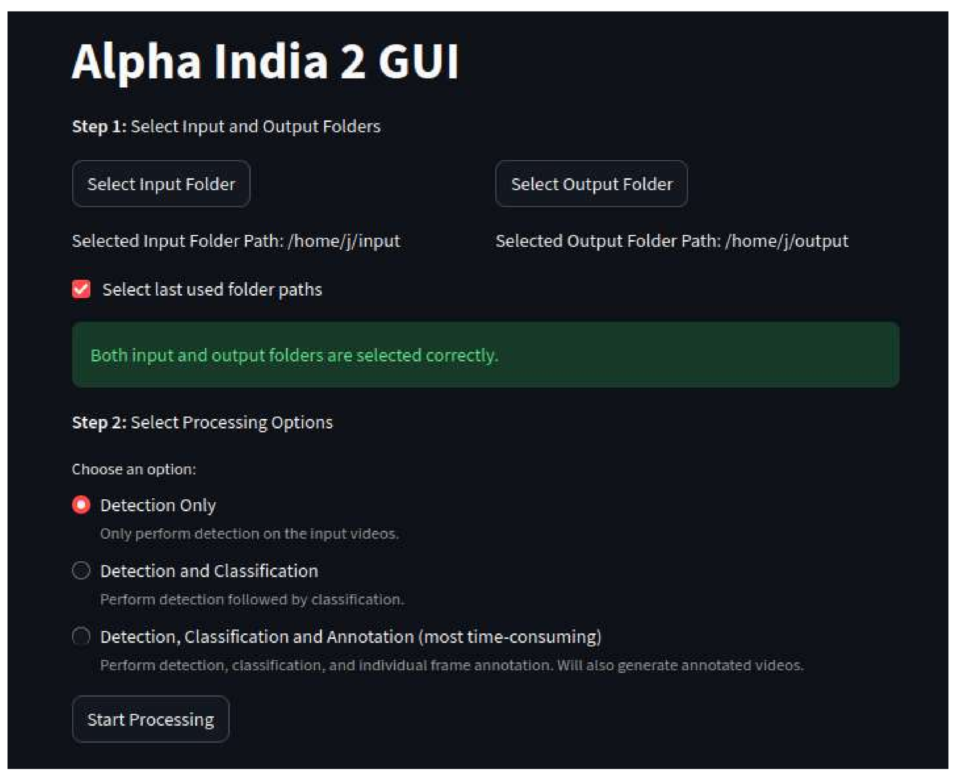


Fig. 2: Alpha India 2 GUI

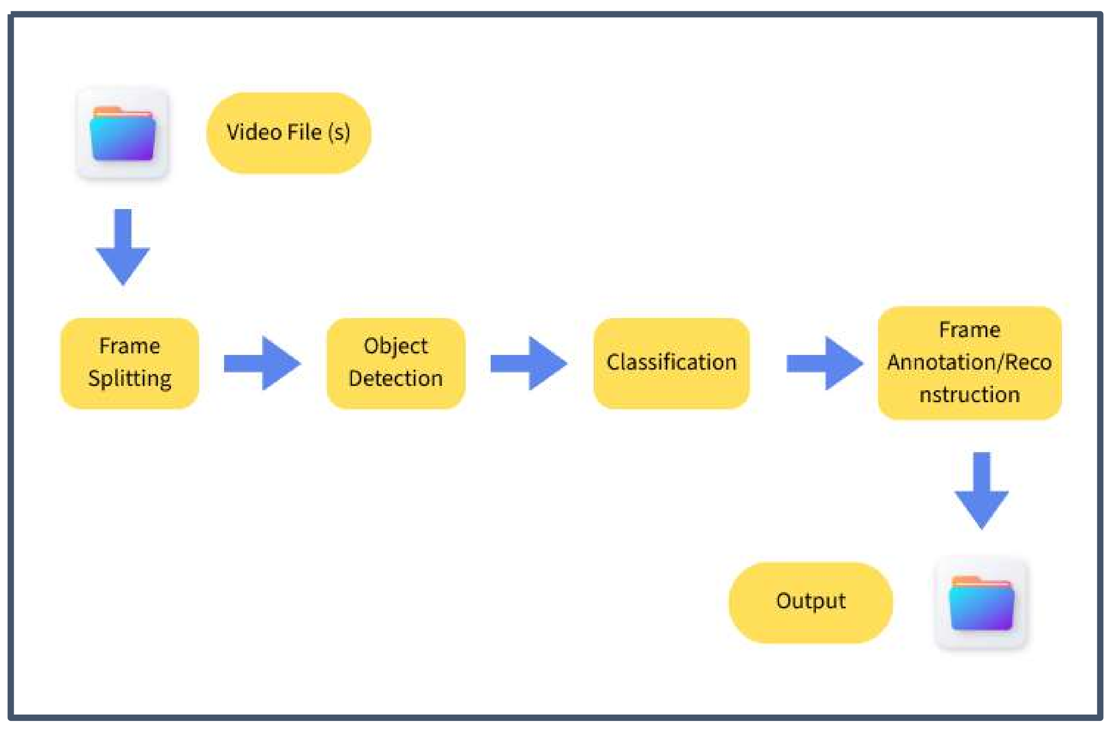


Fig. 4: Flow Diagram of Processing Pipeline

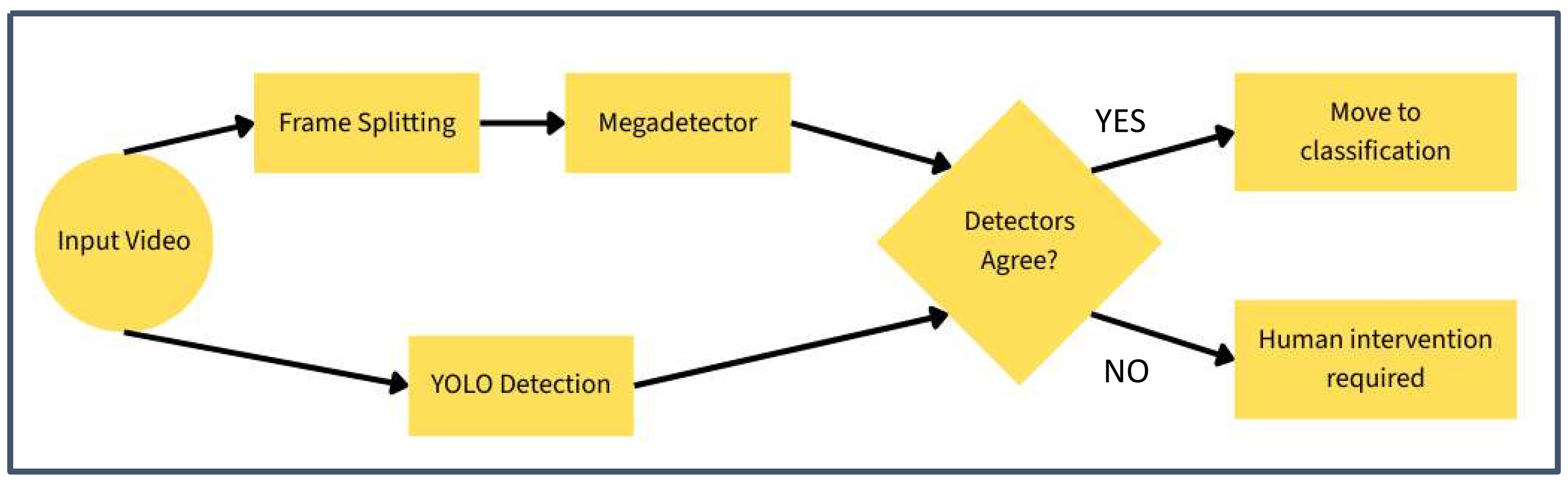


Fig. 3: Flow diagram of planned redundancy in detection stage of pipeline

Remaining Technical Challenges

Behaviour analysis: As of the current progress of the project the current pipeline that has been designed and refined does not analyze or label animal behaviours. This is a significant part of the anticipated best outcomes. If an AI model can be found and utilized for animal behaviour that would potentially far exceed the goal of getting 25 out of the total 75 ABO's.

Filtering video triggers: Currently the camera systems in the SANCTUARI centers are set to record at the slightest movement and change. This is to make sure there is no lost footage of having animals in frame. However, this also means that a vast amount of the footage saved and stored in the system is effectively useless with no animals in frame. If it is possible to filter different triggers to start the recording using AI that could save an enormous amount of storage and wasted processing time.

Continued GUI Development: Although we have a working prototype of the GUI, more work is needed to improve its functionality and testing must be done on real animal data. The output of each video passed through the pipeline must be extracted and transformed to be easily interpreted by the end user. This feature should also be implemented on a per-camera basis, so as to give the end user an idea of what animals are being found on which camera. Also, work is needed to implement detection model redundancy and frame sampling. (**Fig. 3**)

Implications for Company & Economic Impact

Successful execution of this project will enable rapid production and distribution of the devices and educational materials across the entire network of SANCTUARI's carers and supporters. By equipping them with reliable tools and accessible training resources, this will elevate the standard of wildlife care. This also ensures more efficient treatment, faster recovery times, and improved long term outcomes for animals in need. Furthermore, this coordinated effort will strengthen collaboration within the wildlife care community, foster innovation in rehabilitation practices, and build a sustainable foundation for future research and education initiatives.

ELECOMP CAPSTONE
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TUESDAY, DECEMBER 16, 2025

THE UNIVERSITY OF RHODE ISLAND

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Project Echo Mike 3

Post-Release Tracking Device for Small Mammalian Species

SANCTUARI

Team Members: Sophie Plante (CPE), Brian Cam Farmer (ELE), Douglas Fisher (ELE/CPE)

Technical Director: Joe Moreira **Consulting Technical Director: Chris Rothwell**

Project Motivation

Wildlife rehabilitators often lose contact with animals after release, making it challenging to assess survival and the effectiveness of rehabilitation. SANCTUARI, a nonprofit focused on wildlife care, identified modern tracking technology as a way to close this critical information gap. Reliable post-release monitoring supports individual animal welfare while advancing research and conservation practices.

Echo Mike 3 was created to provide a compact, energy-efficient, and affordable tracking solution for small mammals. Many commercial trackers prioritize long-range capabilities and ruggedness but overlook the needs of species like foxes, raccoons, and rabbits. By emphasizing miniaturization, low power use, and consistent data transmission, Echo Mike 3 addresses these limitations. The project directly supports SANCTUARI's mission to use innovative engineering to improve wildlife welfare and enhance understanding of animal behavior and post-release survival.

Anticipated Best Outcome

The best outcome is:

- A compact, lightweight wildlife tracker designed, prototyped, and tested by Spring 2026.
- A low-power controller integrated with GPS and cellular connectivity for reliable real-time location reporting.
- A durable, energy-efficient device that animals can comfortably wear during long-term field operation.
- High-quality post-release movement data that strengthens SANCTUARI's research and rehabilitation efforts.

Key Accomplishments

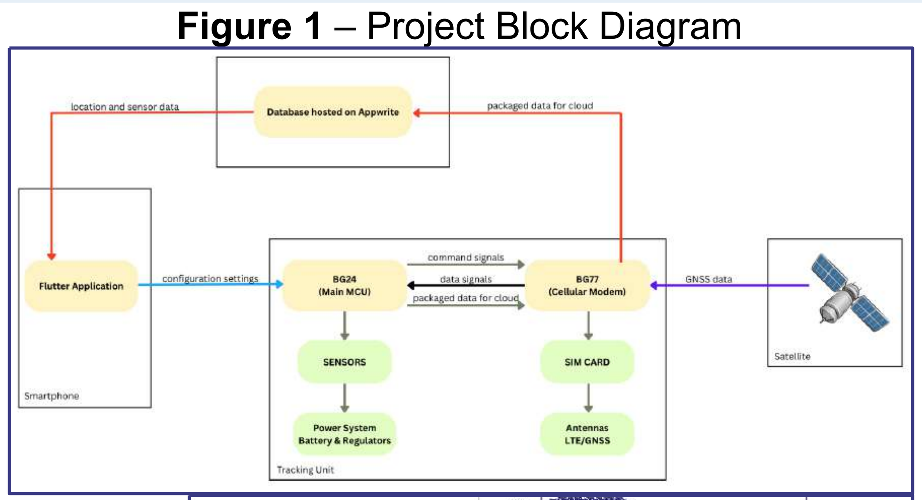
MG24 Schematic: The MG24 is a low-power wireless microcontroller featuring integrated Bluetooth LE, advanced hardware security, and extensive digital/analog peripherals. In our design, the MG24 serves as the main MCU for sensor processing and system control, and its full symbol, footprint, and 3D model are integrated into our KiCad schematic and PCB layout to ensure accurate pin mapping and hardware implementation (Fig. 1 & 2).

BG77 Schematic: The BG77 is a low-power LTE-M/NB-IoT modem with integrated GNSS, designed for reliable cellular connectivity and positioning in compact IoT systems. In our schematic the BG77 interfaces directly with the MG24 over UART and dedicated control lines, forming the core communication link for data transmission and module management. Its complete KiCad symbol, footprint, and 3D model have been incorporated into the schematic to ensure proper pin assignments, antenna routing, and power-domain organization, allowing seamless integration with the MG24 MCU and the rest of the system hardware (Fig. 1 & 3).

Firmware Development & BLE + JSON: Configured and maintained the Simplicity Studio and VS Code toolchains, verified BLE operation on the MG24, and resolved Echo Mike 2 firmware issues including redundant event handlers, SDK mismatches, and inconsistent timeout behavior, establishing a stable foundation for wake-ups, sampling and communication. Implemented tracker_adv.dart to formalize a structured JSON command response framework. This enables consistent BLE messaging between the firmware and mobile application, supporting configuration commands, tracker data parsing, and scalable communication patterns for later Appwrite integration.

Mobile Integration & Mapping: Set up the Flutter environment, validated cross-platform builds, and implemented core UI screens. Added OpenStreetMap (OSM) mapping capabilities, including current location retrieval, map control, and a TrackerLogHistory system for logging and visualizing historical coordinates (Fig. 4). These components lay the groundwork for real-time device tracking and cloud-connected data visualization.

Figure 1 – Project Block Diagram



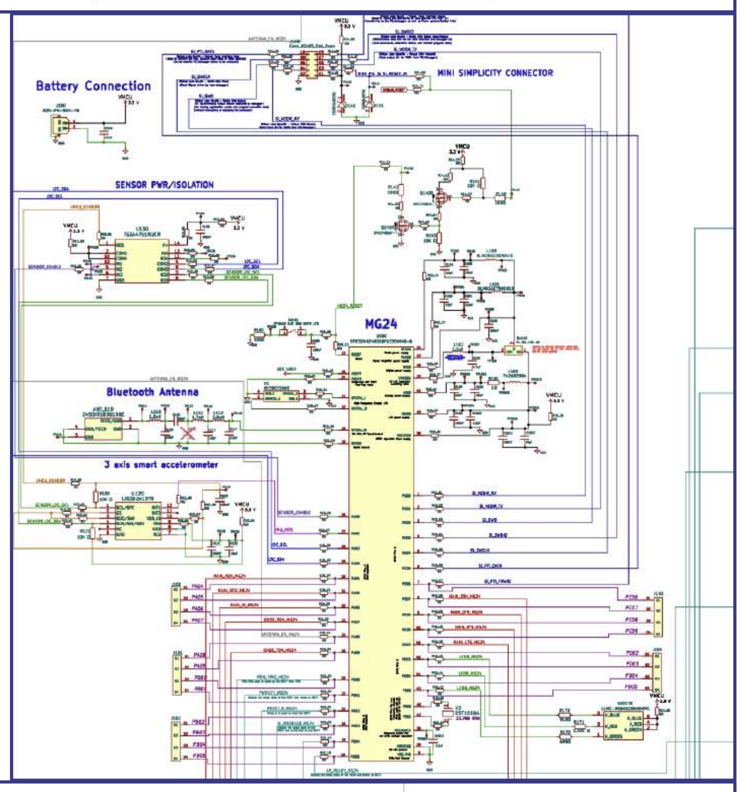


Figure 2
Schematic of MG24

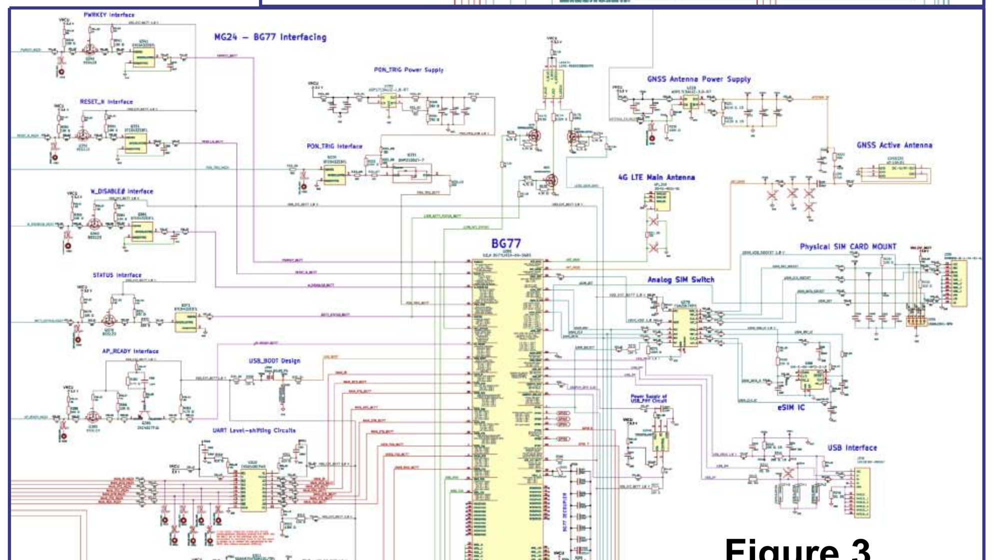


Figure 3
Schematic of BG77

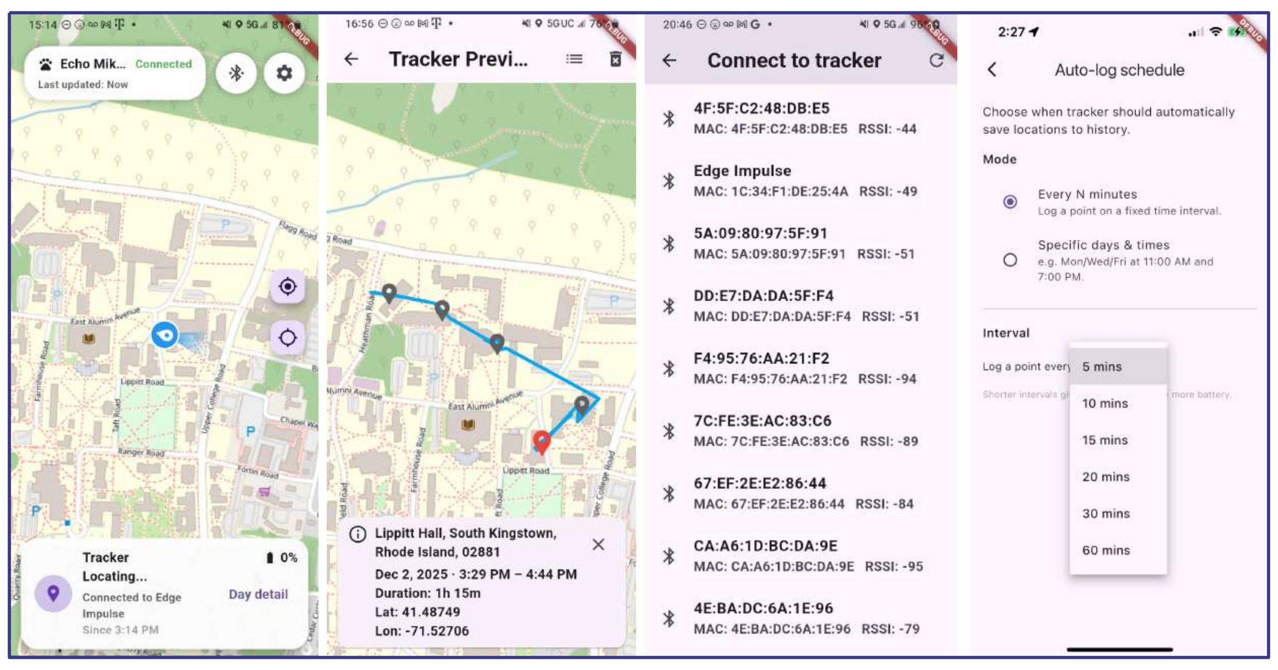


Figure 4 – Echo Mike 3 Flutter Mobile Application

Remaining Technical Challenges

PCB: Remaining PCB challenges include completing precise component placement for the MG24, BG77 sensors, and power regulation stages to ensure proper thermal behavior, signal integrity, and RF isolation. Critical tasks still involve refining the controlled-impedance routing for LTE and GNSS antenna lines, validating grounding strategies, and confirming stable power delivery across all voltage domains. In parallel, every KiCad symbol, footprint, and 3D model must be reviewed against vendor datasheets to eliminate pin-mapping or clearance errors. Final ERC/DRC checks, copper adjustments, and manufacturability reviews are required to ensure the board meets fabrication standards and performs reliably during integration and field testing.

Ordering PCB: Identifying and evaluating PCB manufacturers that can deliver high-quality fabrication and assembly while staying within our project budget. This requires comparing capabilities such as layer tolerances, controlled-impedance support, material options, and turnaround time across multiple vendors. We must also assess reliability, communication responsiveness, minimum order quantities, and overall cost to ensure our board meets our performance requirements without exceeding financial constraints.

Firmware Refinement: Further development of wake-sleep scheduling, GPS sampling, and BG77 cellular communication is dependent on receiving the updated hardware revision. Once available, these modules must be integrated, tested, and tuned to achieve predictable timing behavior and meet multi-week power-budget targets.

End-to-End Data Flow: The BLE + JSON pipeline must be extended to support full configuration control and device-to-cloud data exchange. Finalizing data structures, implementing Appwrite endpoints, and validating two-way communication remain key milestones.

Field-Ready & Mobile Integration: Enclosure design, antenna performance, and environmental durability must be validated, alongside completing the mobile application's tracker-ready features. Final mobile-device interaction and data visualization cannot be finalized until the updated hardware is available for testing.

Implications for Company & Economic Impact

The successful completion of this project will allow SANCTUARI to produce and share wildlife tracking devices with its network of licensed rehabilitators and veterinarians. Reliable post-release data will help improve rehabilitation practices, understand how animals adapt after care, and strengthen long-term survival outcomes. As a nonprofit, SANCTUARI aims to advance wildlife welfare and research rather than generate profit. The design will be shared with local and regional rehabilitation centers, encouraging collaboration and accessible innovation. Even a single well-documented case can influence practices across organizations, ultimately helping countless animals receive more effective care and a better chance at thriving after release.

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TUESDAY, DECEMBER 16, 2025

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Hybrid Crossover Zone Valve

A Smart, Self-Powered Valve for Improving Hot Water Efficiency

Taco Comfort Solutions™ A Taco Group Company

Team Members: Owen Morelli (ELE/MCE), Gabriel Arabik (CPE), Maxwell Gleadow (ELE)

Technical Director(s): Adam Bouchard, Nicholas Costello, Aaron Hertzer, Mike Smith (CTD)

Project Motivation

The Smart valve project aims to reduce water waste during heating cycles. This could not only lead to massive improvements in domestic water usage, but also result in energy savings while reducing wear on hot water heaters. This would be ideal for areas that suffer from water shortages. Creating an automated self-powered system has the potential to influence both residential and commercial standards, potentially leading to major energy savings. The Hybrid Crossover Zone Valve is a proof of concept, exploring the growing field of IoT devices and self-sustainable technology. In this way, success in this project would indicate potential for further investment in similar lineless smart home devices making use of energy harvesting technologies. Ultimately the Hybrid Crossover Zone Valve is conducive to forward-thinking engineering taking a step towards developing more efficient and intelligent systems available to residential homes.

Anticipated Best Outcome

We aim to develop an autonomous, lineless hot water crossover valve. An integrated MCU, actuator, and sensors would serve to intelligently keep hot water at the valve for faster hot usage at the tap. The MCU will take in sensor data and run through predetermined procedures and logic in order to autonomously stroke the valve by usage of the actuator. This will be powered only by energy harvesting methods to keep our product completely lineless and batteryless. The final product that we create will be used as a proof of concept for the potential of lineless technology. .

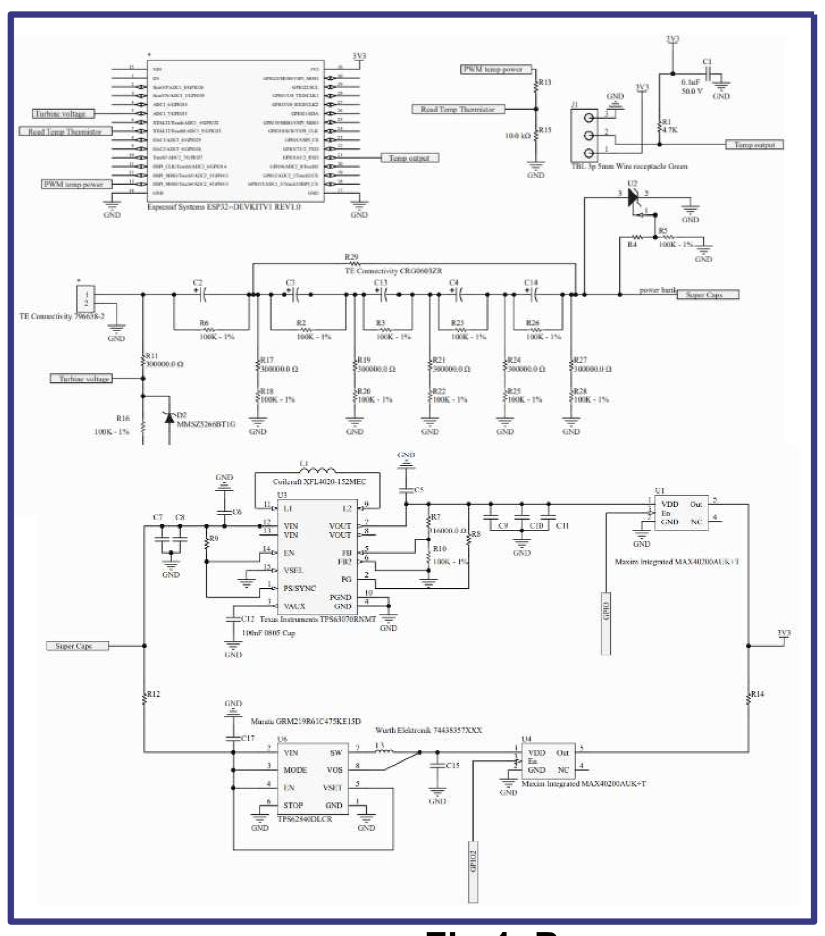

Fig 1. Power Harvesting Schematics

Key Accomplishments

Embedded Systems Design
We are using an Espressif ESP32-C6 as the MCU of our embedded system as shown in **Fig 2**. This allows us to develop a low power system with BLE5.0 and the ability to switch between deep sleep and active modes. Via GPIO we are able to integrate sensors, perform A/D conversion to allow us to integrate this processing unit with our power harvesting circuit.

Power harvesting
As shown in **Fig 1.** rather than a traditional battery we plan on storing energy with the use of a super capacitor bank. This was accomplished by placing multiple super capacitors in series, with high precision balancing resistors. In order to use a super capacitor bank we need the following: account for cell mismatches (maintaining balance among super capacitors), to maintain a fixed output voltage, prevent backwards charging, and prevent overcurrent. We have accounted for all of these via the implementation of an ORing circuit with two switching regulators; one for high current draw and the other for deep sleep mode. This along with balancing resistors ensures a steady and stable power supply for our sensors, actuator and MCU.

Sensor integration
Several sensors are needed for the control system of our valve. A temperature sensor is used to determine if a threshold temperature is met. In future implementations meeting this threshold would cause the MCU to send a signal to the hot water heater via BLE causing the circulation cycle. Voltage output of the turbine as well as the voltage levels of our power supply are monitored with resistor dividers. The current voltage output of the energy harvesting turbine will be used to determine the flow rate and thus the openness of the valve via a reference curve.

PCB design
Our power harvesting schematics were translated to a PCB design centered about the ESP32-c6. This included the addition of test points and pads to populate zero ohm resistors for the purpose of testing. Our turbine, and temperature sensors can be hot swapped with the use of screw in terminals. This REV1 design while likely be irated based on data collected this upcoming semester. This current PCB design is shown in **Fig 2**.

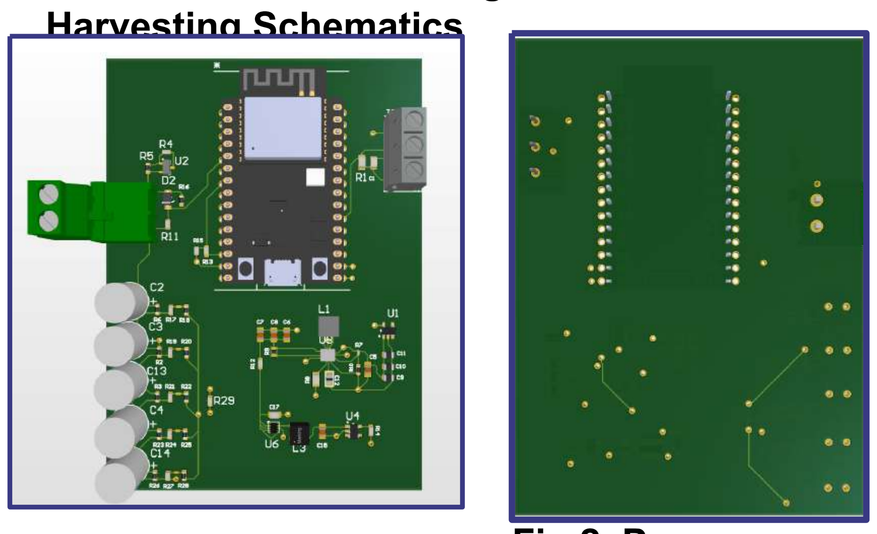

Fig 2. Power Harvesting PCB Design

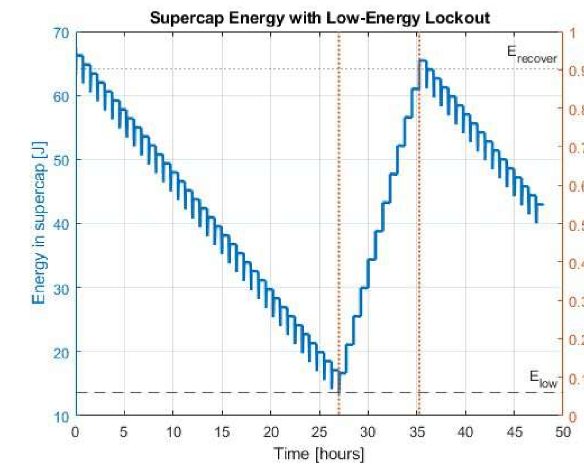

Fig 3. Simulated Power Consumption

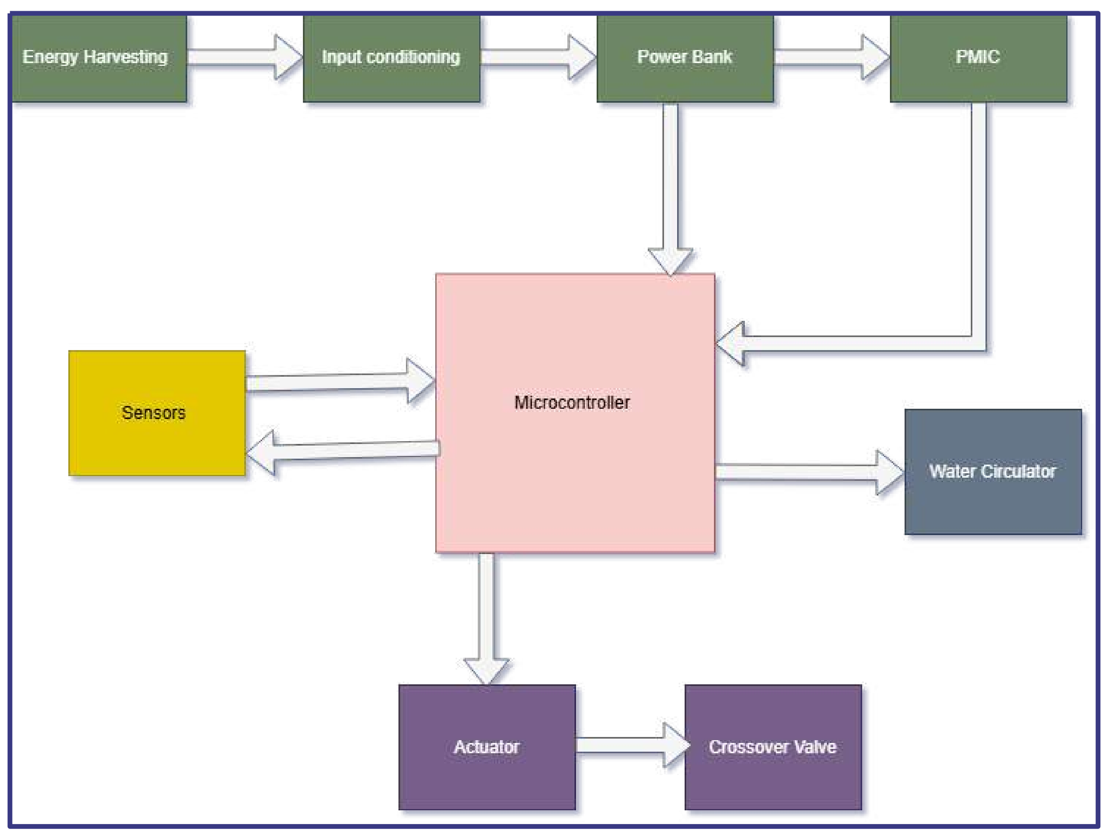

Fig 4. System Block diagram

Remaining Technical Challenges

Our technical accomplishments in the Fall semester can be viewed as a set of schematics and plans that need to be validated this upcoming semester. In this manner, our remaining technical challenges can be characterized by the need to prove that our power harvesting system works as intended. We will perform testing regarding the power harvesting abilities of our systems design.

Power harvesting
By measuring current, and voltage output of various turbines at different flow rates we are able to compile data on the performance of our power harvesting system. This information will inform us on if our power input will be sufficient and what turbine configuration will result in the greatest power harvesting.

Power Bank life cycle
By testing different configurations of super capacitors of various sizes under different BLE conditions we are able to quantify the life-cycle of our system. Likewise, this may be done with different configurations of actuators.

Bluetooth Integration
Ensuring secure communication between the MCU and water circulator via BLE. Optimizing power consumption during bluetooth cycles, ideally reducing time spent receiving and transmitting signals as much as possible.

Valve Automation
Modify a low friction valve to open and close via a latching solenoid actuator. Integrating and design supporting electronics. This actuator will serve automate our system, controlling the flow of hot water through the cross-over valve.

PCB fabrication
Fabricate REV1 of the power harvesting PCB design, test and irate as needed. This includes assembly, and the eventual design of a housing for our system as a single unit.

Embedded system software
Designing the controlling software that controls the driving logic to switch between deep sleep and active modes. This will define procedures for wake up and sleep modes (monitoring voltages, switching between regulators etc)

Implications for Company & Economic Impact

Taco currently comprises a large portion of the hot water heating market, much of this business is located on the East coast and New England area. While the entire nation makes use of hot water at sinks and has common plumbing fixtures, this project could serve as Taco's break into a more plumbing centric market, as a sink connected product. If the smart cross-over valve is successful and achieves the best anticipated outcome Taco would not only break out of the hydronic market but mark themselves as a leader in eco-conscious and sustainable plumbing residential systems.

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OFDM-Sense

Wireless Communication System Prototype Capable of Joint Communication and 2D Localization Leveraging OFDM Signals

ARCS LAB
ADVANCED RF/mmWAVE SENSING AND COMMUNICATIONS LAB

Team Members: O'Malley Sherlock (ELE), Royaljohn Southammavong (ELE)

Technical Director: Dr. Guoyi Xu

Project Motivation

The rise of Internet of Things (IoT) devices, particularly in autonomous systems and robotics, demands fast and robust communication systems alongside environmental awareness. These systems traditionally perform data transmission/reception and localization separately; however, due to increasing power and performance demands within constrained frequency bandwidths, efficient communication systems necessitate an integrated approach.

To meet these demands, we focus on integrating data communication and localization simultaneously via orthogonal frequency-division multiplexing (OFDM), the foundational modulation scheme present in modern Wi-Fi, LTE, and 5G wireless communication standards. OFDM signals feature high spectral efficiency, fast data transmission rates, and minimal inter-symbol interference (ISI). By leveraging OFDM, we hope to develop a communication system prototype capable of simultaneously communicating data and position information.

Anticipated Best Outcome (ABO)

The ABO is a functional mmWave Single-Input Multiple-Output (SIMO) software-defined radio (SDR) communication system utilizing OFDM signals to communicate data and calculate the positions of multiple receivers simultaneously. To achieve this, the following major tasks must be accomplished:

- **Develop** OFDM Transceiver and configure it with USRP X310 and Sivers SDR hardware for single channel communication.
- **Implement** matched-filter-based time delay estimation using OFDM pilots and verify localization capabilities.
- **Scale** single channel communication to multi-channel.
- **Correct** non-ideal communication issues such as carrier frequency offset
- **Perform** 2D trilateration algorithm to locate receiver positions.

Key Accomplishments

SDR Platform Setup: The provided Software Defined Radio (SDR) hardware was set up and configured with the lab PC through Ethernet. The open source USRP Hardware Driver API was installed to enable control of the USRP hardware using C++.

OFDM Packet Generation: A script was developed to enable fast and customizable generation of OFDM packets by either generating random binary data or reading binary data from a file. Packets can be quickly customized based on the number of desired pilot and data symbols, as well as applying a gain or adding artificial noise for rapid testing.

OFDM Transceiver: The OFDM transceiver was developed in Python and fully incorporates SDR control along with OFDM packet decoding and data reconstruction. The transceiver reads the In-phase (I) and Quadrature (Q) samples pre-generated and sends them to the SDR platform to be converted to analog signals with the on-board DAC. The received signals are saved and stored for post-processing.

Schmidl & Cox Synchronization: The Schmidl-Cox algorithm was implemented to allow the receiver to detect the beginning of a received signal. The algorithm calculates the symmetry within a given interval over the entire signal.

Channel Estimation: To enable data transmission, the channel gains of each subcarrier must be calculated. To do this, we implemented an algorithm that uses the known pilot symbol by the receiver to calculate the channel gains for the used data subcarriers. The calculated channel gains are applied to each subcarrier to recover the transmitted data.

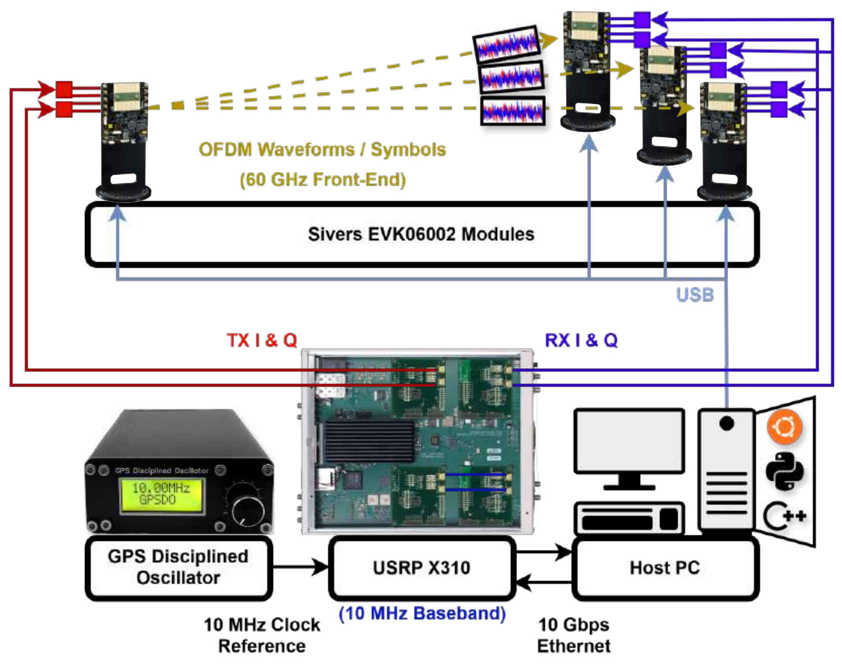

Fig. 1: Hardware setup

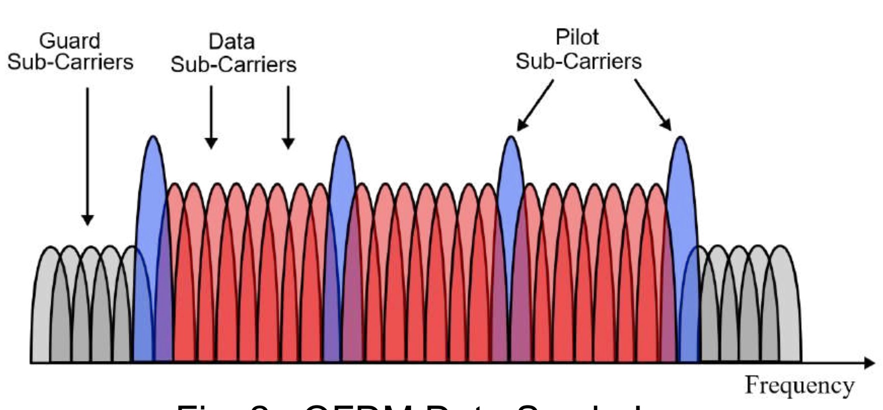

Fig. 2: OFDM Data Symbol

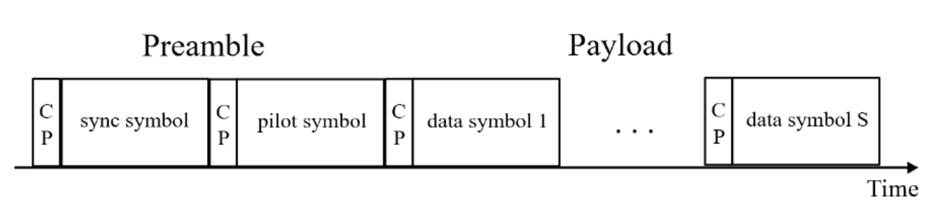

Fig. 3: OFDM Packet

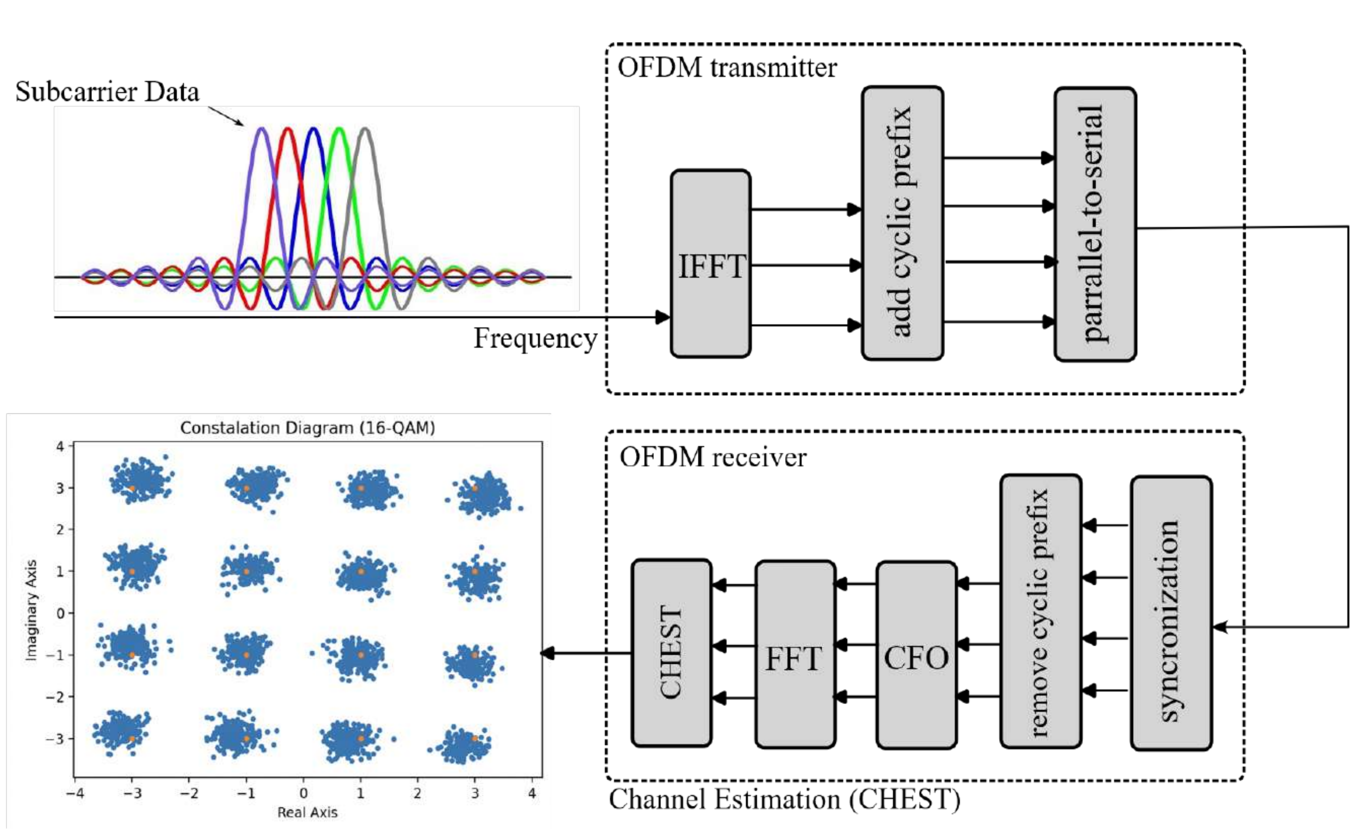

Fig. 4: Flowchart of OFDM Communication

Remaining Technical Challenges

Matched Filter Integration: Transmitted signals arrive at each receiver at different times. A delay can be extracted by computing the correlation between the received signal and a known transmitted reference. While the matched filter has been tested to work, its integration with OFDM, multi-band signals, and wider-band signals remains to be implemented.

Carrier Frequency Offset (CFO) Mitigation: In communication systems, frequency mismatches in TX/RX local oscillators and the Doppler effect shift the received signal in frequency, causing a phase-shift in the received signal. This rotates IQ samples and prevents decoding meaningful data.

Multi-Channel: Scale from single RX operation to multiple RX

2D Localization: Using the delays obtained from the matched filter, calculate distances/angles to enable trilateration, triangulation, or a combination of both.

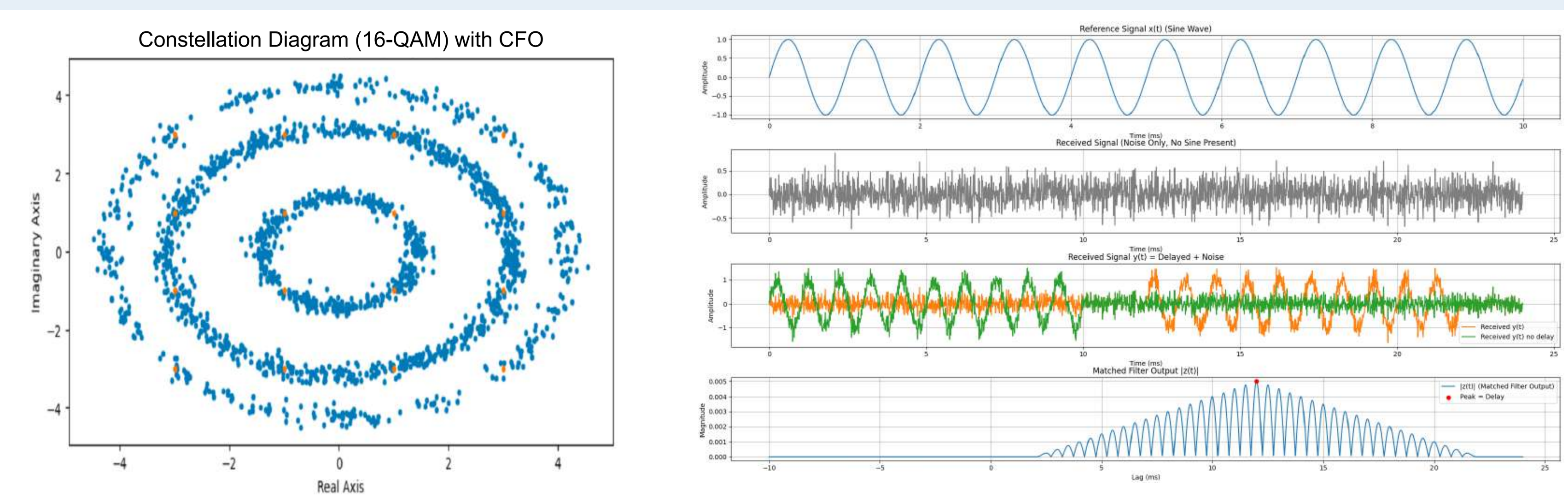

Fig. 5: Example of CFO on received signals; note the rotational property and Matched filter results

Implications for Company & Economic Impact

The infrastructure in place for radar detection and communication share common goals and architectures; both rely on higher sampling rates and operate on beamforming principles. This quality can be taken advantage of with the design of next-generation communication systems that integrate both functions together. The combination of radar and communication within a shared OFDM-based framework can achieve greater bandwidth efficiency while driving down hardware and energy costs. Economically, this would greatly impact home automation, urban environments, industrial processes, and transportation systems by allowing for a scalable sensing system on existing hardware.

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URI CYPHER Center

Real-Time Detection of Man-in-the-Middle Attacks in Industrial Control Systems Using Network Traffic Analysis

CYPHER
Cyber-Physical Intelligence and Security

Team Members: Milan Koshy (CPE), Alejandro Wu (CPE), Ricky DiMare (CPE), Isaac Feldmann (ELE), Jacob Lee (ELE)

Technical Director(s): Dr. Hui Lin, Meem Tasfia Zaman, Jake Nicynski, Zack Notarianni

Project Motivation

Industrial control systems like power grids present a unique cyber-physical infrastructure to collect measurement data and perform control operations to ensure continuous stability. From traditional power systems to recent smart grids, communications networks are critical in sharing information in this domain. Even though they use similar technology to the public Internet, industrial control communications networks serve unique applications, i.e., sharing information related to physical processes and delivering control commands to maintain their stability. The features add new ingredients to infrastructure and network protocols used by smart grids, which malicious actors can leverage to launch cyber attacks that aim to disrupt smart grids' physical processes. Unlike cyber attacks targeting general-purpose computing environments, cyber attacks targeting critical industrial control systems introduce unrecoverable consequences, including power outage, economic losses, and even human casualties.

Anticipated Best Outcome

ABO1: A fully functional ICS including cyber-physical infrastructures. Objective: Enables students to obtain a fundamental understanding of cyber-physical interactions in today's ICSs.

ABO2: A fully functional man-in-the-middle attack through compromising ARP caches in network nodes. Objective: Enables students to grasp the basic knowledge of cyber attacks in communication networks.

ABO3: A fully functional detection module that can detect the implemented man-in-the-middle attacks through network traffic analysis. Objective: Enables students to obtain in-depth knowledge of network traffic analysis, e.g., deep packet inspection.

Key Accomplishments

Socket programming and Network Setup: Implementation of a simulated computer network using 3 Raspberry Pi's connected through a network switch and socket programming in python.
Wireshark: Research into the use and implementation of Wireshark, a tool used to monitor traffic on a computer network. After setting up port forwarding, we were able to detect packets sent between the Raspberry Pi's on our computer network. In addition, we used wireshark to set up and execute mock ARP cache poisoning attacks.
Mininet: Research Mininet to understand network traffic and when and where ARP cache poisoning occurs. Mininet lets us safely simulate a small network to see how ARP cache poisoning works. It allows us to watch how a malicious host sends fake ARP messages that trick other devices into sending traffic to it instead of the real destination. This helps us understand when and why ARP poisoning happens which is usually when devices automatically trust ARP replies.

Construction of example circuit: An example circuit was built using a 3.3k ohm resistor, LED, and a MD-D262 circuit breaker. This circuit is powered by a raspberry pi after establishing the connection to the circuit. This will allow us to code the LED to switch on and off at a certain rate. The following image will display the circuit along with the raspberry pi.
SEL-751A Relay: The manual for the SEL-751A relay was the first step in setting up and configuring it. Next the SEL-751A relay was set up and configured using the acSELerator quickset. The relay is being used as a switch when connected with the example circuit. The relay is being controlled through ethernet connection to a PC from the relay.

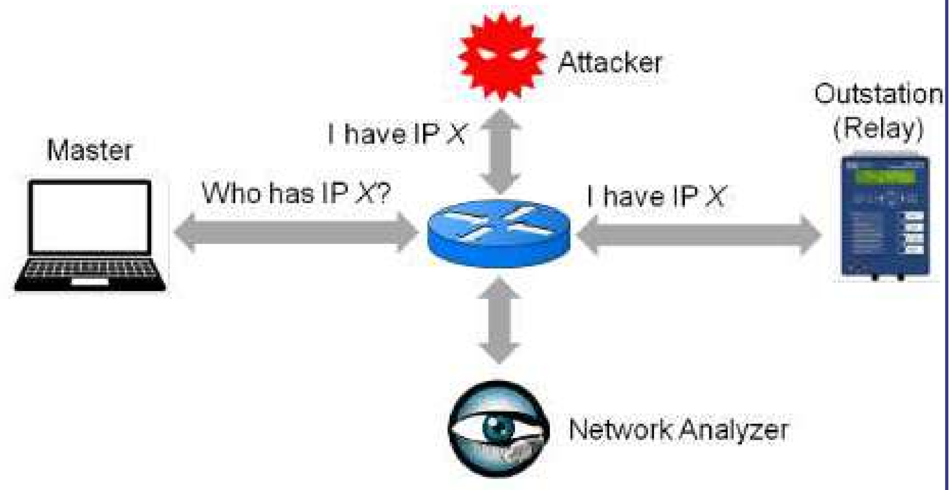
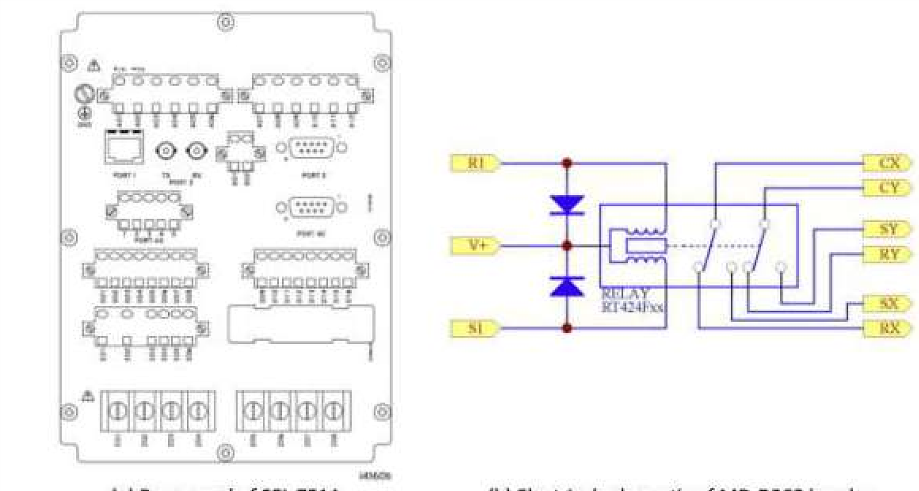
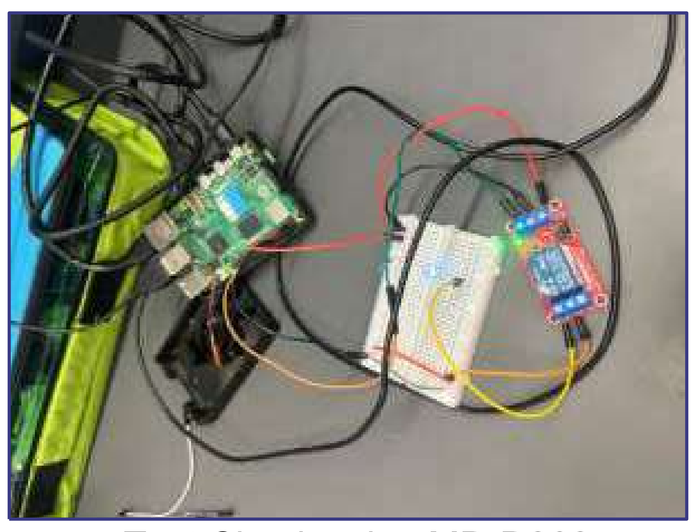
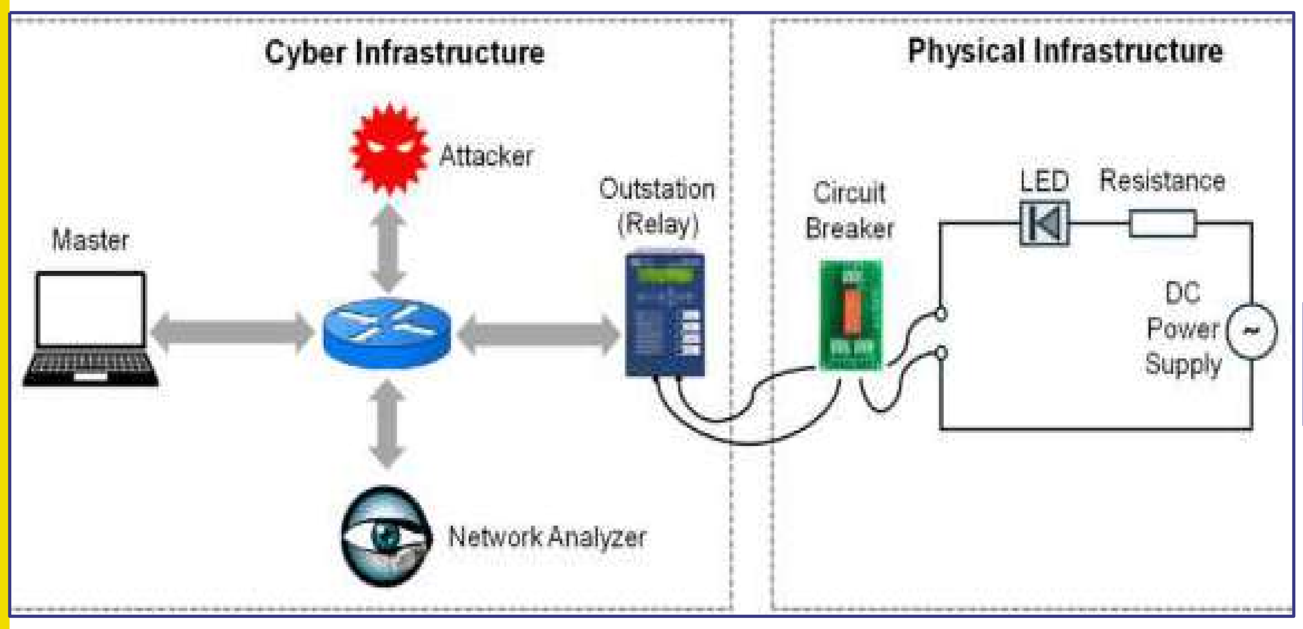


Figure 3. *Block diagram of man-in-the-middle attack*


(a) Rear panel of SEL 751A (b) Electrical schematic of MD-D262 breaker
Figure 4: Example electrical schematic of SEL-751A relay and MD-D262 breaker


Test Circuit using MD-D262



Overall Block Diagram of Project

Remaining Technical Challenges

ABO2: A fully functional man-in-the-middle attack through compromising ARP caches in network nodes.
- We have not yet implemented a man-in-the-middle capability, but significant progress has been made toward it. Over the next semester we will complete a Mininet-based proof-of-concept that demonstrates ARP cache poisoning to redirect traffic between two hosts and validate packet capture and forwarding behavior.

ABO3: A fully functional detection module that can detect the implemented man-in-the-middle attacks through network traffic analysis.
- We plan to develop a detection module that identifies ARP-based man-in-the-middle attacks using network traffic analysis. Implementation and initial testing are scheduled for the next semester and will run concurrently with ABO2.

- Success criteria include:
  - Reliably detecting simulated ARP poisoning event in our testbed
  - Producing alerts with low false-positive rates in controlled runs
  - Providing logs for analysis

Implications for Company & Economic Impact

The nature of the US's aging energy infrastructure has recently come under scrutiny. It has heightened the need to protect our energy grid as it is often the subject of frequent cyber attacks from foreign and domestic entities. The goal of this project is to develop protocols to detect man-in-the-middle attacks through network traffic analysis. The broader research of this topic could help develop and prevent further attacks on industrial control systems such as the power grid.

ElStim

Multi-Channel Electrical Stimulation Circuit for Biomedical Applications

URI InDUS Lab

Team Members: Mckenna Sylvester (ELE), Thomas Vrankar (CPE/ELE), Jarad DeMarco (ELE)

Technical Director: Dhaval Solanki

Project Motivation

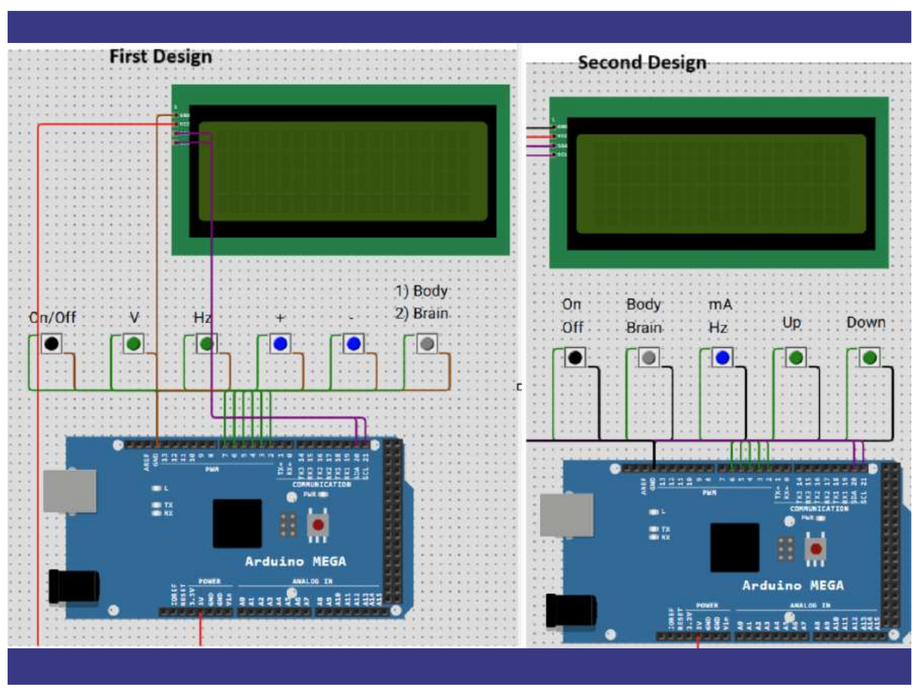
This project strives to develop a portable and low cost electrical stimulation system for biomedical applications such as pain management, rehabilitation, and neurophysiology research. The design integrates programmable stimulation circuitry, a microcontroller-based control unit, and a user-friendly interface with potential biosensing feedback. The overall concept of this project is to create a system that works as a multi-channel electrical stimulation platform, designed to deliver controlled electrical pulses to biological tissue for therapeutic or research applications. This device can be applied to deliver either brain or muscle stimulation, depending on the needs of the patient. The project motivation focuses on developing a compact, cost-effective, and customizable multi-channel electrical stimulation system for biomedical applications. Electrical stimulation is often used to treat conditions like pain, muscle atrophy, and neurological disorders, however current systems are often bulky and expensive. The project aims to create a programmable device that supports personalized and wearable therapies, combining engineering principles with real-world healthcare needs.

Anticipated Best Outcome

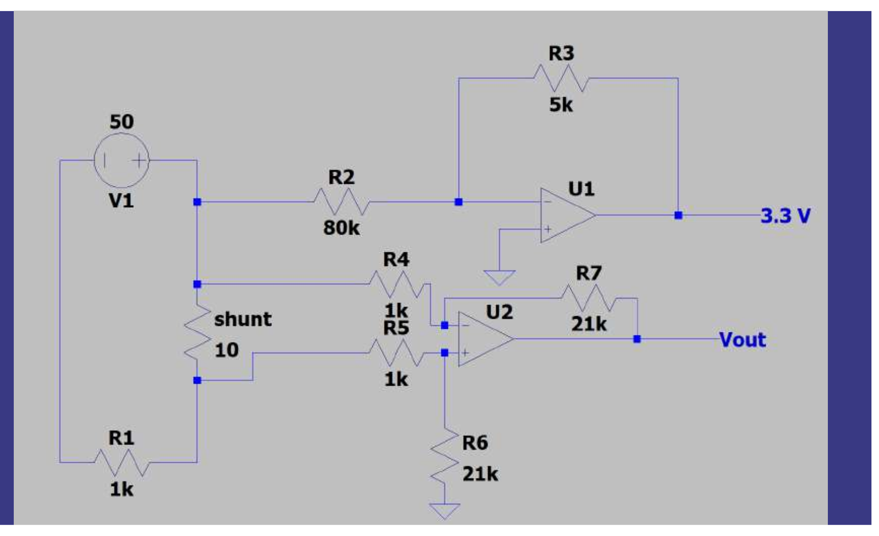
- Fully functional, multi-channel electrical stimulation system
  - Includes safe biphasic stimulator outputs capable of driving loads between 100uA and 100mA
  - Also includes intuitive software interface for configuration and monitoring
  - Operational at selectable frequencies between 100 and 1000Hz in a biphasic signal
  - Include an intelligent control interface and modular design architecture, supported by successful benchtop testing and comprehensive documentation.

Key Accomplishments

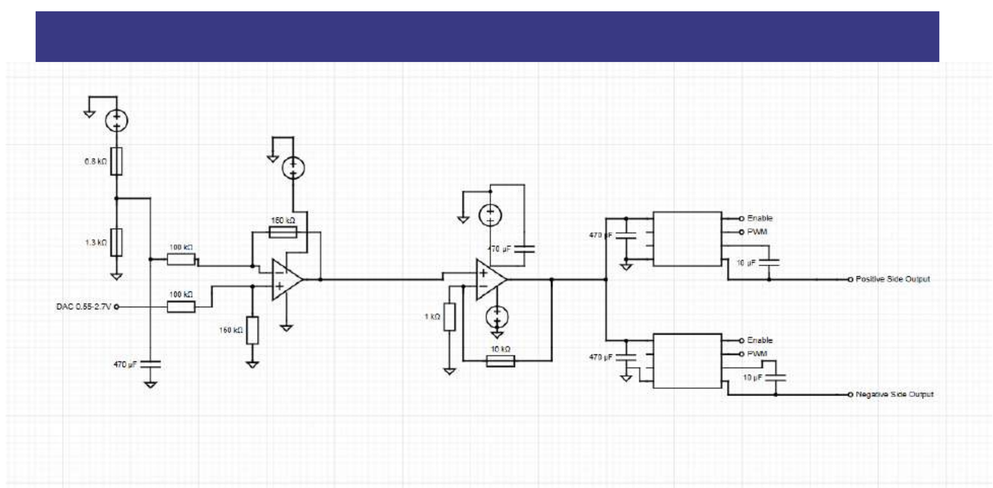
- **Working GUI**
  - The first button on the GUI prompts: 'if this is pressed.' When the user moves to the next button, the code checks the previous choice plus the new one. Each button to the right adds another step, creating a series of checkpoints that follow the user's decisions.
  - First, choose if stimulating the brain or the body. Then change the intensity of the current or frequency of the pulses. For the body or brain mode, the user can make their choice by toggling a button. In the remake version the buttons and code were changed so that both modes are done by toggling.
  - The measurement of current and frequency will display onto the LCD
- **Current and voltage sensor**
  - The current and voltage sensor monitors the current and voltage being outputted, making sure the voltage output is 3.3V and the current drives loads of 100uA and 100mA.
  - The voltage output must be 3.3V to operate the Arduino microcontroller. The voltage source first connects to a high voltage OP Amp (OP454), which outputs 3.3V. However, with this model's pinout, we get a negative voltage, so we have to consider bias. An adding circuit was included on the output of the OP Amp, which will boost the voltage from -3.3 to 3.3V.
  - Below the high voltage OP Amp is a shunt resistance of 10 Ohms and a differential amplifier. The differential amplifier amplifies the voltage. When the voltage is increased, the current also increases.
- **Power Management**
  - Biphasic waveforms are required for adequate stimulation, specifically to avoid over-oxidation of the stimulated tissue. This necessitates the application of positive and negative charges, in this case via an H-Bridge. This method of stimulation, as opposed to the discharge of positive and negative capacitors, is relatively novel but was selected for its wide range of possible waveforms, and for the square wave produced, which contains higher frequency content than standard AC signals.
  - The resistance of skin is not fixed and can vary based on any number of factors, including temperature, activity level, and mood so, a variable current output was required. The part chosen to limit current depends on a feedback resistor between the output and current set pins to turn the output voltage into a current. Since such a wide current range was required, we determined to use an operational amplifier to boost the voltage output of the MCU DAC to a voltage that can be used to control the current set pin by varying voltage, rather than resistance. This will give this project very fine control over the output current.



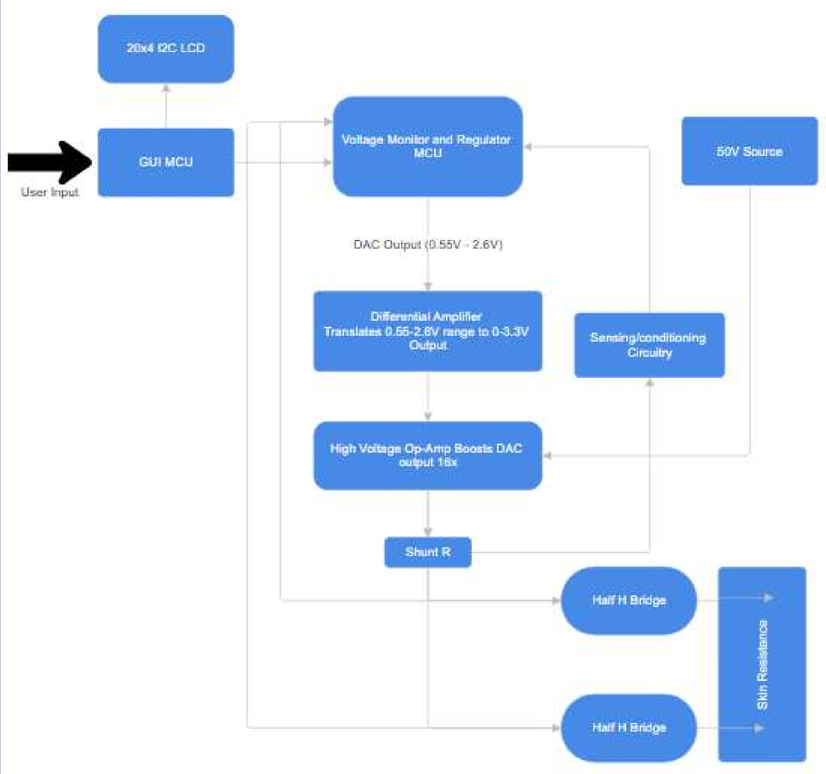
A more intuitive design of the GUI



Schematic illustration referenced when building the current and voltage sensor.



Schematic of power management solution



Block diagram of circuitry

Implications for Company & Economic Impact

The anticipated economic impact involves a valuable impact as a medical research device, facilitating the stimulation of both brain and muscle tissue, allowing researchers to measure and control with precision the frequency and current provided regardless of skin impedance, which was a limitation of previous devices. Additionally, by reducing the cost and size of bioelectronic therapy devices, this project lowers barriers to adoption for clinics, rehabilitation centers, and wearable-tech companies, which are all markets that are often high priced with limited availability. This customizable, modular design also enables rapid adaptation for multiple therapeutic applications, improving market scalability and allowing manufacturers to serve patient populations with a single platform.

Remaining Technical Challenges

- **Finishing the prototype:** As we approach the final couple of weeks until the symposium, we are working on making any final fixes to our circuits before connecting the pieces of the circuits together.
- **Design considerations:** From the GUI point of view there are still design improvements to be made. Before I move forward and change any of the button layout I'm going to take my design to different people and without explaining it to them ask them to show me how they would use the device. After that I will ask them questions about if they can think of an easier way that this could work. The goal is to make it as intuitive and easy to use as possible
- **PCB Layout:** This is the part where it starts to look professional. Once this is done there will be no more bread boards and it will look like a real circuit. It is still a challenge though and making a good working PCB board is a skill in itself. If the final product was done on breadboards it would be very bulky and wires would be everywhere. A PCB board has layers and signals being sent very close to each other. The design will require both circuit analysis skills and skills in understanding the physics behind electrical circuits.
- **Connecting GUI and Circuit:** The interface and circuit working as one unit is a challenge in the near future. Right now the GUI values are just representations of things to come. The circuit is where the real functionality is right now but there is no way to tell it what to do. The MCU on the circuit side will need to talk to the MCU on the GUI side. This means that the code controlling the circuit must ask questions and the answer to those questions are the values that the user is entering with the button presses.

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URI Power Electronics Laboratory

Innovative Design Automation Framework for integrated Power Building Blocks (iPEBB)

Team Members: Marc Delgado (ELE), Daeven Goel (ELE), Nicholas Rossi (ELE), Maximus Matarese (CPE)

URI PEL
University of Rhode Island Power Electronics Lab

Technical Director(s):Dr. Yeonho Jeong, Xueshen Zhang, Fuwei Li, & Sooan Park

Project Motivation

Modern Power Conversion Systems (PCSs) are essential for efficiently delivering energy for electronic applications. However, their design process remains complex, time-consuming and require multiple iterations. To overcome long design process and development cycles of traditional PCS, the project aims to implement the integrated Power Electronics Building Block (iPEBB) framework. The iPEBB framework offers a scalable solution to unmanned aerial vehicle (UAV) applications that can meet diverse power requirements. Consequently, the benefits extend into the manufacturing field by accelerating the production of PCSs.

Anticipated Best Outcome

This project aims to develop two fully functional PCS designed for two different drone applications: 6-S hexacopter and 4-S quadcopter. The initial stage involves the design, implementation, and testing of a single iPEBB, capable of meeting the electrical requirements of a 2-S configuration . After successful evaluation, multiple iPEBBs will be integrated and tested to achieve the power rating of each drone, and ultimately assembled into the two drone platforms for final demonstration.

Key Accomplishments

1. **Converter Topology Selection (LLC Resonant and Flyback Converter)**
   a. **Flyback Converter Analysis**
      i. Flyback converter was tested in Continuous and Discontinuous Conduction Modes (CCM/DCM)
      ii. Switching waveforms matched theoretical analysis, confirming efficiency and voltage gain predictions
   b. **LLC Resonant Converter Analysis**
      i. Half-Bridge LLC presents higher conduction losses on the primary side compared to the Full-Bridge LLC Resonant
      ii. Current waveforms matched expectations, and achieved Zero-Voltage Switching (ZVS) by operating in the inductive region
   c. **Analysis in PLECS and PowerSIM simulation tools**
      i. Simulations confirmed stable output under light and heavy loads, and validated our theoretical calculations
      ii. Selected **LLC Resonant Converter** due to achieving higher efficiency and soft-switching operation.
2. **Hardware Design and Testing**
   a. **Custom Transformer: LLC Resonant Converter**
      i. Selected **ferrite core** (PQ 32/30-3C90) and winding wire **12 AWG Litz wire**
      ii. Inductance of transformer deviated slightly from our initial theoretical calculations
   b. **Operation: LLC Resonant Converter**
      i. Resonant Tank operation below resonance was verified for light loads and shown in Fig.4.
3. **Controller Development and System Integration**
   a. TI LaunchPad was utilized to create an open-loop PWM signal to successfully drive Full-Bridge square-wave generator

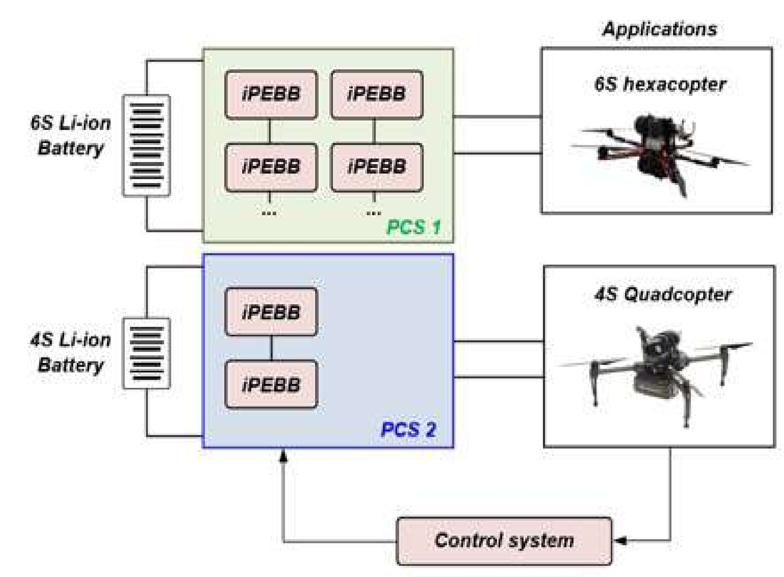

Fig.1: Block Diagram for Multiple Integrated iPEBBs

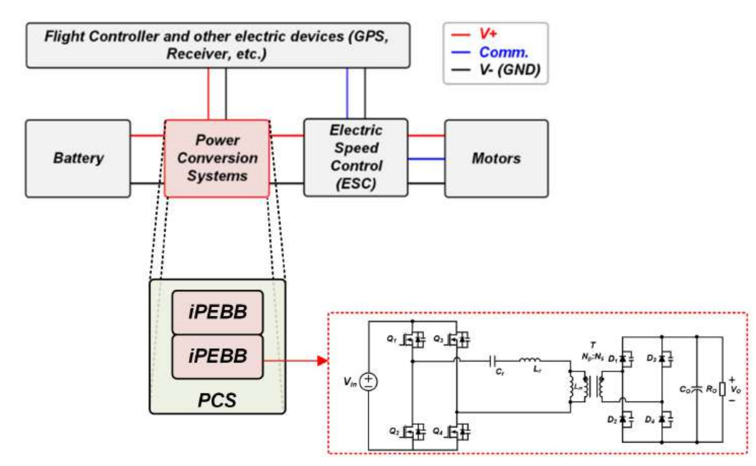

Fig.2: Block Diagram for Drone Applications

Fig.3: Quadcopter and Hexacopter for iPEBB Applications

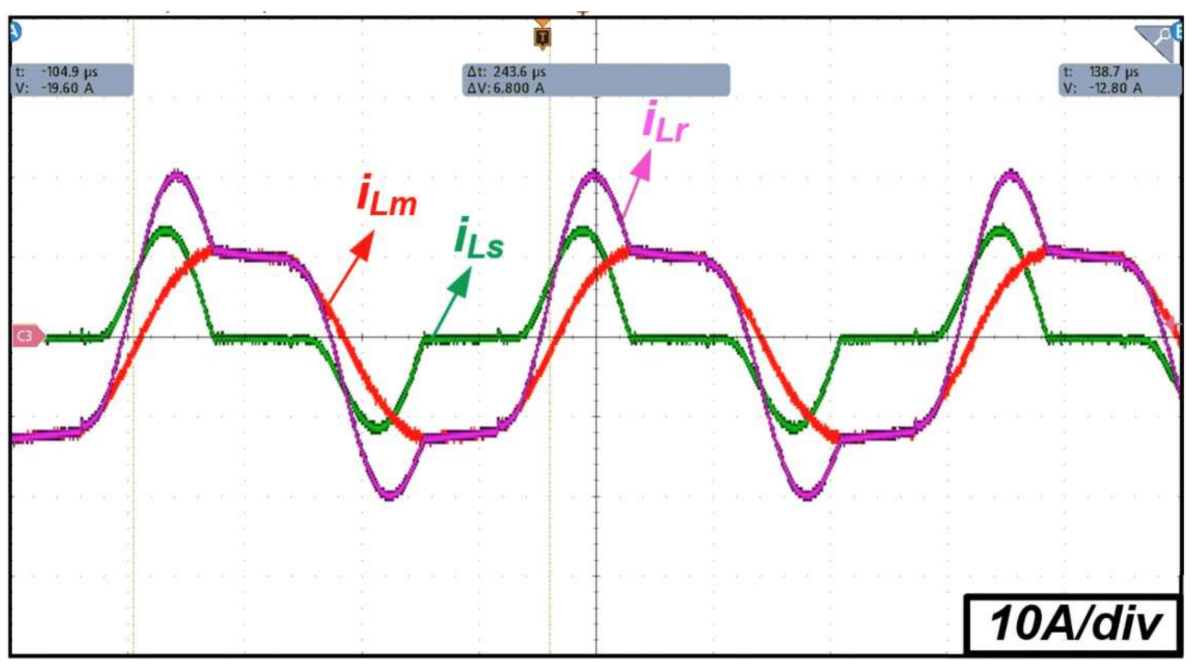

Fig.4: LLC Resonant Converter operation below resonance

Implications for Company & Economic Impact

The iPEBB concept offers major benefits for the power electronics industry by **reducing design time, manufacturing costs, and system complexity.** Standardizing modular building blocks allows a single converter design to be integrated and reused across various applications, decreasing time-consuming development cycles. Achieving high power density and improved thermal performance of the iPEBB leads to greater energy efficiency and reliability, along with key factors in UAV and defense systems. For URI PEL, this framework strengthens its research capabilities and while providing scalable, cost-effective solutions that can be adapted to future efforts across automotive, industrial sectors and consumer applications.

Remaining Technical Challenges

1. **Hardware Implementation and Testing of a Single iPEBB Unit**
   a. Optimize component selection to further decreases losses and increase efficiency
   b. Optimization of LLC Resonant Tank to verify operation and gain under heavy loads
   c. PCB must be designed to handle **30 A RMS** while minimizing stray inductance
2. **Closed-Loop Control Design and Implementation**
   a. Design, develop and test closed-loop system with single iPEBB
   b. Test closed-loop control system with multiple integrated iPEBBs
3. **Integration of Multiple iPEBB Units**
   a. After single iPEBB functions correctly, multiple units will be integrated as seen in Fig.1
   b. Integration introduces multiple challenges such as current balancing, the synchronization of switching signals and the communication between controllers
4. **Thermal Management and Protection Circuits**
   a. iPEBBs must include protection features: over-voltage, over-current, and short-circuit protection
   b. Proper cooling method will be necessary to prevent overheating
5. **Simulation-to-Hardware Verification and Drone Integration**
   a. Integrate multiple iPEBBs modules to create PCS units for each drones in Fig.3
   b. Verify expected power delivery from each PCS during flight simulations as seen in Fig.2

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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: Joseph Rose (CPE), Jack Petrarca (ELE), Gage Testa (ELE), Cade Birrell (ELE)

Technical Director(s): Dr. Paolo Stegagno, Cameron Amaral

Project Motivation

Exposure to computer science at a young age can promote social equity by increasing representation and access to technology careers. Developing programming skills early can open pathways to well-paying jobs, helping provide long-term financial stability for marginalized groups that have historically lacked such opportunities. Greater participation from under-represented communities also enhances diversity in computing and helps expand the overall STEM workforce. The ICRobots Lab is partnering with the URI College of Engineering to deliver robotics-focused STEM programs to Rhode Island's most diverse K–12 schools. However, tools designed for teaching programming and robotics in early education (K–5) remain limited. Young students are still developing basic reading and math skills, which makes traditional programming—even in graphical form—difficult, especially when it relies on computers, mice, and keyboards. These tools also lack the hands-on, manipulative experiences essential in early childhood. Creating new robotics platforms tailored for early learners will help bring high-quality STEM education to the communities that need it most.

Anticipated Best Outcome

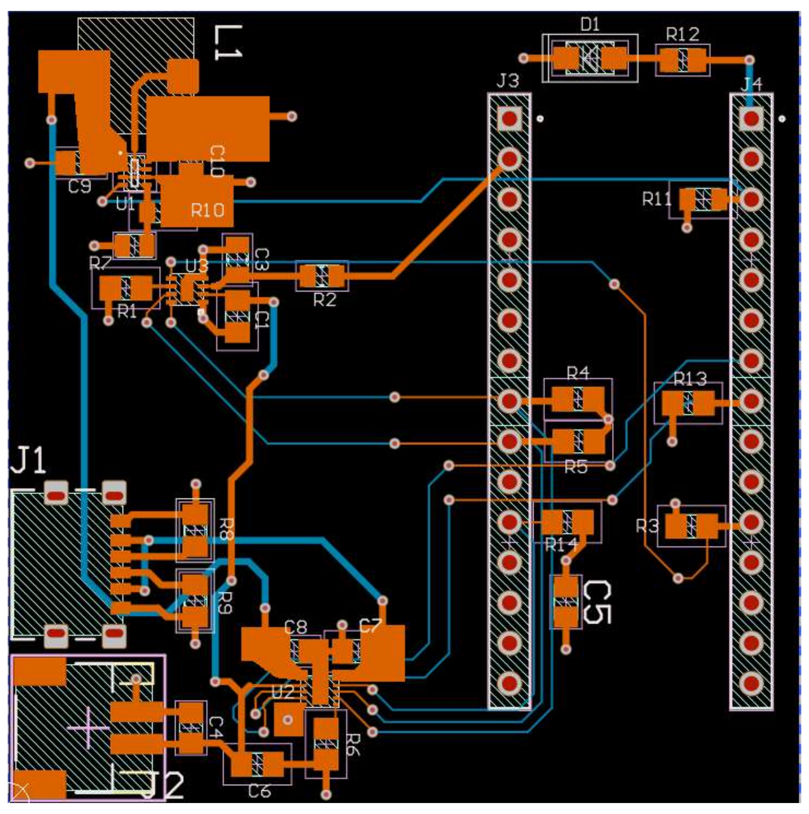
The Anticipated Best Outcome (ABO) of this project is a fully functional single-board prototype that integrates the Arduino, motor driver, and input buttons. The board must fit inside the robot's body, read 12 rows of 8 buttons, two IR sensors, and a microphone, while also driving motors and producing sound. Powered by a Li-Ion battery, the robot will read a sequence of 12 blocks representing code lines, with up to 16 visually distinct commands, including movement, sound, loops, and conditionals. Additional features include obstacle warnings and sound-based reactions. Firmware will follow a Finite State Machine structure for reliability and debugging.

Key Accomplishments

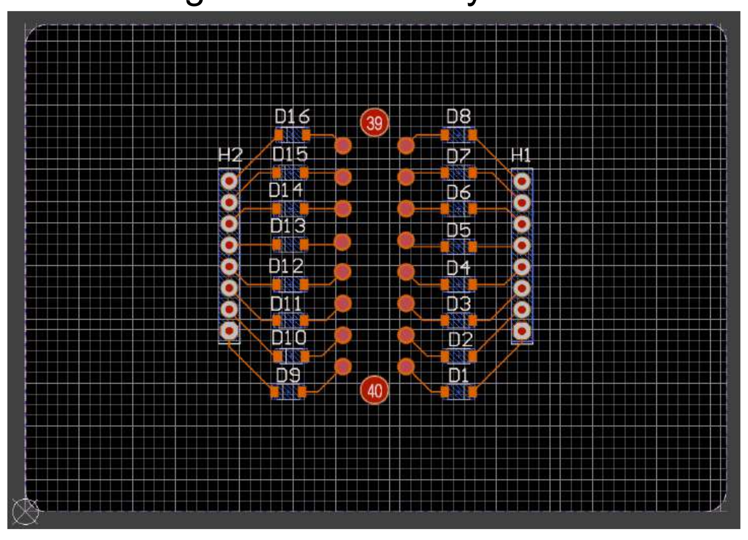
Li-Ion Battery Charger:
The PCB design has been completed and is in the process of being put together. As of now the board almost completely assembled however there was one hiccup with the soldering process and further work needs to be done to rectify the issue. More parts are in order for a complete rebuild if necessary. We expect a fully functional assembly for our showcase.

Button Matrix and Pogo Pin Matrix:
Both the button and pogo pin and button matrix have their phase 1 designs completed and are having them fabricated by the URI 3D printing lab for fast turnaround and testing. As of 11/15/25 the boards are being printed and should complete within the week to allow for a demo at the URI symposium.

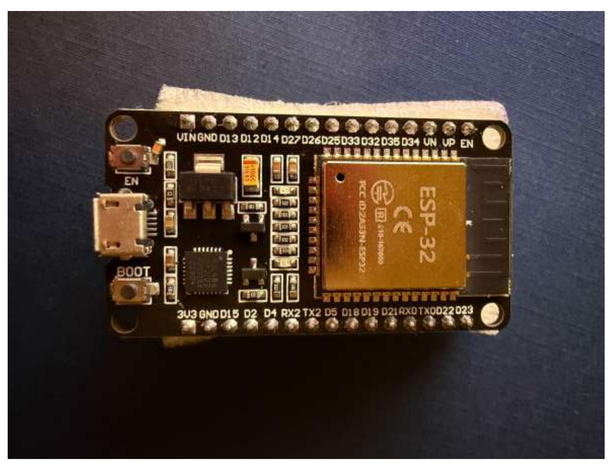
Programming and Selection of RoboToy Microcontroller:
Throughout the first semester of work on Robo-Toy there was a lot of deliberation on the best microcontroller to use for the project. At first we were going to use an arduino nano and realized that will not allow us to run tasks in parallel, so we opted to add another arduino to create a dual processor. However XMOS had provided a microcontroller capable of task parallelisation to our capstone director. We attempted to work with that part since it would perform the duties we would need, however there was not enough documentation about it so we decided to move on with our final option which we have settled on. We have decided to run an ESP32 since it is a dual core microcontroller with plenty of documentation and happens to be cheaper and more capable then our dual arduino idea.



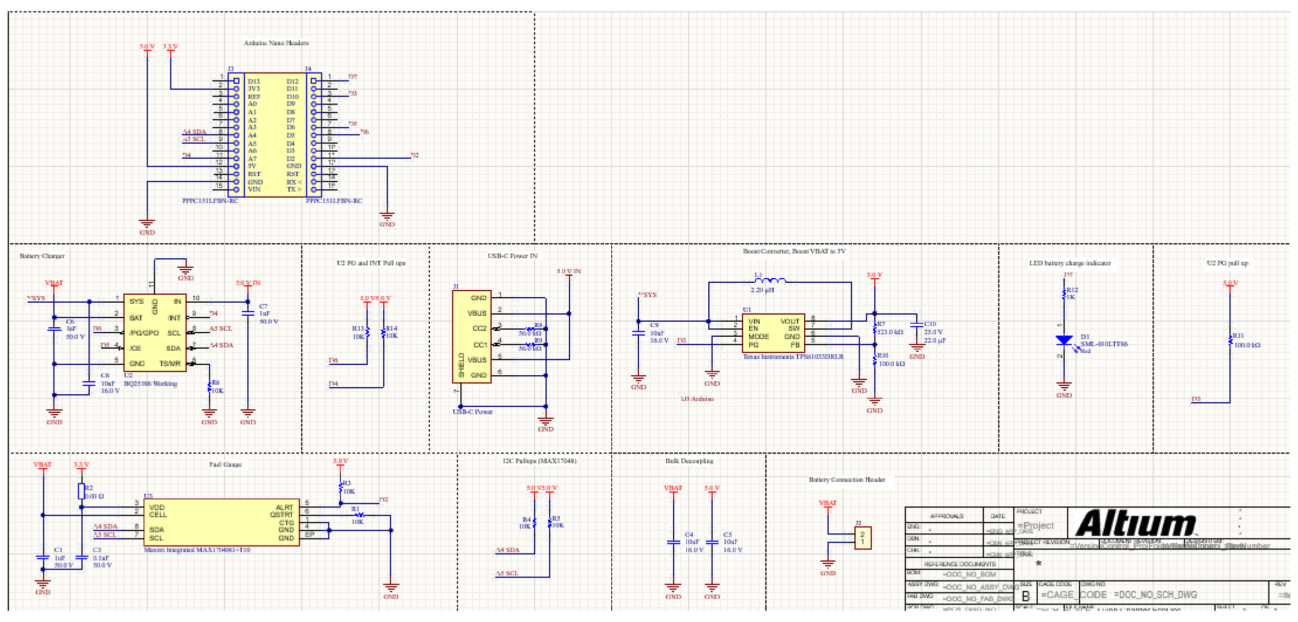
Routing of Li-Ion Battery Schematic



Pogo-Pin Routing



ESP-32



Li- Ion Battery Charger Schematic

Implications for Company & Economic Impact

The developed robotic kit will serve as a prototype for a final product that will be produced and delivered to Rhode Island schools. Achieving the ABO will assist the ICRobots lab in its mission to bring robotics, programming and STEM to the communities that need it the most. By doing so, the ICRobots lab will be able to inspire a generation of Rhode Island students, establishing itself as the center of robotics in Rhode Island. In the long term, this will attract a diverse population of high-quality local students to the ICRobots lab.

Remaining Technical Challenges

Li-Ion Battery Charger:
We have faced challenges regarding the placement of our PCB components, such issues are that our battery charging IC had a short across some of the outer pins reducing the functionality of the component. This was caused due to the nature of the part we are working with, the part was a QFN IC which means the pins were underneath the part and hard to access. Although this is not ideal, the current shorts will still allow us to use the battery charger but lose out on some functionality such as being able to program the charging to be on or off. In its current state it will always be charging the
battery. During our attempts to fix the IC we had temperature cycled the part quite a bit which could have damaged it. We will be testing the design the following week and if it does not work we will replace the part to start and if that does not work we will then create a new board from our backup parts.

Button Matrix and Pogo Pin Matrix:
No significant challenges have inhibited our progress on these parts. We just had to do some research to determine the printing capabilities of the 3D printing labs PCB printers. Once all required information was gathered we continued production and are currently working printing the PCBs for testing.

Programming and Selection of RoboToy Microcontroller:
As mentioned above there were some challenges around finding the best microcontroller option. No real problems have occurred, just slow downs due to the nature of having to learn the different microcontroller capabilities and programming languages. We now have a good understanding of all of our options and are prepared to move forward with no further implications.

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Prober Error Tracking & Evaluation

Web tool to display error frequency and messages associated with in-house hardware.

VICOR

Team Members: Robbie Stevens (CPE), Evan O'Neill (ELE)

Technical Director(s): Alfred Binder, Liam Crisfield

Project Motivation

Vicor utilizes a variety of equipment to electrically test die on their silicon wafers that will be used in their assembled parts. One of these pieces of equipment that are used is called a prober. The probers are designed to test multiple wafers and run tests on all the die contained in each wafer. The process is extremely time consuming, and can run both overnight and into the weekend. Because of this, one problem that occurs is that the probers can encounter errors that will pause the testing process. The process will remain halted until an operator can fix it. To tackle this problem, Vicor wants to know how often the probers stop during the testing process, and why the test had to be halted. With the information gathered from tracking the probers, Vicor will be able to accurately schedule maintenance for faulty equipment, and allocate personnel efficiently based on the data collected by the tool.

Anticipated Best Outcome

The Anticipated Best Outcome for this project is to research, design, and implement a fully functioning system that collects and displays information about these prober errors. The system will include collecting data recorded by the probers, data processing to organize and calculate the data as needed, database management to organize and store the data in an easily accessible way, and data access for users to be able interact with the data directly. When the system becomes fully operational, then data driven decisions can be made.

Key Accomplishments

Extraction of Key Files & Information: Each prober outputs three types of files: event, error and profile logs. By extracting and understanding the files being output by the prober, we were able to make critical decisions in our scripting to determining what points we will be able to show on our web tool, based on the display messages.

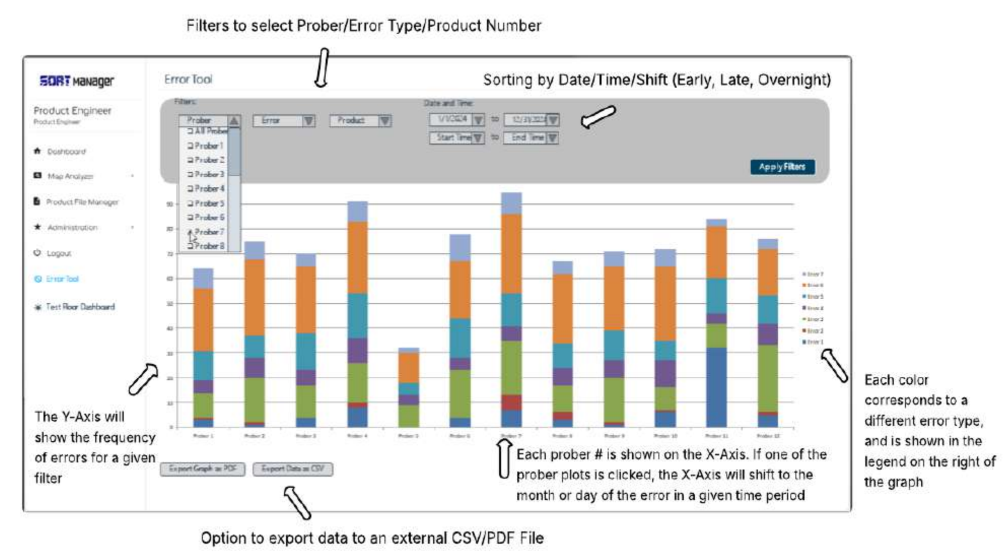
Parsing, Organizing & Storing Data Points: Intensive modular scripting developed by the team allowed us to sort through the logs being output by the probers, and extract key data points about each process that is being run at any given time. This approach allowed us to have short scripts with key components and documentation to support the data we are extracting, and output them into easily readable files for our developers, and further software integration.

Correlation of Event & Error Logs: Across two of the logs, event and error, there are many instances where an event and error occurred in unison, and one message could explain when and why the other happened. By combining the results of correlated events and errors into one data point, our tool will be able to display this critical information to troubleshooters who can work efficiently to rectify the machine.

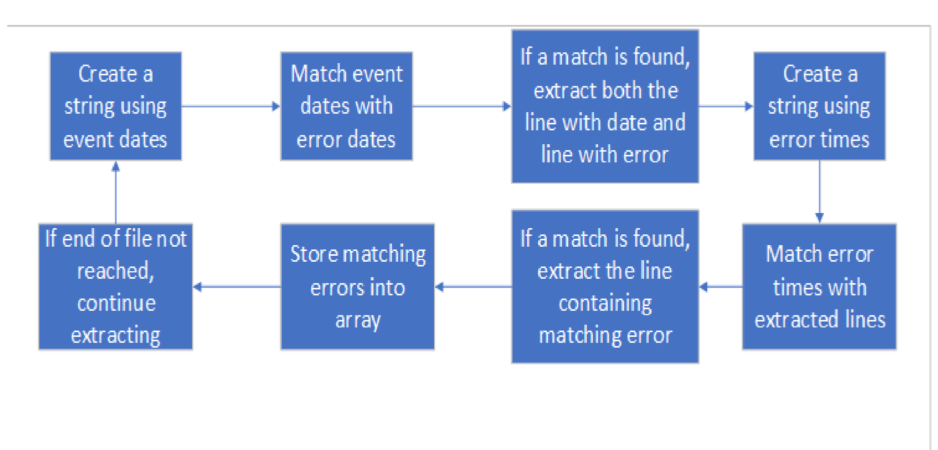
Prober Downtime Calculations: When a prober stops running a process for a long period of time, it causes immense delays in the testing process run by VICOR. By implementing a script to show patterns and causes of these downtimes, it will be easier to schedule personnel at certain stages of the process to reduce these instances.

Web Tool Development & Research: To meet the requirements in our ABO, it was essential to conduct intensive research on an API that will query the database, and display accurate and descriptive results to users who use our web interface to gain accurate knowledge of possible errors.

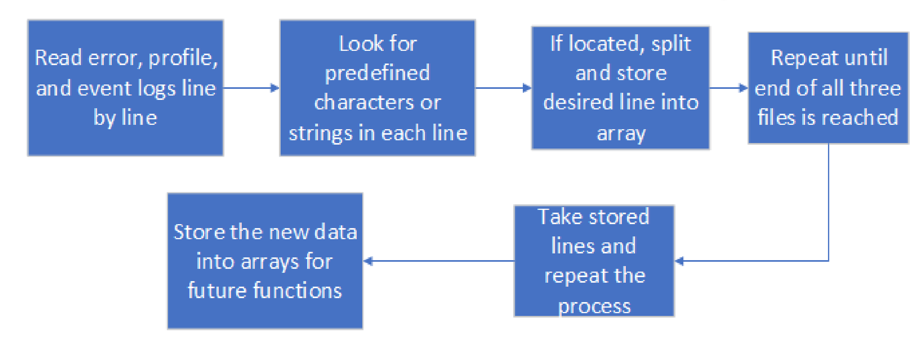
Database Schema Development: All of the data that is collected by the logs must be stored into a well organized database in order for our web tool to perform queries to display the information. The intensive database schema collects all of the relevant information for our web tool, which readily displays important data points.



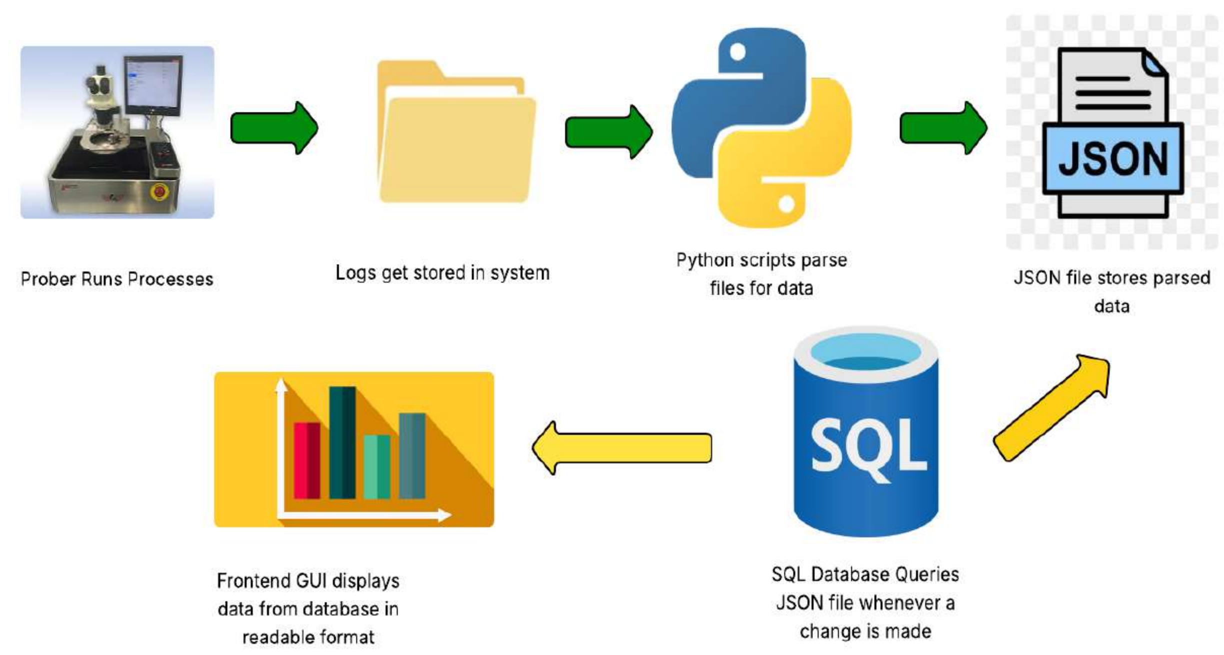
Anticipated View of the Frontend Tool



Error Correlation Functionality



Data Extraction Functionality



Overview of Key Project Components & Workflow

Remaining Technical Challenges

Implementing a Database: With the data we extracted from the prober files, we want to be able to store the normalized data into an extensive database to make data points readable and easily accessible for anyone trying to utilize them . The database should be able to store all the required fields extracted from the probers, and store it in an organized fashion, while also being easily accessible by any program.

Graphical Representation of Data: In addition to our database, we also need to create graphs that represent the trend of the data throughout the duration of the prober's running time. The graphs are meant to show specific trends that are recorded by the probers and extracted by our script. One example of this data is to show what kind of errors were recorded during the days written in the log files, and which probers experienced these errors.

Web Tool Implementation: Once the database is implemented, we also want to implement a web tool that allows users to interact with the database and generate graphs based on which data type they want to utilize. The web tool allows the user to specify which data they want to view. One example of this is to allow the user to specify what range in time they want to view. The user specifies the start and end time, and the web tool then displays the data from that range. This can include which events occurred during this time frame, what errors

Implications for Company & Economic Impact

If the Anticipated Best Outcome is reached, the implemented system will allow Vicor to test their parts more efficiently and can gain a better understanding of when certain errors occur and how the company can react to them. Using this system will also allow Vicor to track utilization, increase throughput while testing, and provide direction on repairs. Additionally, this system could be used in identifying any potential off-shift personnel hiring.

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TUESDAY, DECEMBER 16, 2025

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RMA/FSI Resource

RMA/FSI WORK INSTRUCTIONS

Team Members: Denilo Semedo (ELE), Benjamin Blechmen (ELE)

Technical Director: David Paul, Liam Crisfield(CTD)

Project Motivation

Vicor's customers require failure analysis labs to examine excursion and outlier failing modules and components identified through Returned Material Authorization (RMA). These items undergo submission validation and may need Fail Site Isolation (FSI) before destructive processing to expose physical failure characteristics and determine corrective actions. This process varies based on failure types and product designs. As Design Engineering standardizes solutions, improved Failure Analysis success rates and reduced cycle times would enhance customer confidence in product quality and control.

This project focuses on developing a prototype curve trace solution for a controller in a cut-in module. The goal is to create and verify two work instructions for product ramp-up, ensuring RMA modules with new P07X and P08X integrated circuits can be: (1) validated through ATE and Unpowered Curve Trace Testing using Robson Technologies Inc., and (2) processed through Fail Site Isolation with Functional Bench Testing.

Anticipated Best Outcome

1. Develop clear **work instructions** for Electrical Analysis and Fail Site Isolation (FSI) of RMA failures.
2. Document procedures to preserve module packaging during **curve trace** and **ATE validation**, in collaboration with Test Engineering.
3. Include **backside bench techniques** for FSI and coordinate with Design Engineering on **failure-excitation methods** (thermal cameras, Scanning Optical Microscopy, programmed test modes).

Key Accomplishments

Electrical Analysis Research

- Completed in-depth study of electrical characterization methods used in semiconductor FA, including curve tracing, IV sweeps, and leakage/breakdown detection.
- Mapped abnormal electrical signatures to likely defect mechanisms and their role in Fail Site Isolation (FSI).

ATE Validation Process Review

- Analyzed Automated Test Equipment (ATE) validation flows, parametric limits, and correlation procedures.
- Established understanding of how electrical failures are screened, categorized, and routed toward RMA and FA.

Backside Fault Localization Methods

- Researched backside analytical approaches such as silicon thinning, IR techniques, and laser-based excitation.
- Identified scenarios where backside access improves localization of buried or inaccessible defects.

Documentation Standards

- Reviewed internal documentation expectations, including revision control, formatting, and work instruction structure.
- Ensured future deliverables align with professional engineering standards.

FSI Tools & Fault Localization Techniques

- Studied operational principles and best-use cases for tools such as SOM, Thermal Imaging, and Emission Microscopy.
- Compared contrast mechanisms and excitation strategies to determine ideal methods for specific failure signatures.

Hardware Development

- Selected and validated appropriate pogo pins for test reliability.
- Designed and developed a custom daughter board to support FA and FSI testing.

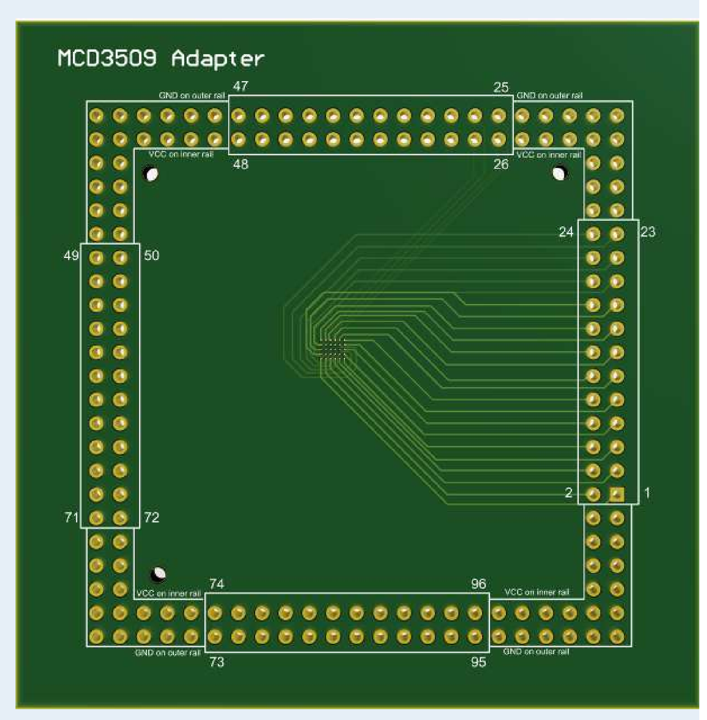

Figure 1: Designed Daughter Board

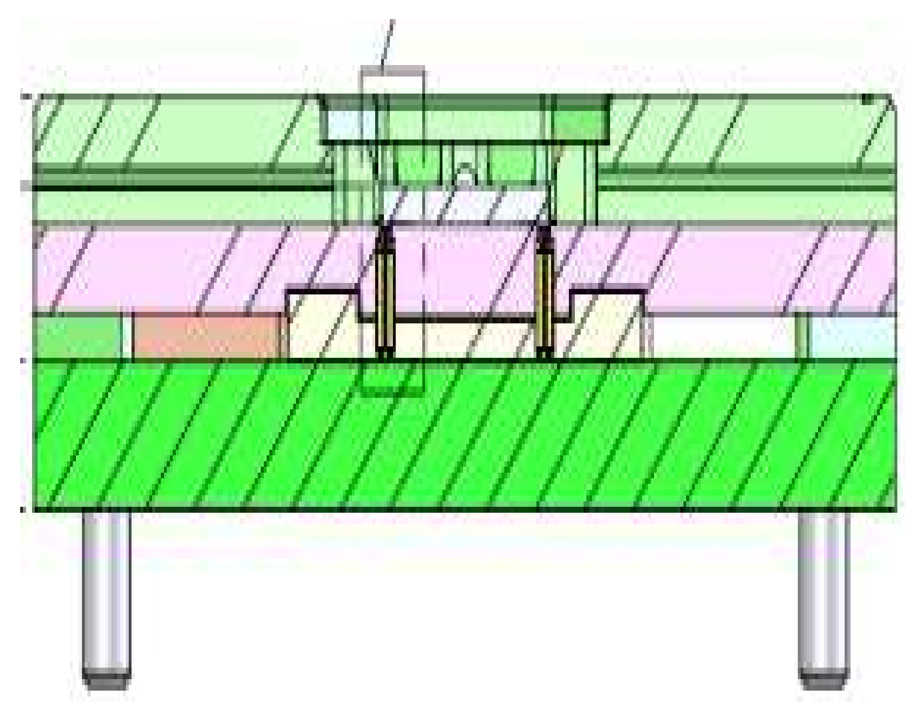
Figure 2: PCB and probe stackup

Figure 3: Multitrace machine

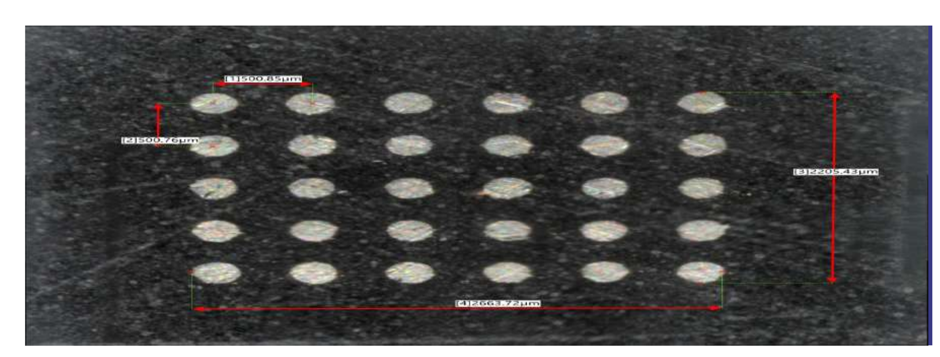
Figure 4: Array measurements of a module

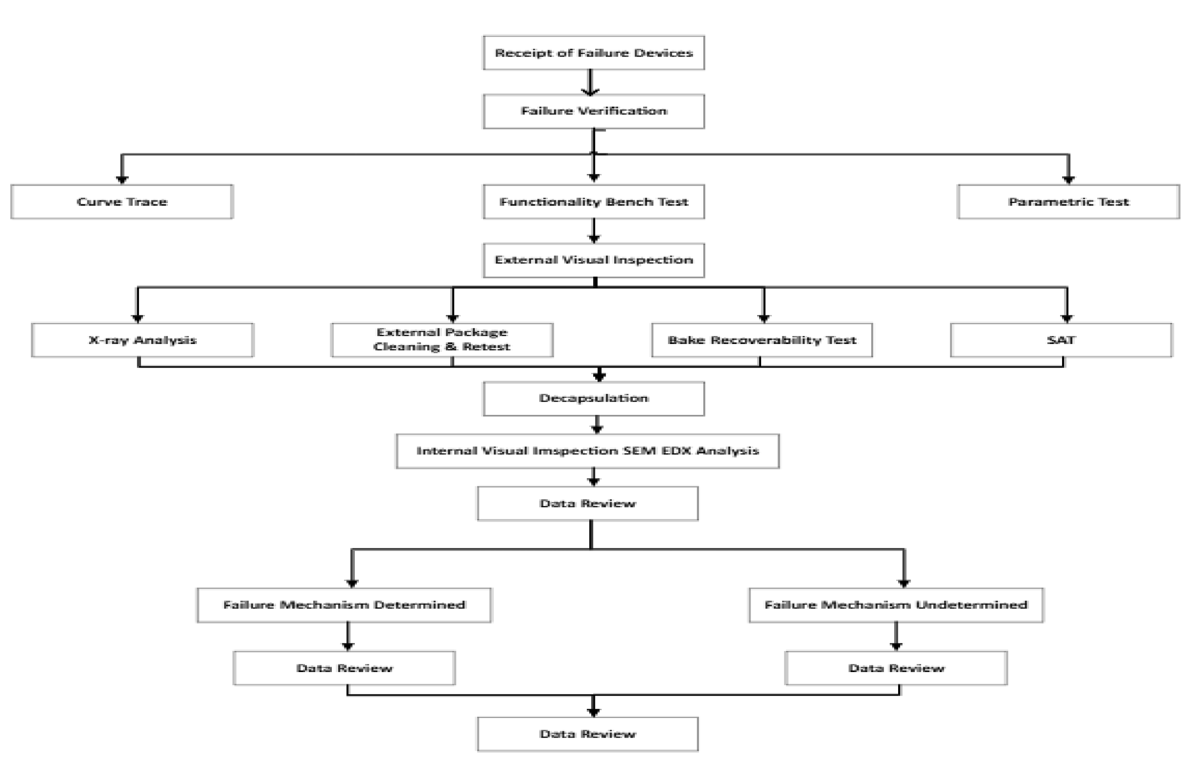

Figure 5: Flow Chart of the FA process

Remaining Technical Challenges

Apply Electrical Analysis to Physical RMA Units

- Perform curve tracing, IV characterization, and ATE signature review directly on returned devices.
- Validate theoretical understanding through controlled testing, repeatability checks, and interpretation of anomalous electrical signatures.

Develop a Structured FSI Decision Framework

- Create a formal process linking specific electrical behaviors to appropriate FSI techniques.
- Optimize analysis efficiency by reducing unnecessary sample preparation and selecting the correct localization method early.

Gain Hands-On Operation of Advanced FSI Tools

- Acquire practical experience with SOM, thermal imaging, and emission microscopy systems.
- Learn calibration, parameter optimization, sample preparation, and noise-reduction methods to ensure reliable defect localization.

Correlate Electrical Signatures with Physical Defect Sites

- Establish a systematic approach for aligning ATE anomalies and curve-trace deviations with thermal, optical, or emission-based signals.
- Develop precise cross-referencing techniques to account for multilayer semiconductor structures and buried defect locations.

Complete Formal Documentation & Work Instructions

- Produce comprehensive, traceable documentation for all RMA cases.
- Create clear work instructions, organize measurement data logically, define revision histories, and ensure compliance with internal documentation standards.

Implications for Company & Economic Impact

Achieving this ABO will enable Vicor to better understand and contain yield failures during production ramp, reducing RMA quantity and cycle time through improved failure analysis. The project will provide guidance on validation, curve trace, and FSI setups while anticipating needs for specialized boards and sockets to reduce cycle time.

It will help identify failures obscured by destructive processing and pinpoint ATE screening requirements for critical production issues. Work instructions for failure validation and FSI will accelerate containment screen development, increase yields, and enhance customer satisfaction with semiconductor products. Training engineers to foresee problems and demand root cause analysis will foster a culture of excellence and quality.

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VoltServer: CLEAR

LED Sequential Communication Protocol Application

VOLTSERVER® DIGITAL ELECTRICITY®

Team Members: Joshua Pereira (CPE), Ryan Tattrie (ELE)

Technical Director(s): Camilo Giraldo, Chris Rothwell(CTD)

Project Motivation

The status codes for each VoltServer device are different but follow the same general style of light-blinking sequences. Currently, VoltServer engineers must manually decipher these codes, which involves looking them up and watching the sequence repeat multiple times. This process is inefficient, slows down troubleshooting, and can be troublesome for both engineers and technicians working in the field. As VoltServer systems expand, relying on manual interpretation becomes even less practical. The VoltServer Clear project aims to address this issue by developing a cross-platform application capable of recording and automatically decoding these blink patterns through a mobile device's camera. By streamlining interpretation and reducing dependence on documentation, the application can significantly improve diagnostic speed and accuracy. In addition, because the codes will be scanned digitally, there is an opportunity to embed real data within high-frequency LED blinks, expanding the usefulness of existing status indicators and enabling more robust device communication.

Anticipated Best Outcome

The Anticipated Best Outcome for the VoltServer Clear project is a proof-of-concept cell phone application that can use the camera to scan blinking LEDs on a VoltServer device and determine what the LED code is telling the user. There will also be a blink code test board with embedded microprocessors, sensors, and LEDs that will be used to simulate the LED codes. The best outcome consists of both the cellphone application and the blink code test board working together to demonstrate the feasibility of embedding data through the LEDs

Key Accomplishments

OpenCV Provisional Script:

To process LED blink patterns, the team used OpenCV for its reliable video analysis capabilities. A Python prototype was developed to detect red LEDs in live or recorded footage by applying a color mask and generating a binary array representing each frame's detection state **(Fig. 1)**. Using the video's FPS metadata, the script converts detected subsequences into precise time intervals. A secondary version also supports pre recorded video files, with all results output to the terminal.

Flutter Camera Application and Firebase Pipeline:

During development, we evaluated several Flutter camera packages and selected the video_player library for its stability, ease of integration, and strong community support. Using this library, we built a prototype app **(Fig. 2)** that allows users to record a video or select one from their device's media library. Once a video is selected, it's uploaded to Firebase Cloud Storage. This triggers Eventarc, which notifies our containerized Flask service running on Cloud Run to perform the OpenCV processing. After extracting the data, the service uploads the results to Google Cloud Realtime Database for the Flutter app to use.

PCB Test Board Schematic and Layout:

During the design process of the schematic, we researched various parts that accomplished the tasks we needed the board to accomplish. We had to switch out the microcontroller near the end of the design process to alleviate the need of having a bluetooth connection with the app to control what tests are being blinked. That was the only obstacle we faced pending any size issues with certain components such as resistors and capacitors, but initial looks at the sizes seem to point towards everything working as intended. We were able to review the final design schematic **(Fig. 3)** and move on to the next step. We then were able to create the layout for the PCB **(Fig. 4)**

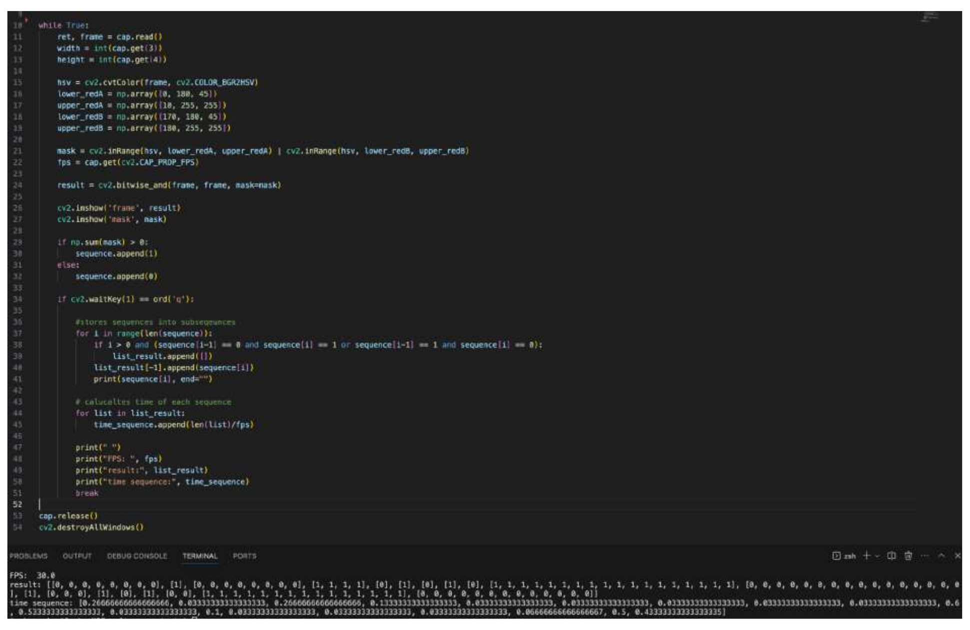

Fig. 1: The OpenCV Color Detection Program and Example Output

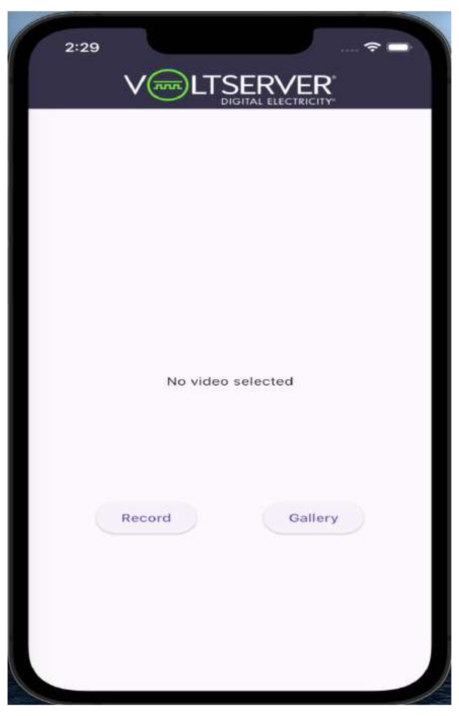

Fig. 2: The Flutter App UI

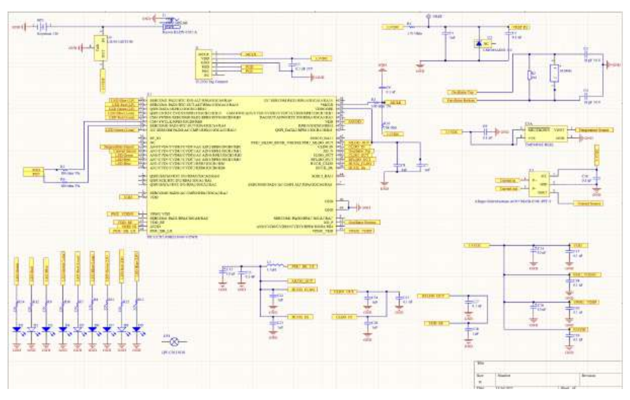

Fig. 3: The final design for the PCB Test Board schematic

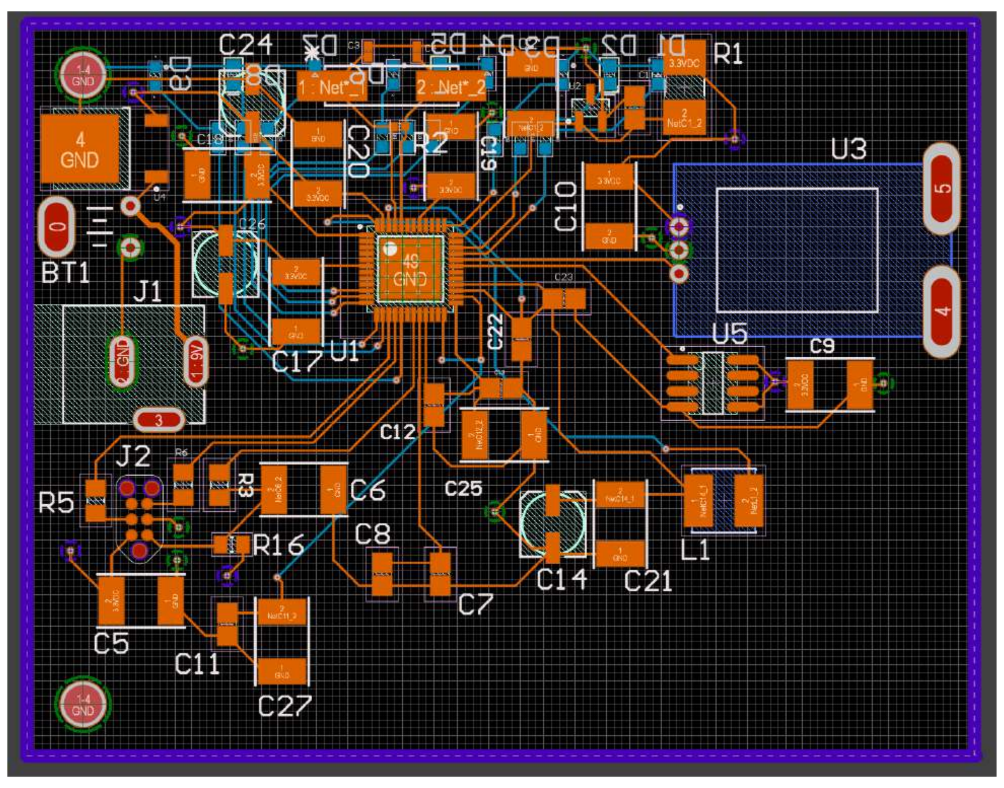

Fig. 4: The layout of the PCB Test Board

Remaining Technical Challenges

OpenCV Cloud Processing:

We still need to implement the logic to upload the extracted LED data to the Google Cloud Realtime Database so the Flutter app can retrieve and display it. We also need to develop the sequence-matching algorithm that compares the detected LED patterns against our predefined blink codes to generate the final decoded output.

Flutter Bluetooth Implementation:

We also need to research Bluetooth communication options and integrate them into our Flutter app so users can select which blink code to run on the test board. This involves choosing a reliable Bluetooth package, establishing a stable connection, and implementing a simple interface that sends commands directly to the board from the app.

Order and assemble PCB Test Board:

After the layout is approved, we will order the board and components. We plan to assemble the PCB board ourselves rather than the manufacturer doing so as to save on cost. The assembly of the board will not be too intensive as to compromise the timeline of the project. After the assembly of the board, we will then move on to the testing portion of the process.

Program and test PCB board:

After assembling the PCB board, we will then draft code in MPLab and push it to the board's microcontroller. The code will communicate with the app we are developing to select various different blink codes and which LEDs to test. The LEDs that are selected will then blink the code that is being tested. This will be coded within the MPLab IDE, which includes multiple code libraries that could potentially help move the process along faster.

Implications for Company & Economic Impact

For the company, having a functioning proof-of-concept for testing will allow VoltServer the ability to convert LED-sequence based error messages and status codes into a readable format on an on-demand basis. This new communication protocol will also allow more information to be broadcast to the user in a much quicker and concise manner. Additionally, making device status data available directly through the LEDs will allow VoltServer products to display more informative messages about system behavior. Providing this insight upfront will reduce troubleshooting time and improve efficiency. Additionally, enabling accurate, on-demand decoding of LED sequences will help technicians diagnose issues correctly, ultimately decreasing the number of VoltServer units mistakenly identified as faulty in the field.

XMOS - XNAV

Realtime Robotic Control on xcore.ai

Team Members: Aidan Donnellan (CPE), Zachary Weinstein (CPE|ELE), Emily Katz (ELE)

Technical Director(s): Dr. Andrew Cavanaugh and Chris Rothwell (CTD)

Project Motivation

A mobile robot is the perfect platform to demonstrate some of the key benefits of xcore.ai chip: precise IO control, high performance processing cores, and software defined communication interfaces. Of these interfaces will include one linking the xcore.ai chip and the roomba, one linking the chip and the wireless transceiver, and the last linking the chip to additional sensors. Robotics demands tight synchronization between sensors and actuators. xcore.ai's hardware level deterministic timing and multi-threaded I/O enable reliable, low-latency handling of encoders, motor drivers, ultrasonic sensors, and more without relying on external peripherals or interrupt-heavy MCU code. The parallel architecture and real-time scheduling of xcore.ai allow it to run closed-loop motor control, sensor fusion algorithms (e.g., IMU + odometry), and obstacle avoidance logic concurrently, on a single chip. This demonstrates how the xcore.ai chip can handle complex, time sensitive workloads typically spread across multiple components (XMOS).

Anticipated Best Outcome

The anticipated best outcome of this project would be to show off the capabilities of the XMOS xcore.ai chip in a real-world robotics context. In doing this it would be showcasing the unique capabilities in deterministic real-time control, parallel processing, and low-latency I/O. Proving the performance and reliability of this application through this project helps XMOS' strategic goal of expanding into the robotics, industrial automation, and intelligent edge systems markets. Beyond this we may combine ABOs with our sister team XROS. This would combine our ABO with theirs of creating a micro-ROS server furthering our main goal of proving the xcore viable for robotics.

Key Accomplishments

Robot Platform Selection (Roomba 600 series): The team went through a few different options for pre built platforms that would be best for the project. The Roomba platform was chosen over others for a couple reasons. Roomba 600 series has support to connect with any external microcontroller through Open Interface and is highly documented. The prebuilt comes with almost all sensors we need out of the box, and the platform is the cheapest by far compared to other platforms we looked at.

System Architecture Design: The initial system architecture has been defined and documented. The Block Diagram (Fig. 1) outlines the interactions between the xcore.ai processor, built-in and external sensors and telemetry. Through this diagram we have planned out how we intend to reach our anticipated best outcome through this system design. The diagram is robust but also will be easy for us to modify as we learn more about the hidden challenges that come with any technical project.

Xcore.ai Board IO Testing: We learned how to utilize the XTC Tools in order to control and create tests for the xcore.ai processor and its board. We were able to create C programs to test and control the IO of the board. First we tested basic IO with a LED. Then we were able to test the internal timers and impedance of the board (Fig. 2 & 4) important information for communication with the sensors and the xcore.ai processor.

Machine Learning Application Planning: Machine learning will be used in computer vision navigation systems on the robot. However, this can be developed in a number of different ways. We have to consider if this model will be on the robot itself or done server side and transmitted. As we discussed options with our technical directors we started to create a list of many different machine learning applications beyond computer vision and created a diagram of use cases (Fig. 3)

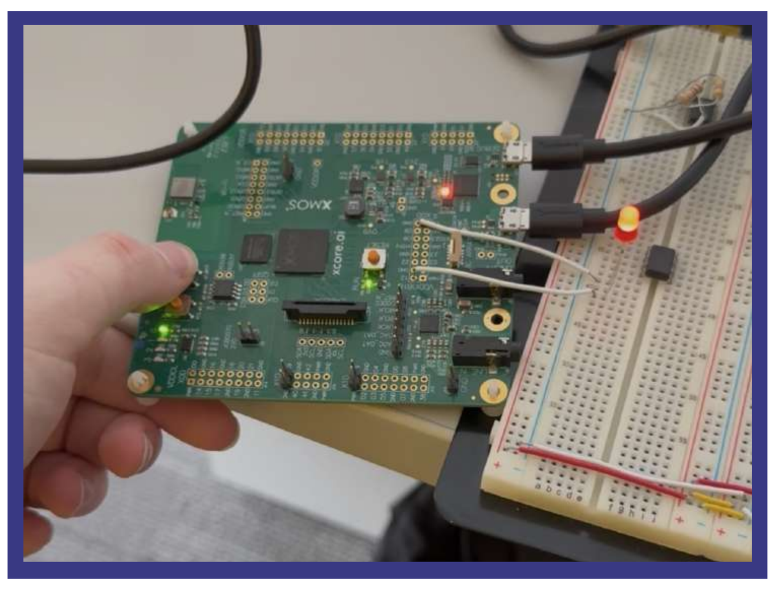

Fig. 2: *Basic IO Implementation*

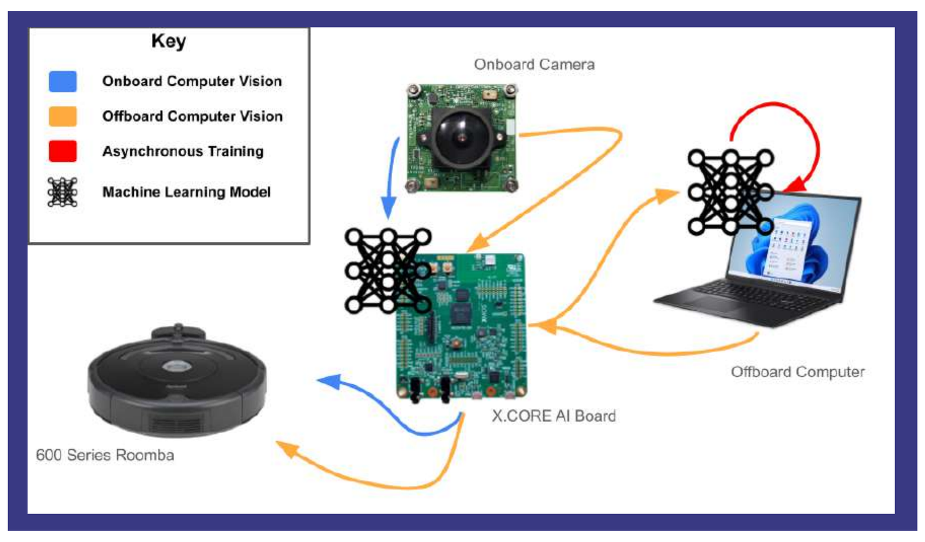

Fig. 3: *Machine Learning Application Diagram*

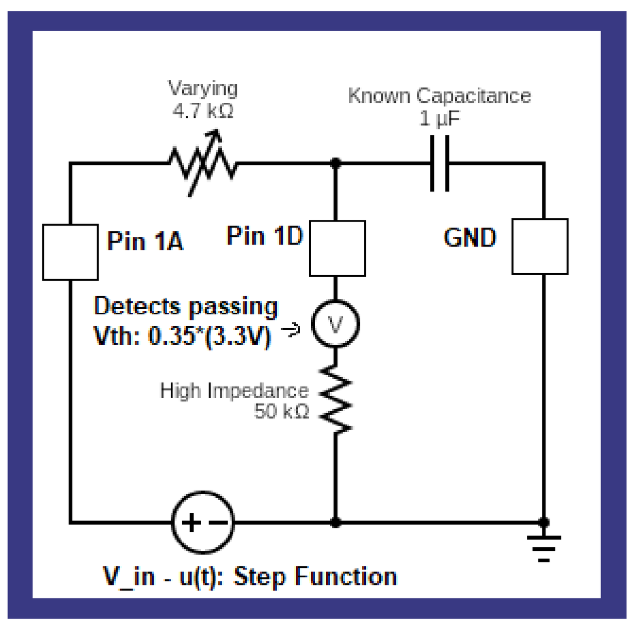

Fig. 4: *Test of the RC Charging Circuit for resistor determinants*

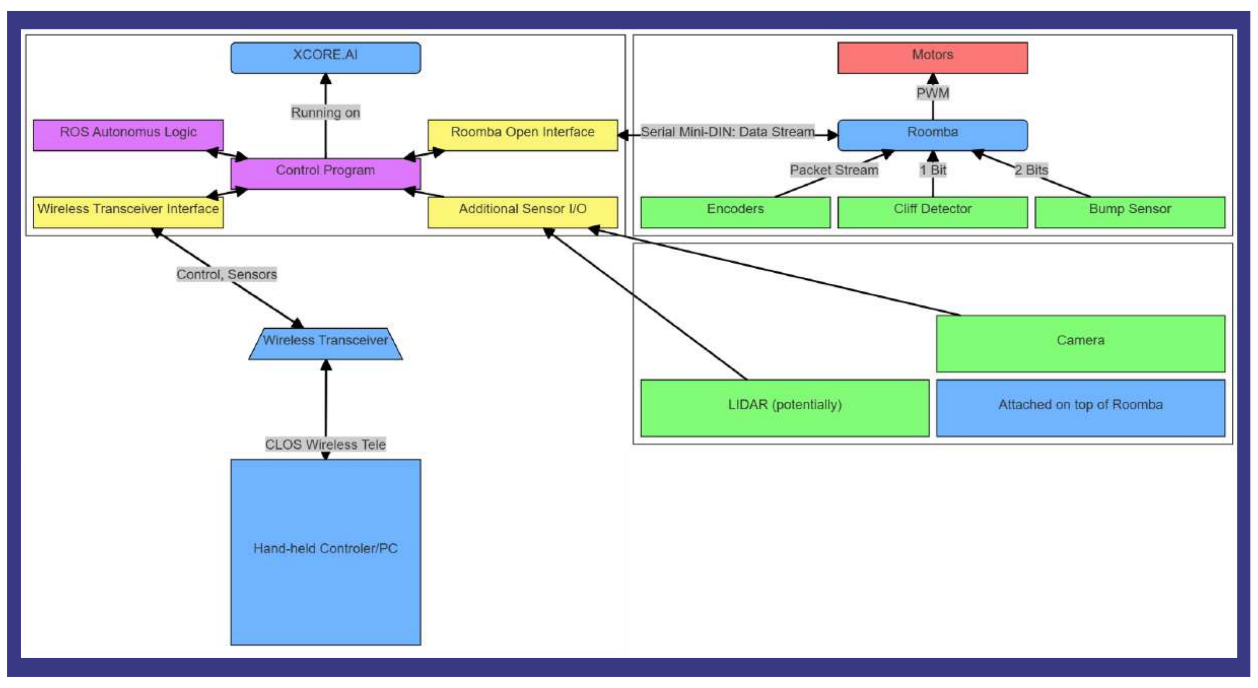

Fig. 1: *Block Diagram of System Architecture*

Remaining Technical Challenges

External Sensor Integration: The roomba prebuilt system might already have all we need to reach our anticipated best outcome. However, adding extra external sensors like a camera, IMU and LIDAR (Fig. 1) will make the system more robust and improve our ability to show off the parallel capabilities of the xcore.ai processor. The camera will allow for better navigation through computer vision and the IMU and LIDAR will help with maintaining a consistent pathing throughout the course proving robustness.

Telemetry and Data Stream Setup: we plan to add a wireless transceiver to the robot system in order to wirelessly track telemetry (Fig. 1). Having some type of telemetry is part of the requirements for our anticipated best outcome. We will also have options for wired telemetry as a fallback onboard the robot system. Having this transceiver also opens up opportunities for remote control and off board machine learning applications. We can host the model server side and transmit the commands (Fig. 3).

Autonomous Navigation: One of the main objectives of the XNAV project is to create an autonomously navigating robot. Specifically a robot capable at the very least of following a set path and can respond to outside stimulus without user input. This stimulus could be in the form of bump detection, path following through computer visions or even echolocation options of navigation.

Testing Course Creation: Setting up and deciding how the robot will autonomously navigate goes hand in hand with how we design the testing course. The testing course is what we intend to present as the final product and as proof of us completing our best anticipated outcome. We are still in the process of figuring out what this may look like, but the basic idea would be to set a course the robot has to follow but could include more depending on design breakthroughs.

Implications for Company & Economic Impact

If we are able to achieve our best outcome it means furthering XMOS's strategic goal of breaking into the robotics and other aforementioned markets. Between the rise of artificial intelligence and other robot assistance, the field of robotics is an ever growing and profitable field in the current market and beyond.

The project could yield some real-world usable software, hardware and integration patterns that could accelerate further endeavors into the field. Having a proof of concept system will reduce customer adoption friction and on a broader scale could show that there could be a market for software-defined architecture in these fields.

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TUESDAY, DECEMBER 16, 2025

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THINK BIG WE DO™

Porting Micro ROS to xcore.ai

XMOS

Team Members: Abigail Tadamala (ELE), Jacob Mathews (CPE), Lyneth Mendoza (CPE & ELE)

Technical Director(s): Dr. Andrew Cavanaugh and Chris Rothwell (CTD)

Project Motivation

Robotics applications increasingly depend on standardized middleware like ROS 2 to support modular development, real-time data sharing, and system interoperability. Although ROS 2 is widely used in research and industry, its adoption in resource-constrained, real-time embedded environments remains limited. The project will attempt to address this challenge by extending ROS 2 concepts to microcontrollers, support for the XMOS xcore.ai platform, a highly parallel, deterministic, and software-defined embedded processor is currently missing.

This project aims to close that gap by bringing micro-ROS to xcore.ai, demonstrating how a modern embedded architecture can operate as an efficient, reliable ROS 2 compatible node. With its unique combination of parallel compute, deterministic I/O, and low-latency execution, xcore.ai is particularly well-suited to robotics and time-critical control applications. Enabling micro-ROS on this platform not only broadens its applicability within distributed robotic systems but also reduces dependence on external communication processors and highlights XMOS technology within an industry-standard robotics ecosystem.

Anticipated Best Outcome

The best outcome is :

- Running micro-ROS node on XMOS xcore.ai publishing/subscribing to a ROS 2 network. This network should include a node running ROS 2 on a Raspberry Pi and connect to the xcore.ai using CANBUS.
- Benchmark round-trip latency and jitter.
- Example integration with a robot or simulation
- Integrate with XNAV project and create a production release

Key Accomplishments

A major accomplishment of our project has been developing a functional ROS 2 server capable of bridging communication between the xcore.ai platform and external micro-ROS nodes (Figure 1). We designed the core server architecture, integrated it into our development environment, and ensured seamless interaction with the XTC Tools and XMOS SDK. We successfully validated this system by testing it against an ESP32 running micro-ROS, confirming stable topic publishing, subscribing, and message integrity over serial communication (Figure 2). Alongside this, we established the project's system design, researched ROS 2 image compatibility across various platforms, set up our Raspberry Pi development host, and created a clean, maintainable repository and developer workflow to support ongoing development.

A second major accomplishment has been successfully flashing a basic version of FreeRTOS onto the xcore.ai. This provides the foundation for running our micro-ROS node natively on the platform. The FreeRTOS build currently reads IMU data, essential I/O functionality which will be necessary for future RTOS-based development. In addition, we determined the tile mapping for optimal utilization of the xcore.ai (Figure 3), dedicating the majority of the logical cores to the FreeRTOS with microROS node and reserving two cores for required drivers and tile interconnect. This mapping will guide our resource allocation strategy as we scale up the complexity of our application.

A third major accomplishment has been establishing the groundwork for our micro-ROS test environment. We have identified and selected the sensors and motors aligned with our project goals and our planned collaboration with the XNAV team. With the necessary components now procured (Figure 4), we are planning to begin assembling the robot platform that will serve as our test environment. Once operational, this platform will allow us to validate our microROS node performance on the xcore.ai hardware and begin deeper integration with the XNAV project beyond the ABO stage.

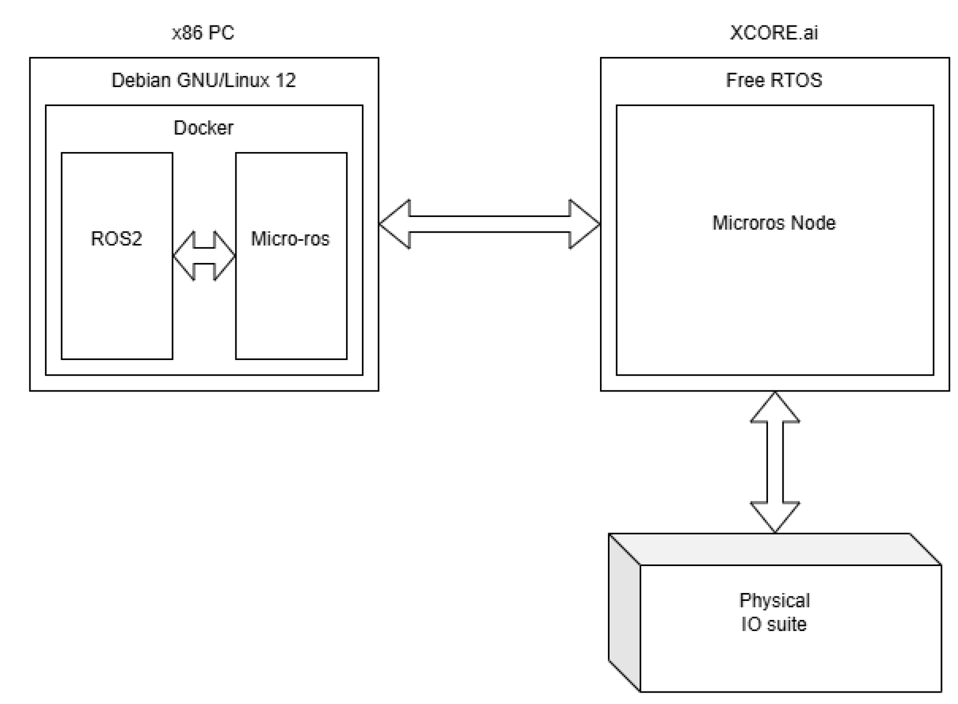

Figure 1 - High Level Project Overview

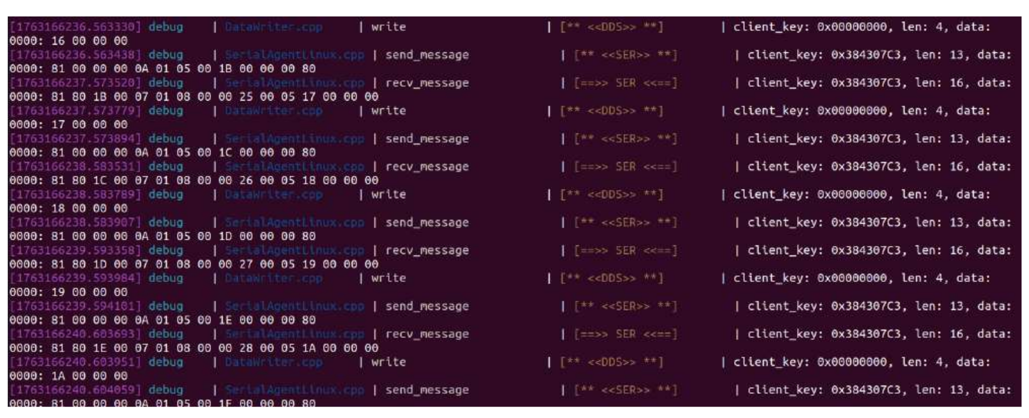

Figure 2 - Ros Server to ESP32

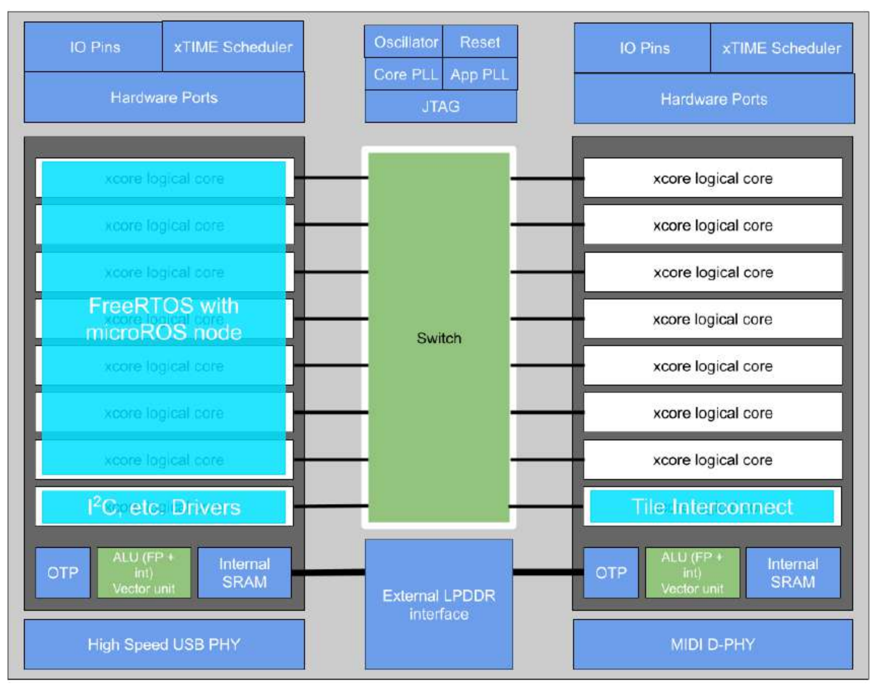

Figure 3 - xcore.ai Tile Mapping

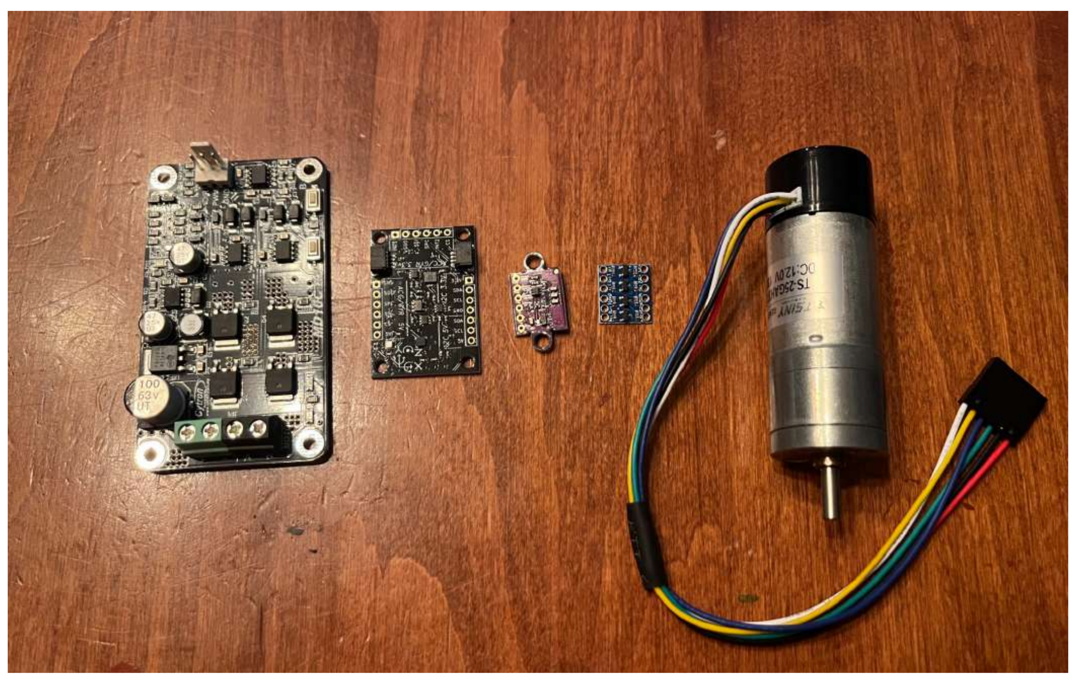

Figure 4 - Test Environment Components (Left to Right: Motor Driver, Gyroscope, Laser, Level Shifter, and Motor)

Remaining Technical Challenges

One of the remaining technical challenges is running the ROS 2 server on our Raspberry Pi, as the server currently depends on x86-based tooling and libraries that are not directly compatible with the Pi's ARM64 architecture. This creates issues when building or executing components that assume an x86 environment. To address this, I plan to deploy the server inside a container that emulates an x86 userspace on the ARM64 host. By using an emulation-backed container, we can reproduce the expected environment, validate functionality on the Pi, and ensure consistent behavior before fully transitioning to a native ARM64 solution later in development.

Another remaining challenge is building the robot. After researching sensors and motors, we selected a temporary test setup and confirmed the sensors. Now, we are challenged with physically building the robot, integrating the components, and creating a stable development environment. We expect a learning curve with wiring, calibration, and testing. When issues come up, we will rely on my TDs, ask questions, and research independently.

A third remaining technical challenge we faced is preparing for the integration of ROS 2 and micro-ROS communication with the xcore.ai, a deterministic, event-driven architecture that differs significantly from typical microcontroller platforms. Even before implementation, this required understanding how ROS 2 assumptions about threading, memory allocation, and serial communication would need to be adapted for the xcore.ai's unique execution model. Additionally, planning an efficient tile and logical-core mapping for the xcore.ai has been challenging, as we must anticipate the computational demands of FreeRTOS and the future micro-ROS node while reserving cores for drivers and tile interconnect, all while preserving deterministic performance.

Implications for Company & Economic Impact

The best outcome for the company would be a demonstration of a compelling real-world robotics application of the XMOS xcore.ai processor. This aids in XMOS's goal of expanding into markets like robotics, industrial automation, and intelligent edge systems. Economically, this project creates potential for accelerating future product development or form the basis of customer reference designs. Having a successful outcome makes XMOS technology more marketable providing demonstrable proof-of-concept systems, reducing customer adoption friction, and highlighting differentiators against conventional microcontrollers or system on chips. In time, this can contribute to increased design wins and licensing opportunities.

Zebra AI / ML

Empowering Printer Calibration with Object Recognition & Analysis

Team Members: Richard Buckley (CPE), Sergio Herrera (CPE), Jacob Silva (CPE)

Technical Director(s): Matthew Corvese, Patrick Hegarty, & Yashaswini Mandalam (CTD)

Project Motivation

Thermal label printers are expected to deliver consistent, high-quality output across a wide range of label stocks, including many low-cost third party media. Large enterprises (e.g., Amazon, FedEx, USPS) aggressively pursue cost savings, and small differences in media pricing add up at scale. However, every change in media chemistry or supplier can alter print behavior, affecting dot gain, bleed, and overall readability. Today, Zebra engineers spend significant time manually tuning printer parameters, responding to customer requests to make a new media type "print correctly".

By introducing AI-driven analysis of printed patterns, Zebra can automatically detect print defects and recommend or apply optimal settings. This reduces manual calibration work, shortening deployment time for new media; allowing engineers to focus on higher-value design and innovation.

Anticipated Best Outcome

The best outcome for this project is:

- Develop and train a machine learning model that:
  - Identifies printed patterns and objects on printing labels
  - Compares them to an “ideal” reference
  - Automatically adjusts print parameters to achieve optimal printing quality

Key Accomplishments

Hardware Selection: We identified and set up a platform (Raspberry Pi) to orchestrate the communication between the printer and camera. This platform must also have the capabilities needed to run inference of an AI model.

Driver Development: Since code and documentation relating to communicating with a Zebra Label printer is proprietary, confidential code owned by Zebra, we needed to develop our own USB driver. We completed this by using Python and PyLibUSB.

Camera Calibration: In order to effectively write a script in order to capture data, that will run reliably, every time, we must be able to relate the size of a pixel seen on the microscopic camera to the size of one dot printed by the label printer. As part of our deliverables, we have included a calibration module, which identifies where on the printed label the camera is viewing, how large one pixel is in relation to dots, and is used in the script driving the print-capture for data collection.

Print Capture Data Collection Script: In order to train an artificial intelligence (vision) model to calibrate a printer, we must first curate a dataset. In order to automate this process, we have a module, which is solely for printing and capturing a set graphic. This module depends on the camera calibration results, as this reveals the size of the camera viewport and allows us to minimize the amount of whitespace on the label. Once printed, the camera takes multiple pictures of the label, and then uses computer vision to stitch them together (the camera viewport is short relative to the graphic that we must print in order to calibrate the printer). The stitched image is then segmented into our training dataset allowing for dot scoring of individual dot patterns (**Fig. 3**).

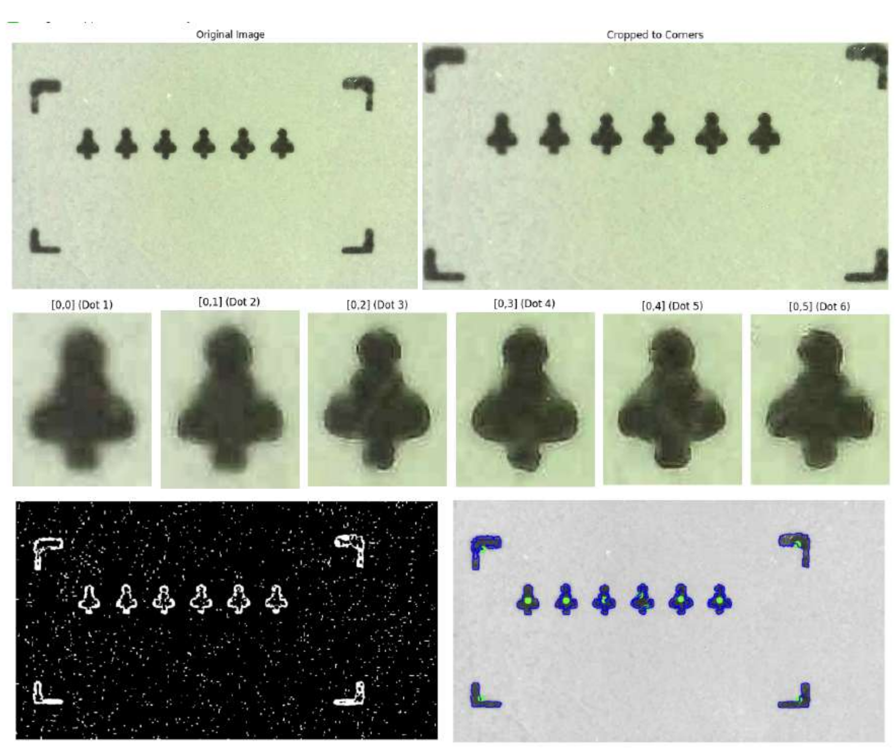

Fig 1: Extracting printed data from images

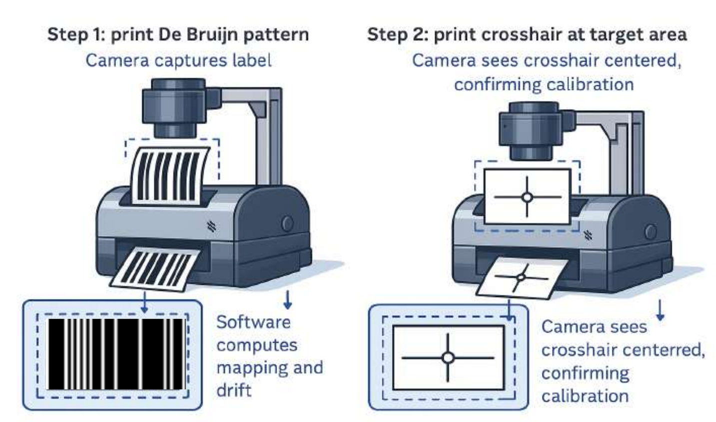

Fig 2: Illustration showing camera calibration

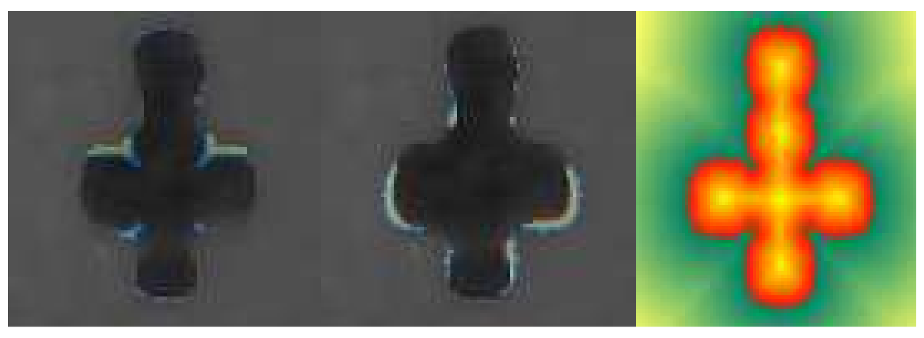

Fig. 3: Color-coded Heatmap of Print Defects

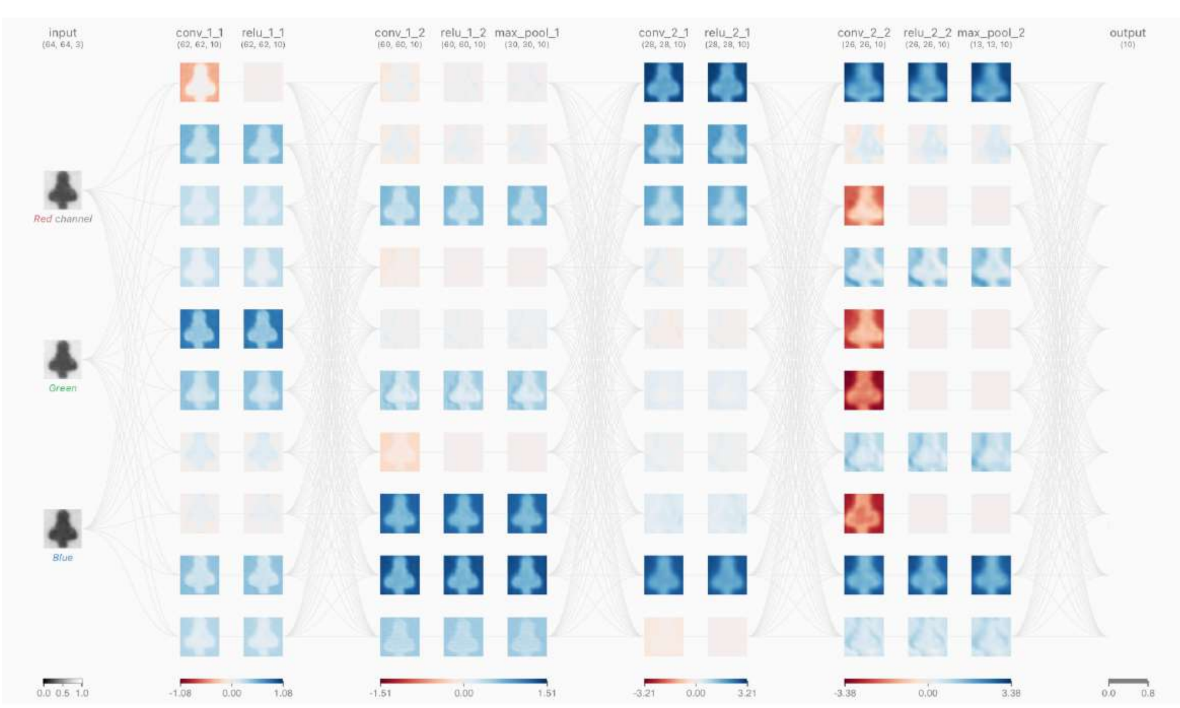

Fig 4: Illustration showing CNN for training our model

Implications for Company & Economic Impact

Reaching the anticipated best outcome of this project will allow Zebra Technologies to automate important parts of their sensing and print quality processes. This will allow their engineers to dedicate time on more demanding tasks besides routine improvements. By integrating artificial intelligence to their products, the company can lower design and development costs while also increasing flexibility to make changes on smaller programs.

Over time, this will help Zebra maintain its leadership in direct thermal printing by continuously improving their product. The result from improved efficiency and higher quality output will provide both economic benefits and a competitive advantage in the industry.

Remaining Technical Challenges

Data Tracking and Experiment Management: While training the model, use a tracking system to record the following; training metrics, hyperparameters, and model versions across all iterations. The purpose of this is to ensure that every experiment is documented and allows for the comparison of different configurations to objectively determine the optimal model settings for the final system.

Model Selection and Accuracy-Size Tradeoff: Make a final decision for the selected model, then test that it achieves high accuracy without sacrificing its speed or its efficiency. This includes testing against pre-trained models and tuning settings. The deployed model should not be too big and must run both efficiently and accurately in order to suit real deployment.

Objective and Compact Inference: Determine the model output, for instance, a quality score or recommended printer settings. This means the model needs to be small and fast while providing stable predictions across various media types and print conditions.

Parameter Mapping and Safety Rails: Once the model has made a prediction, find a way to turn that prediction into actual printer setting changes. These changes must stay within the bounds and be easy to undo if print quality gets worse. This requires a clear mapping from outputs to printer parameters, as well as simple rollback rules when testing new settings.

Experiment Pipeline: An entire experiment pipeline should be created with the following components: print, capture, curate, train, evaluate, and deploy. This pipeline will log the used version of the dataset and model, handle bad images or missing frames, and make it easier to go through training again in the future. Ensuring this process is repeatable and efficient allows us to compare models reliably and make further improvements.

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TUESDAY, DECEMBER 16, 2025

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Zebra - Resonance

On-Metal RFID

Team Members: David Rodov (ELE), Destiny Moua (ELE), Nathan Vierkant (ELE)

Technical Director(s): Eric Liberato, Joe Moreira, & Mike Smith (CTD)

Project Motivation

This project aims to evaluate the feasibility of manufacturing on-metal RFID tags at Zebra. The primary focus is on testing a wide range of antenna designs, studying how their geometry and tuning respond to metal. Our goal is to develop specialized tag constructions optimized for performance on metallic surfaces. Through extensive experimentation and analysis, the project seeks to identify the most effective design approaches that maintain strong read performance and reliability in challenging environments. By gaining a deeper understanding of materials, design principles, and production methods involved, the team intends to assess the practicality of shifting the production process in-house for Zebra. This would not only enhance control over product quality and customization but also potentially reduce cost. This project's main objective is to build a solid foundation for future in-house manufacturing of on-metal RFID tags, ensuring Zebra can deliver efficient, high-performance solutions tailored to industrial and logistical applications.

Anticipated Best Outcome

The anticipated best outcome of this project is to achieve a clear and measurable improvement in the read range of a UHF passive on-metal RFID tag across both FCC and ETSI frequency bands. On-metal environments often present significant challenges for tag performance, so if we are able to demonstrate consistent gains in read distance we can validate the effectiveness of the new antenna designs and constructions that we test. Reaching this outcome will confirm that the project's design strategies successfully address detuning and signal interference caused by metal surfaces. This would also support the long term goal of developing reliable, high performance on-metal RFID solutions.

Key Accomplishments

Our primary goal so far has been to center the resonant frequency of our RFID tag around the United States standard of 902-928 MHz. We've also been trying to maximize the return loss and to impedance match our antennas.

Our tags could have incredible read range, but if it's not within the frequency range then it is useless. Our first set of antenna designs were all overshooting the desired frequency by quite a bit. After making adjustments, we began undershooting the resonant frequency, but it was closer than before. The most recent tag design (as of writing) is right about where we want the resonant frequency to be as seen in **Figure 1**. This value is actually a little above the frequency standard because there is a detuning that occurs with on-metal tags causing your resonant frequency to dip.

In terms of return loss, our first designs were achieving around the -10dB mark. We are aiming for at least -15dB in all of our tags. We made tags that have a return loss of -30dB; however, their resonant frequency is too high. Our tags that undershot the resonant frequency were in the -20dB to -30dB range; one of the designs can be seen in **Figure 2**. The tag that was in the desired frequency range was around -15dB.

The last and most difficult part of our technical work is the impedance matching. To maximize power transfer, we need to match the impedance of the chip and antenna. The best tag we have had so far only has a read range of ~0.9 meters while our goal is at least 3 meters. Even though it has a decent return loss and the desired frequency, it is likely not impedance matched very well. This is the final piece of the puzzle and the one we are working on improving right now.

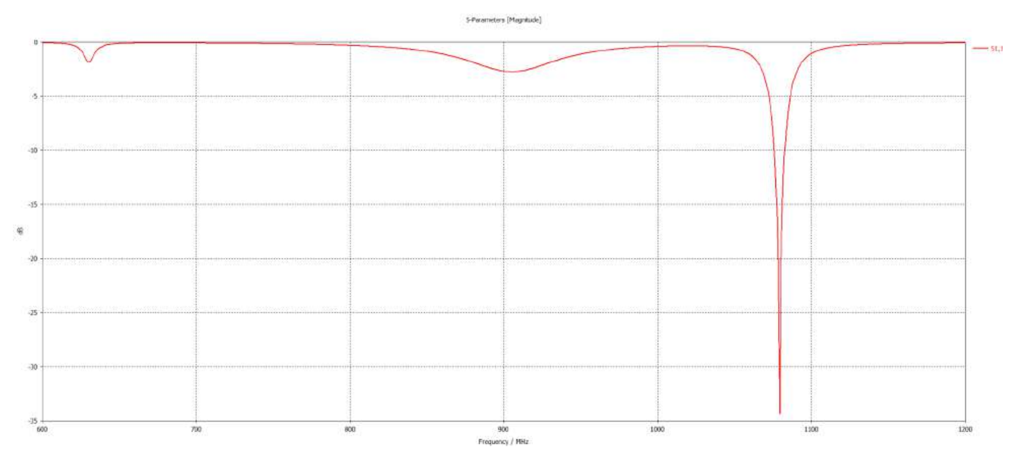

Figure 1. Simulated S_{11} parameter of the up-scaled antenna design while keeping feed lines original size. The model achieves improved impedance matching with a deeper return-loss dip (–34 dB), but its resonance frequency shifts to ~1080 MHz, which is higher than the target frequency for the intended reader.

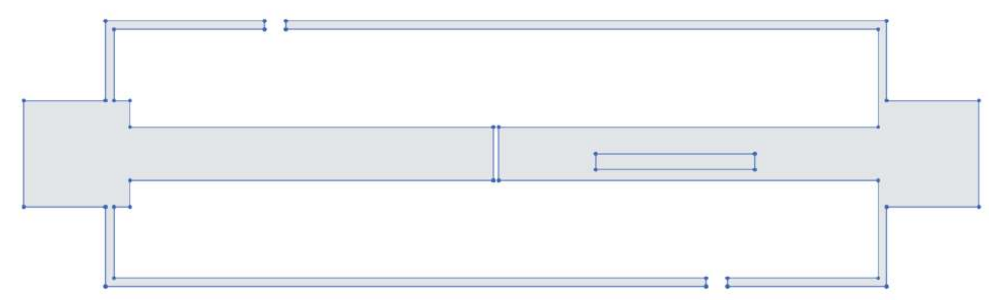

Figure 2. Antenna design using capacitive gaps that are 2mm wide. When simulated the return-loss dip is -25 dB with a low resonance frequency of 890 MHz.

Figure 3: Photo of our lab setup. The white square is a fixed reader. The black box is an interface for us to read the data from the scanner. The small block is an antenna attached to a metal block to be read by the scanner.

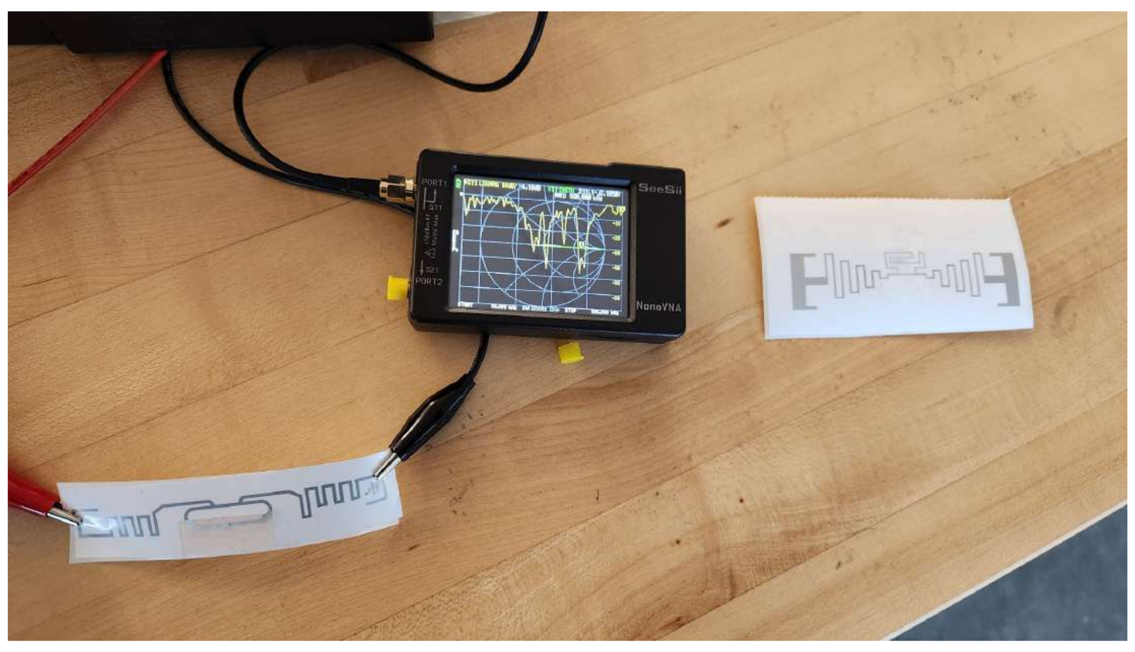

Figure 4: Photo of a VNA. We will be using the VNA to determine the impedance of our antennas. The VNA plots on a Smith chart and allows us to see the impedance of our antenna (the small green line) and the return loss (yellow line)

Remaining Technical Challenges

Although our current prototypes demonstrate promising return-loss performance and improved impedance matching, several challenges remain before the design can fully meet the target specifications needed to show measurable read-range improvements across both FCC and ETSI bands. One of the main issues is the resonant frequency seen in simulation. Our antenna designs are currently either not tuned to the desired resonant frequency or do not reach the target impedance-matching level. This shows that the design is still highly sensitive to scaling and the influence of the metal surface beneath it. Bringing the resonance back into both regulatory bands while maintaining a strong return-loss dip will require more refined tuning of the geometry and spacing materials, along with potential adjustments to the ground structure.

Another challenge is achieving stable performance across different on-metal environments. Metal surfaces vary in size, thickness, and shape, and each of these factors affects how the antenna behaves. A design that performs well on one surface may become detuned or lose efficiency on another. To meet our anticipated outcome, the antenna must maintain acceptable impedance, bandwidth, and radiation characteristics across these varying conditions.

Fabrication constraints also remain important. Some of the designs that perform well in simulation rely on foam or ground layers that must be printed at a specific thickness to remain compatible with multiple printheads. If these layers become too thin or uneven, the spacing between the antenna and the metal surface changes, which can shift the resonant frequency and reduce performance. Maintaining consistent layer thickness across print runs is therefore a key challenge as we move toward a design that can be produced reliably.

Finally, accurate validation remains difficult. On-metal read-range measurements are sensitive to orientation, test setup, reader power, and reflections. Reliable and repeatable testing will require consistent procedures and careful calibration to ensure that any observed improvements reflect actual antenna behavior.

Implications for Company & Economic Impact

Zebra Technologies currently creates and sells many different types of RFID tags; however, they do not produce their own RFID tags for on-metal tags. If the anticipated best outcome is achieved, it will allow Zebra technologies to transition to in-house production of on-metal RFID tags using the printers and other equipment they already make . Currently, Zebra procures these tags from a third party increasing costs. In-house production will allow Zebra to save costs on outside manufacturing, and it will allow Zebra to sell the tags as their own increasing revenue opportunities.

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Peltier-Based Thermal Control System

Team Members: Jimmy Prior (CPE/ELE), Racquel Raphael (ELE), William Lucas (ELE)

ZEBRA

Technical Director(s): Anthony Helberg, Patrick Hegarty, Matthew Corvese, & Mike Smith (CTD)

Project Motivation

Thermal management plays a critical role in the performance and reliability of Zebra Technologies' industrial printers. During high speed or continuous operation, uneven temperature distribution across the printhead can cause print quality issues, increased wear, and potential component failure. Existing systems rely on passive or limited control methods that cannot dynamically respond to changing thermal loads. This project was motivated by the need to develop a smarter, more responsive thermal control solution capable of maintaining consistent printhead temperatures under varying conditions. By integrating Peltier coils, a microcontroller, and the printhead's internal thermistor circuit into a closed-loop hardware control system, the team aims to enhance temperature stability, improve energy efficiency, and extend the operational life of Zebra's printing hardware.

Anticipated Best Outcome

By April 14, 2026, we expect to deliver a fully functional thermal control system prototype capable of maintaining the printhead temperature within ±1°C across a range of printing conditions. The system will integrate Peltier coils, a thermistor, and a microcontroller to actively regulate heat. All hardware, firmware, and documentation will be completed, validated through control testing, and presented to Zebra Technologies as a proof of concept for potential product integration. The final outcome will include performanced data demonstrating improved stability, responsiveness, and overall efficiency compared to the current thermal management approach.

Key Accomplishments

Selection of Microcontrollers for Control System:
The microcontroller is the core component of the control system, dictating the entire system's functionality. For this project, the Arduino Nano R4 and NUCLEO-F303K8 were selected. Both microcontrollers are equipped with high-resolution analog-to-digital converters(ADC). This high resolution is crucial, as it allows for more precise readings from the printhead's internal thermistor. The resulting enhanced accuracy directly contributes to more efficient temperature control, which is essential for ensuring optimal printing quality. After a comparative analysis of their performance, one microcontroller will be selected for integration into the final product**(Figure 1)**.

Hardware and Software Implementation of Closed-Loop Control System:
For the primary control element of the system, the Arduino Uno was selected for initial testing purposes**(Figure 2)**. Code was developed for the Uno, utilizing its Analog-to-Digital Converter (ADC) pins to accurately sample temperature data from the printhead's internal thermistor. This digital temperature reading provided the crucial feedback signal necessary to regulate the system's thermal element: the Peltier coils. The microcontroller actively drove these coils, which possess bi-directional heating and cooling capabilities. Currently, the system's prototype is configured to operate solely with the cooling function**(Figure 3)**.

Cooling Performance Evaluation Setup:
We developed a controlled testing setup to evaluate the cooling system's effectiveness under real printing conditions. Using Arduino IDE for temperature data acquisition and a Python script for logging and visualization, we continuously track the printhead temperature while marking when printing starts and stops. This allows us to directly compare thermal performance across different print durations and label quantities, identify performance gaps, and guide future design improvements**(Figure 4)**.

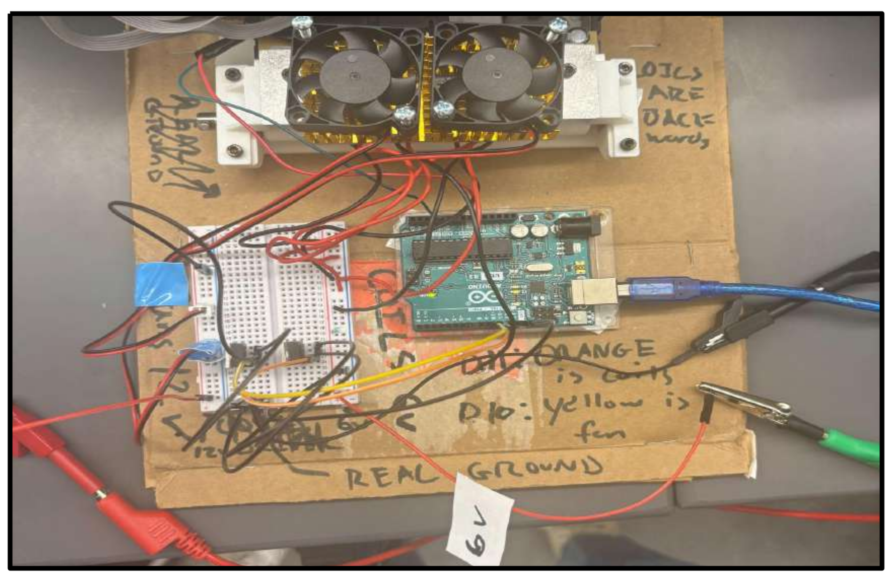

Figure 1. Functioning Prototype

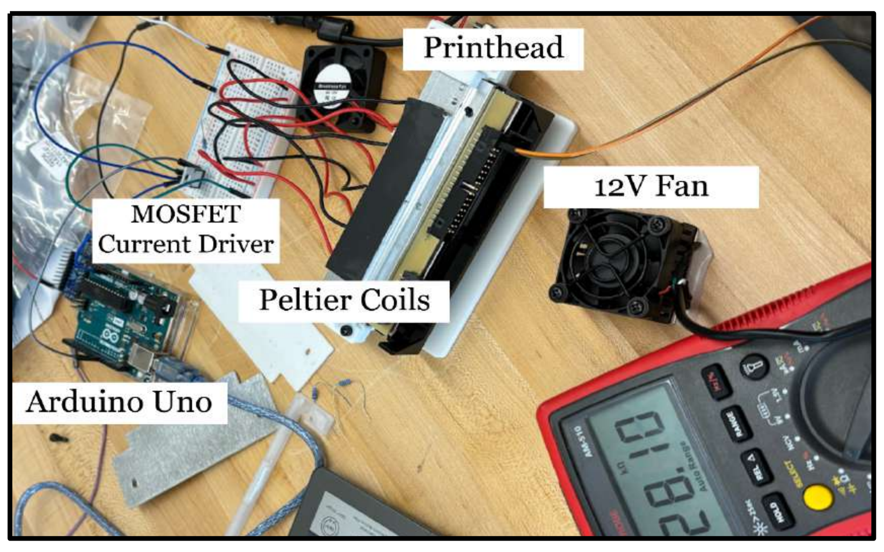

Figure 2. Developmental Stages of Prototype

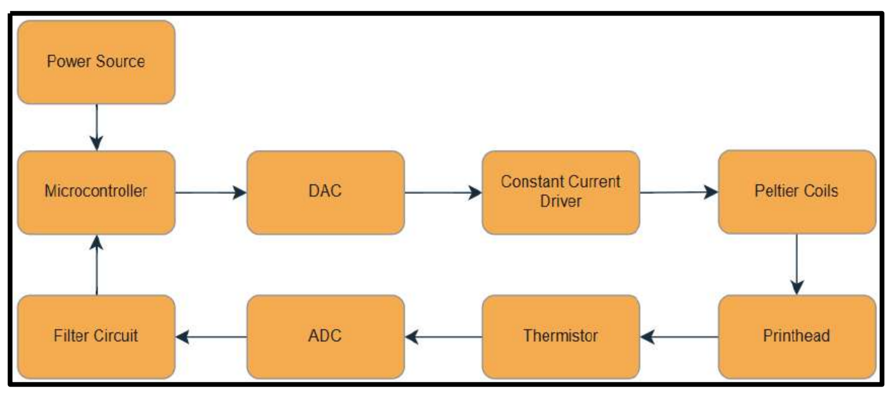

Figure 3. High-Level Block Diagram

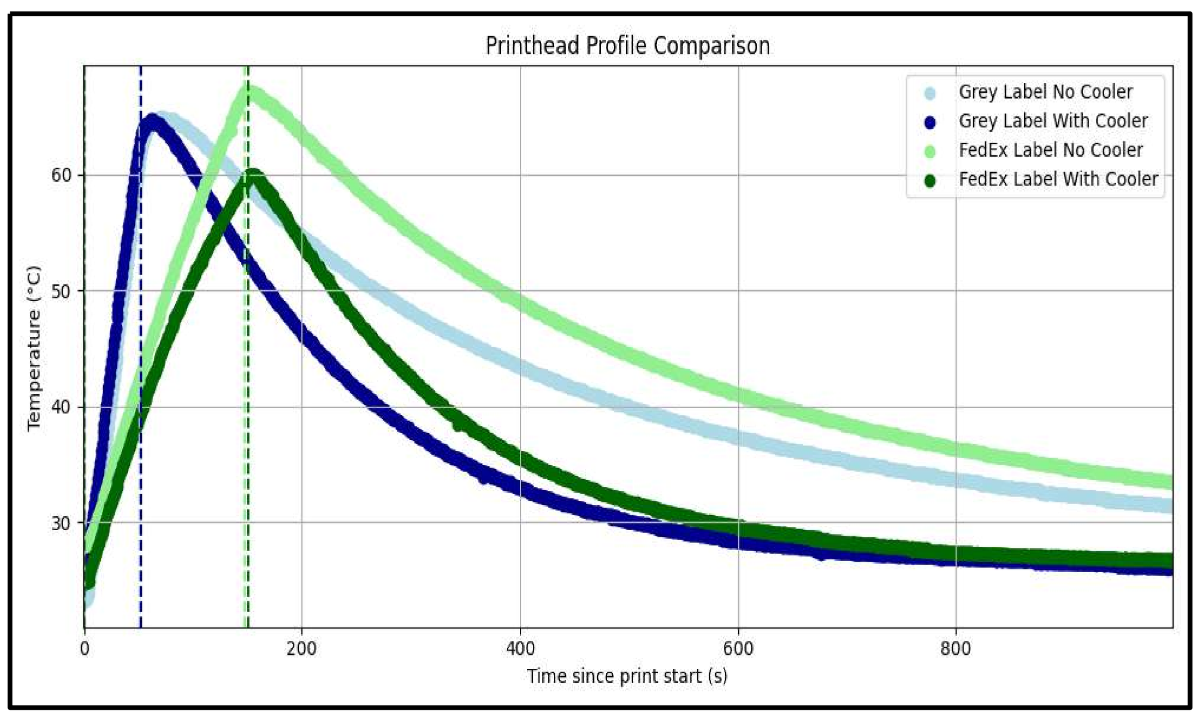

Figure 4. Printhead Profile Comparison

Remaining Technical Challenges

Implementation of Hardware-Based Closed-Loop Control System:
The current system successfully cools the printhead, but the cooling performance is not yet as effective as required for high-speed printing. We need to validate the control behavior with the printhead installed and running real print jobs, where the thermal load is more dynamic. As we move beyond benchtop testing, a key challenge will be physically integrating the control hardware and wiring inside the printer so that it operates seamlessly with the existing circuitry during normal operation. Improving cooling efficiency and confirming reliable performance under actual printing conditions will be essential for the final design.

Advanced Microcontroller Integration:
While the Arduino Uno is ideal for rapid prototyping, the final system requires a more capable microcontroller for accurate control and sensing. These advanced microcontrollers introduce a steeper learning curve, requiring custom firmware development, new debugging processes, and integration with the printer. Addressing this challenge is essential to achieving a fully embedded and reliable control design.

Power System Integration:
For prototype testing, external bench power supplies are used to power the Peltier coils, fans, and microcontroller in the closed-loop control system. As we transition toward a finalized design, a more permanent and integrated power solution must be developed to reliably support system operation.

Modular Design Requirements:
Developing and implementing a modular design for the control system will allow for future upgrades and potential adaptation to additional printer models. This requirement must remain a priority throughout the design process and presents a challenge, as the system must maintain full compatibility with the current printer while still supporting future modifications.

Implications for Zebra & Economic Impact

When the printheads in Zebra's printers overheat, the printer must slow down to prevent damage, which lowers productivity. Integrating an active cooling system allows the printhead to maintain higher print speeds for longer, improving overall performance and output efficiency. This reduces the number of printers needed to meet demand and provides a competitive advantage in the thermal printing market by delivering faster, more reliable printing solutions.

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Torque Measurement

Torque measuring test fixture for stepper motors used in Zebra printers

Team Members: Cole Giordano (ELE), Daniel Sanguino (CPE)

Technical Director(s): Morgan Malone, Joseph Moreira, Jeff Berry

Project Motivation

The motivation for this project comes from Zebra Technologies' need for a more compact, replicable, and efficient method of characterizing stepper motor performance. Current in-house testing systems rely on large power supplies and bulky braking mechanisms, making them difficult to duplicate across facilities. Zebra printers depend on precisely controlled stepper motors, and understanding how torque, speed, voltage, current, and resonance frequencies interact is essential for ensuring consistent print quality. However, limited characterization data under varying load conditions makes it challenging to predict or diagnose torque-related issues. This project aims to solve that gap by developing a dedicated, streamlined testing fixture that integrates a torque transducer, particle brake, and STM-controlled measurement system with a GUI, as illustrated in figure 1. The fixture will enable engineers to record, visualize, and analyze real-time torque, speed, and resonance behavior under controlled conditions, ultimately improving motor configuration, stability, and reliability across Zebra's printer lineup.

Key Accomplishments

Component Research & System Architecture Development: Extensive research was conducted to understand the electrical, mechanical, and control requirements of the torque-measurement fixture (figure 1). This included evaluating multiple motors, one of which being the Epoch T4222 stepper motor (figure 3), motor drivers, torque transducers, particle brakes, and op-amp configurations to determine the most reliable, compact, and repeatable solution. Through this analysis, we identified the Placid B1 magnetic particle brake, the T25 torque transducer, and a low-side current-regulated brake driver as the foundation of the system. After initial testing with the A5984 stepper driver, we determined that upgrading to the DRV8424EVM would give the team more advanced features, including adjustable motor-phase current and improved decay-mode control.

Particle Brake Driver Circuit Development: We designed and refined a custom current-controlled driver circuit for the particle brake using the IRLZ44N MOSFET, Schottky diode, a sense resistor, and an op-amp, as illustrated in figure 4. Early prototypes using the LT1001 required a dual-rail supply, but further research led to selecting the OPA340PA, a rail-to-rail, single-supply op-amp, which will also be used for a low-pass filter for ADC conditioning for the T25 measurements. Multiple voltage-divider configurations were tested, and a final design now maps the STM32's 0–3.3 V output to ~0–0.75 V at the op-amp input, producing a controlled 0–75 mA braking range appropriate for stalling the test motor.

Motor Driver Integration & STM32 Control: We established communication between the STM32 NUCLEO-F767ZI and the A5984 driver board, achieving controllable step rate, direction, stepping modes and frequency through the various I/O pins available as shown in figure 2. A current probe and oscilloscope were used to successfully visualize phase-current waveforms at different microstepping modes. We were also able to implement a desired voltage output for the particle brake driver circuit from the STM32 board. Work is ongoing to transition this control framework to the DRV8424EVM for expanded capability.

Torque Transducer Cable Fabrication: A soldered T25 cable was fabricated with proper pin mapping and shielding to ensure noise-free signal readings for upcoming ADC testing.

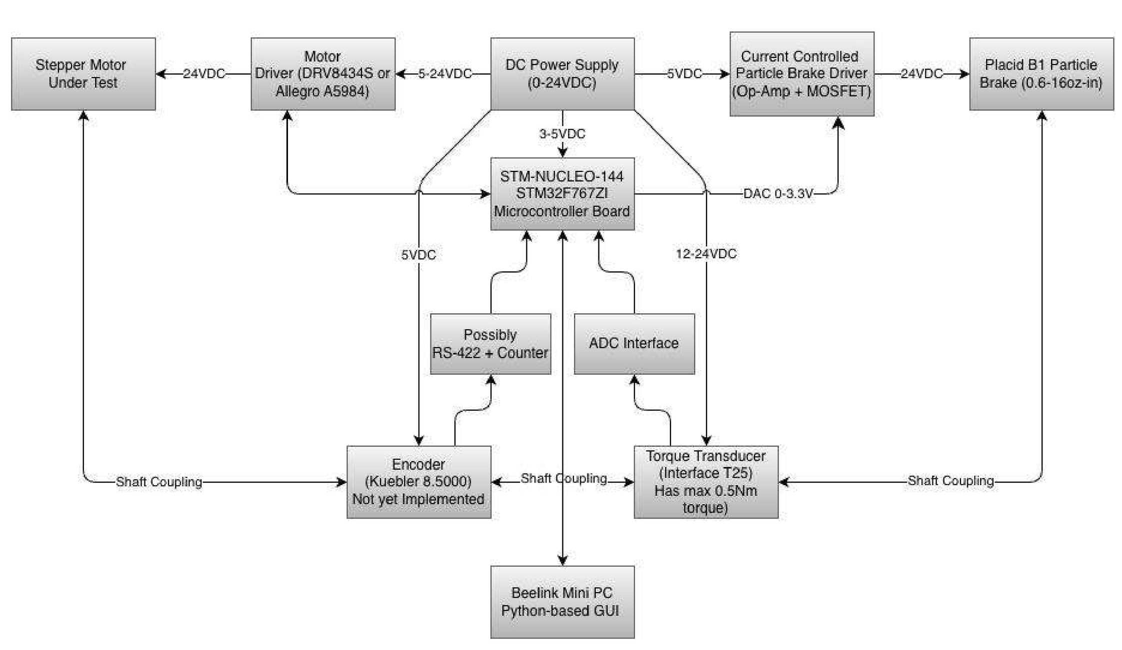

Fig. 1: Full System Block Diagram

Implications for Company & Economic Impact

The successful development of this torque measurement fixture will give Zebra Technologies a compact, mobile, and easily replicable system for evaluating stepper motor performance across all printer platforms. By replacing the current bulky, stationary test setup with an integrated unit containing the particle brake, torque transducer, and control electronics, Zebra engineers will be able to perform consistent, high-resolution torque and resonance-frequency characterization using far smaller power requirements. This fixture will support interchangeable testing of motors used in mobile, desktop, and tabletop printers, helping identify unstable operating regions, optimize motor configurations, reduce troubleshooting time, and improve long-term print reliability across Zebra's product lines.

Anticipated Best Outcome

The anticipated best outcome is to develop a fully functional and adaptable stepper motor testing fixture capable of accurately measuring motor torque and speed under controlled conditions. The system will integrate an STM32 microcontroller board, mini PC, and a python-based GUI to allow technicians to control motor parameters, apply and monitor loads using a current-controlled particle brake, and visualize real-time performance data. Automated data collection will generate torque-speed curves for performance comparison. The project will also deliver a consolidated 24V power distribution network, validated driver boards, and a compact, modular fixture design to enable reliable, repeatable testing across Zebra facilities

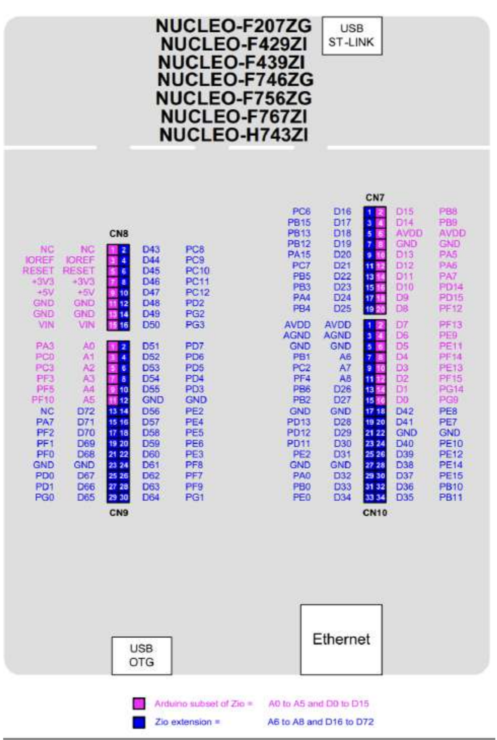

Fig. 2: STM32 Nucleo F767ZI Pinout

Fig. 3: Epoch T4222 Stepper Motor

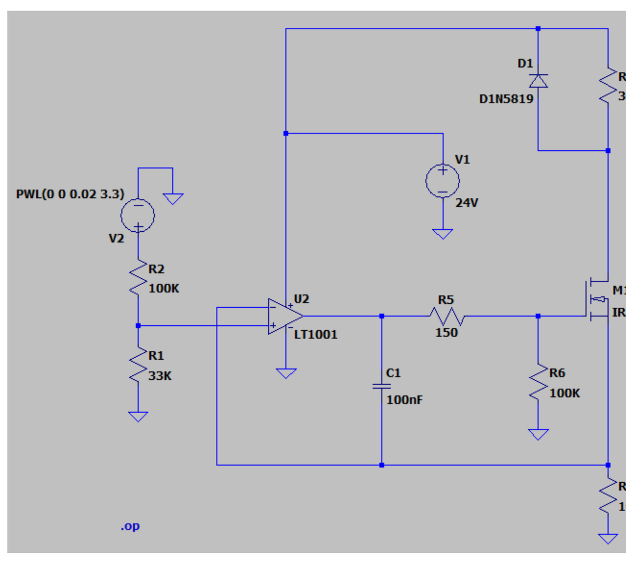

Fig. 4: Particle Brake Driver Circuit

Remaining Technical Challenges

Torque-Measurement Signal Path Completion: The STM32 still cannot read real-time torque because the T25 transducer output requires conditioning before ADC sampling. A low-pass RC filter must be designed, built, and calibrated so the STM32 can reliably capture torque data during load ramps and stall tests. Firmware updates are required to scale the filtered voltage into physical torque units using Zebra's calibration equation

Encoder Integration for Speed & Stall Detection: Although the T25 includes a 360-PPR (1440-count quadrature) encoder, it has not yet been integrated into the control loop. Proper decoding, noise rejection, and counter synchronization are required for start/stop detection, speed measurement, and dynamic test automation. Future work also includes evaluating a 5000-PPR external encoder for resonance-frequency characterization.

GUI-to-STM32 Communication & Automated Testing: The existing Python GUI must be adapted for the STM32 F767ZI so technicians can send test commands and receive live torque, speed, and brake-current data. Significant work remains to implement stable UART packet handling, ensure timing consistency, and automatically generate torque-vs-speed plots during characterization routines.

Full Integration of Particle Brake Driver & Power Architecture: The OPA340/IRLZ44N particle brake driver circuit is validated on the bench, but it must now be fully integrated into the shared 24V power system, which also requires a functioning ± supply rail for the transducer and signal-conditioning stages. Ensuring stable current regulation under extended tests, minimizing noise, and validating the brake's linear torque response across motors are remaining challenges.

Motor Driver Expansion & Control Firmware Refinement: While the A5984 driver is functioning, the DRV8434S/DRV8825 must also be integrated for compatibility with higher-current motors. Firmware must incorporate new microstepping modes, decay-mode management, and synchronized brake–motor control to support automated torque-speed sweeps

Fixture Scalability & Higher-Torque Brake Upgrade: The fixture must be prepared to support the Placid B2 brake for motors requiring up to ~40 oz-in. This requires revisiting brake-driver scaling, verifying MOSFET thermal performance, and ensuring mechanical compatibility with the future upgraded assembly.

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Universal Printhead Fixture

A Universally compatible test bench fixture for thermal printhead evaluation

ZEBRA

Team Members: Yasumin Vongvilay (CPE), Kyle Ludwig (ELE), Liam Hudak (ELE)

Technical Director(s): Morgan Malone, Dan Donato, Chris Rothwell, and Joe Moreira

Project Motivation

The Universal Printhead Fixture project seeks to accelerate and improve the development cycle of Zebra Technologies thermal printhead evaluation. Currently, the qualifying process for new printheads often requires dedicated firmware and hardware setups for each model, increasing engineering time and cost. Developing a single, reconfigurable test fixture and firmware eliminates the need to design from scratch for every printhead variant, reducing the product-development cycle.

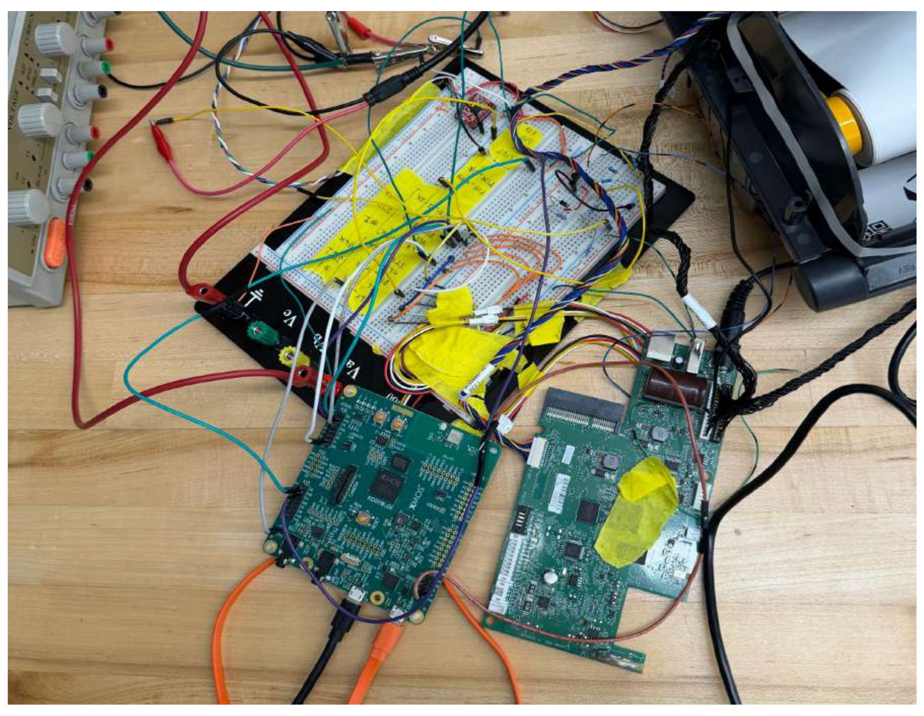
This project directly supports Zebra's goal of accelerating thermal printhead evaluation by creating a modular test environment. It integrates multiple engineering disciplines including embedded control, power electronics, and software design to simplify future testing and calibration when evaluating new printheads for Zebra products.

Anticipated Best Outcome

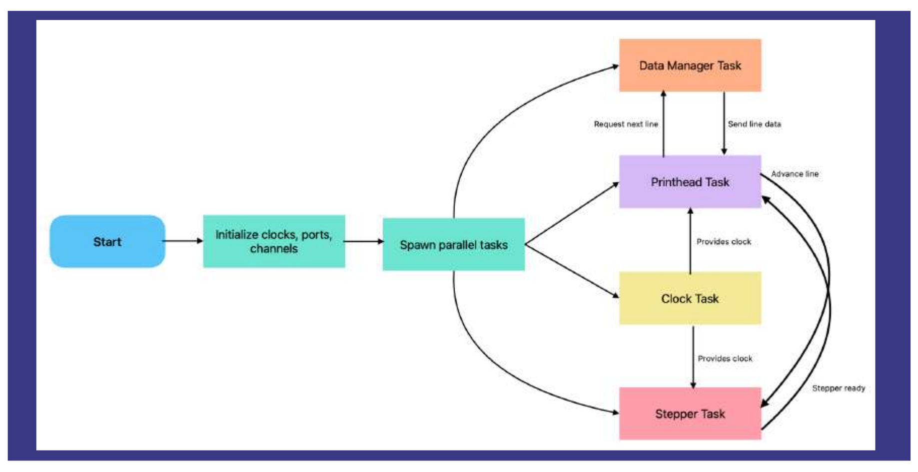
- Complete custom electronics capable of controlling any thermal printhead for use in a Zebra product (desktop, mobile, industrial, etc), supporting configurable voltage and logic delivery.
- Firmware and PC software interfaces that allow motor speed control, sensor calibration, and bitmap printing through a user-friendly interface.
- Successful demonstration of coordinated control between the motor, sensors, and printhead to produce a uniform printed output from a preloaded set of test prints (onboard image processing not within scope).
- Full documentation of hardware schematics, firmware, and user procedures to enable future iteration and use in the development process

Key Accomplishments

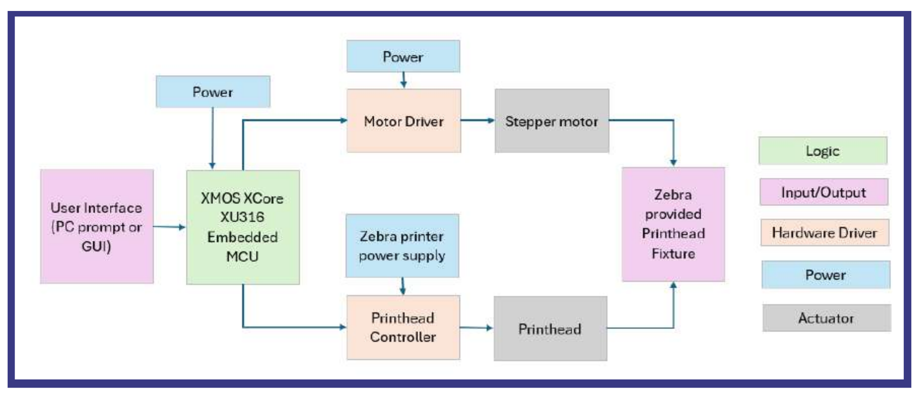
- **Proof of Concept Test Bench Development:** Fully functional modular wiring harness with printhead and motor integration using existing Zebra hardware to provide power to printhead driven using Arduino for temporary logic control. Illustrated operational proof of concept and a baseline with which to build off of.
- **Implementation of XMOS Processing:** Transition from Arduino scripts to full firmware utilization for driving of motor and printhead circuitry.
  Firmware development began with Arduino control scripts, later transitioning to the XC language for compatibility with the xcore.ai microcontroller. With the capability of parallel programming, tasks can run concurrently, with more precise timing and higher operation speeds.
- **Printhead and Motor Synchronization:** Initial synchronization framework between the printhead firing cycle and stepper motor motion has been developed and tested, using XMOS parallel tasks. With proof of reliable, concurrent operation, a guideline for coordinated-timing is established for the future.
- **Testing of Subsystems with XMOS firmware:** Diagnostic print patterns and controlled stepping sequences were performed to confirm reliable operation of all core hardware components. Timing signals, data output, and motor control behavior were verified through this testing on the latest firmware.
- **Logic and Voltage Delivery Systems Development:** Printhead voltage and logic controls vary by application (mobile, benchtop, industrial, etc.) and manufacturer. A specification was established to ensure the maximum number of printheads will work with the custom hardware and firmware solutions being developed.
- **Custom Hardware Solutions:** To power the printheads used on the test bench, a custom printhead control PCB was developed based on the operation of a wide range of printhead variations and configurations. A motor control PCB was also developed to drive an off the shelf step motor controller.



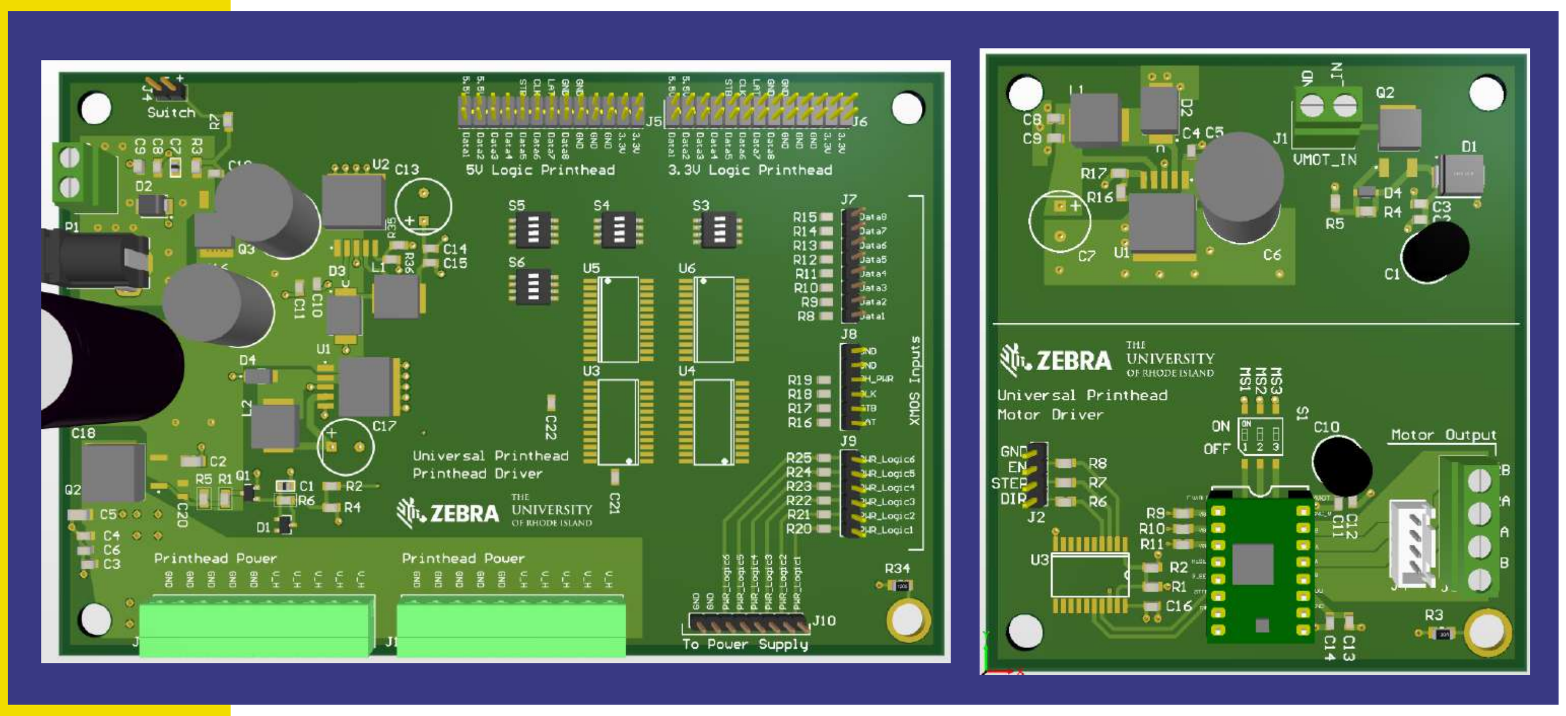
Current functional XMOS Core-AI powered test bench



High-Level Flowchart of Firmware Architecture



Operational Flowchart of Fixture Hardware



Printhead Control Board Design (left), Motor Control Board Design (right)

Implications for Company & Economic Impact

A successful best outcome of this project would strengthen Zebras overall efficiency and global competitiveness. The fixture will:

- Reduce R&D costs by eliminating the need for new printhead-specific firmware and hardware setups which will save engineering and manufacturing resources.
- Accelerate the time to market by allowing engineers and technicians to qualify new printhead designs faster, enabling a more nimble production process given supply chain constraints.
- Enhance product quality by supporting more strenuous and repeatable testing procedures yielding higher print uniformity and reliability.
- Support future expansion by providing a modular foundation that can be updated for new printhead technologies and test procedures when deemed necessary.

Remaining Technical Challenges

- **Custom Driver Board Manufacturing and Validation:** Printhead and motor driver boards will be ordered over Winter 2025. Validation of proper functionality and printhead power capabilities across established voltage range, logic configurations, and data rates before integration with printhead use.
- **High-Speed Signal Integrity for Printhead Data:** Reliable data transfer from the XMOS controller to the printhead at high speeds is critical to prevent image corruption. This involves validating line impedance, tuning series resistors and ferrites, and confirming clean strobe/latch timing across multiple printhead models.
- **Bitmapping Pipeline/Data Processing:** A complete rasterization pipeline allows a variety of image data to be processed and tested. This also ensures smooth, high-speed data streaming to the printhead.
- **Integrated Hardware-Firmware Stress Testing:** Final verification requires flashing the validated XMOS firmware and testing fault conditions, timing margins, and sustained operation under realistic print loads. This confirms the fixture's readiness for ABO acceptance as a production-relevant test platform.
- **Universal Fixture Electrical Validation:** Evaluate the fixture using a wide range of Zebra printheads, each supporting different voltage levels, data rates, and drive requirements. This requires full electrical characterization of the power, motor, and logic paths to verify operating limits before formal ABO validation.
- **Test Procedures and Documentation:** Prepare full fixture operation documentation to hand off to Zebra engineers to ensure smooth adaptation.

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