ELECOMP CAPSTONE
VIRTUAL SUMMIT
FRIDAY, MAY 7, 2021

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FaultLine

SmartPDU1 Fault Detection Unit Integration

Acumentrics
TRUSTED POWER INNOVATIONS®

Team Members: Anna Skelly (ELE), Dylan Keezer (CPE), McKensie Sherlock (ELE), Oscar Ramirez (CPE)

Technical Directors: Brenden Smerbeck ('17), Mike Majdalani ('18) | Consulting Technical Director: Najib Ishaq

Project Motivation

All electronic devices require energy to operate – which can be derived to a voltage and current value. In these electronics, power consumption changes over time; consuming a varying amount of power depending on the intended action. By analyzing the consumption of power, a system can not only uniquely identify a specific device amongst others, but also learn how that device operates. The SmartPDU1 houses a state-of-the-art computing system specifically designed for Machine Learning and Artificial Intelligence. Last year's ELECOMP students were successful in designing and implementing a Fault Detection Unit (FDU) – capable of analyzing the power signature of an electrical appliance and detecting fault states in real-time. Having the FDU integrated into the SmartPDU1 would continue the cutting-edge technology. The SmartPDU1 was designed to be the first fully featured and commercially available product to utilize the FaultLine FDU to perform non-intrusive load monitoring (NILM) in order to identify faults before they occur.

Key Accomplishments

Machine Learning (ML) Crash Course: For this project, all members of Team Acumentrics FaultLine were required to take Google's Machine Learning crash course (with TensorFlow APIs). This crash course walks students through key ML concepts including but not limited to: Hyperparameter Tuning, Feature Selection, Splitting data into Training, Validation, and Test sets, Loss Reduction, Feature Crossing, and Inference.

ML Model Pipeline: Last year's Team developed a script to train a Recurrent Neural Network (RNN) using TensorFlow. The process included splitting the data into appropriate datasets (training, validation, and test) and then training this ML model on data windows from the training and validation data sets. After the model was trained using both the training and validation sets, the accuracy of the model was evaluated using the test set. The reworked version of last year's model pipeline changed how data is passed through the model **(Fig. 1)**. When data is collected using the FDU, the user must now place the collected data within the model's "data directory". Within this directory, there are folders labeled "train", "validate", and "test", which house the appropriate data for the continuing growth of our ML model. The data in each of these folders is then groomed to be read and passed through the model through a script called pre-parse. The data is separated like such in order to ensure one specific data set cannot intersect with another set. After the data is cleaned and formatted, it is now ready to be trained by our model.

Populated FDU Board for Three-Phase Power: While the FDU board was designed to monitor a three-phase device, it had since only been used for single-phase devices. Therefore, the correct configuration on the FDU for three-phase power was implemented. The team had to learn about three-phase power and how to correctly implement it on the FDU without documentation. **Fig. 2** shows the FDU populated for three-phase power.

Implemented Mock Three-phase Collection and Prediction Capabilities for the FDU: The previous collection script for the FDU was modified, depicted below in **Fig. 3**, where features corresponding to the two new phases were added. A model that can predict faults in a three-phase device was created using the new model created for the 8-outlet PDU as a base. Due to safety concerns, the team did not test the board with an actual three-phase power source or device, and instead simulated a three-phase device using three fans, one for each phase.

Move Models to PDU: The models we are using for our project are being trained on a desktop before they are moved to the PDU. This is because of the size of our datasets being incredibly large. The training for these models is being performed using the Nvidia GeForce RTX 2060 Super graphics card on one of our team member's home workstation. Right now, the key factor we are trying to overcome is increasing the model's accuracy. As soon as we have a model with an accuracy greater than 80%. We can transfer this high accuracy model onto the PDU, and establish the inference data pipeline to the web application.

Design Web App for the PDU: Developed a web application with Python and a framework called Streamlit. How the web application works is that during live inference the PDU will always output a CSV that will state the status of each fan. Once CSV is read by the web application then it will output the results on the webpage displaying to the user if a fan is in working order or not. Also, since live inference will be producing a new CSV file every second the web application will also display new results every second. On the web application you also have the option to stop live inference if needed. **Fig. 4** shows the web application during live inference.

Anticipated Best Outcome

The ABO of Project Faultline is twofold. Firstly, a Power Distribution Unit (Acumentrics SmartPDU1) must be integrated with last year's Fault Detection Unit (FDU). The integrated system must both model multiple connected devices as well as detect abnormalities in each device's behavior. The system must also read the power signatures of each connected device through non-intrusive load monitoring and perform real-time inference to indicate each device's state. The team will also attempt to use the embedded computing platform to train the machine-learning models in the eventual PDU implementation, rather than training the models externally. Secondly, the original FDU implementation, board and ML model, must be converted to three-phase power.

Project Outcome

The Anticipated Best Outcome was achieved.

Figures

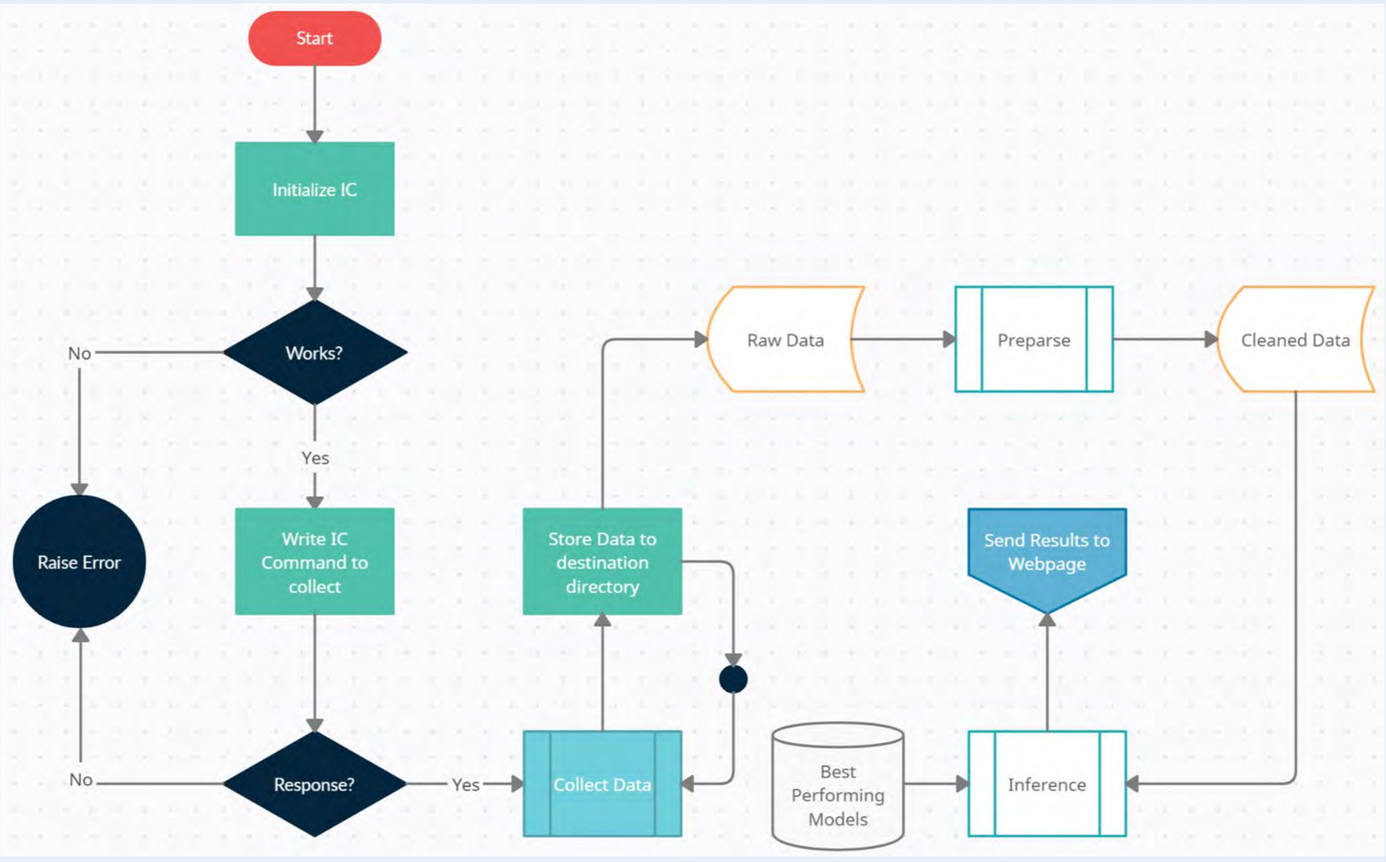

Fig 1. Block Diagram of the SmartPDU1 Data Pipeline

Fig 2. FDU populated for Three-Phase Power configuration

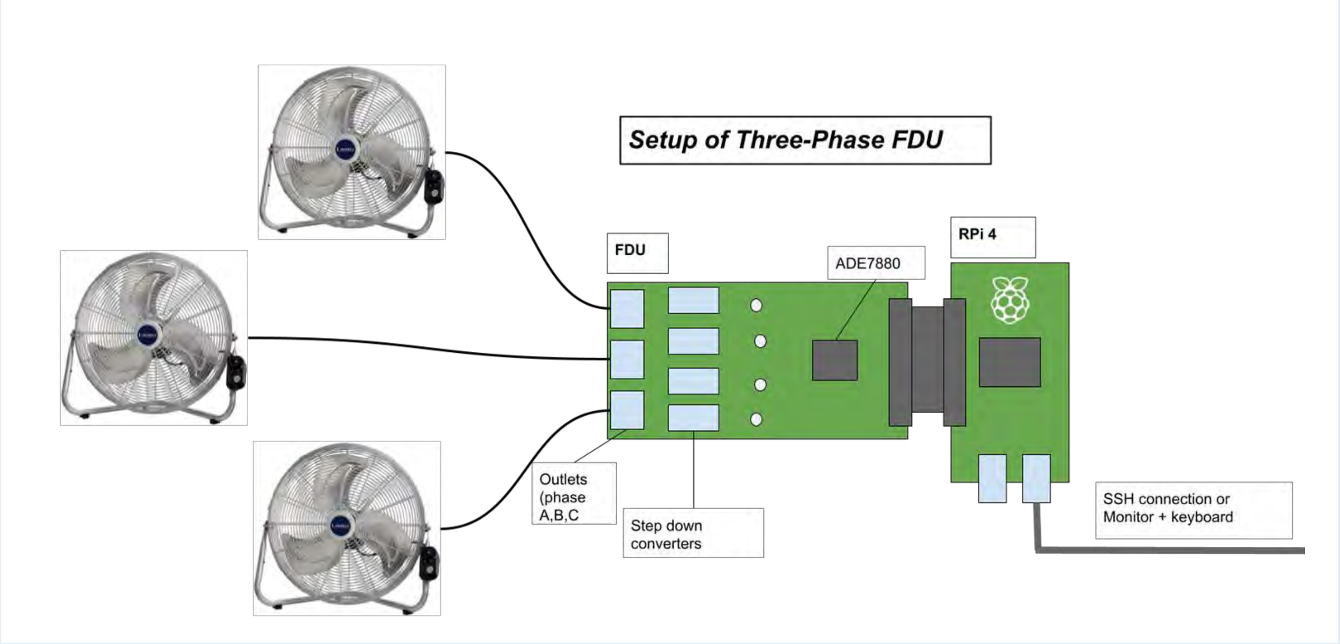

Fig 3. Diagram of the three-phase FDU

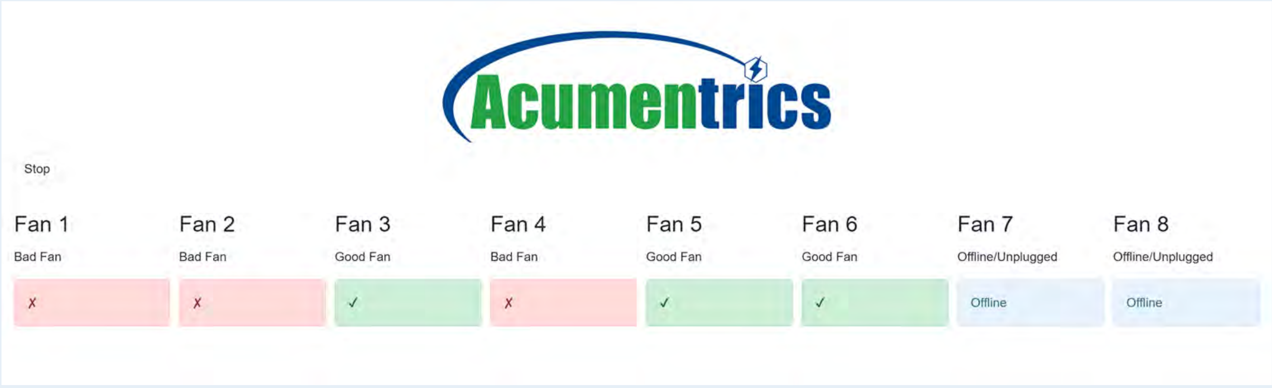

Fig 4. Web Application during Live Inference

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone

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Acumentrics N-Plus

Optimization of Parallel Uninterruptible Power Supply (UPS) Operation

Team Members: Nathan Chofay (ELE), Rute Gidey (ELE)

Technical Directors: Brenden Smerbeck ('17), Mike Majdalani ('18)

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Project Motivation

A parallel-redundant UPS system is one in which two or more modules are installed on the same system in what is termed an N+X arrangement. Parallel redundancy allows for the failure of one single UPS module in the configuration without the need Page 3 of 6 for the protected load to be transferred to mains power. In such an event, the other UPS modules can take over the total load. Control of parallel UPS is normally managed using a primary/secondary arrangement whereby a primary controller acts as the brains of the system and determines operating parameters: how UPS modules synchronize their outputs, how they share loads, and where their control information comes from. It does, however, requires complicated control wiring between UPS modules. Inconsistencies in manufacturing and assembly result in parallel load failures. To reduce the occurrence of faulty cables and to reduce the cost of manufacturing, a simplification and design revision is proposed.

Key Accomplishments

Hardware Familiarly: Within the current parallel cable there consists one primary board and multiple secondary boards based off design. The primary board is assigned to the primary UPS to help determine communications to the secondary UPSs that are also in use as shown in **Fig. 4**. A cable redesign is looked to be accomplished by inputting a combined primary and secondary circuit board into each UPS. The cable input with be the identifier for if the UPS that it is plugged into is the primary or secondary board

Components: Multiple websites were searched in order to find similar components used in the current project design. These parts were necessary to be identical in order to match the test provided by Acumentrics exactly. Due to some current PCB components not having a similar through hole equivalent, adopters were needed to be purchased as well. Adopters that were used for PCB to through hole conversions needed to be soldered for the identical results. The green components are the adaptors used in this project as seen in **Fig. 1**.

Assembling: Using the components purchased, two breadboards were used to assemble two pairs of the combined primary and secondary boards, depicted in **Fig. 1**.

Testing: The signal mapping diagram shown in **Fig. 2** was used to help with signal testing. With use of a frequency generator and oscilloscope, we were able to confirm that the CUR_CRTL_IN_SLAVE was mimicking the same signal as that of the CUR_CRTL_IN_MASTER that was being inputted. This confirmation will help with future testing involving the combination of the primary and secondary boards

Hardware design: The two original primary and secondary schematics were updated to be combined and with seven 4-switch components. These switches will help to distinguish between primary and secondary signals from the UPS's. Each switch will be defaulted to direct the computer board signals to the primary portion of the board. The switches will then look for a five-volt signal from the input connector of the UPS to toggle over to secondary.

PCB design: The original PCB design consisted of the primary board and the secondary control boards being placed in separate locations. The software that was used to create this schematic is PADS Professional. The new combined board schematic uses both the control boards on one PCB, that way a single combined PCB can be placed in individual UPS's instead of the separate cables that communicate with the UPS's. The primary section of the board sets the UPS as a primary power supply initially, then the switches and the connectors, which are implemented in this new PCB design; depicted in **Fig. 3**, determine whether it serves as the primary UPS or secondary UPS. In the parallel N+X arrangement that is being used, there is direct signaling from the control board to the computer board of the UPS that will let it know whether to act as a primary or a secondary power supply and allow it to communicate to corresponding UPS without the need for complicated cables located externally. The printed board can be seen in **Fig. 5.**

Cable reconstruction: The new cable design is important because the two plug-in connections to the UPS will be the new way in determining if the UPS is a primary or secondary. Before this primary or secondary call out was established by adding the circuit boards in the middle of the cable wire. To make this design simpler, our idea is to have two connectors on the back of each UPS and move the combined PCB board into each UPS. This design will call out the switches to toggle to secondary if the input connector on the back of the UPS is plugged in (with five volts coming in). This will save time and money because the PCB board is taken out of the custom cable and the new cable design will not require there to be a costume cable for each customer. The new cable wire now just acts as a wire pass through and is easier to make.

Anticipated Best Outcome

The team will combine the current two PCB modules that are built into the cable and integrate the newly designed PCB module inside the Rugged-UPS™ 2500. The PCB module will be capable of acting as either primary or secondary. This allows many UPS's to be placed in a parallel-redundant system. In addition, if the primary UPS was to break down or stop working, the secondary UPS would receive that signal and act as the new primary UPS. To accommodate the integration of the PCB module within the Rugged-UPS™ 2500, the original parallel cable will be redesigned.

Project Outcome

The Anticipated Best Outcome of the project was not achieved. Our PCB board has been printed and is currently being populated. We are aiming to test its functionality soon.

Figures

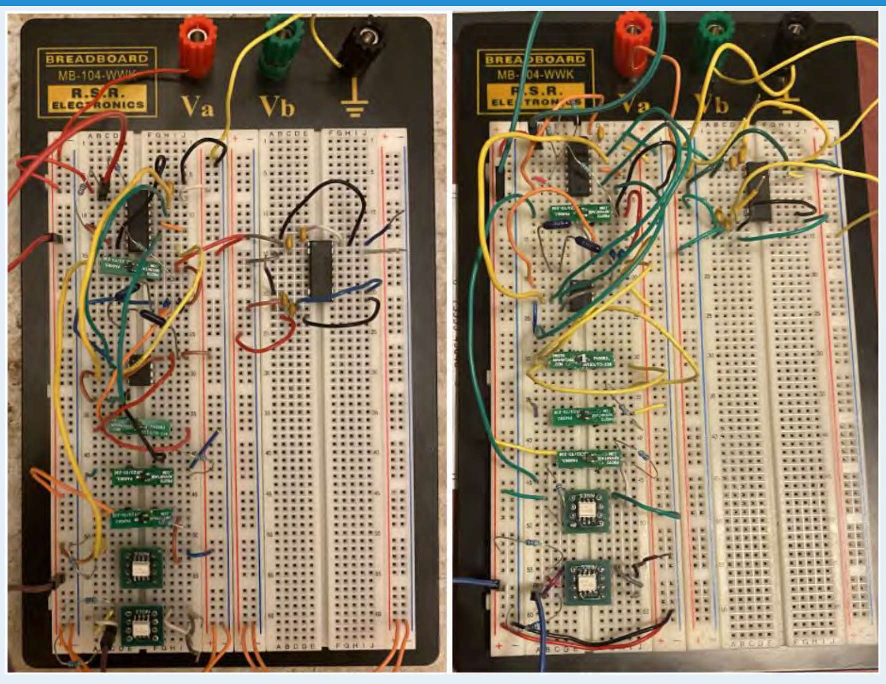

Fig. 1: Two circuit boards built combining primary and secondary

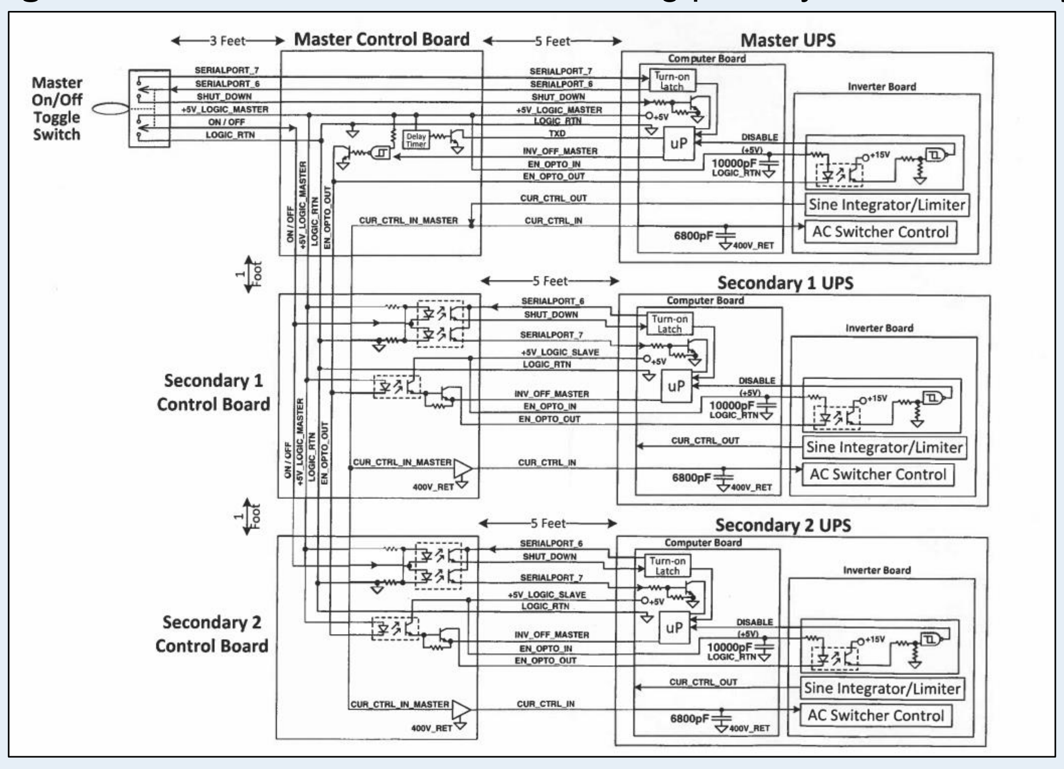

Fig. 2: Full System Diagram

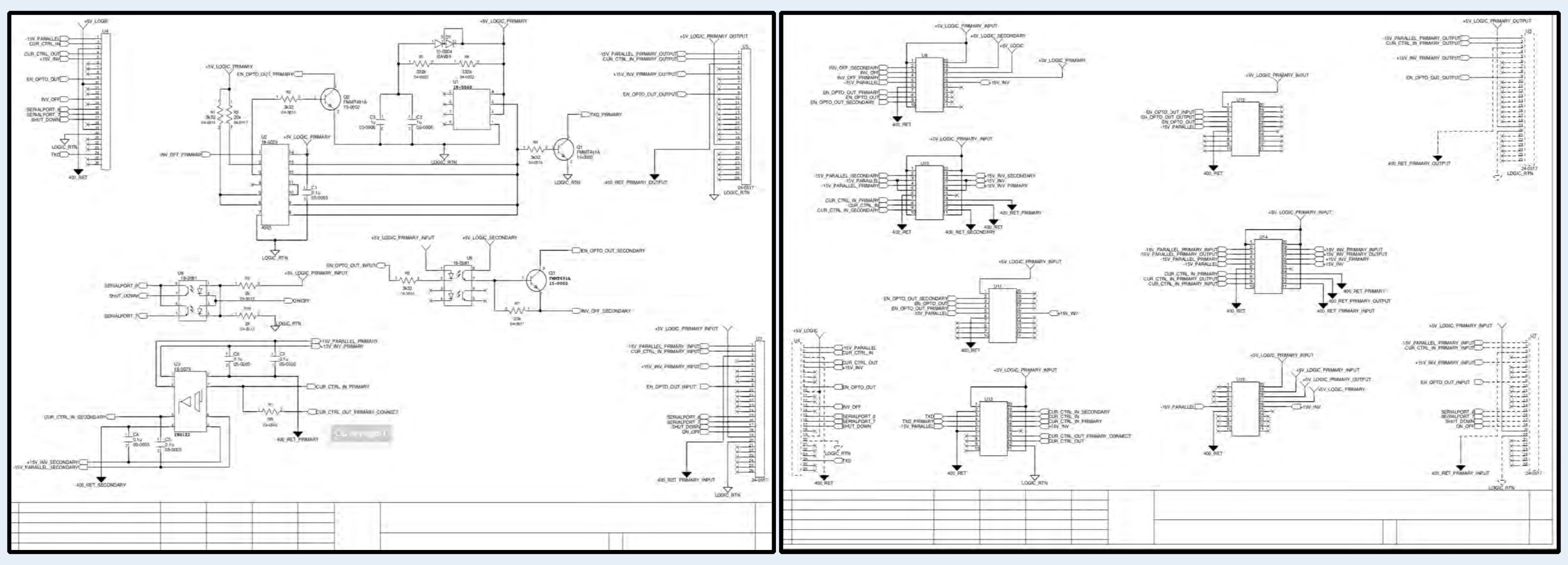

Fig. 3: PADS Designer schematic of combined PCB with switches

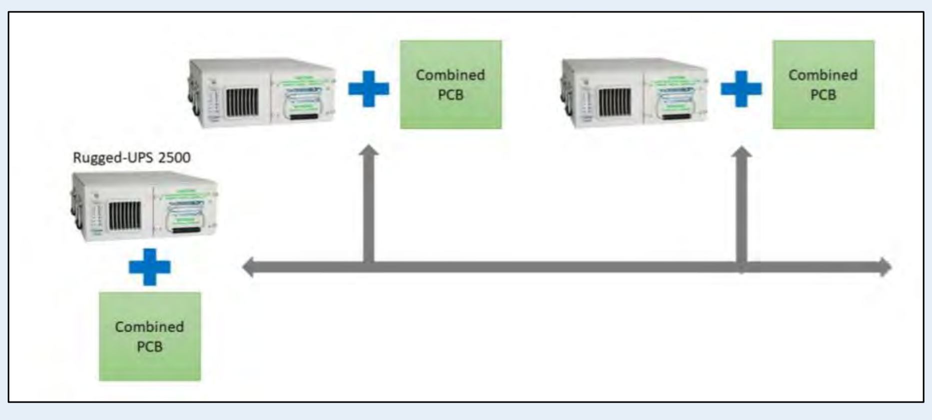

Fig. 4: Flowchart of communication between UPS devices

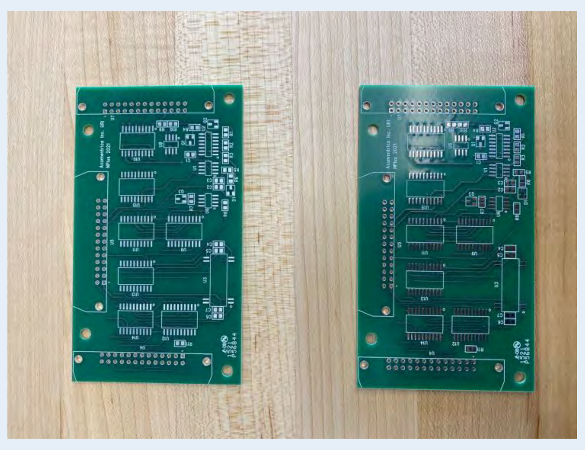

Fig. 5: PCB

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone

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AM-BATS

Advanced Modular Battery System

EAGLEPICHER TECHNOLOGIES

Team Members: Adam Bouchard (ELE), Alexis Charpentier (ELE), Nicholas Clavette (CPE), Daniel Mark. Jr. (CPE), Jeremy Zarro (ELE)

Technical Directors: Daniel Wertz, Dan Noreck, Frank Puglia | Consulting Technical Director: Brenden Smerbeck ('17)

Project Motivation

Performance and lifetime are major factors in designing battery powered products. Lithium-ion batteries in particular are vulnerable to stresses experienced throughout their service life. Additionally, the circuits responsible for controlling and monitoring cells in a battery must be capable of performing under the same stresses. In a complete battery design, the cells, management circuits, and control schemes must work together seamlessly. Many aspects of battery design and performance are well understood. However, there are some persistent topics that plague the ability to accurately predict and track the performance of Li-Ion batteries. Design questions may include: How long will a charge last? How many cycles can the battery survive while enduring temperature extremes? Will the system tolerate faults? If a fault occurs, will the system adapt or fail? New approaches to design and reliability modeling are needed. Exploring possible solutions to the questions above is the project motivation for EaglePicher.

Key Accomplishments

Analog Front End (AFE) Hardware Selection:
A key feature of a battery management system (BMS) is its ability to accurately measure important information about a battery under management. These measured values are analog and include the voltages of the batteries' cells, the temperature of the batteries' cells, and the electrical current going into and out of the battery. The part of the BMS responsible for recording this key information is known as an analog front end (AFE) of a battery management system. The hardware selections used in our AFE are described below:

- **Microcontroller Selection:** The Linduino One microcontroller, DC2026C, was selected as the main A/D hub. It is a modified Arduino, which allowed for easy programming to establish data collection from the AFE hardware.
- **Battery Cell Voltage Sensing:** The DC2259A 12 cell battery evaluation board was selected to provide cell voltage measurements. An isoSPI transcoder board, DC1941D, was selected to interface the Linduino with the evaluation board. isoSPI provides an isolated SPI signal for long distance data collection applications.
- **Battery Cell Temperature Sensing:** For temperature sensing, 10kOhm thermistors were selected whose outputs would be read by the analog pins of the Linduino. Two CMOS 8-channel multiplexers are used with the thermistors to reduce the number of analog pins needed for sensing.
- **Current Sensing:** A current sense circuit was designed with the primary intention of using measured currents to perform Coulomb counting, **Fig. 4**. The secondary function of the current sensing circuitry is to drive a FET in the charging circuitry as part of its safety functionality. The current sense circuit is based on a bidirectional current sensing design from the LTC6101 datasheet with custom tailored gains on each of the two amplifiers that are scaled to output approximately a 4V maximum when the batteries are both charging and discharging. While charging, the discharge branch of the circuit is deactivated, and vice versa. The outputs of this module are passed to analog-in pins on the Linduino to be converted to digital signals and then recalculated as current based on the respective channel's gain equation.

Programmable Battery Discharger:
In order to test algorithms for SoC and SoH, we needed a way to discharge our batteries. We created a programmable loading solution that allows any load applied to a battery to be emulated easily and repeatedly. A load driver circuit was designed to throttle current out of our battery through a resistive load bank shown in **Fig. 3**. The load driver circuit uses a power MOSFETs operated in linear mode to throttle current through a resistive load bank. The load driver circuit also has under voltage protection, clamping the NFETs gates to ground, stopping discharging if need be.

Programmable Battery Charger:
In order to test algorithms for SoC and SoH, our BMS needs to be able to control charging the battery. We developed a charging circuit consisting of safety cut-offs, a current sense input, and PFETs which is shown in **Fig. 2**. The safety sub-circuits use a comparator op amp ADCMP391 and implements hysteresis to prevent over voltage or over temperature. The PFETs were chosen because of their high-power dissipation rating. There are two PFETs with their sources and gates connected to ensure that the current is flowing in the right direction.

User Interface: A user interface was programmed using Python's tkinter library. It allows a user to define the parameters of a test and data collection. It is the front-end interface to a driver script, which drives the hardware above through a battery test **Fig. 1**. Some parameters which can be defined are the number of charge / discharge cycles to be performed and the custom battery charge and battery load signals for the programmable charger and discharger. Once the parameters are defined, the user can start the test and see the current, temperature, and cell voltage data. This data is also be stored in a spreadsheet.

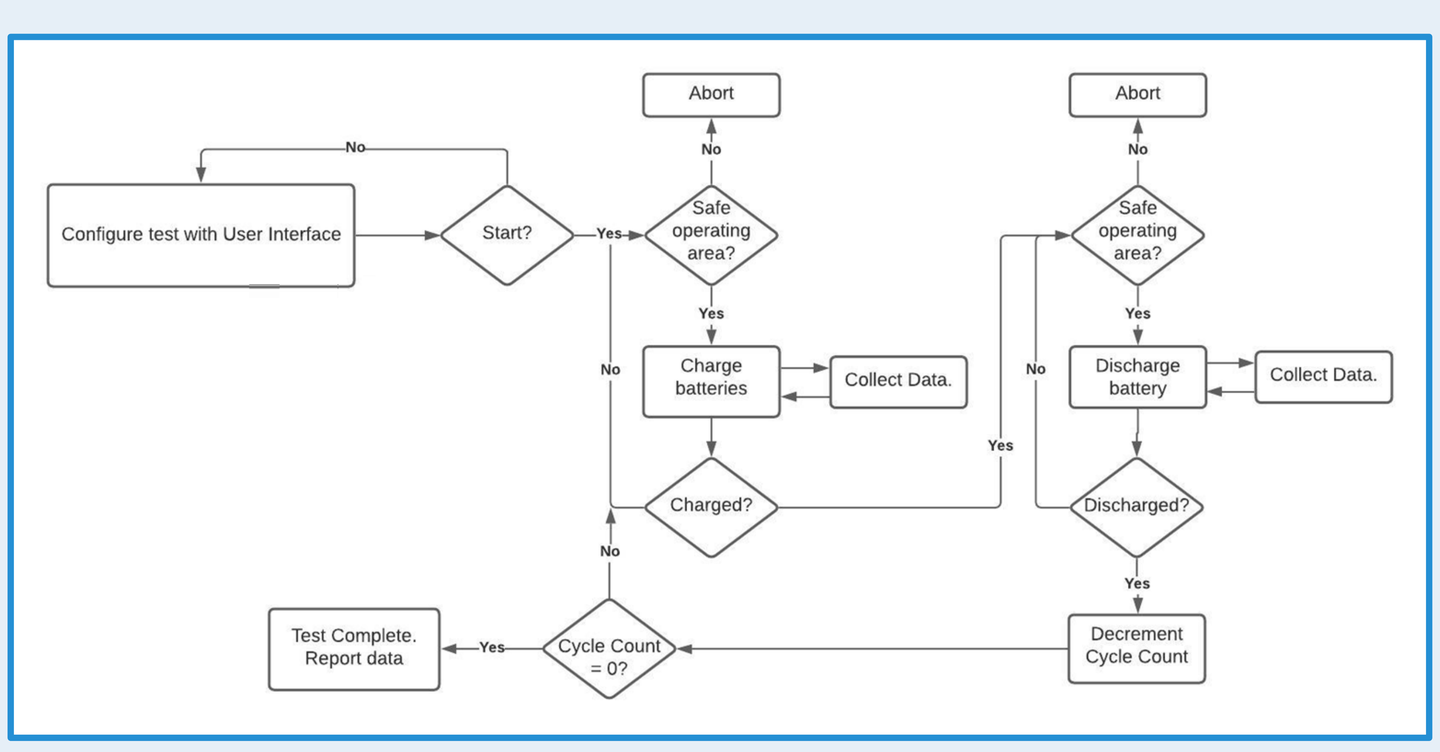

Fig. 1: A simplified flow diagram describing the processes executed during a battery test.

Anticipated Best Outcome

The original anticipated best outcome for the project consisted of two goals: To identify methods that would improve the correlation between the design intent of a battery management system and the actual observed performance, and to develop predictive models to compensate for natural cell degradation over time. However, challenges encountered throughout the course of the project caused the ABO to shift to a more obtainable, focused goal: To develop a reliable battery testing platform, which will allow successors to easily test battery SoC algorithms through controlled charging and discharging cycles. It includes in-depth details of what has been done in the project thus far, why certain choices were made, and the lessons learned from experiencing the complexities.

Project Outcome

The Anticipated Best Outcome was achieved! The team was able to create a system capable of monitoring the properties of batteries and executing automated tests. Future Capstone designers will be able to build upon the system to become more advanced and continue research into battery management algorithms.

Figures

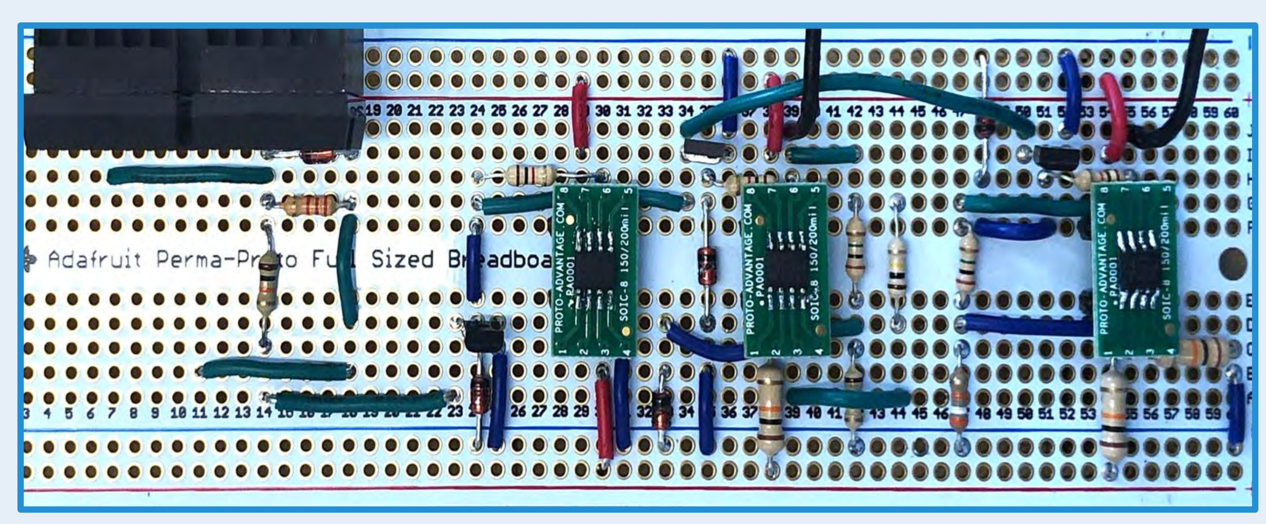

Fig. 2: The charging circuit driven by a programmable input signal. Overvoltage and overtemperature protection circuits seen to the right.

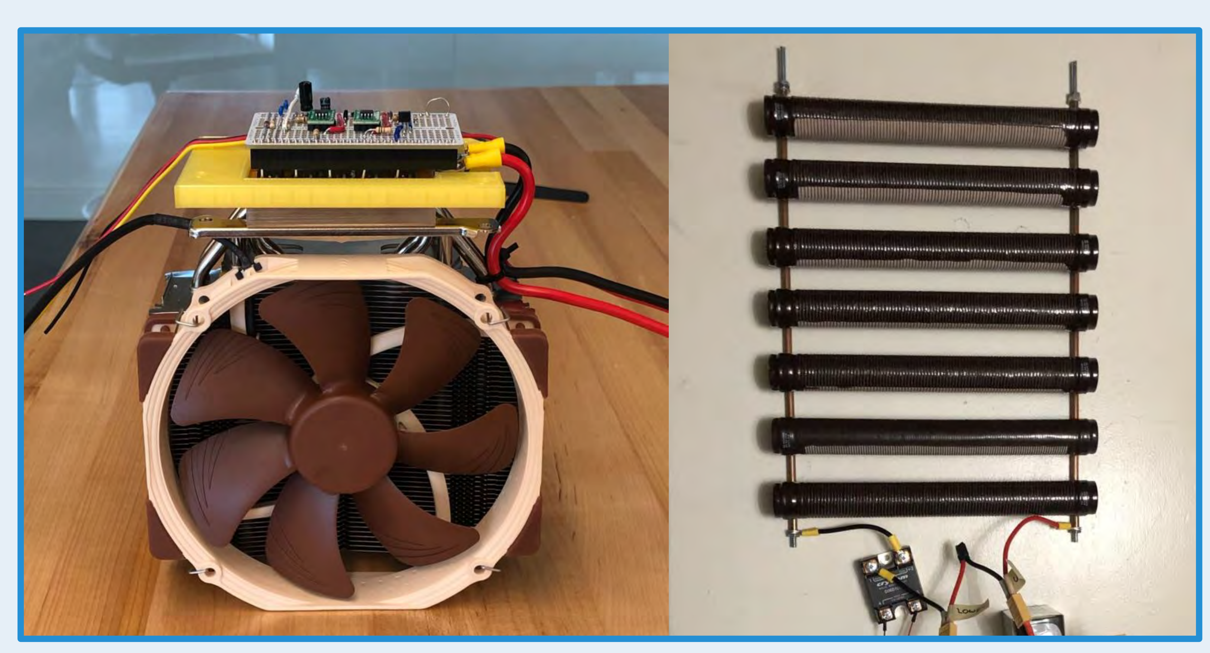

Fig. 3: The programmable load driver circuit and FET cooling solution (left) and power resistor load bank (right). Battery load current is throttled through the load bank with the load driver circuit.

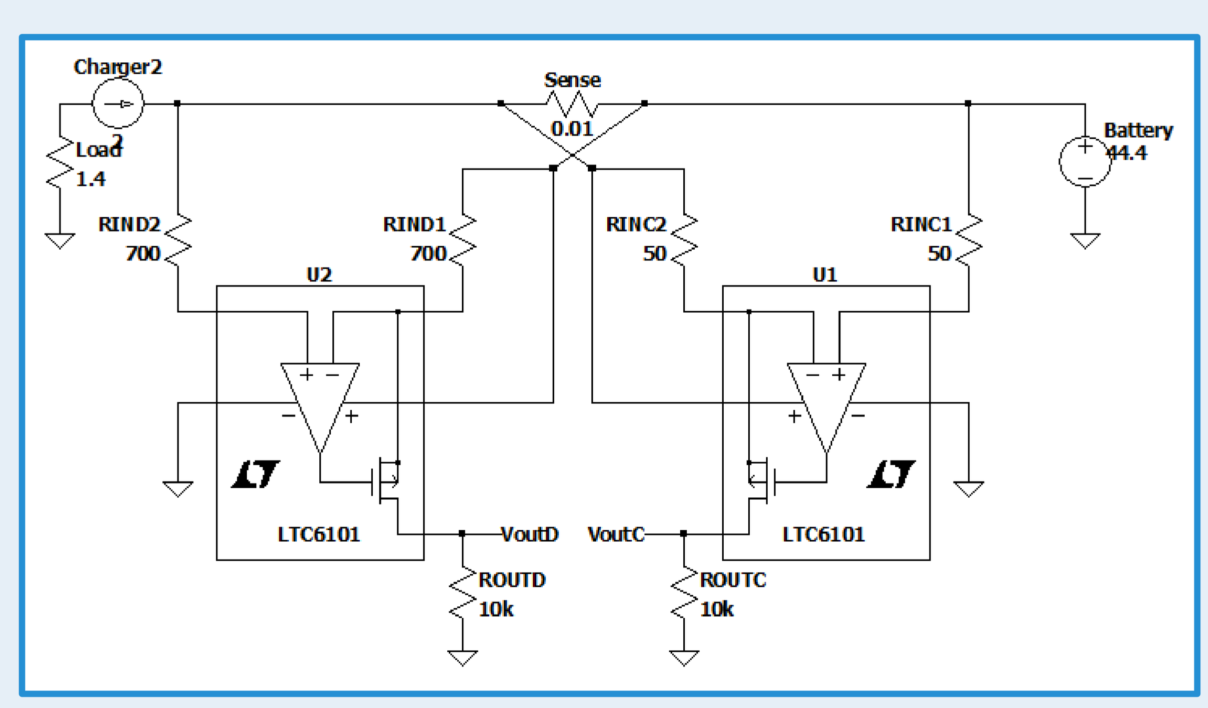

Fig. 4: The bidirectional current sense circuitry. Input resistors tailor the amplifier gains based on the anticipated maximum currents. The direction of current flow also turns on/off the amplifiers depending on whether the batteries are charging or discharging.

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BE-SAFE

Battery Event Safety Alarm Fixture

EAGLEPICHER TECHNOLOGIES

Team Members: Sarah Arribas (ELE), Christopher Conklin (ELE), Joshua Minasian (ELE), Jacob Muller (CPE)

Technical Director: Dan Noreck | Consulting Technical Directors: Daniel Wertz, Frank Puglia, Brenden Smerbeck ('17)

Project Motivation

Unique safety challenges are posed in the manufacturing, transportation and use of modern battery designs, which are ever increasing in power and capacity. Recognizing inherent hazards, EaglePicher Technologies (EPT) is committed to providing the safest possible environment in the manufacturing of these potentially dangerous batteries. The DC voltage of a charged, high-voltage battery creates some potentially deadly shock hazards when immersed in water, and challenges in detection of these hazards from a distance. While live AC power lines can be detected from a distance by devices often carried by firemen and utility workers, DC fields do not propagate through the air and require different means of detection. The motivation of this project is to determine if an effective method for detecting shock hazards in proximity to high-energy batteries can be identified, and to develop a device to provide an early warning that such a hazard exists.

Key Accomplishments

Initial Research:
Various sources regarding the resistance of a human, existing battery voltages, data analysis, physics of electric fields, and existing DC current detection technologies were consulted to create initial mathematical models of the scenario and to determine possible solutions in DC field detection from a distance.

Simulation of Scenario:
A power supply set at various voltages had its leads submerged in tap and simulated sea water and measurements of both voltage and current were taken at predetermined intervals to find the voltage and current distribution in water, on a 10"x36" scale with two separate puddles and an 8'x8' scale with a single puddle. Human resistance when immersed in water was measured by connecting an ohmmeter to two copper plates in water and having various test subjects complete the circuit. This determined resistance was simulated by a 2.7kΩ resistor and used to find expected current at various distances from the source.

Mathematical Modeling:
Using the data obtained from the experiments, the scenario of a high-voltage DC source immersed in water was modeled using Matlab to visualize the experimental data and to extrapolate and determine a risk radius in a real-life scenario (**Fig. 2**).

Preliminary Design:
A prototype and a bill of materials (BOM) was designed, using a Raspberry Pi Zero W, as the primary microcontroller, an LED strip to display risk level, and an analog/digital converter to convert the sensed voltage to a digital value for the microcontroller to use. A voltage clamp was designed to isolate the sensor voltage from the internal A/D converter to prevent it from completely damaging the device if it does encounter a high voltage across its probes. This voltage clamp automatically would reduce the input voltage if a dangerous condition was met.

Build Concept:
The parts were chosen to fulfill an attenuation factor which allowed for attenuated reading to be recorded from terminals submerged in water. This attenuated reading was read by an evaluation module which outputted the reading through Texas Instrument's provided GUI (**Fig 1**).

Buoyant Housing:
A suitable housing was created to be able to keep the device's sensors in the water without subjecting the device to total submersion, which may have damaged it. The design was buoyant, easily-maneuverable, and retrievable in most water conditions.

Concept Bench and Field Testing:
The concept was bench-tested for functionality before field testing in tap and salt water. These tests were recorded and analyzed in 3D plots generated on Matlab (**Fig. 2**).

Research Prototype Functionality:
Research was done into Bluetooth and Wi-Fi functionality, but was decided to not be applicable after conducting market research.

Software Development:
An Arduino was chosen as the best microcontroller to use for the prototype device. A programming flowchart was created to better understand how to function the TI ADC and light the LEDs to warn users **(Fig. 3)**. Code has been written to power on the ADC.

Prototype Design Battery:
Research was done into specific battery selection, determining that a three terminal battery would allow for Voltage Overload protection. It was decided that the battery would possess 140 working minutes, but it was decided that future generations of the project must work to reduce this.

Prototype Design Microcontroller:
Research was done into a specific microcontroller to use, settling upon the Arduino Nano 33 BLE due to the fact that the BLE possesses a 64 MHz core clock and a 12 MHz clock for SPI transmission. Theoretically the normal Arduino Nano could be utilized if a specific set of steps are utilized.

Prototype Design PCB and Schematic:
A PCB was designed utilizing an Altium-based program to represent a polished circuit ready to be printed (**Fig. 4**). This design was also constructed utilizing a schematic made in the same program (**Fig. 1**).

Anticipated Best Outcome

The Anticipated Best Outcome (ABO) is a functioning Proof of Concept that is capable of detecting dangerous conditions caused by a high-voltage DC battery immersed in water and providing a warning notification when dangerous conditions are met. The device must be able to operate in both tap and salt water, be able to detect danger without a common ground voltage reference, and notify the user from a distance to maintain the user's safety. The ideal outcome would be the beginning construction of a portable device that is usable by first responders through the designing of a PCB, 3D housing, schematic, and pseudo-code.

Project Outcome

The current state of the project is a functioning Proof of Concept Device that is capable of detecting dangerous conditions. Research has been conducted and plans have been laid out for a future Prototype Design.

Figures

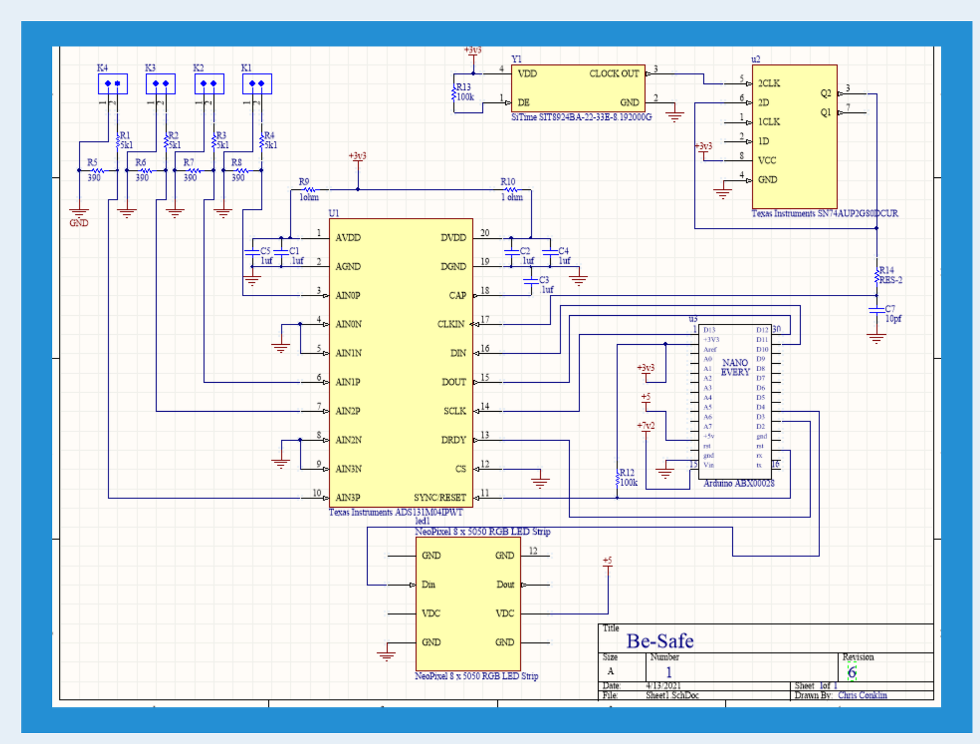

Fig. 1: Schematic of Prototype Design: This schematic design features the evaluation module connected to an Arduino, which then is connected to an LED strip. This was built on CircuitMaker, an Altium-based program.

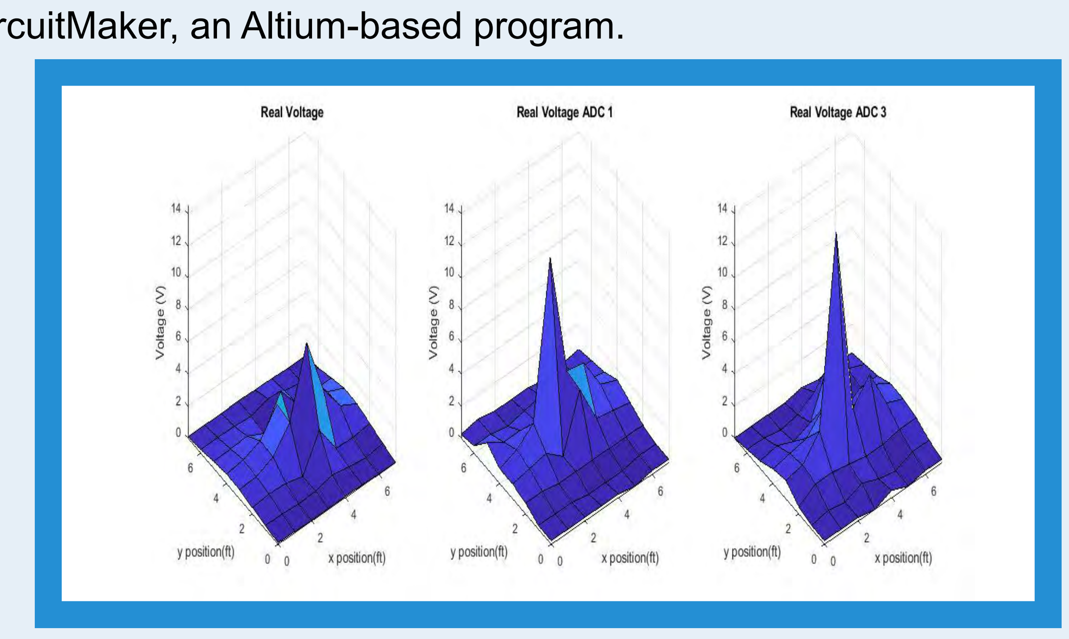

Fig. 2: 3D Mapping of Analog-Digital Converter Data from Proof-of-Concept Water Testing. As in previous tests, voltage measurements were taken in an 8' x 8' box with an average of one inch of water depth throughout and 300V from a DC power supply applied in the center of the box. The mapping transforms the nominal ADC readings to what the expected real voltage would be at each point based on past data.

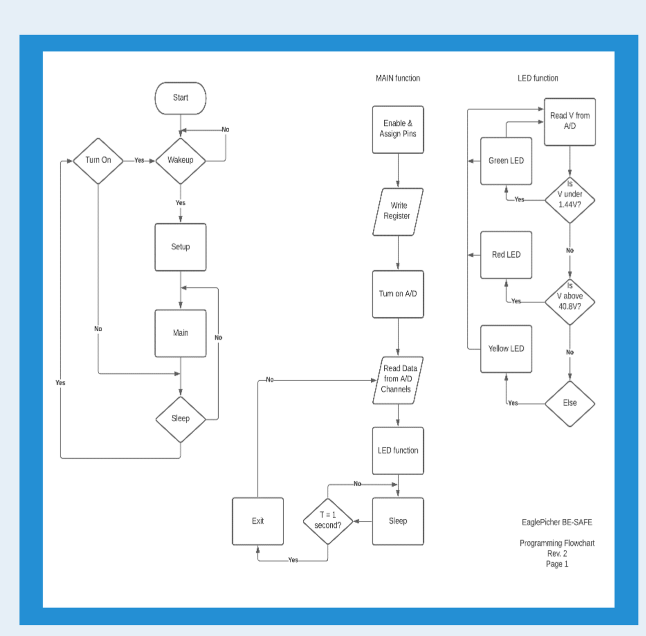

Fig. 3: Programming Flowchart: This chart shows the process of the Arduino code needed to turn on and off, setup, and read voltages from the TI ADC as well as light an LED to warn a user if there are dangerous levels of voltage present in surrounding water.

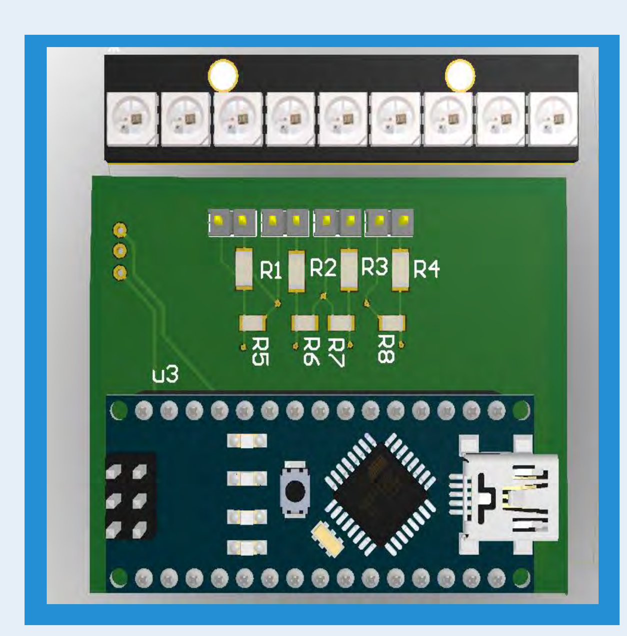

Fig. 4: 3D Model of PCB: A 3D generated printed circuit board constructed using an Altium based program. On the board it can be seen that the Arduino is regulated to ones ide, and the main circuit is regulated to the opposite side.

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Network Control Signaling - Precise Timing Control via Ethernet

FARSOUNDER

Team Members: Scott Brennan (ELE), Justin Hall (CPE)

Technical Directors: Matthew Coolidge, Matthew Zimmerman

Project Motivation

FarSounder's sonar has a transmit system that must be synchronized with the receiver's data collection system. The receiver system electronics are stored in the in-water portion of the system (the Transducer Module). Transmit system electronics are stored in the on-board portion of the system (the Power Module). A custom bundled cable with ethernet, transmit signal, power supply, and DIO conductors connects the power module and transducer module. The cable currently being used by FarSounder is clunky, large, and heavy, making it difficult to install and more costly to ship. The cable also requires many potentially unnecessary parts that increase the price of the cable. For our project, we hope to reduce the size of the cable by removing the potentially unnecessary DIO conductors, and using the existing ethernet cable connection to transmit the necessary data (**Fig. 1**). Reducing the size of the cable and the number of conductors within it will allow for a cheaper and easier to use product.

Key Accomplishments

Communication Method Selection: An ethernet-based network protocol was selected that meets our timing requirements in terms of accuracy. This protocol was identified to be the Precise Timing Protocol (PTP) (**Fig. 2**). It offers the capability for a master-slave style clock synchronization that can be within 10µs of accuracy. It was also necessary to identify some peripheral communication methods for interfacing with other devices in the sonar system.

Microcontroller Selection: A microcontroller evaluation kit was selected that allows for prototyping an ethernet-based clock synchronization implementation and has capabilities to interface with other devices in the sonar system. The device is NXP's MIMXRT1060-EVK. This board features an ARM-based MCU, 100mbps Ethernet with support for the Precise Timing Protocol (PTP), multiple USB ports, and much more. Development for this platform is done with the MCUXpresso IDE.

Learned development for our platform of choice: Through the use of many included demos and functions available for the MIMXRT1060, a strategy for development was put together. This included learning how to demonstrate program execution without a debug host controlling the execution. In other words, show the board booting from a power source and running a program of our choice without the intervention of a PC or IDE. Other tasks included learning to write values to GPIO, as it may be done to send signals to other parts of the sonar system.

Demonstration of Network Activity: We identified a C library that allows for the implementation of a full TCP/IP stack used for sending and receiving data: the Lightweight IP library (lwip). Using this library and its included functions, we can ping the development board from an ethernet-connected PC.

Conversion of AN12149 Demo Project from IAR-EW to MCUXpresso: We found a demo project that provides the foundation for what we hoped to accomplish with this project. It allows for PTP clock synchronization between two boards connected via ethernet. This demo was originally for an IDE called IAR Embedded Workbench. In order to use this demo project, we had to first make several modifications to get it to work in our IDE of choice, MCUXpresso.

IEEE 1588 Implementation on two microcontrollers connected by ethernet: After getting the demo to work, we demonstrated a successful PTP clock sync between two MCUs, using one board as a PTP master and the other as a PTP slave. We confirmed the results by using an oscilloscope to watch the delay between the master and slave signals decrease with time (**Fig. 3**).

Determine how long it takes for the sync offset to reach 10µs: Our technical directors specified that a delay of 10µs was a good threshold to determine that the boards had achieved sufficient synchronization. We determined that synchronization generally takes an average of 30 seconds. However, it can take as little as 10 seconds and as long as 60 seconds.

Test Synchronization with more variables: We tested to ensure the clock synchronization method works with other nodes in the network. This was done by adding a switch in between two of the boards. In doing so, we found that the switch imposes additional clock offset (**Fig. 4**). The added transmission delay from the switch affects the accuracy to which the slave is able to synchronize, as the master's recommended adjustment becomes less accurate in keeping the slave's clock in time with the master.

Determine how much bandwidth is being used: We determined how much bandwidth of our 100mbps link is consumed by PTP traffic. This is to determine how much headroom there is for sending other data over the network connection, such as sonar data or other control signals. By using WireShark and an Ethernet hub to analyze the traffic between the two boards, we were able to find that the protocol consumes only about **5.88kbps** of bandwidth on average.

Develop a set of instructions so that our work can be easily replicated: We have developed a set of clear and concise instructions that FarSounder employees can use to expand upon our work. We have provided all necessary steps to operate the IDE software and recreate all of our experiments from throughout the year. This is to help FarSounder with using our work to create a new and improved sonar system.

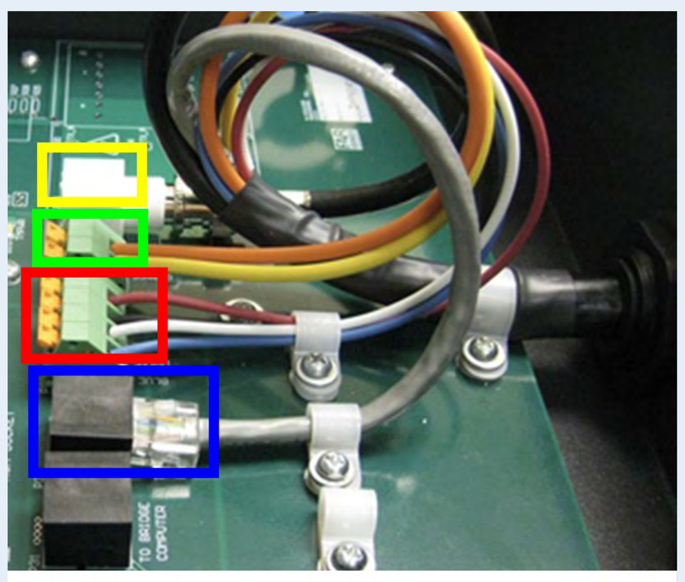
Anticipated Best Outcome

As originally planned, our ABO is to have successfully produced the sample source code for the development boards that meets FarSounder's requirements and can be used as a reference design by FarSounder for implementation in a future version of their electronics. This solution will be an entirely ethernet-based method to synchronize the transducer module and the power module in time. By implementing this method, FarSounder should be able to remove the 4 DIO conductors from their custom bundled cable. Overall, we hope that our solution can be used in the future in order to create a cheaper and more efficient product.

Project Outcome

We have achieved the Anticipated Best Outcome of our project. We completed all necessary tasks to create the foundation for an ethernet-based method to synchronize the transducer module with the power module.

Figures



Yellow: Transmit Signal
Green: Power Supply Conductors
Red: Digital I/O conductors
Blue: Ethernet

Fig. 1: FarSounder's currently used custom bundled cable

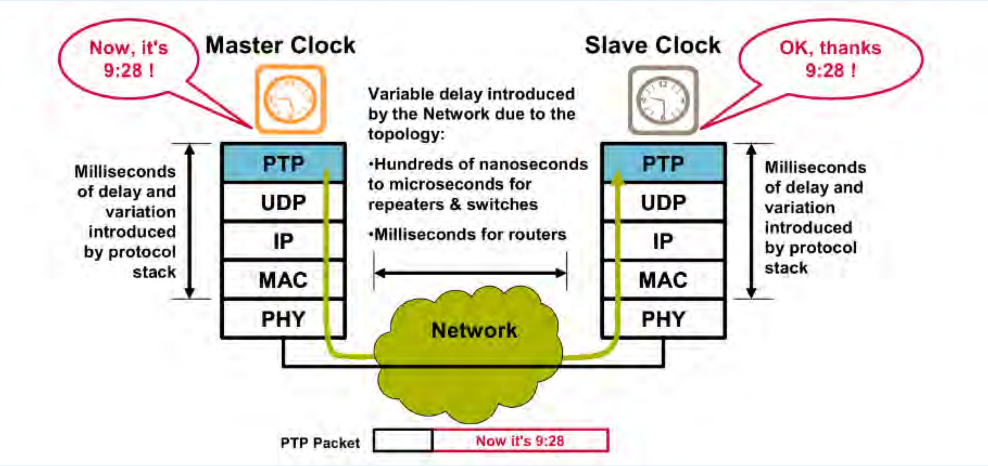


Fig. 2: Brief explanation of how PTP works on two microcontrollers connected via an ethernet network

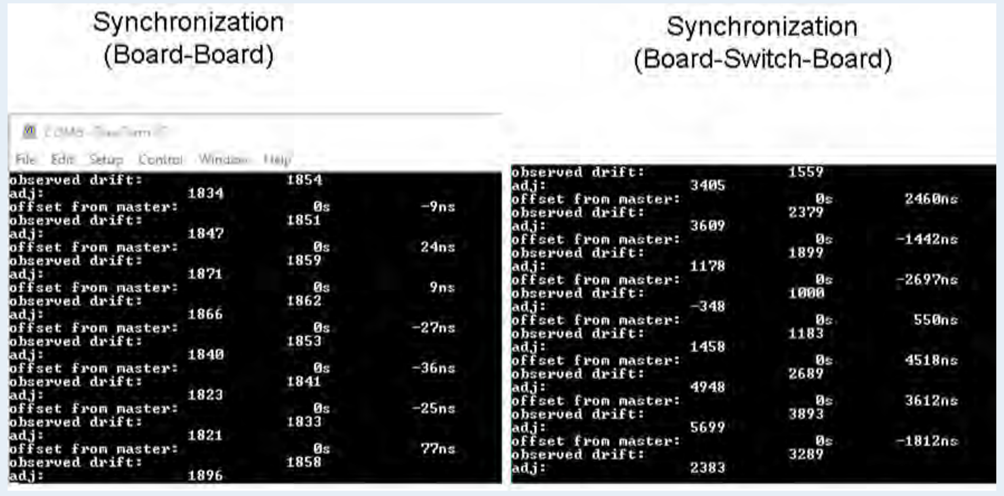


Fig. 3: Difference in achieved synchronization between a point-to-point connection and a connection involving an Ethernet switch.

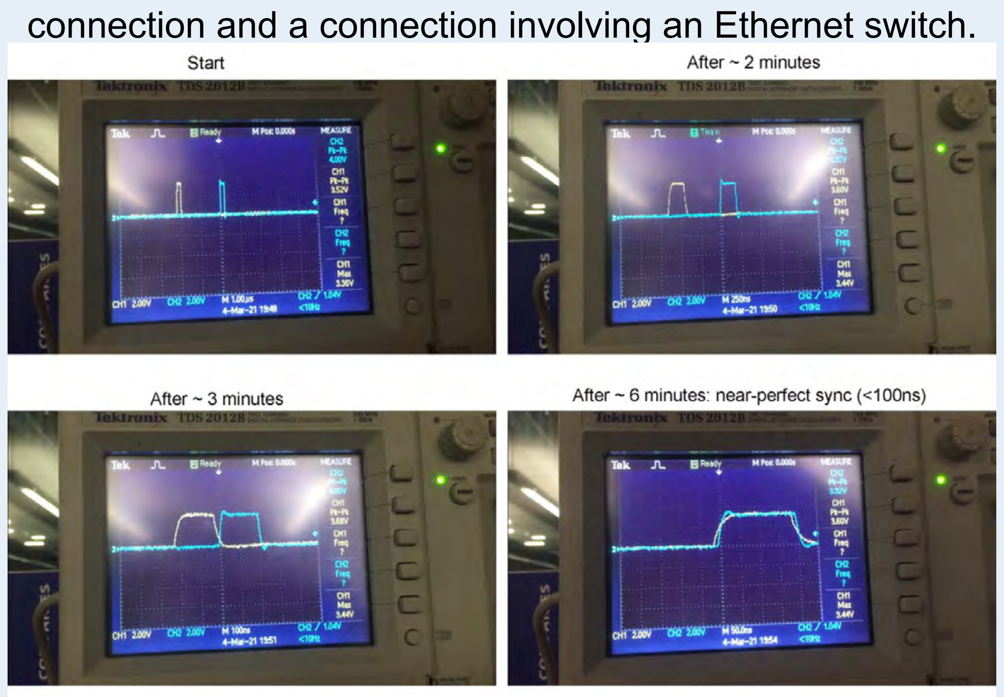


Fig. 4: PTP synchronization process shown on an oscilloscope

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Commercial off the Shelf Design of a Digital and Analog I/O Acquisition System

GENERAL DYNAMICS
Electric Boat

Team Members: Gary Zeng (CPE), Jornel Medina (ELE)

Technical Directors: Art Viola, Adam White, Douglas Marshall | Consulting Technical Director: Alex DePetrillo

Project Motivation

Utilizing Consumer Off-the-Shelf (COTS) products is an effective approach to reducing cost and schedule while designing systems, particularly for Military applications. COTS allows for a rapid and agile system at a fraction of the cost of a custom designed product. The Versa Module Europa(VME) computer bus standard was developed around 1981 yet current militarized systems are still reliant on this old technology. Due to the rapid decline and lack of support for the VME computer bus standard, research of alternative technologies have to be conducted in order to replace this standard. The goal of this project is to create a prototype system that will rival this standard and utilize newer technology to ensure the longevity of this system. This project will consist of various COTS products to minimize the cost of the system while still creating the best alternative to the VME computer bus standard.

Key Accomplishments

Top-Level Requirements (TLR):
Developed seven Top-level specifications that need to be met to achieve the desired outcome of the project.

System-Level Requirements (SLR):
Developed thirty-two SLRs that are traceable to TLRs to describe constraints or functions of the system.

Bill of Materials (BOM):
The BOM was created to ensure that we will remain within our budget while still selecting the best possible components for our system.

Critical Design Review Presentation:
A presentation that ensures the system can proceed into the next steps and meets the requirements within cost, schedule, and risk. This review was conducted when the baseline of the project was achieved and the final design for the system was approved.

Graphical User Interface (GUI):
A GUI (**Fig.1**) was created to allow the user to interact with the system. With this GUI the user will be able to manage and view the data that is sent and received from the Raspberry Pi and the user's computer. The GUI will display different buttons depending on which I/O demonstration is currently being run.

Client-Server Application:
A client-server application was created to allow data transfer from the server (Raspberry Pi) to the client (User's computer). This application was created to act as a command and status program to obtain all of the data acquired by the system.

Test Procedure Document:
The information provided in the document provides detailed steps to allow the operator to test the product; ensuring all requirements have been met and collect Technical Performance Measures**.** There will be an in-depth description on how to utilize the hardware and software that is required to conduct the I/O operations.

Technical Performance Measures (TPM):
TPM have been documented to show how efficient the prototype system is in data acquisition. These measurements include the ideal frequency on the Function Generator I/O demonstration, the field of view of the Ultrasonic Sensor in the Covid Away Demonstration, and the range that our photoresistor will take in the Desk Lamp demonstration. With this data the system will be able to compare the efficiency of the Raspberry Pi by conducting similar tests with the VME to juxtapose the competing technologies.

Function Generator Demonstration:
This demonstration **(Fig. 3)** will be using an Analog-to-Digital converter to obtain data from the function generator and send into the Raspberry Pi. With this information the GUI will then collect a certain amount of this data before plotting it. The graph will display the type of wave that the function generator is producing.

Desk Lamp Demonstration:
The Desk Lamp demonstration **(Fig. 4)** has four main components: a photoresistor, a passive infrared sensor (PIR), a momentary pushbutton, and a lamp. In this demonstration, the system will be able to detect whether the lamp light is currently on with the photoresistor. With this information, the system will be reading the input from the PIR to detect whether there is someone sitting in front of the lamp. If there is someone in front of the lamp, it will stay on. However, after a certain amount of time, the lamp will turn off. The automatic shutoff time can be set from the GUI. During this time, the PIR will constantly check for motion. If motion is still present, the light will stay on and the timer will reset. The momentary pushbutton can also control whether the lamp is on or off.

Covid Away Demonstration:
The system **(Fig. 2)** will utilize an ultrasonic sensor to detect how far away an object is from it. The ultrasonic sensor will then notify the system to turn on LEDs indicating the object's distance. The system will light a Green LED when an object is more than 2 feet away, then a Yellow LED when the object is within 1 to 2 feet, and lastly the Red LED will light up once the object is within 1 foot. The detection distances can be altered within the code.

Anticipated Best Outcome

The best anticipated outcome of the project will be a functioning system that is an effective alternative to VME. The final product will be a prototype system that will be able to evaluate these alternative technologies. The system will be designed with a set of hardware and software-based tests to ensure the system is performing all of its tasks properly. Technical performance measurements will also be identified and documented to ensure that our prototype system is an efficient substitute to the VME computer bus standard. With the final product we will also be delivering a Test Procedure Document that will enable any user to operate this system.

Project Outcome

The Anticipated Best Outcome was achieved; additional features were added in addition to the initial goal.

Figures

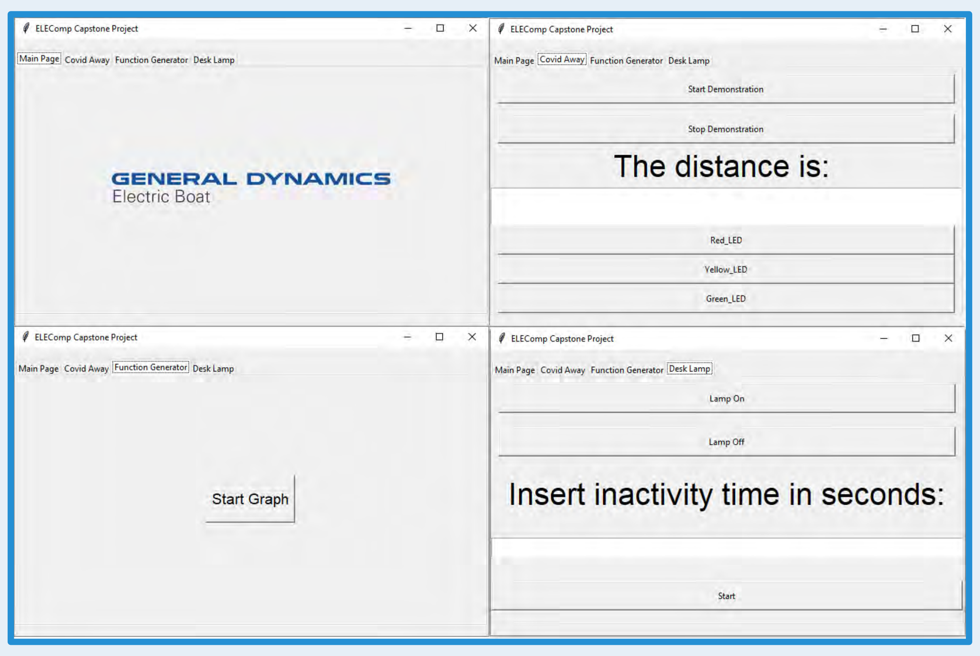

Fig. 1: The GUI will be displayed on the client side of the system.

Fig. 2: The COVID Away circuit utilizes an Ultrasonic sensor that measures how close an object is from the system. The Raspberry Pi will light one of three LEDs depending upon how close the object is to the system.

Fig. 3: The Function Generator circuit utilizes an Analog-to-Digital converter to sample a signal from the Function Generator. The software plots the sampled signal.

Fig. 4: The Desk Lamp circuit turns on the lamp in three ways: by pressing the momentary pushbutton, detecting movement in front of the PIR, or from the GUI. The photoresistor detects whether the lamp is on and starts a timer which will turn off the lamp due to inactivity.

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Part ID-2

Part Identification and Post-Processing using a Collaborative Robot

HEXAGON METROLOGY

Team Members: Oliver Hazard (ELE), Sergio Cardona (CPE)

Technical Director: Jonathan O'Hare

Project Motivation

Manufacturing is becoming more automatized. To stay competitive, manufacturers must adapt. One critical piece of machinery in the manufacturing process is the Coordinate Measuring Machine (CMM). CMMs provide dimensional analysis needed to verify that a process is conforming to the specifications. Therefore, collaborative robots (COBOT's) and other automated machinery could effectively improve all these aspects. Additionally, there are downsides to leaving operation of a CMM to humans. It is time consuming to load parts and wait while a test is being run. Testing on a CMM is currently a bottleneck in manufacturing for this reason. Moreover, an operator can mistakenly identify one part for another similar one, enter a serial number incorrectly, or load parts on the CMM in the wrong orientation. An embedded solution with proven success would not have these same limitations. Having this process automated allows a skilled technician to spend their time on something more productive for the company.

Anticipated Best Outcome

The ABO would be a fully functioning process where an object detection algorithm identifies a part, a Cobot then grabs the part based on this information and orients it so its unique identifier (UID) can be read by an Optical Character Recognition Algorithm (OCR). Then, the Cobot places the part on the CMM. The method must produce reliable results with object and UID recognition accuracy of 99% taking no more than 5 seconds to complete the task. Processes must be compatible with existing hardware and be uncomplicated to teach new parts. Better than the best anticipated outcome, the addition of a subsequent process is to make the system capable of barcode reading and or OCR reading of labeled or marked parts.

Key Accomplishments

Improvements to Turntable: To have a machine learning algorithm recognize a part, many pictures of the part in different orientations are needed to train the algorithm. Previously, a turntable was built using a stepper motor and Raspberry Pi to acquire these pictures, but it was not functional. The system was fixed, and additional functionality was added. This includes higher step resolution (1 degree minimum), more cameras at different angles (up to 4 cameras), automatic lighting during testing, and automatic directory creation for new test data. Additionally, a larger 17'' diameter base was fabricated, and a larger lightbox that better diffuses light was created.

Scanning of the Parts with Hexagon Romer: Using a laser scanner, 3-D models of Smith and Wesson receivers were generated. This allows for synthetic images to be generated to train the part recognition algorithm. With this, the team can analyze the effectiveness of training with real vs synthetic images of parts which allows us to determine the most effective way of identifying parts.

Creation of tools for prototype and Testing (Fixture, Clamp, and 3D model): For a functional simulation of the different possible distances/positions between drawers and the cameras, a Raspberry Pi in conjunction with a 5 Megapixel Raspberry Pi camera module, commanded by a Python program will allow us to establish the more efficient way to identify the parts. A 150 centimeters structure with a detachable tube that can be moved every 10 centimeters to try different distances from a 40x40 centimeters squared base (size of half of a drawer) was made to simulate a camera fixture that would identify parts or UIDs. A clamp attachment for UR5 Cobot was built to be used in place of Robotiq 2 finger gripper (Fig. 1). In addition, a 3D model of the provided parts was designed and printed for demonstration of the desired final process. (Fig. 2)

OCR Testing algorithm: From the beginning of the project. Creating a prototype OCR algorithm from an open source was essential to the testing of different aspects of the project. An algorithm using the OCR Tesseract engine running with python code has been created. The algorithm was constantly edited to add new functions. The algorithm is capable of recognizing letters and numbers from different surfaces. Also, the algorithm has the ability to double or half the size of the original image provided. In addition to that, different filters such as the black and white filter were added. The program edits the image to create a square around each individual character recognized to then save these images as an "image name"_result.jpg .(Fig. 3) All these functions are completely necessary to improve the effectiveness of our tests and extremely necessary in order to recognize the characters in the images. Above all, this algorithm is for testing purposes, and the creation of the final prototype of the ABO.

Cobot Implementation: A code has been written for the UR5 Cobot (Fig. 4) that demonstrates the entire desired process. The code is instructed to pick up one of two parts in two different locations based on user input. From there it positions the part so that its UID is in front of a camera. Then, the Raspberry Pi is instructed to take a picture of the UID for OCR analysis. The part is then moved to an arbitrary spot that would be the CMM jig. It then moves the part to where it was originally held. This prototype system and process works as an example of the product that Hexagon is looking to develop and shows the feasibility of such product.

Project Outcome

The Anticipated Best Outcome was achieved. It was to create a proof of concept that a fully automated CMM process is possible and to provide Hexagon with recommendations for what they should do moving forward to make this a marketable product.

Figures

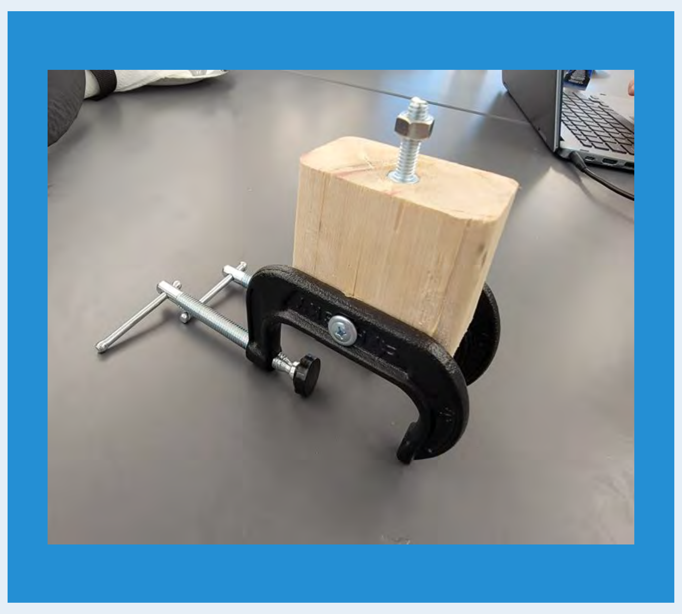

Figure 1: Clamp for UR5 Cobot used in place of Robotiq 2 finger gripper

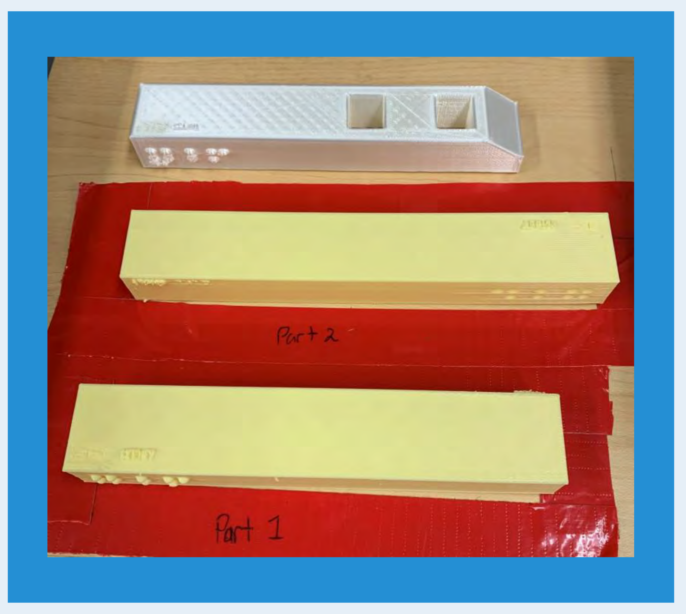

Figure 2: Printed 3-D models of parts created for demonstration

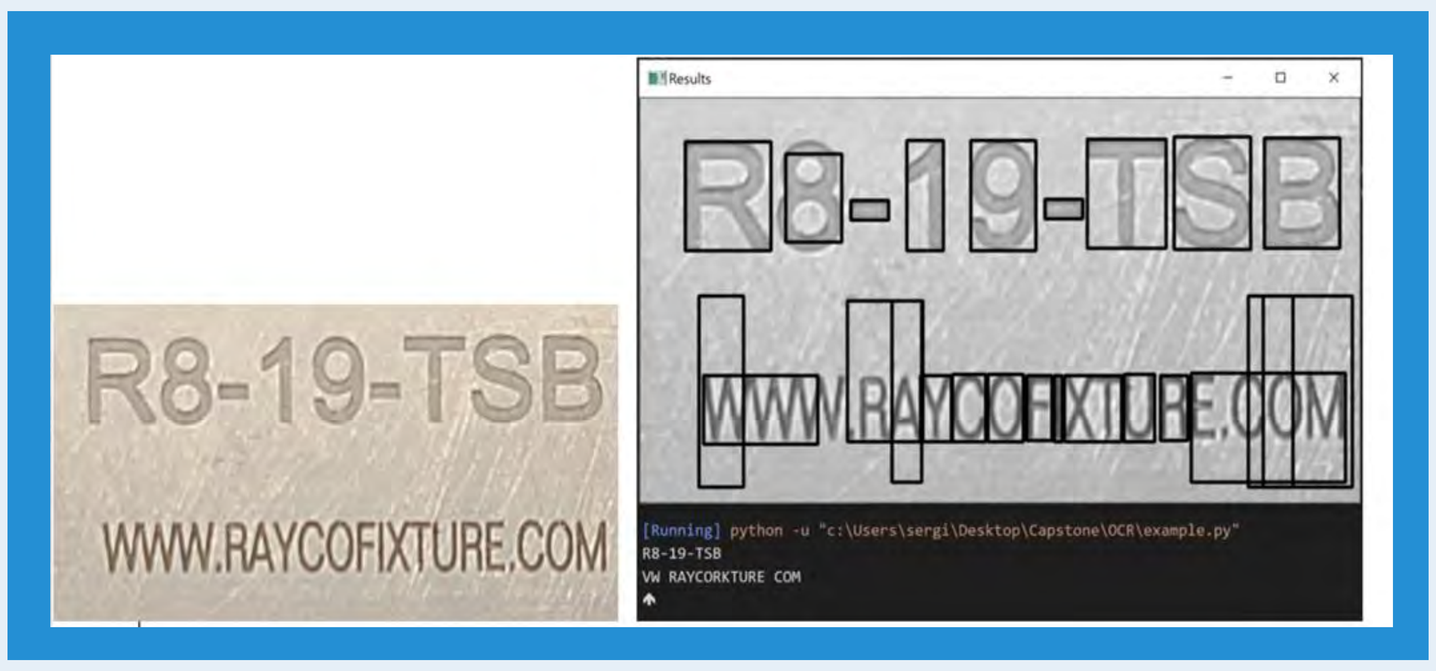

Figure 3: OCR Testing pictures

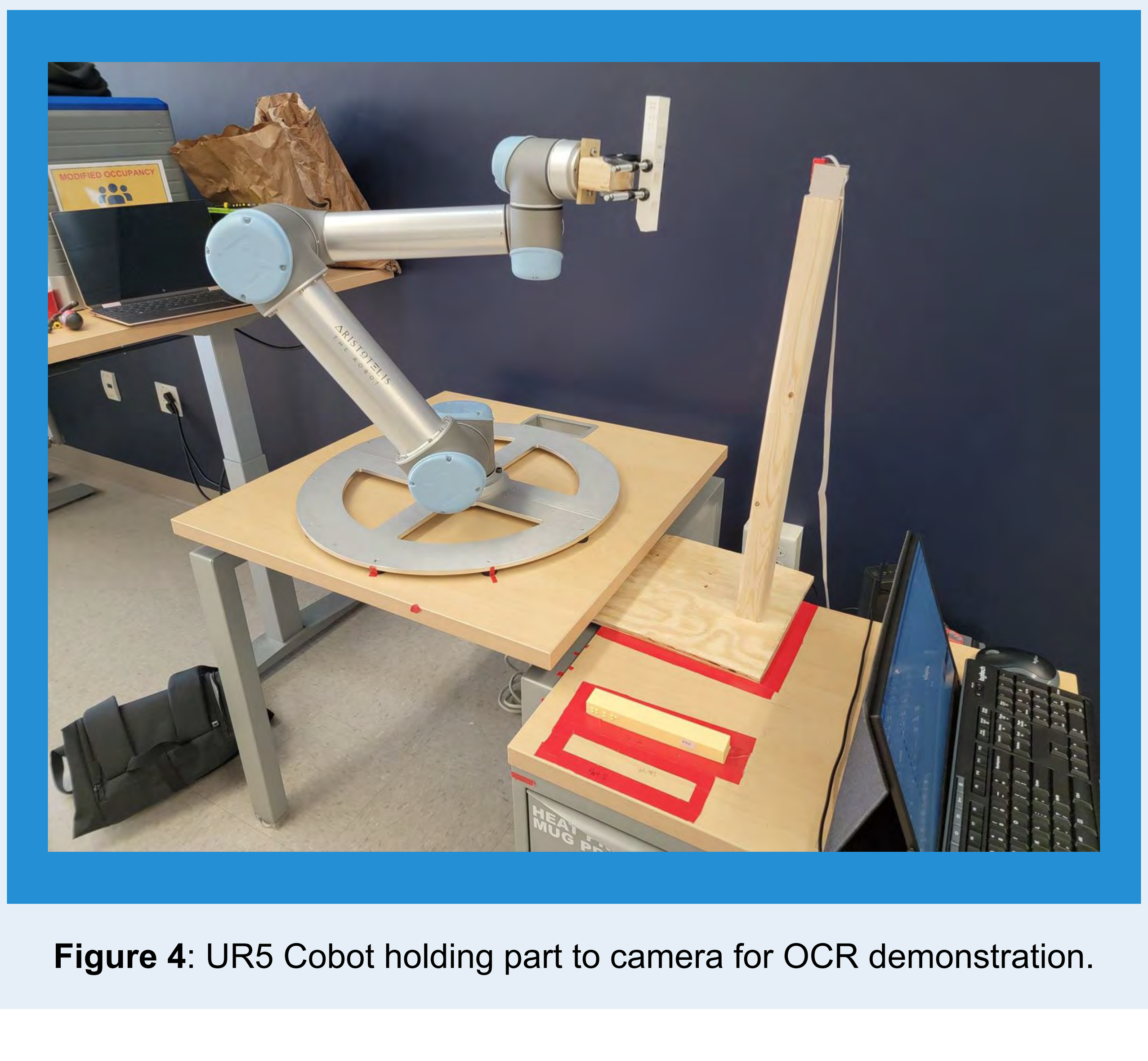

Figure 4: UR5 Cobot holding part to camera for OCR demonstration.

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone

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T.R.A.I.N.N

Track Real-time Artificial Intelligence Neural Network

in-depth engineering

Team Members: Eric Gardiner (CPE), Giles Lanowy (CPE), Andrew Skavicus (ELE)

Technical Directors: Bill Matuszak, John Vernaglia, David Helms | Consulting Technical Director: Alex DePetrillo

Project Motivation

Air traffic control and maritime traffic management are aided by platforms reporting their own position, speed and course. These self-reported tracks are used by control towers and nearby platforms for situation awareness, spatial separation and route planning. Air traffic uses a surveillance technology called ADS-B (Automatic Dependent Surveillance–Broadcast). Maritime traffic uses a system called AIS (Automatic Identification System). In both systems, vehicles broadcast positional data derived from Global Positioning System (GPS) satellites. Machine Learning (ML) Neural Networks can be trained on typical AIS or ADS-B datasets and used to perform motion pattern analysis, behavior identification and spoofing detection on new data sets. A significant challenge to developing (ML) algorithms is the availability of large datasets for training (ML) models. This project seeks to address this limitation by developing a system that gathers its own training data. These newly collected datasets will aid in the classification of ship types through (ML) Neural Networks.

Key Accomplishments

Data Parser (AIS): Before AIS data can be analyzed properly, it is first put through our python coded parser. This python script drops irrelevant ship data that does not need to be put into the Machine Learning model, such as ships that don't have enough data points, ships that are missing key data (i.e missing the longitude, latitude, course, and speed data), and ships that have incorrect data (i.e they have improper MMSI numbers). Additionally, this script normalizes the features and One-Hot encodes the labels prior to input into the Neural Network.

Machine Learning (ML) Model (AIS): A one-dimensional Convolutional Neural Network (CNN) was selected for our project to enable effective training of ship data. CNNs, specifically one-dimensional CNNs, are particularly effective in preserving the spatial relationship in temporal data, and are therefore more than capable in classification of ship types given multiple time series inputs. The script for running the ML model was done using Tensorflow and Keras, which analyzes the data split between train and test sets.

AIS/ADS-B Signal Receiver: The signal receiver is composed of two Raspberry PI microcontrollers, a QK-A026 AIS receiver, a FlightAware ADS-B receiver, a hard drive for data storage and two antennas(one for AIS and ADS-B). The range of our receiver is approximately 10 nautical miles for AIS and around 250 for ADS-B and we can consistently receive signals every 30 seconds or so depending on the conditions and the distance **(Fig. 3)**. The raw data is also received from the antenna and can be transmitted through a serial connection from the QK-A026 to the Raspberry PI microcontroller. The ADS-B signals are collected on a web server called FlightAware.com and raw data can be accessed using an API.

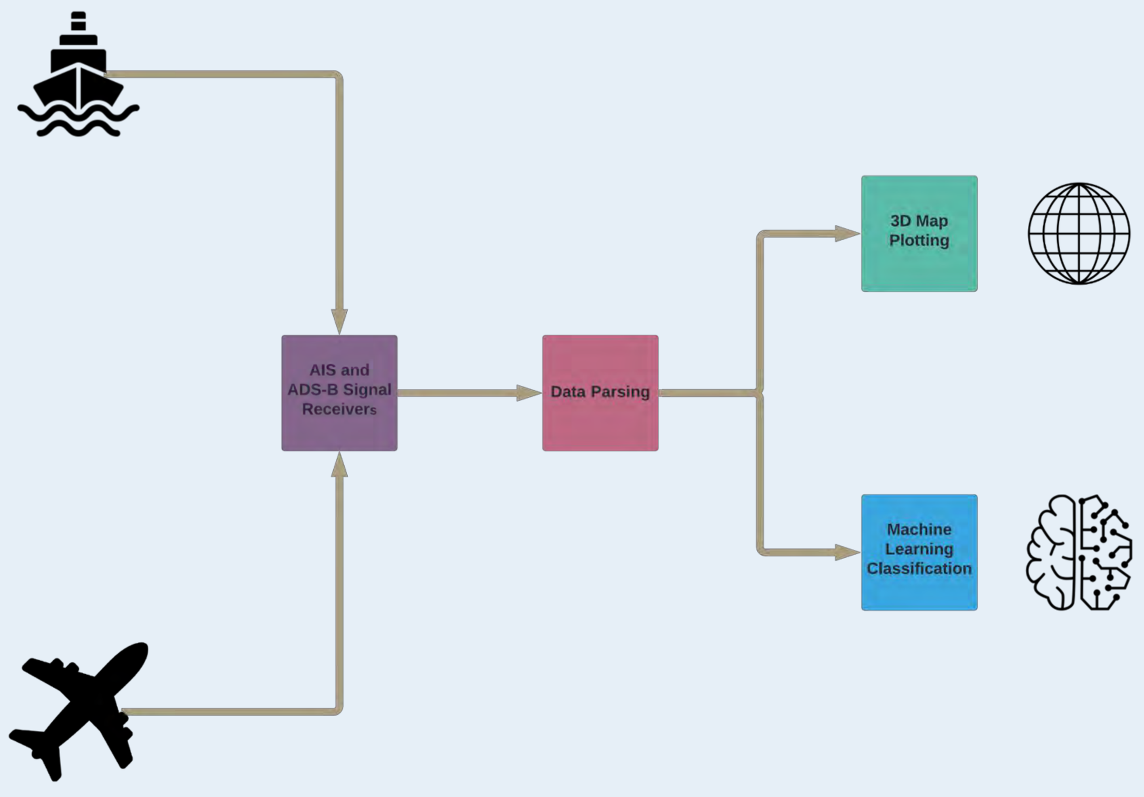
GeoPlotter (AIS): When looking for AIS spoofing there is typically a disconnect between the recorded tracks of AIS data. An example of this can be seen below **(Fig. 4)**. Using a python script and Google Earth Pro, we have parsed and plotted data from the AIS signal receiver. These plots can then be used to further verify flags thrown by the ML model.

GeoPlotter(ADS-B): This geoplotter is very similar to the AIS plotter however there are a couple additional data points included like altitude. The track is plotted in three dimensions showing altitude and speed for every transmission **(Fig. 2)**.

Machine Learning Models (ADS-B): Similar to the AIS portion of the project, the ADS-B uses two convolutional neural networks to predict both aircraft species (airplane, helicopter, gyrocopter) and type (specific models of aircraft). It uses the aircraft's longitude,latitude, and altitude to make such predictions. It is programmed using python and the Keras API. An example of accuracy and loss curves for a model can be seen below **(Fig. 1)**.

Machine learning GUI: In order for the user to easily interface with the ML models, a GUI was programmed in python using the tkinter library. This allows for the user to insert their own specific ship/aircraft data with a file browser into the model, for the model to give out the predicted ship/aircraft type, and whether or not this matches up with the reported type given in their signals.

Block Diagram



Anticipated Best Outcome

The best outcome for this project is two properly trained machine learning AIs. One to analyze AIS data and one to analyze ADS-B data. The data will be recorded using two Raspberry Pis. The first pi records raw AIS signals received through an antenna. It then decodes these signals and places the data into a csv file for the AI to access. Our ADS-B data has been recorded with the FlightAware's Pi based software PiAware. The AIs will flag ships and aircrafts if it detects an error. This ship's data can then be isolated using the AIS GUI app and generates a kml file for the recorded track. This kml can then be plotted to verify if spoofing has occurred.

Project Outcome

We did meet the Anticipated Best Outcome and delivered the final product to our TDs. The final product can collect AIS and ADS-B data, store the data and the machine learning AI can accurately predict airplane and ship types.

Figures

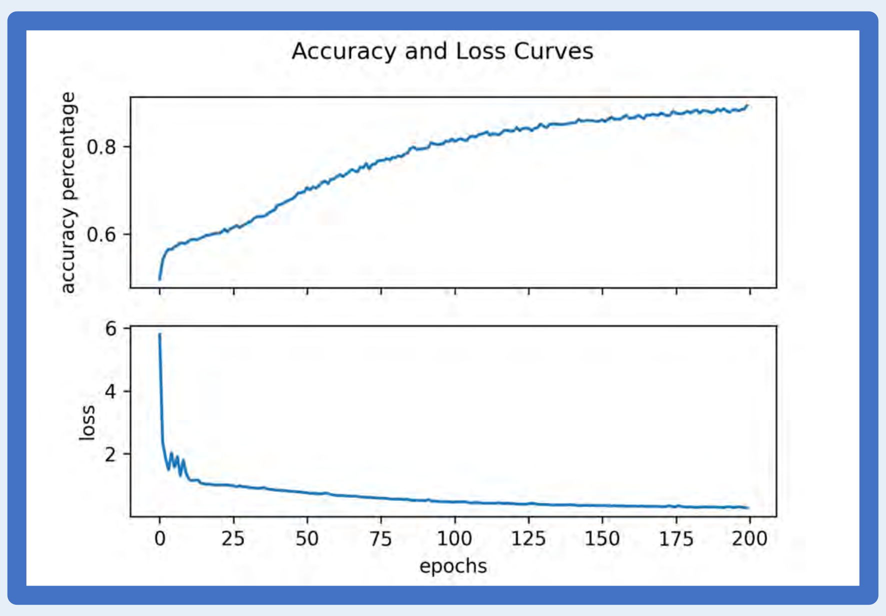


Fig. 1: The accuracy and loss of curves of one of the ADS-B models during training. Over the course of several epochs the model is able to learn more patterns from the data and better predict the species/type.

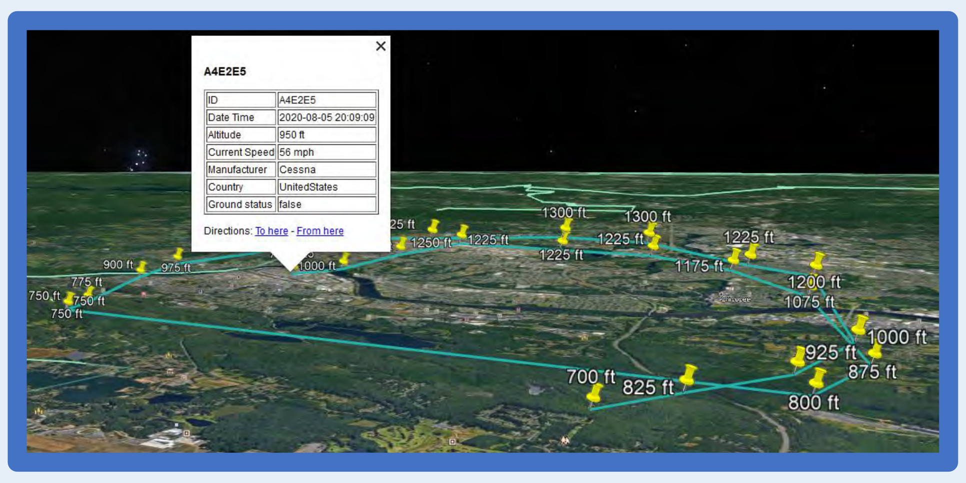


Fig. 2: A sample screenshot of the ADS-B geoplotter. It consists of 9 minutes worth of recorded ADS-B signals. .

Fig. 3: Image of AIS/ADS-B Receiver

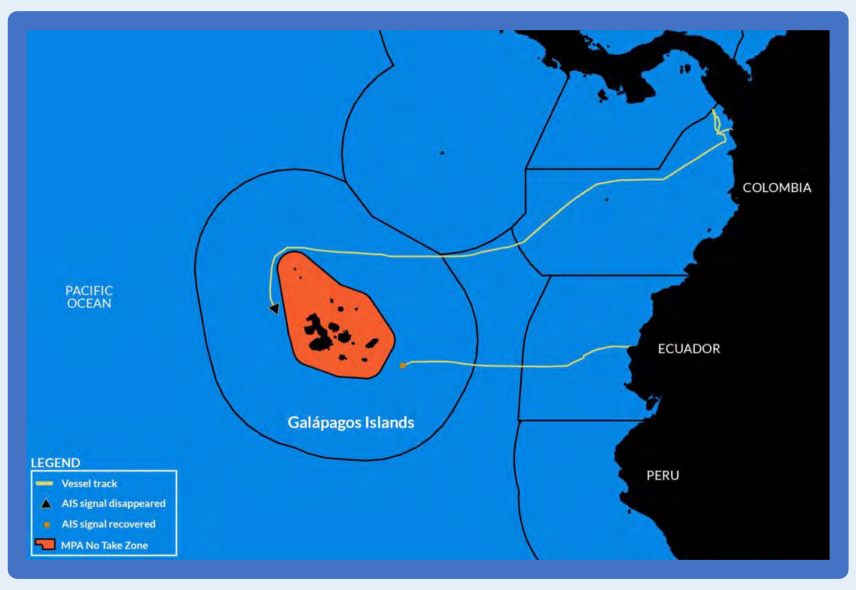


Fig. 4: Spoofed AIS data

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859 ELECOMP Website: uri.edu/elecomp-capstone

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Programmable Load Slammer

Infineon

Team Members: Noah Gibb (CPE\ELE), Abraham DeMartino (ELE)

Technical Directors: Yong Zhou, Kumar Gandharva | Consulting Technical Director: Alex DePetrillo

Project Motivation

The Infineon applications team and customers need a programmable electronic load to emulate a CPU/GPU/ASIC load signature. Commercial electronic loads cannot emulate the 1000 A/µsec load transients that are typical in these systems. Infineon has developed a “Load Slammer” for AC loads which uses a function generator to control the AC current profile. This setup is cumbersome and cannot be moved around easily. Infineon uses several of these electronic loads in their labs and ships these loads to customers, they would like to introduce a programmable load controller directly onto their “load slammer.” This will reduce test equipment costs (no function generator required), increase test system density, provide repeatability with stored load waveform patterns, implement current feedback to ensure the correct load pattern is generated, and provide an easy-to-use customer graphical interface with the ability to run various load scripts.

Key Accomplishments

Hardware Design: A circuit was designed using a base schematic that was provided to the team. Two of the main components are the Infineon IRF8301 power MOSFET and an OPA-690 operational amplifier. The design of the feedback loop capacitor was optimized to the range of the load voltages that would be present on this circuit. The sense resistors on the source of the NMOS were adjusted to achieve the desired amperage. In **Fig.1** there is a POL(point of load) board that consists of a motherboard, a test board, and the load slamming board. A load adjust is built into the motherboard that was used to test that it was working. This board was used to test the PSoC to make sure it was able to control the slamming of the board like the function generator or load adjust could. We are still having issues with the PSoC being able to control the load slammer because it does not have the drive current that is needed. We are in the process of adding external components to achieve this. We are adding a breakout board with two op-amps to buffer and allow for more current. The load adjust is providing 75mA at 400mV, the function generator is providing 15mA at 400mV mean, and the PSoC is only providing 500µA at 400mV.

Function Generator: The PSoC5 microcontroller shown in **Fig. 2** was used to design a trapezoidal waveform generator using the IDE in **Fig. 3** that could have the slew rate, amplitude, period, and duty cycle adjusted to user preferences. The slew rate adjustments are from about 100ns to 180ns for the rise time and 128ns to 190ns for the fall time. The amplitude adjustments are from 172mV to 3520mV. Duty Cycle is adjustable between 10 to 90 percent. The Period is 1us to about 1ms. The WaveDAC8 component, shown in **Fig. 3,** is used for the lower frequency waveforms. Since the WaveDAC8 component is an arbitrary function generator, waveforms such as triangle and sawtooth can be easily created.

Software Design (Communication): The PSoC5 microcontroller shown in **Fig. 2** is being accessed via its J2 communications port to update its memory through a Python based GUI. In Cypress Creator, the PSoC device is set to loop continuously and open its ports to the USB data bus, as seen in By creating a USB device, the PSoC is able to send and retrieve data over the bus, despite not being connected to the MiniProg4, an I2C programmer and debugger for PSoC that could not be used for this application due to its low data rate. In order to program the board with a Python based GUI over USB protocol, the device’s secondary J2 port is used. The board is able to be powered on and programmed through any commands over the bus from the GUI.

Software Design (GUI): The graphical user interface shown with examples of its plotting capabilities in **Fig. 4** is the interface that will allow the end user to control the mini slammer and test load boards with different waveforms that can be recreated, as well as sweep parameters. Features to control the PSoC5 microcontroller have been added in order to perform testing. These features include frequency and duty cycle control as well as the ability to change the PSoC’s output amplitude. However, these features are only for higher frequency testing with square waveforms, of which the amplitude and frequency are adjusted. WaveDac8 functionality, as seen in **Fig. 3**, will be added to the GUI in order to create unique waveforms at lower frequencies, without losing the ability to modify their amplitude or duty cycle from the GUI.

Anticipated Best Outcome

The microcontroller-based load controller shall have a minimum 50A load step in 1µsec capability with a duty cycle from 10% to 90%, up to 1 MHz. The load controller shall also support DC loads and programmable load current slope profiles like triangle, saw tooth, and sinusoidal with a minimum frequency of 10 kHz. A Graphical User Interface (GUI) application shall allow a user to create piecewise-linear current profiles and dynamically control the load. The application shall read and store current profiles into the microcontroller. The application shall be self-contained without the need for special support drivers and transportable between compute platforms.

Project Outcome

The Anticipated Best Outcome of the project was not achieved. The microcontroller that was used could not be turned into a robust function generator without adding external components. The schematic design was finished too late to be put into PCB design and the GUI worked but could not be fully tested due to the microcontroller issues.

Figures

Fig. 1: Motherboard top picture, test board lower left, load slamming board bottom right.

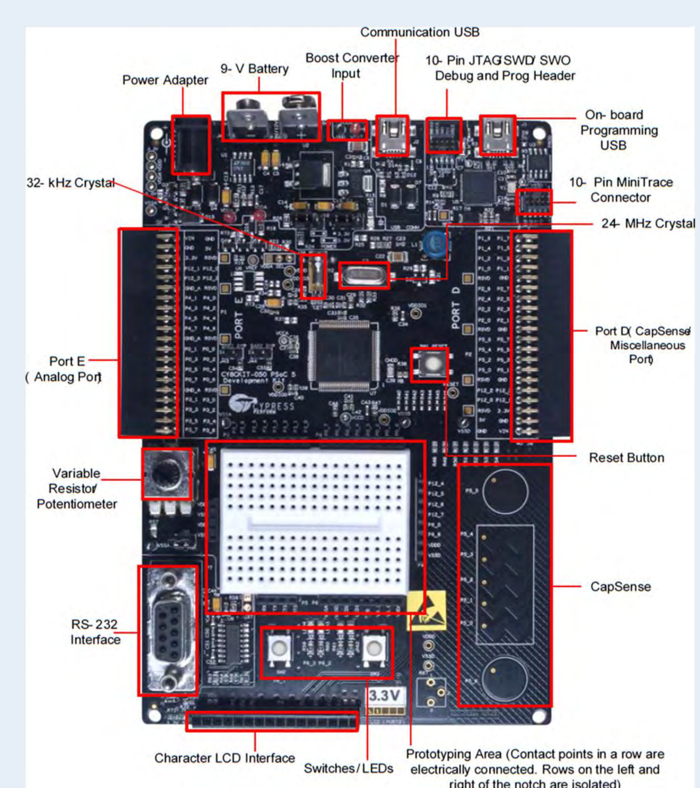

Fig. 2: PSoC 5LP Development Kit

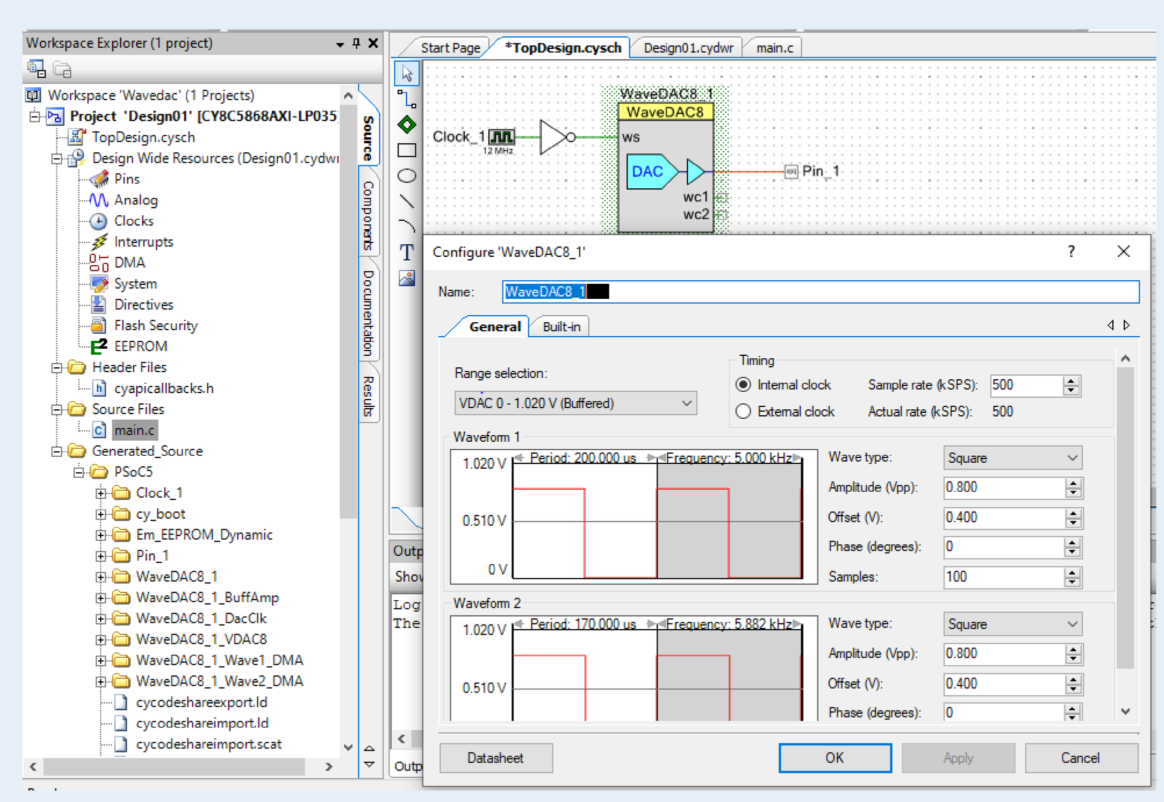

Fig. 3: WaveDAC and PSoC Creator IDE

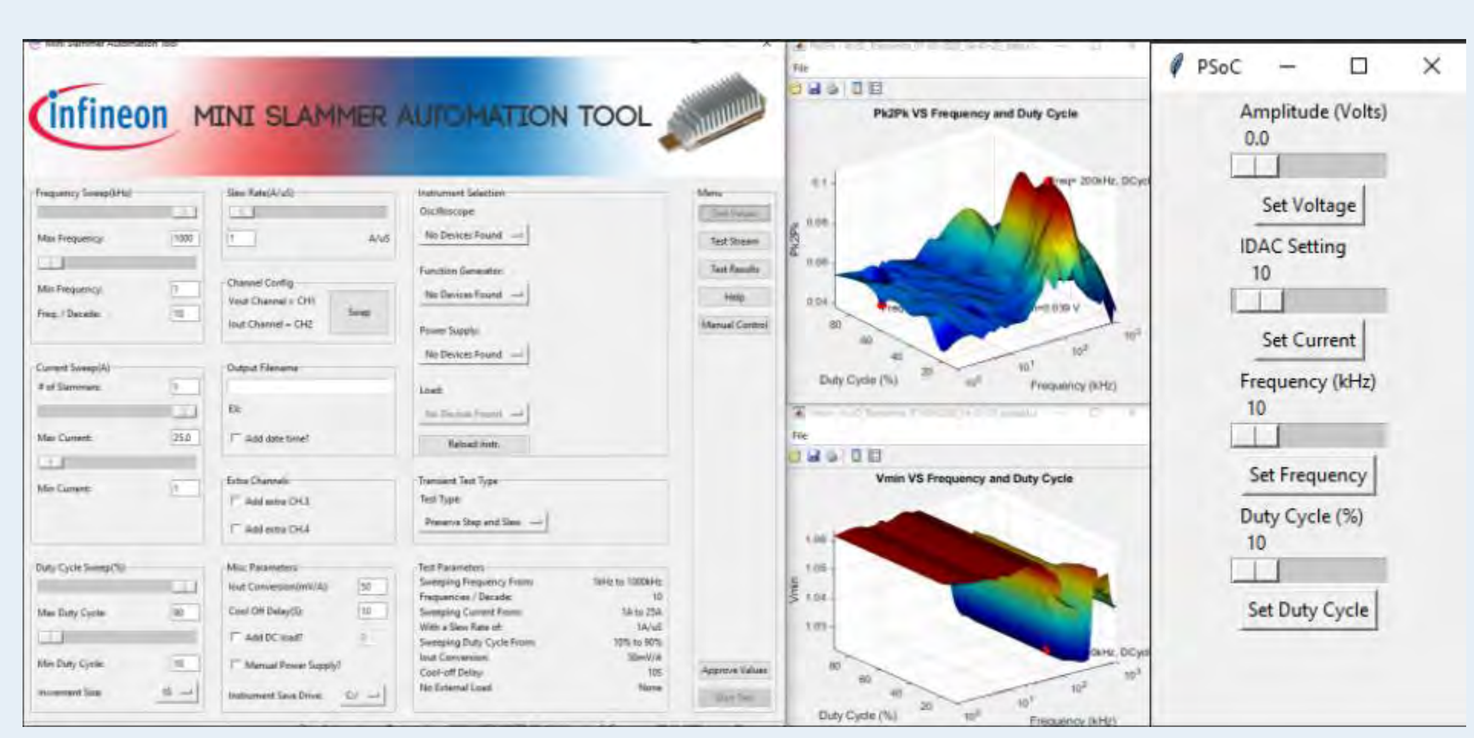

Fig. 4: Mini Slammer GUI with PSoC control

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GAPS-COMM

Cooperative Global Acoustic Positioning System

Team Members: Cruiz Marcille (CPE), John Travis Hunter (CPE), Kyle Keefe (ELE), Arianna Angeloni (ELE)

Technical Directors: Patrick Moran, Daniel Nugent, Robert Greer | Consulting Technical Director: Jeremy Peacock

Project Motivation

The Global Acoustic Positioning System (GAPS) combines the position and motion measurement accuracy of the iXblue Defense System's PHINS INS with the acoustic positioning accuracy of a USBL system. iXblue's GAPS devices are used to track unmanned underwater vehicles with acoustic beacons. Currently GAPS are configured by an operator based on the mission requirements. In cases where there is a large offshore operation that includes multiple systems, each GAPS is configured and operates individually. This project proposes to provide a simple solution using the GAPS technology as is, leveraging the existing product capabilities to add in a software control layer, and a hardware/ software communication layer.

Key Accomplishments

Software Requirements Specification (SRS) Document: This document describes how each software module operates and how all the modules work together to manage the GAPS Network. The SRS document describes the individual tasks that each software module will execute, along with their inputs, outputs, and where they belong in the software pipeline.

Research and Experience as a GAPS Operator: Entering this project, the team had to research and prepare for the development ahead. This involved learning the Python programming language, researching and understanding the current iXblue GAPS system, and experiencing how the physical device works in the field. Through experiencing how the device is used in the field, the team gained an understanding of how the software will impact the end user, our clients.

Flowcharts: The Flowchart Diagrams explain how the software modules cooperate with each other, how each software function works, and how the physical and software components of this project interact. These diagrams provided a roadmap for the software development process. (Fig. 2)

Local Network Configuration: The team purchased two routers and set up a local network as a prototype for the GAPS cooperative mesh network. (Fig. 1)

Graphical User Interface (GUI): The GUI allows users to connect and configure multiple GAPS and beacons. A real-time plot of the GAPS and Beacon positions along with the settings menu can be seen in Figure 4.

GAPS-COMM Main: The main file was created for testing modules and creating visual plots. The structure is simple and allows for easy debugging when testing modules.

Spatial Track Module: The Spatial Track calculates GAPS and beacon velocities and filters the incoming data for validity. This module then calculates an average of the recent few velocities to be used for the Beacon Handover's predictive calculations.

Beacon Handover Module: The Beacon Handover software module calculates when to hand over a beacon from one GAPS unit to another. If the beacon is almost within the listening range of another GAPS, the software predicts where the beacon and GAPS will be next. If the beacon is predicted to be inside the range of the next beacon, then the beacon is handed over to the new GAPS. (Fig. 3)

Simulated Test Data Generator: The GAPS-COMM team developed a test data generator to provide the team with different simulated scenarios, which is used to test the functionality of the software.

Data Reporting: Functions have been implemented into the modules to report how the data is processed throughout the system's pipeline. The GAPS-COMM's software console provides detailed real-time information of each device's position, how the data is being processed, and actions the system is taking. Plots of distance ratio (Fig. 3) and device positions (Fig. 4) are provided during and after operation.

Simulated Lab Testing: In April of 2021 the team ran the GAPS-COMM software solution on a mesh network consisting of an iXblue GAPS device and a simulated GPS-Spoofed GAPS device, along with one simulated Beacon. The physical GAPS device remained stationary while the simulated GAPS moved towards and away from the stationary simulated beacon. The GAPS-COMM software solution accurately performed the beacon handovers from one GAPS to the other. This test proves that the cooperative operation of multiple GAPS devices is possible and achieves the Anticipated Best Outcome for this Capstone project.

Anticipated Best Outcome

This project delivers a software and hardware prototype system for the cooperative operation of the GAPS. Documentation of all software and hardware components such that the project can be expanded upon in the future is provided. The anticipated best outcome is to perform hardware in the loop testing and validation of the prototype with two GAPS systems in water. System deliverables include: a prototype network to control multiple GAPS, software and hardware documentation, test data, and a final report covering all results.

Project Outcome

The team was able to successfully provide a software system that manages multiple GAPS and facilitates beacon handover between GAPS. Software and Hardware documentation has been provided.

Figures

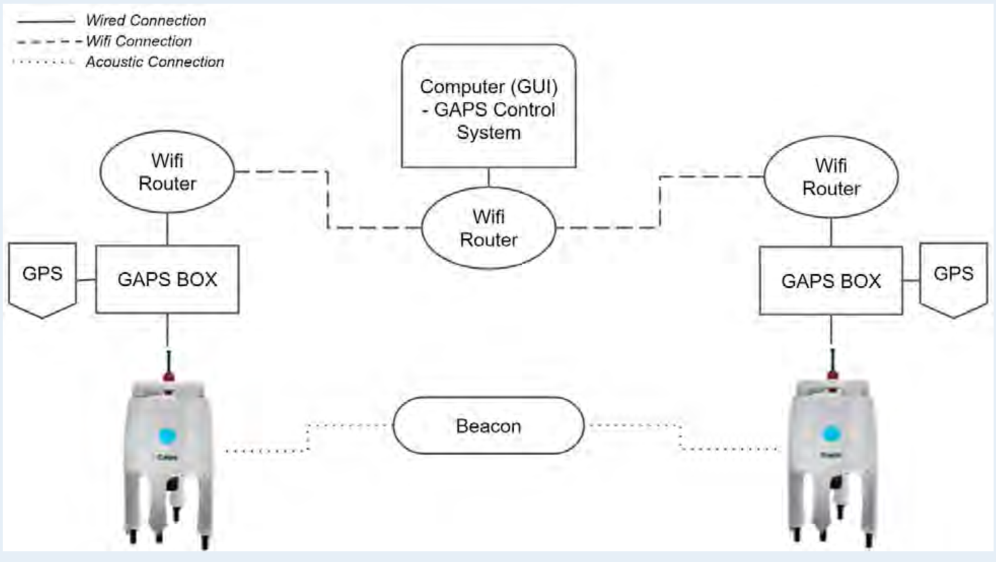

Figure 1: Hardware diagram of a system with two GAPS Transponders connected in a mesh network.

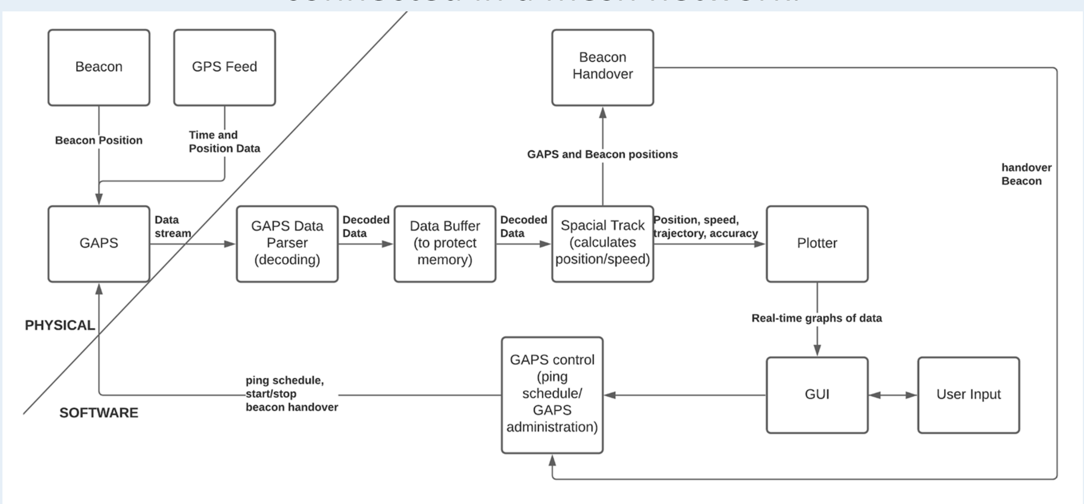

Figure 2: System Physical and Software Flowchart

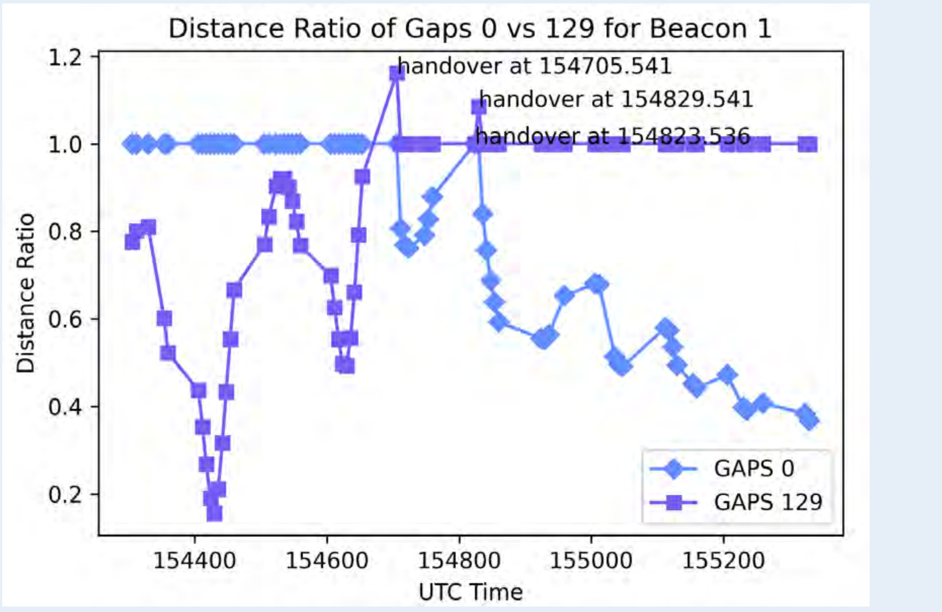

Figure 3: Plot of the distance ratio from each GAPS to the Beacon, showing when a handover occurs

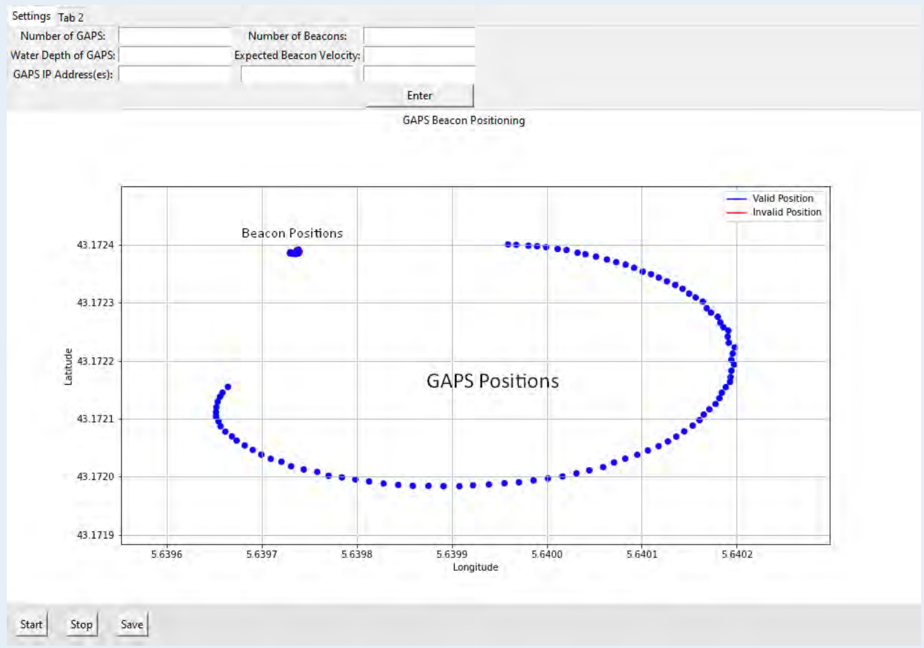

Figure 4: GUI with real-time position plotting

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone

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Precise Point Positioning (PPP) GNSS Receiver

iXblue

Team Members: Christopher Matulaitis (CPE), Peter Puelo (CPE), Joshua Clift (ELE), Colin Sullivan (ELE)

Technical Directors: Guirec Morvant, Elliot De-Toldi, Jean-Baptiste Lacambre | Consulting Technical Director: Jeremy Peacock

Project Motivation

Most iXblue products, including Inertial Navigation Systems (INS), depend highly on Global Navigation Satellite Systems (GNSS) such as GPS, GALILEO or GLONASS to provide its position to a user. Depending on the application, different levels of precision in positioning are expected. GNSS have multiple operating modes that enable it to reach various levels of precision of localization from meter range to centimeter. The natural operating mode, that uses only satellites emitted signals, allows it to reach a level of precision of a few meters. To reach the highest levels, additional information may be used. For instance, Satellite-Based Augmented System (SBAS) solutions use broadcasted information in some parts of the world to have a localization error of less than a meter. Another solution, Real Time Kinematic (RTK), uses information from a nearby base station that helps to correct the user position and reach the centimeter level of precision. Those solutions are used as standard today but have strong requirements. A new form of correction is predicted to be the next step in precise positioning: Precise Point Positioning with Ambiguity Resolution (PPP – AR). The biggest drawback of PPP used to be the time it needed (~30mn) to achieve a precise localization, but research papers have shown that with the multiplication of information available from satellites, broadcasted corrections, and the improvement of receivers, it would be realistic to obtain quickly a centimetric level of precision without relying on a nearby base station. From this statement, iXblue goal is to evaluate this technology, and if it demonstrates the expected performances in real life conditions to integrate it in iXblue products.

Key Accomplishments

GNSS PPP Receiver

- Buildroot Operating System
  - By using Buildroot we were able to build an operating system for the I.MX 6 board. We were able to include all libraries necessary and it is easily editable for any future issues, as well as load the operating system onto a SD card that is inserted into the I.MX 6 board. This design is easily reproducible as was a main focus of the deliverable outcome.

Software Documentation

- Network Interface Setup
  - Allowing the i.MX6 to connect to the internet was crucial for our project. Unlike other computers, you must first install the corresponding libraries that contain the commands for the setup. This allows for the board to connect to the internet and be able to ping different websites for testing. This also allows for the use of the “wget” command to easily install libraries and packages needed from websites.
- Thorough User Manual for Ease of Replication
  - As the project progressed, we had been documenting all of the steps necessary to be able to recreate our project with our Technical Director revisions on a weekly basis. These constant updates and completed progress are compiled in a clear, concise, and thorough manual to aid in the reproduction of this system for future applications.

Hardware Documentation

- Enclosure Design for Functional Hardware Setup
  - By using the 3D design program, SolidWorks, and with the assistance of an undergraduate mechanical engineer we were able to build and print an enclosure to protect the I.MX 6 board that will still allow access to the necessary ports.
- Two-Dimensional Design Documentation
  - By using AutoCAD we were able to design a schematic for this project, including all necessary components. This was necessary because we had to connect multiple pieces such as a RadioLynx board, wifi adaptor, USB splitter, antennas, and a GSM module to the I.MX 6 board and the AutoCAD image showed a simplified view of where everything was connected.
- Functional and Efficient Hardware Setup
  - The I.MX 6 board is mounted to a Lexan sheet to provide protection from electrical static discharges as well as heat. This also allowed for all of the components to be connected and organized in a safe and portable manner.

Figure 5: I.MX6 with Antennas fully enclosed

Anticipated Best Outcome

The anticipated best outcome consists in the delivery of an integrated electrical board able to compute a PPP-AR solution that could correct the position of the inertial navigation solution of existing iXblue products in real-time or postprocessing. Adequate documentation of all software and hardware such that the project can be expanded upon or drawn from in the future should be updated periodically throughout the project. The following deliverables will be developed through the course of the project:

- GNSS receiver embedding a PPP software for live and offline processing
- Software design document
- Software documentation detailing the operation of the software
- Hardware documentation detailing the physical system components and justification of the components choices
- Test strategy
- A final report covering all results, test data, project progress, and suggested next steps

Project Outcome

Our Anticipated Best Outcome(ABO) was not achieved, but our project did complete with an outcome that is acceptable to our sponsors. Our team designed and created a cost-effective GNSS solution platform for our sponsors to integrate their software to at a later date.

Figures

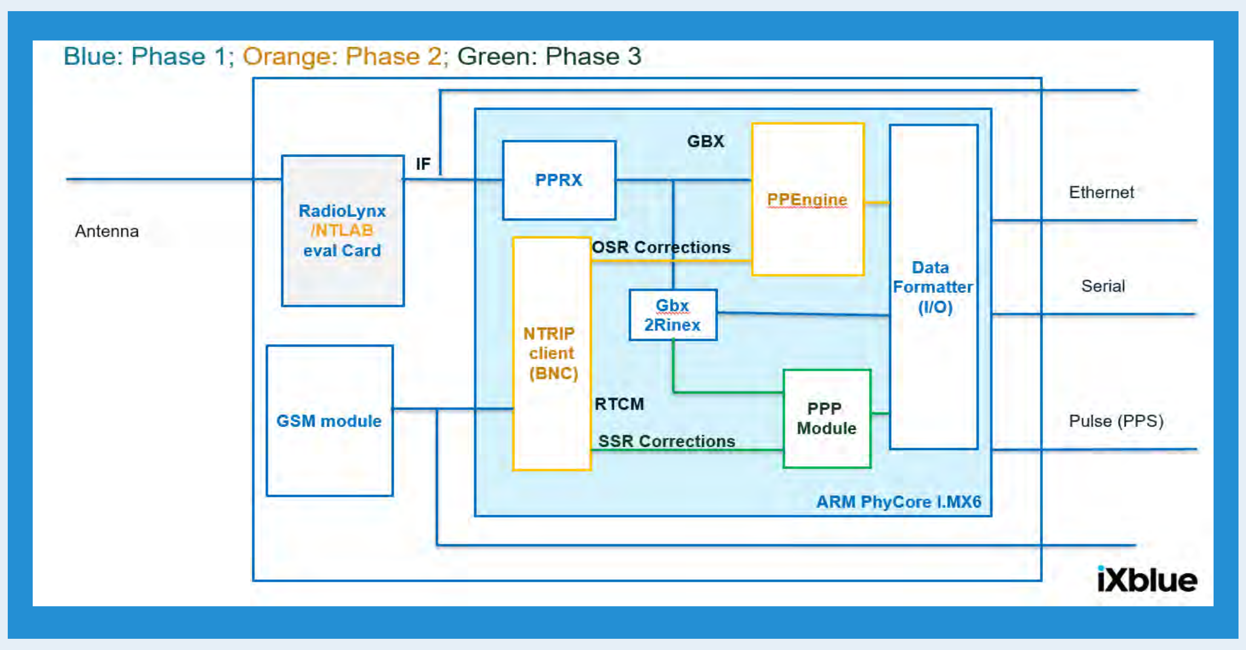

Figure 1: Project Overview Proposition

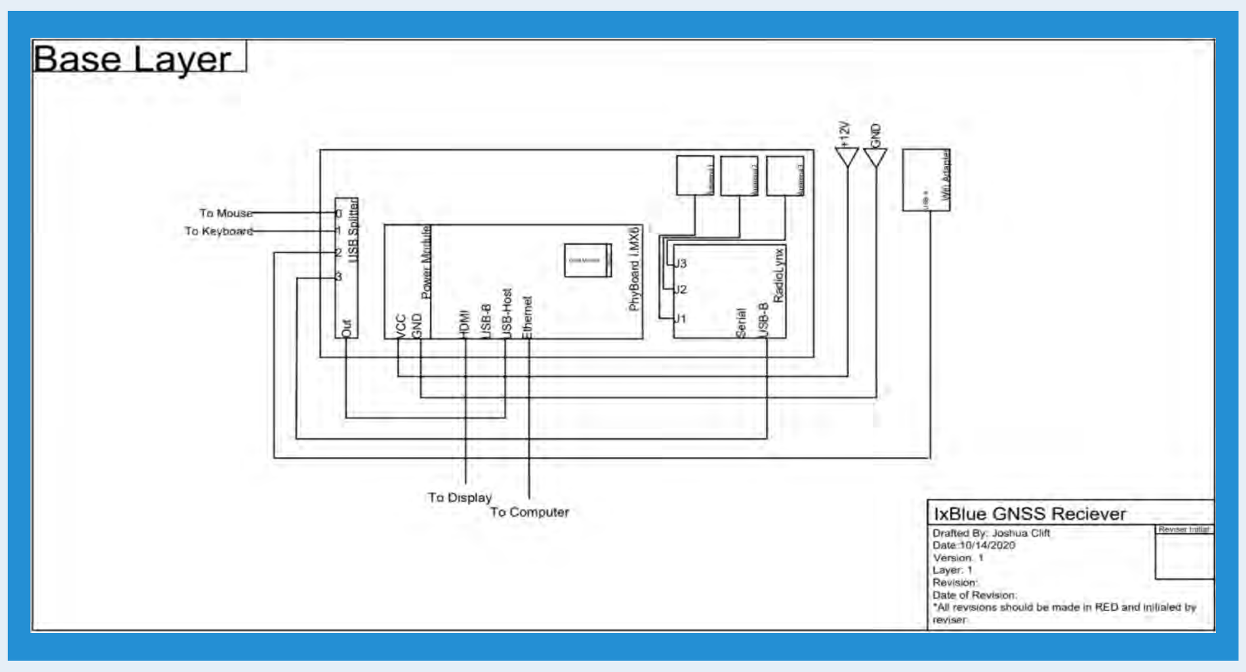

Figure 2: Base Layer Schematic

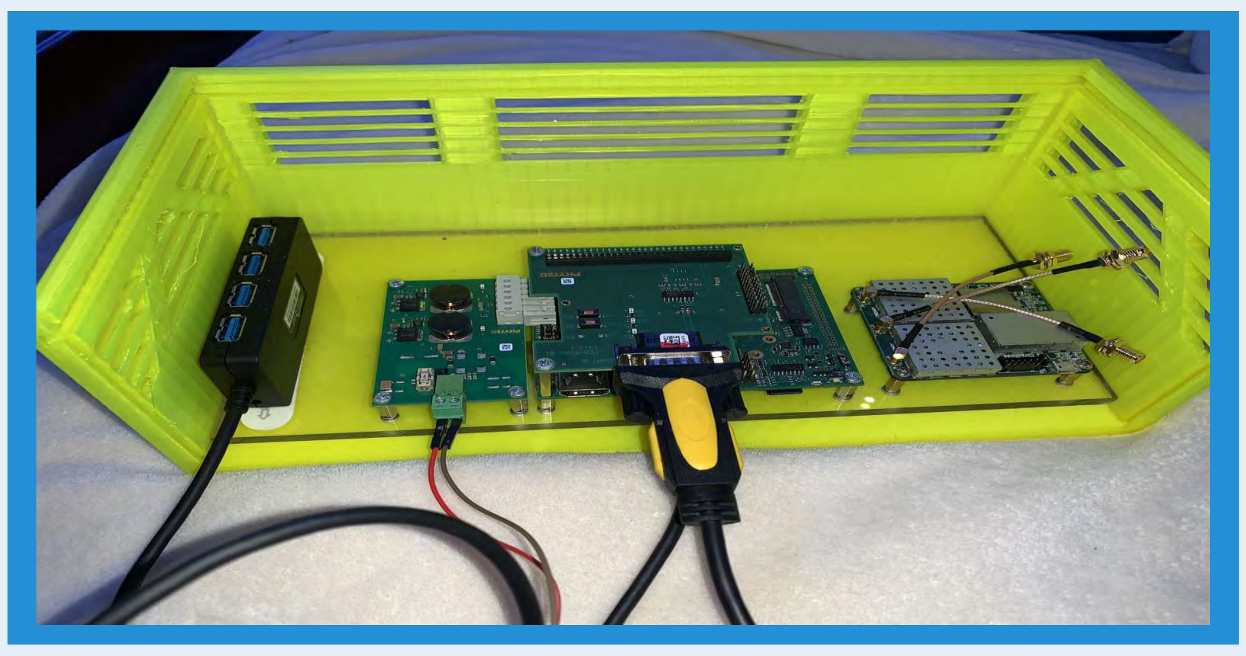

Figure 3: 3D Enclosure Design with I.MX6

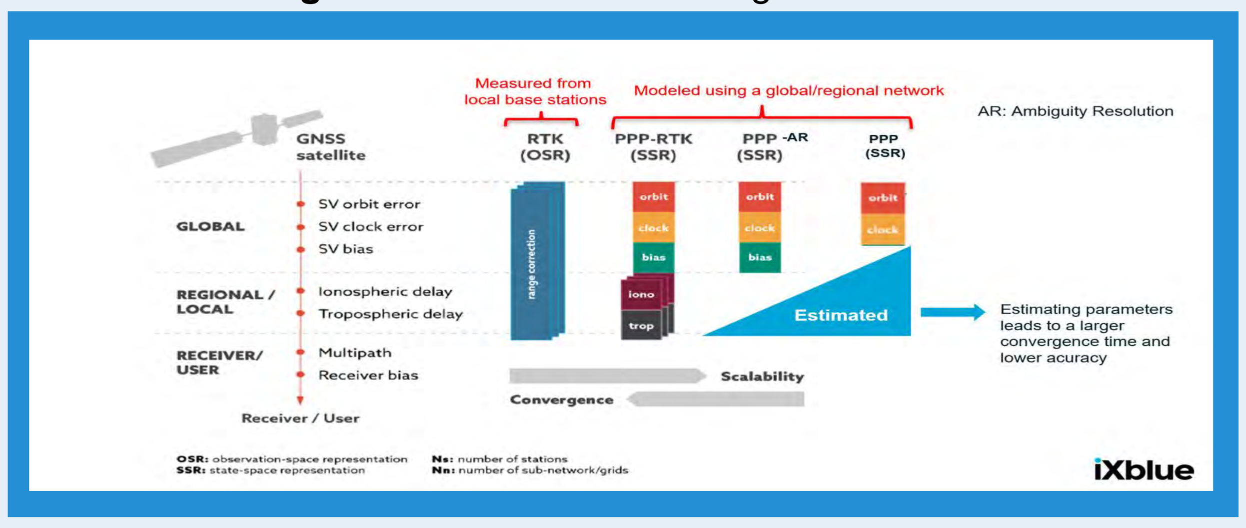

Figure 4: How to RTK and PPP

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859 ELECOMP Website: uri.edu/elecomp-capstone

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Fiber Optic Annunciator

Team Members: Eric Tattrie (ELE), Ayman Usmani (ELE), Brandon Bisgyer (ELE)

Technical Director: Sandro Silva | Consulting Technical Director: Mike Smith

Project Motivation

Recently there is a higher demand for systems that are immune to Electromagnetic Interference (EMI). Our controls circuits are monitored by Annunciators that collect data and status of breakers and then transmit the data anywhere it needs to go. This system collects digital alarm signals and transmits them via fiber optic transmission lines. The fiber optic signals are then converted back to digital and displayed on Annunciator. EMI in a system such as this can cause an alarm to not be tripped when needed, or give false alarms, both of which will cost valuable time and money to the company. Currently, there are many annunciators on the market that can monitor circuit breakers, but none use fiber optic cables. Having an annunciator that transmits data via fiber optics will give the company more confidence in their system and will have an extra layer of security while monitoring their breakers.

Key Accomplishments

Alarm Sequences A, M, F1A and F3A (Fig. 3):
An alarm sequence was designed in order to satisfy the security requirements of the ISA. Alarm Sequence A is the simplest of the four that have been implemented, with an automatic reset. The subsequent ones add states and manual resets.

Memory-Mapped I/O:
The memory mapped IO **(Fig. 4)** was implemented to use an 8-bit data bus to read and write addresses and data to and from 256 8-bit registers. A further addition to the memory mapped I/O was to allow the FPGA to read and write data and address to the data bus as well.

Alarm Horn dependent on severity:
A 10-bit counter was used to adjust the length of the horn sound depending on what severity the alarm is set at. The severity is an input decided by the user and the more severe it is, the longer the alarm lasts.

Schematic and PCB creation (Fig. 1):
Last year's Team PEC started to create their schematics based on what their prototype looked like. This version of the schematics had some of the general components needed for the new revamped version but was still missing many features that needed to be added. We were tasked with combining the switchboard and input board onto one PCB and revamping the annunciator and display PCBs. New components were added to the PCBs which included an Arduino nano every on both the input and annunciator board, a buzzer/alarm on the display board, bicolor LEDs for the display board, non-volatile memory, a second fiber cage for expansion, power conversion from 125VDC to 3.3VDC, and adding cosmetic details such as blue solder mask and a white PEC logo. Both PCBs were created in Circuit Maker and then routed.

Received Annunciator and Input PCB and Hand Built Display PCB:
During the winter break, the team received our completed design from the manufacturer. We made the decision to hand build the display board as it was a very simple design that could be easily done with lab tools available to the team.

GUI Development for Customer Customization:
Going into VHDL code to customize a product is not a very effective or simple task for a customer to undertake. Having a customer change the code can result in mistakes and making the product unusable. We are planning on creating a GUI that will allow the customer/user to plug directly into the system using USB and have all customizable options available **(Fig. 2)**. The main feature that the customer will be customizing is each individual alarm input and output. This will allow quick changes to be made if the system that is being monitored changes at all.

Arduino Implementation for Memory Mapped IO:
An interface has been designed to allow the memory-mapped I/O that has been programmed into the FPGA to communicate with the Arduino in order to use the registers in the memory mapped I/O (Fig. 4) to save data and addresses. This would allow the FPGA to store severity settings and control the alarm flash settings, the horn length and severity and the alarm settings the user would like to choose. The Arduino will be programmed to work with the GUI to provide the user easier access and control to the user without them needing to access the inner workings of the system.

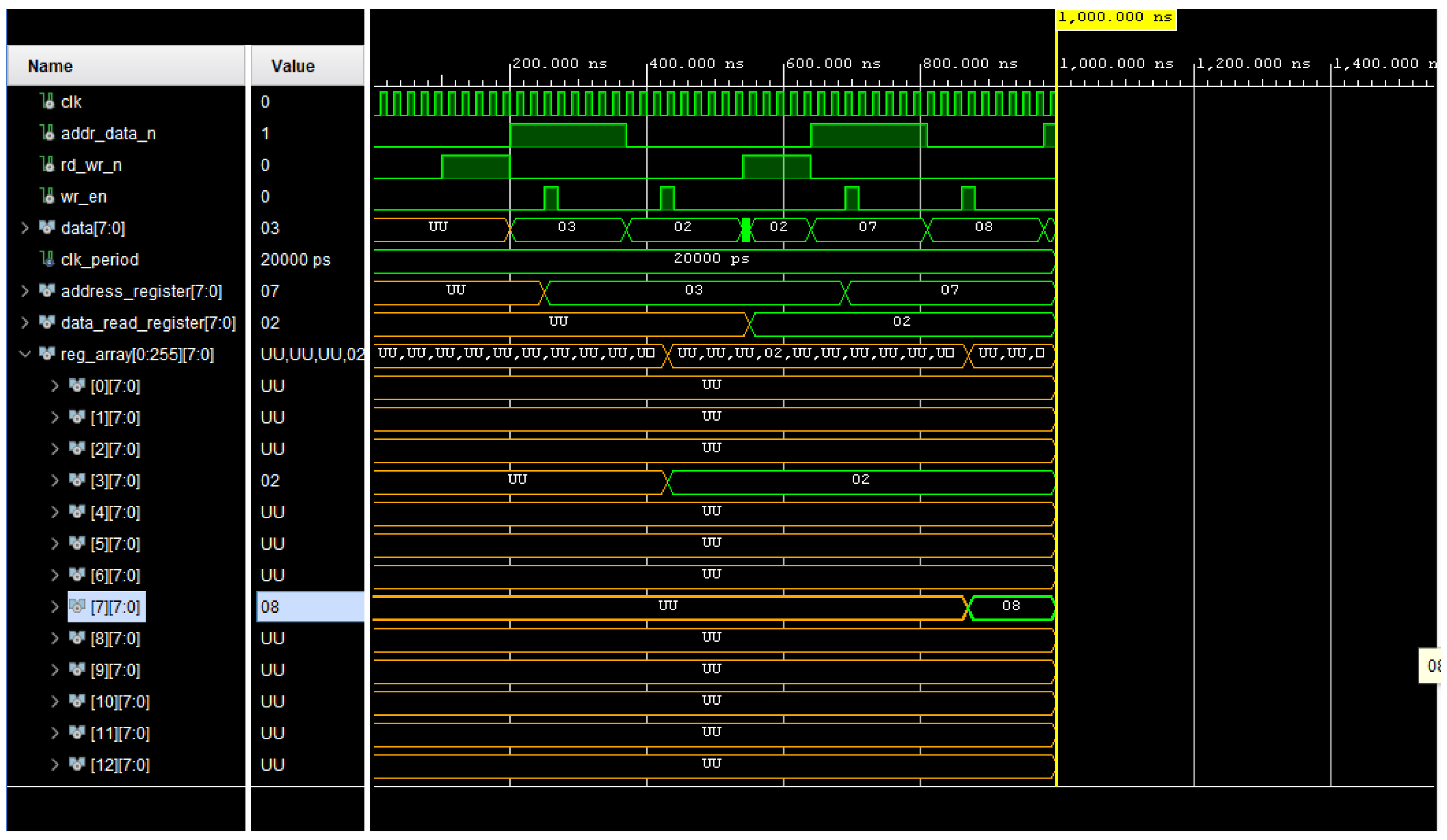

Fig. 4: Screenshot from virtual simulation of the memory mapped IO receiving an address register signal, a read/write signal, and a write enable signal along with the data sent to/from the FPGA.

Anticipated Best Outcome

The Anticipated Best Outcome (ABO) for this project is a functional and working production prototype of a fiber optic annunciator system based off last year's Team PEC's design. This new design will condense the project into three distinct PCB boards which are the input board, the annunciator board, and the display board. There will be many added features that will allow the purchasing company to customize the product how they like. A successful design and application of the fiber optic annunciator will lead to a highly secure system that will greatly benefit the companies that decide to purchase it.

Project Outcome

The Anticipated Best Outcome was not fully achieved. Many unfortunate setbacks occurred that delayed much of our progress. We were not able to get to all the items that we hoped to have in our final product. These items that we did not get to will be left for a future team to complete.

Figures

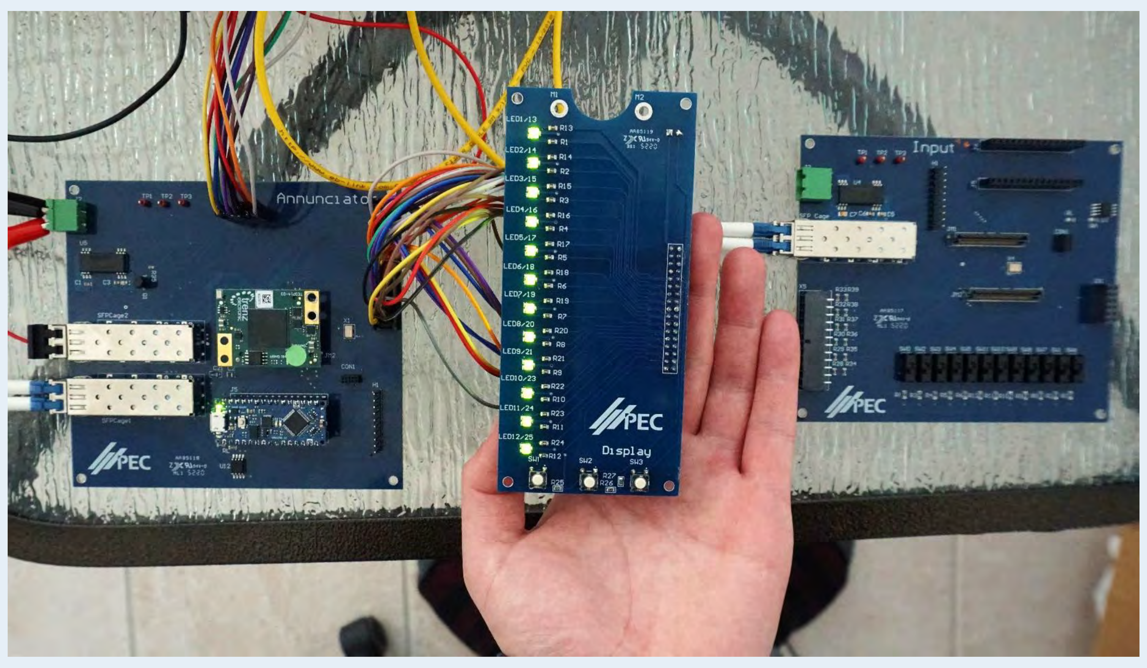

Fig. 1: The complete setup of the Fiber Optic Annunciator. Picture is the input board (right) connected by fiber to the annunciator board (left) and the display board with LEDs (middle) connected to the annunciator.

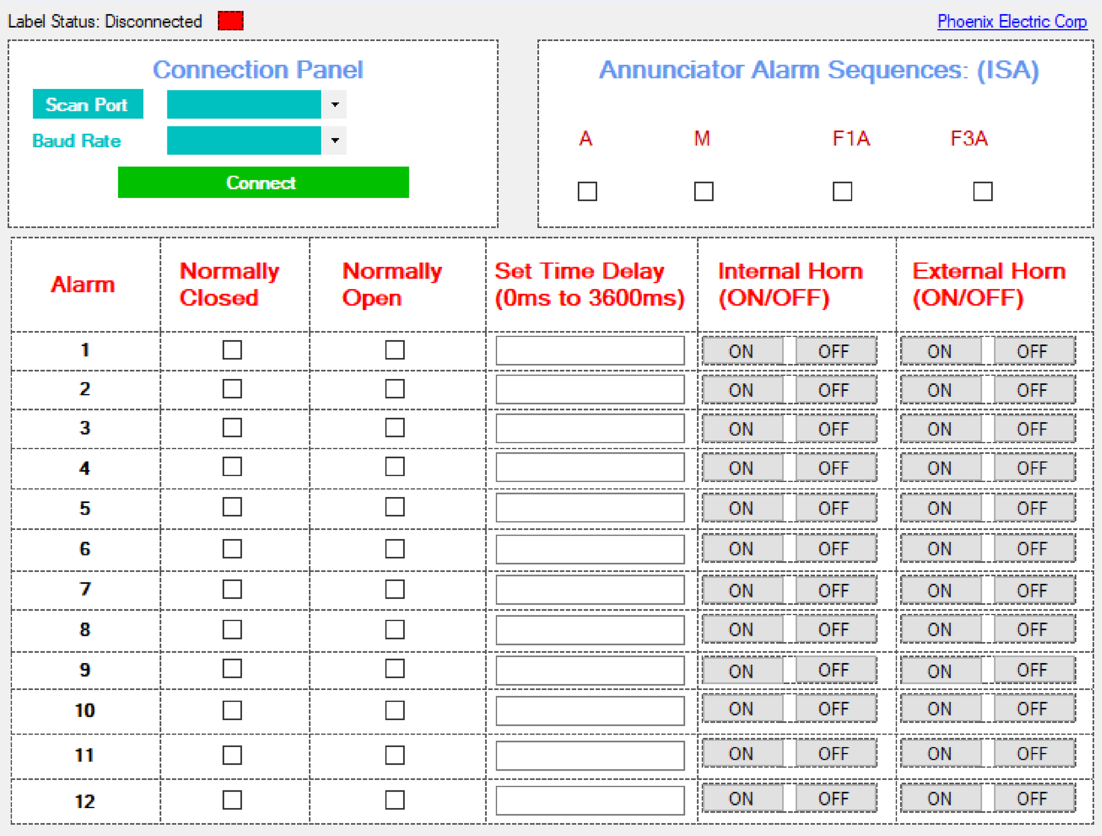

Fig. 2: The Graphical User Interface that allows the user to customize the various alarm sequences implemented in the Fiber Optic Annunciator. The user can select which alarm sequence they would like to use and then choose which alarms they would like to be normal open/closed and an internal/external horn on or off.

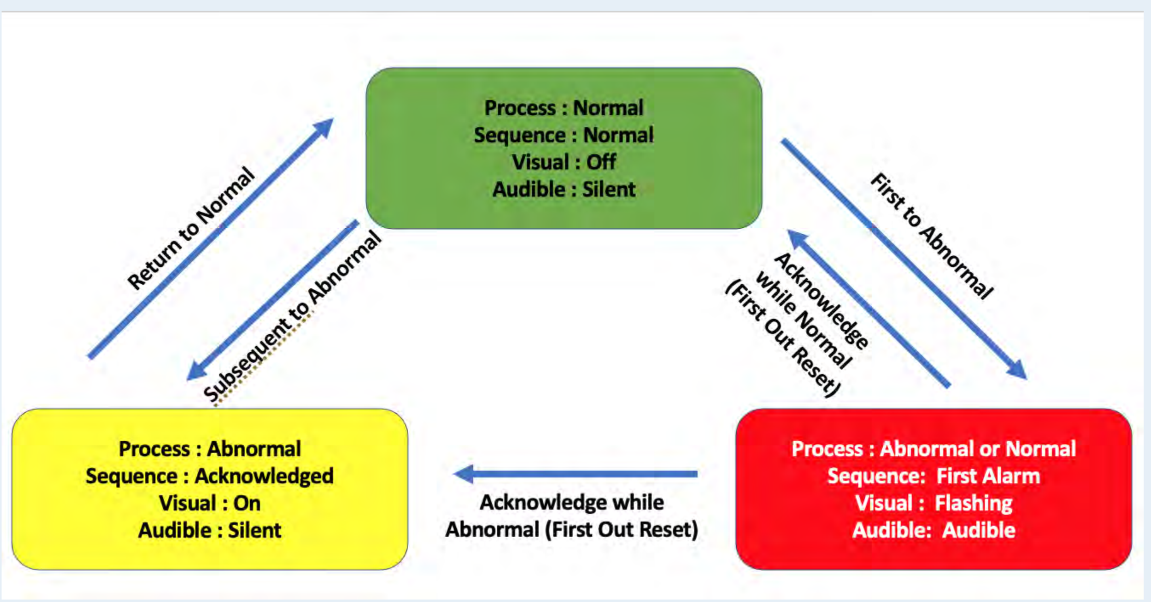

Fig. 3: A visual block diagram of Alarm Sequence F1A showing the overall functionality of the alarm sequence.

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859 ELECOMP Website: uri.edu/elecomp-capstone

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Drones and the Bay

A program for mapping ocean currents using drone footage

RHODE ISLAND CONSORTIUM FOR Coastal Ecology Assessment Innovation & Modeling

Team Members: Seth Wojciechowski (ELE), Danny Cruz (ELE), Matt Cecchini (ELE)

Technical Director: Dr. Baylor Fox-Kemper | Associate Technical Director: Dr. Stephen Licht

Project Motivation

Green and renewable energy is becoming a necessity in coastal areas. Rhode Island being a coastal state with almost 150 square miles of bay area, there's no question why researchers are looking into new types of renewable energy. Researchers at the University of Rhode Island's school of oceanography are looking to place underwater turbines throughout the Bay. As part of this research, we need a low-cost and reliable method to measure ocean currents throughout the Bay.

Our team developed an accurate method to detect currents using a drone. This method is low cost when compared to using satellites, buoys or sonar and is much more convenient and precise than drifters. Using a still, downward facing video taken with a drone, our team can find water surface currents in a matter of hours, giving researchers the opportunity to take precise measurements of powerful, sufficient velocity, consistent and reliable waves for efficient use and placement of marine turbines.

Key Accomplishments

Functioning Code: The code was properly debugged and ran as expected (Fig 1 & Fig 2). The main issue in installation was finding the correct pathing for each individual user and the set up of the mediainfo resource tool. A simplified guide was created to help future users of the program install and use it; along with added instructions on how to calibrate the script, which is key to use with different drones and resolutions. An extremely useful method was added to the code which saves the analyzed data values that we look for into an excel sheet (Fig 3). The added feature created for convenient comparison and studying of the data.

User Friendly: The code has been adapted to make it as easy as possible for any user to install and run through the program each time without having to manually change pieces of the code. It is now much simpler to select the desired video and save the results obtained in MATLAB to selected folders. This causes less confusion running the program and limits touching the code which can lead to possible errors.

Github: A GitHub repository was successfully created to tackle or change the code more effectively as a team. The program allows for easier adaption of code changes or implementations completed by other members, opposed to digging through different parts of the code copy and pasting the changes. The repository allows for an easy one time update of any changes made which makes debugging many times easier. A section is dedicated to this in the guide if users are interested in making changes to the code.

Code Guide: The guide was created with the intent to help users have an easier experience installing and adapting the code for their own use. It includes the steps for installing the code along with its components (focused more for the windows OS). There are detailed instructions on how to create a calibration file when using a non DJI drone and a drone with a different resolution. A section is dedicated to the square size parameter (among other parameters) for comparison of how different values change the amount of windows for analyzing footage which affects accuracy, time and cost, all dependent factors the user seeks. An added section is included for other troubleshooting problems encountered when debugging and altering the code.

Flying Conditions: The user guide includes a section to show users the proper flying conditions of the drone including weather conditions, altitude above the water and proper lighting. The largest factors that affect the accuracy of the program are shaky drone footage, improper lighting and any light reflection coming off of the water, therefore the user guide walks potential research teams through the process of buying the correct drone for the project, and how to try to mitigate any negative effects caused by improper lighting.

Going Above and Beyond: The team has started collecting data at the Providence river near the Save The Bay campus, the data that is being collected will show the movement of hypoxia around Narragansett Bay. This will give Baylor's research group up-to-date information on how the Bay is changing over time, rather than working with past data, his research group now has the ability to collect data much faster than was previously possible.

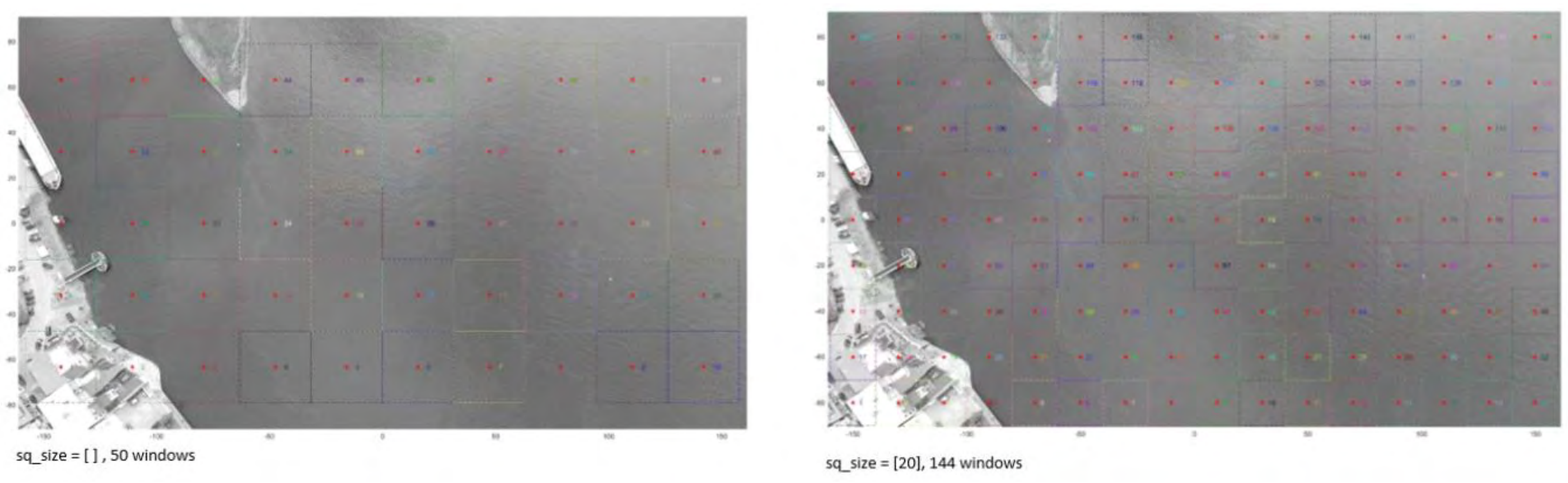

Fig 4: One of the changeable parameters (sq size) that dissects the video image from stcfit script into separate windows for more accurate analysis but at the cost of longer time (default value vs 20)

Anticipated Best Outcome

The best outcome is :

- A complete MATLAB program that is able to measure wave velocity fields and create a velocity gradient map for each video taken with a drone
- Instructions were also created for the program; so the project can easily be adapted by other users. It will include: optimal weather conditions, ocean conditions, a guide for drone flying, and how to install and run the program to obtain the most accurate wave velocities.
- Further steps have been taken to find the current fields throughout Narragansett Bay; this will help Dr. Baylor in his goals for finding where to place hydroelectric turbines.

Project Outcome

The Anticipated Best Outcome has achieved as confirmed by our Technical Director. A fully functioning system has been refined to give ocean current velocity vectors using a drone, a video and the Matlab Code.

Figures

Fig 1:Software flow diagram

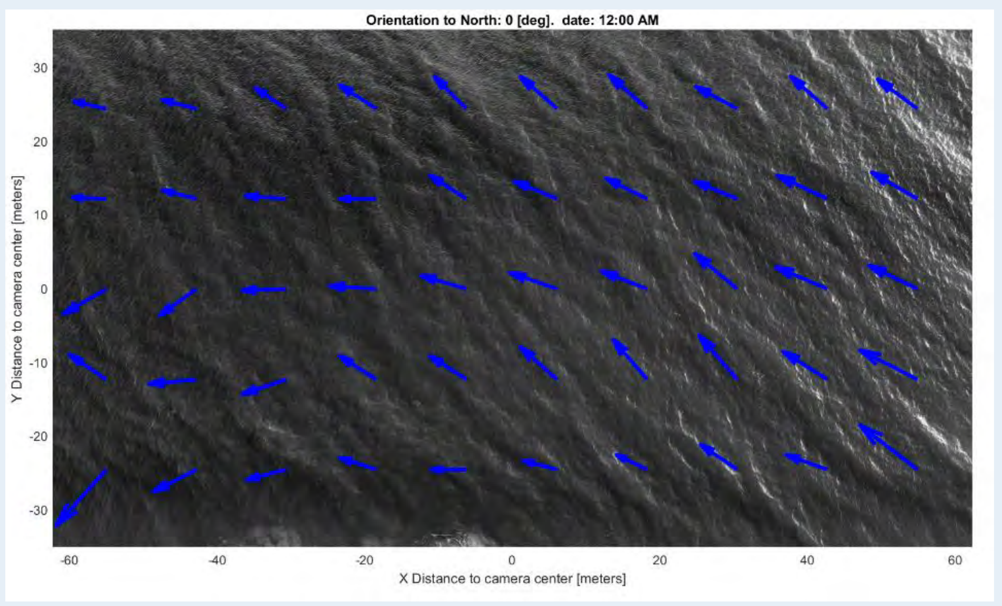

Fig 2: Video taken 300 ft above the shore of Misquamicut Beach, analyzed for 30 seconds: Program run time: 1.917 Hours

0.3	0.82	29.456294	Longitude	41.32272396	time_limits	0	3
0.3	0.78	27.486823	Latitude	-71.80347595	dt	0.1	
0.3	0.7	22.427654	Height	102	sq_size_m		
0.3	0.52	22.796457	Timestamp	0.000418888	sq_dist_m		
0.2	0.4	26.821364	Yaw	0	mask_2D		
0.2	0.25	27.187211	Pitch	-90	nan_percentage_thr	5	
0.2	0.01	29.141185	Roll	0	Ux_limits_FG	-2	2
0.2	-1.38778E-16	25.578819	Extra	1	Uy_limits_FG	-2	2
0.4	0.22	25.034687	Run Time	10 Minutes	U_FG_res	0.1	
0.3	0.5	20.131553	Frames	75	w_width_FG	1	
0.1	-0.18	36.562853			U_SG_res	0	
0.2	-0.21	27.305234			w_width_SG	0.5	
0.2	-0.2	35.482657			waveLength_limits_m		
0.1	-0.17	44.655572	**Date**	11/13/2020	wavePeriod_limits_sec		
0.2	-0.17	41.901763	**Drone**	Mavic Mini	water_depth_mask_2D	10	
0.2	-0.3	41.317685	**Location/ Coordinates**	Misquamicut Beach: 41.3248893127819, -71.79057074319458			

Fig 3: Excel implementation to automatically save important analyzed data (portion of full data saved)

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone

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AutoML Ship Classification

Utilizing AutoML for a standalone Ship Classification System

Team Members: Nathaniel Trozzi (ELE), James Chen (CPE)

Technical Directors: Thomas Santos, Chuck Angell, Akintoye Onikoyi, Ken Hartlaub | Consulting Technical Director: Jeremy Peacock

Project Motivation

Rite-Solutions has successfully demonstrated using weakly supervised learning to automatically generate labels for non-curated datasets to train ship recognition and classification machine learning (ML) models. Although this approach is successful, cloud-based solutions are not a viable approach for customers in situations where network communications to a cloud do not exist or are bandwidth limited. Additionally, public cloud solutions present a security problem when the sensitivity and level of confidentiality of the data cannot be ensured and adequately protected. Thus, having an open-source Automated Machine Learning (AutoML) solution available in a standalone environment will effectively address these concerns. Due to these faults with Google Cloud AutoML, Rite-Solutions strives to move away from the cloud and become private. Using the new devices that will be received, Rite-Solutions hopes to improve the speed of the training from a new AI workstation, along with improving or having a consistent accuracy when running models to distinguish ships.

Key Accomplishments

AI Workstation: Finding an artificial intelligence and machine learning-based computer was the first and most important part of the technical task. The workstation needed to be faster and more precise than what was previously used which was google cloud AI. The workstation that was selected was the Dell Precision 7920 Tower**.** Which is a top of the class private AI workstation.

Graphics Processing Unit (GPU): To increase the speed of the training on the workstation, a high powered GPU was needed. After narrowing down the top three best GPU for AI acceleration, they were the Nvidia RTX 3080, Nvidia RTX 3090, and Nvidia RTX Quadro 5000. Finding out the Nvidia RTX Quadro 5000 was the best fit for the Dell Workstation, that is what was picked.

Single Board Computer (SBC): To perform the models in real life with real images from the tested models of the Dell Workstation a single board computer needed. The single-board computer will be a standalone device powered by a battery pack. The single-board computer that was picked is the Nvidia Jetson Xavier NX **(Fig.1)** The SBC will use multiple cameras to classify different ships and their class.

AutoML Solutions: Open-source AutoML tools were researched, identified, and evaluated through a Pugh matrix methodology and supporting criteria. The criteria factors in each tool's strengths and weaknesses, as well as ability, to determine the best solution to test for the project. Such criteria include: AI workstation compatibility, ability to detect objects in images, ability to classify images, saving and loading models for inference, ability to train with a GPU, and more depending on the need of determining factors. See **Fig. 2** for the utilization of one of the solutions.

ML Model Setup: Every AutoML solution is accompanied by developing a script to enable training on a dataset of ship images **(Fig. 3)**. The script includes loading and splitting the dataset (i.e. training, validation, and test), training the model with the split dataset, evaluating the model for accuracy on the test dataset, and using the model to predict images as an input.

Power solutions: The power solution that will be chosen will be a rechargeable battery. Which would need to be waterproof, shockproof, dustproof and will need to power the board for a considerable amount of time.

Integrated still and video camera: The camera will need to be able to connect to the SBC. these cameras will be used to classify images and videos of ships, using tracking and a modeled training program.

Setup and configuration of the Dell workstation: When the Workstation arrives at the office after ordering. It will need to be set up and configured. A couple of preliminary tests will need to be performed to make sure every aspect of the computer is up and running. After that, the workstation will be put to the test and run model training. This is a very important part. This is where it is found out if the workstation training is faster than google cloud AI.

Integrate, assemble, and test all hardware components: When all the parts and devices are delivered they will need to be tested to make sure they are working to our specifications. This includes running the model training test that was designed.

ML Model Accuracy: Improving the accuracy of the predictions of the ML model is the main focus in the model training. There are several methods used to increase the accuracy of the ML model. These methods include modifying the input parameters (i.e. batch size, image size, and epochs), manipulating the sequence of layers of the neural network, tweaking model hyperparameters, and manipulating the image dataset to diversify the input data.

AI Inference Environment: Once the ML model training is completed to accurately classify images of ships, a model will be exported as a compatible file format (i.e. TensorFlow Lite) and deployed on the SBC along with an AI hardware accelerator for inference **(Fig. 4)**.

Anticipated Best Outcome

The Anticipated Best Outcome, as defined by Rite-Solutions, is to design and develop a standalone AI device that incorporates an AI hardware accelerator for use in an edge computing environment to support ML model execution. The AI device consists of a single board computer with integrated cameras in real time to classify different ships. This device will be used in multiple locations which is why having it mobile is very important. Using the models trained on the new AI workstation, testing the workstation to ensure its speed of the training to be faster then what was used before. Combining all of the devices to produce the required outcome for Rite-Solutions need.

Project Outcome

The Anticipated Best Outcome was achieved. After working towards our ABO for two semesters, we were successful in training ML models to classify ships on three different edge devices

Figures

Fig.1: Nvidia Jetson Xavier with a 12 MP IMX477 camera.

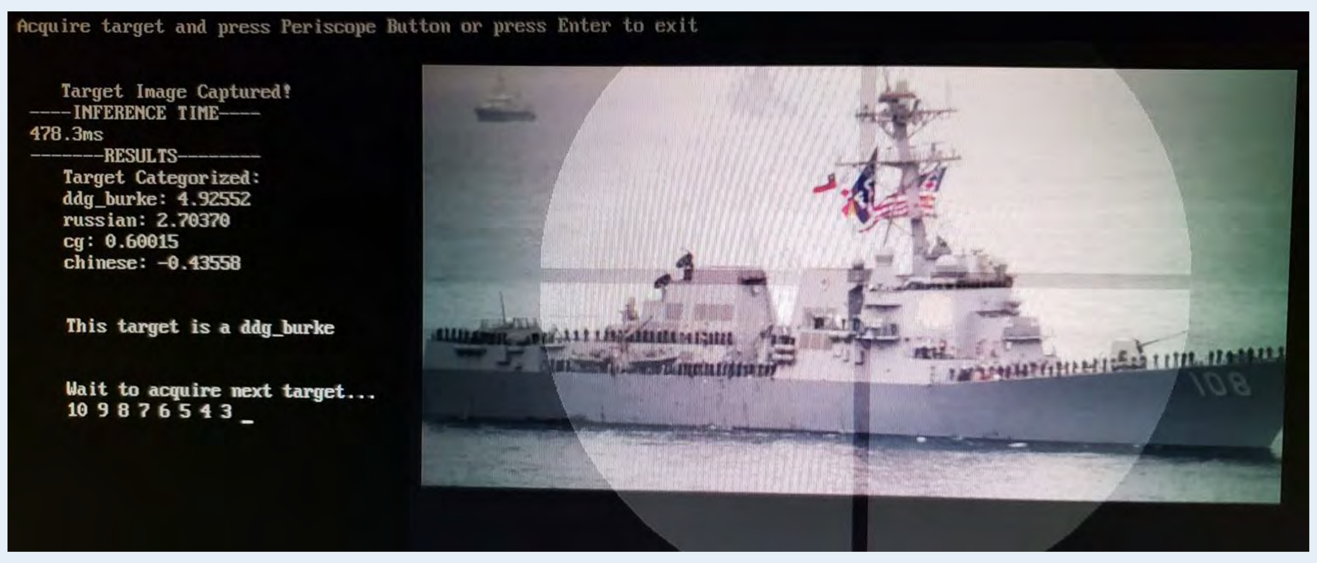

Fig.2: Inference performed on a Raspberry Pi with the Coral USB Accelerator and a camera.

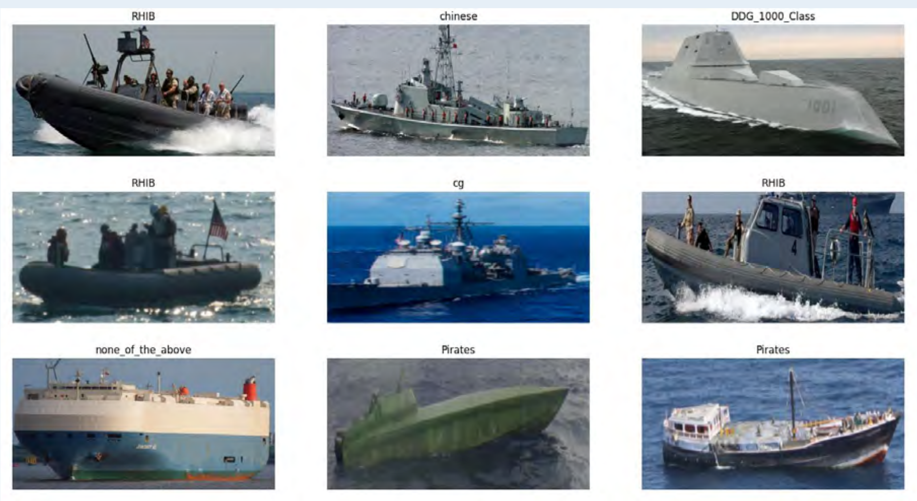

Fig.3: Sample of dataset of ship images that is used for training.

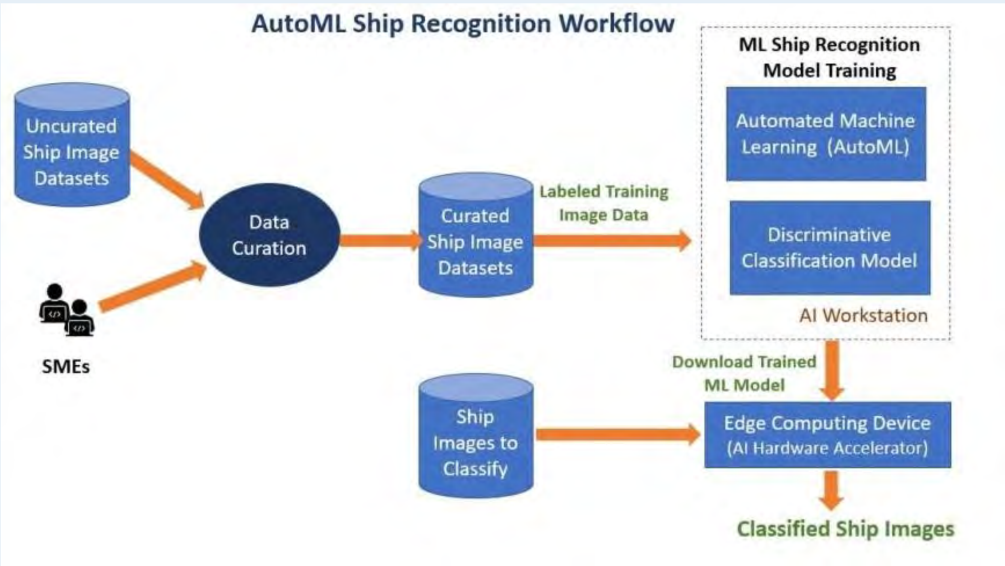

Fig.4: The process of realizing inference on an edge computing device.

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone

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Applying ML Research for Undersea Object Detection

Team Members: James Morris (ELE), Anthony Neves (CPE), Andrew Gomes (ELE)

Technical Directors: Thomas Santos, Dana Brown | Consulting Technical Directors: Noah Daniels, Al Gaines ('88), Najib Ishaq ('20), and Jeremy Peacock ('20)

Project Motivation

A difficulty of utilizing Unmanned Underwater Vehicles (UUV) is accounting for physical obstacles in the path of that UUV that may require additional navigational commands. Rite-Solutions is collaborating with Dr. Noah Daniels and his graduate research team to develop a machine learning model that can identify objects on the seabed. This technology could be applied across several commercial industries, as well as the Navy. The technological advantages of the machine learning model include avoiding potentially hazardous objects for the UUV, searching for and identifying objects, and eventually aiding in autonomous UUV operations.

The software package being designed to satisfy the above criteria requires translation of existing Python/Tensorflow code into a language with a higher focus on safety, Rust, to implement the software onto standalone devices properly. To test the software package prototype, a MATLAB program will be created to simulate an active side-scan sonar, where results can be validated under different conditions of the sea.

Key Accomplishments

- **Sonar Emission:** The MATLAB simulation of a side-scan sonar requires both an emission of energy that can be applied to an object, as well as sensors that receive feedback from energy bouncing off of an object. The emission of this energy from a sonar sensor has been simulated in a very simplistic form, which is the foundation of the High-Level Design Flowchart for our MATLAB program.

- **MATLAB Examples:** Several MATLAB resources are influential to the Sonar emission, detection, and object detection codes that we are creating. While creating a simulation of a side-scan sonar in MATLAB, we are also editing and applying the "Underwater Target Detection with an Active Sonar System" mathworks program to our own coding. By utilizing this example, the group can evaluate which methods of sensor and signal representation best fit our goals as we progress.

- **Objects as MATLAB Targets:** Replacing the targets of Sonar example codes with solid objects instead of designated targets strength objects is a key step in the development of the MATLAB code. The desired output is the feedback from the sonar simulation when energy is reflected off of the object, therefore targeting that object with the sonar emission is critical.

- **Rust Translation:**
  The existing Machine Learning model for Object Detection is written in Python and, to make the project more safety-oriented/operable on a standalone machine, the code must be translated into rust. There are many parts to the CLAM code created by Dr. Daniels and his research team, and parts of that code are completely translated into rust. The Graph portion of the code has been implemented, with key functions throughout the code translated into Rust as well. This was an entirely new language, and a large foundation has been created to move forward with the complete translation of the program into rust **(Fig 4)**.

- **Cylinder Target**
  The MATLAB program produced data from a side-scan sonar simulation, projecting energy onto a cylinder underwater. The data is in the form of Integrated Pulse Data, with the measurements being voltage, time, distance from Sonar source, and angle with the receiver **(Fig. 2)**. The data is simulated under ideal conditions, with a flat seabed and a speed of sound underwater that represents mild ocean conditions with no obstacles. This data is then intended to be tested with Machine Learning, to reproduce the 3D-object, only using the Integrated Pulse Data.

- **MATLAB Object Viewer:**
  The MATLAB simulation includes a script to view the object created for data simulation. The objects are created using target strength patterns, which rely on azimuth and elevation angles, and well as length, width, and a stacking method. A 2D-Object is repetitively stacked based on the target strength formula, and a 3D-object is created as a result. The MATLAB Object Viewer allows the user to view the slices that are created that make up the object as a whole **(Fig. 1)**. This provides insight into how the objects are created, as well as a good guideline for moving forward to create more objects to be tested. The object viewer also serves as a test for the object's shape before testing with machine learning, to make sure the desired object is actually represented **(Fig. 3)**.

- **Target Strength Sphere:** Attempts to use several different MATLAB functions were used to produce different target strength objects, including a target strength sphere. Similar methods were used as were done with the target strength cylinder, including tracking the output data of the target object and initiating different inputs for the MATLAB script to run. At the time of this report, the methods of the cylinder have not worked for the sphere. The misuse of the necessary functions and parameters can be a leading possibility to why such issues arise.

Anticipated Best Outcome

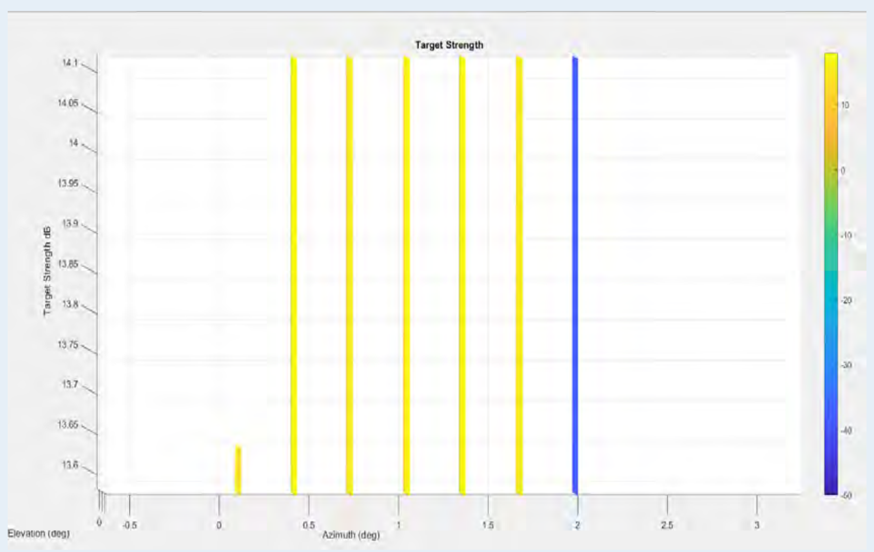
The primary objective of the project is to design a software package that can quickly and accurately detect objects underwater. In order to accurately test this software package, the simulated sensor data from MATLAB must be created and verified to be working properly as well. As a result of the translation of the existing Python code into Rust, the effectiveness of the new programming language Rust can be evaluated as well for future products with similar purposes made by Rite-Solutions. The best possible outcome would be realized with an effective Rust and MATLAB software package that can simulate side-scan sonar data and detect underwater objects from that data accurately.

Project Outcome

The Anticipated Beat Outcome was not achieved, whereas of right now, the final deliverable product is a compilation of Rust and MATLAB software to be used moving forward with Undersea Object Detection. The results from the MATLAB code from the Sonar Simulation are for the cylindrical targets with different sizes, angles, and locations. While this code is being sent to Dr. Daniels' team, the main body of the Graph implementation is thoroughly documented. This documentation is to ensure clarity and understanding in both how to properly utilize its individual components as well as the overall architecture of the program.

Figures

Fig. 1: The MATLAB Object Viewer is seen here for a Box Target. The individual slices are seen as rectangles, the x-axis representing the azimuth angle of the target, and the z-axis representing the Target Strength in decibels, the color bar on the right serves as a visual aid for seeing the target strength.



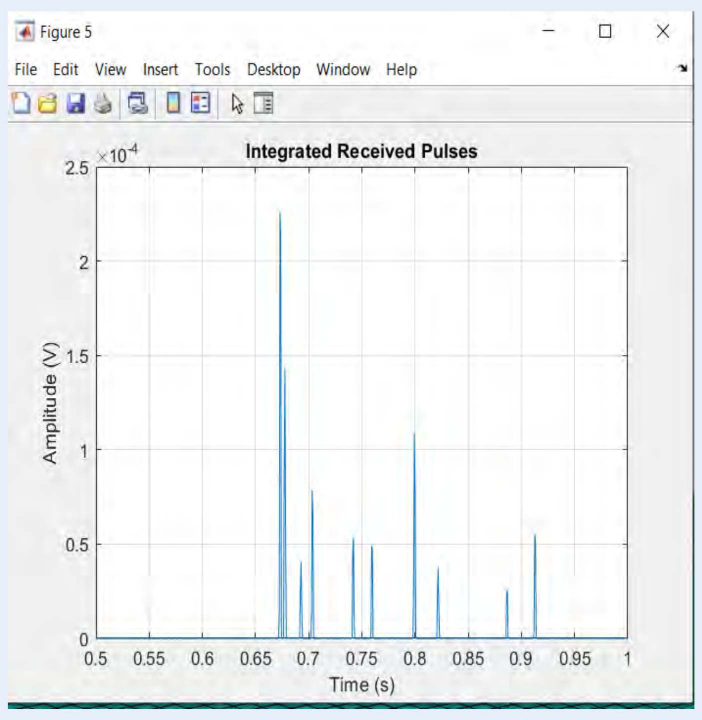


Fig. 2: The Integrated Pulse Data of a cylindrical target is seen here, with a total of 100,00 samples. There is a data point taken for every meter that the sound wave from the Sonar moves, about 1,520 samples per second. The spikes in data represent energy bouncing off of a higher target strength, with an amplitude of 0 representing no returned signal.

Fig. 3: The stacking of slices can be seen here with the partial Cylinder recreated from the cylinder target. When viewed from the angle of the source, the target appears cylindrical, although the figure is rotated here to show all axes and that the target generated does not need to be completely solid, it must only appear solid to the sonar.

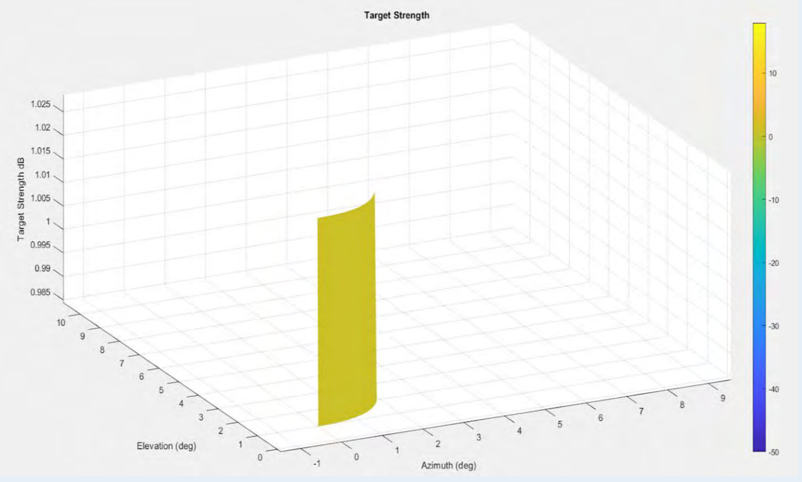


Fig. 4: The overall coded implementation of the Graph program. This program takes in a mass of clusters (clustered data points) and creates edges between them. This essentially makes a wireframe mash for the future CHAODA implementation to take as input to differentiate different objects.

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859 ELECOMP Website: uri.edu/elecomp-capstone

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Vacuum & Temperature Monitoring System (VTMS)

Seascan Inc.

Team Members: Michaela Bellisle (ELE), Chris Alexander (ELE), Mariah Messinger (CPE)

Technical Directors: Richard Arthur, Peter Jones | Consulting Technical Director: Mike Smith (URI '01)

Project Motivation

Seascan Inc. is a small company that manufactures oceanographic instrumentation and equipment to be used primarily in scientific research and development. They create a number of pressure tolerant enclosures to protect electronic equipment and battery packs when submerged in water. The housings are tested by using a vacuum pump, ball valve, and vacuum gauge and then monitored for 12 to 24 hours to ensure proper functionality.

This project is driven by the need to guarantee the enclosure is sealed every time it goes into the water once it is in the hands of the customer. The usage of vacuum, temperature, and humidity sensors will assure the user that the state inside of the enclosure is within the desired parameters. Additionally, a set of LEDs installed inside and/or outside of the housing would allow the user to easily check the status of the enclosure.

Key Accomplishments

Firmware Development: Firmware has been developed using the Arduino IDE for the ESP32 board and peripherals**.** There are BLE functions responsible for transmitting and receiving packets of data to and from a BLE python client. The user is able to define the parameter settings with the GUI and the client will then transmit the data to the ESP32. The data packet contains the user defined parameter settings: device name, data collection frequency, desired sensor ranges and tolerances and the current date and time. If no data is received, the firmware will use the default parameter settings. Regardless of a BLE connection, the system will read the sensor data from the BME280, get the timestamp and store it on the microSD card. If there is a BLE device connected, the time stamp and sensor data is transmitted to the client. The system will also stay powered on as long as there is a BLE device connected. When there is no BLE client connected, the system will run through an LED sequence to indicate the status of the environment within the enclosure. If the sensor value is within the desired range, the green LED will be set high. If it is not, the firmware will either set the blue or red LED high for values that are lower or higher, respectively. After 5 cycles of sensor readings, the RTC alarm will be set and the system will be powered off.

Schematic and PCB Fabrication: Using a program called Circuitmaker, the selected components were placed and wired together on a schematic. Then a custom PCB was designed by placing and routing the components using the PCB design tool on Circuitmaker. An additional external circuit board with LEDs and a Reed Switch were also created for use with opaque pressure housings.

Power Scheme: The boards operate on a 5V battery and when not in use is in a "power efficient" mode. To turn on the board it activates through a variety of methods. The output of a load switch is triggered by at least one of three possibilities. The first is through an external RTC which provides a signal to the load switch at a user specified interval. The next is a reed switch which is triggered by a user swiping a magnet past the LED board or the main board. The final signal is from the ESP32 so that the board remains in the operating mode.

Testing Prototype: Both PCBs were populated, and initial tests were performed to ensure there were no shorts between signals. Afterwards, testing was conducted using the developed software and sample data to give varying results. There were some issues found during the testing but were resolved with some rework and firmware adjustments.

Software: Using PyCharm as an integrated development environment, the software for this system was written in Python, primarily using Tkinter, Bleak, and Asyncio. Tkinter was used to create a graphical user interface, Bleak to establish BLE communication with a peripheral device, and Asyncio to manage processes that needed to occur concurrently. The software can scan for nearby BLE devices, present them to the user so that they may choose one to connect to, then connect to the selected device. After connecting to the device the software will automatically read and store any data advertised. The graphical user interface also provides a way to view gathered data and enter desired parameters for the peripheral device.

Anticipated Best Outcome

The ABO is a functional prototype that can monitor vacuum, temperature, and humidity levels and report the status to the user. Software will be created to display sensor data, remaining battery life, and accept user inputs. The system needs to be able to send and receive data between the main circuit and software via Bluetooth or WiFi connection. A schematic and PCB will also be fabricated for the hardware prototype. A system user manual describing the hardware and software components will accompany the prototype, along with test results and a demonstration of the working system.

Project Outcome

The Anticipated Best Outcome was achieved.

Figures

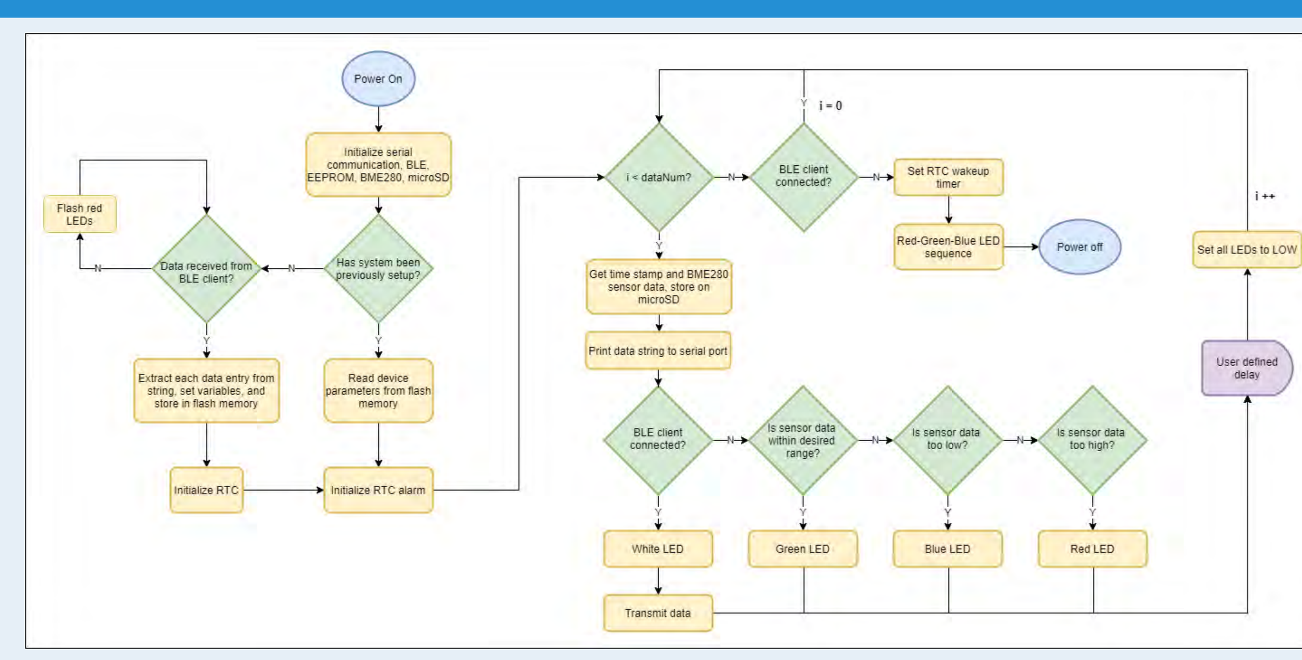

Fig. 1: Flowchart of embedded firmware

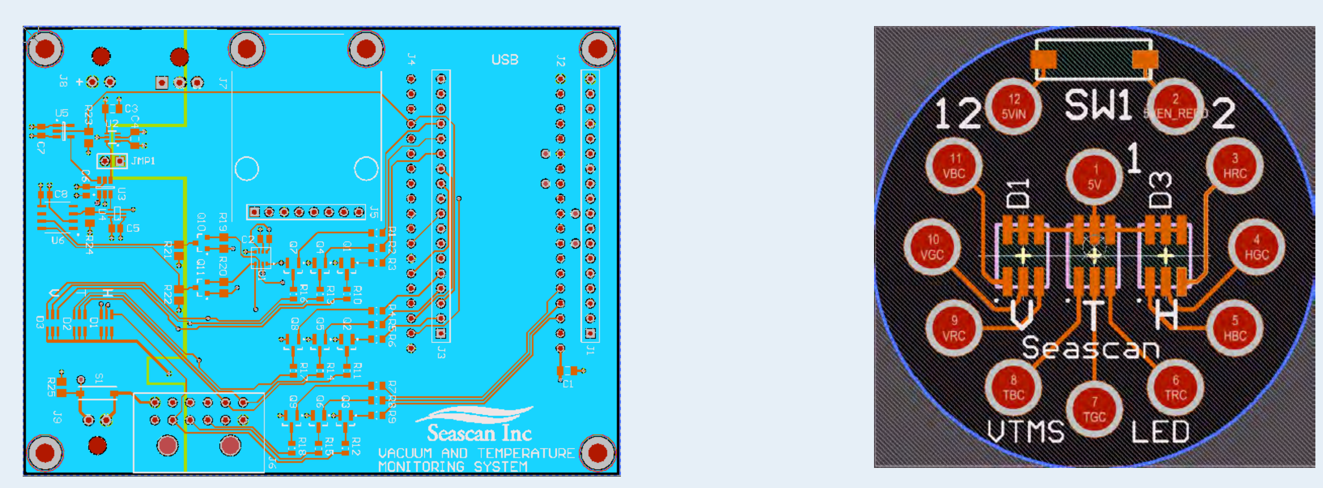

Fig. 2: The completed design of the Main PCB (left) and the external LED PCB (right) as seen on CircuitMaker

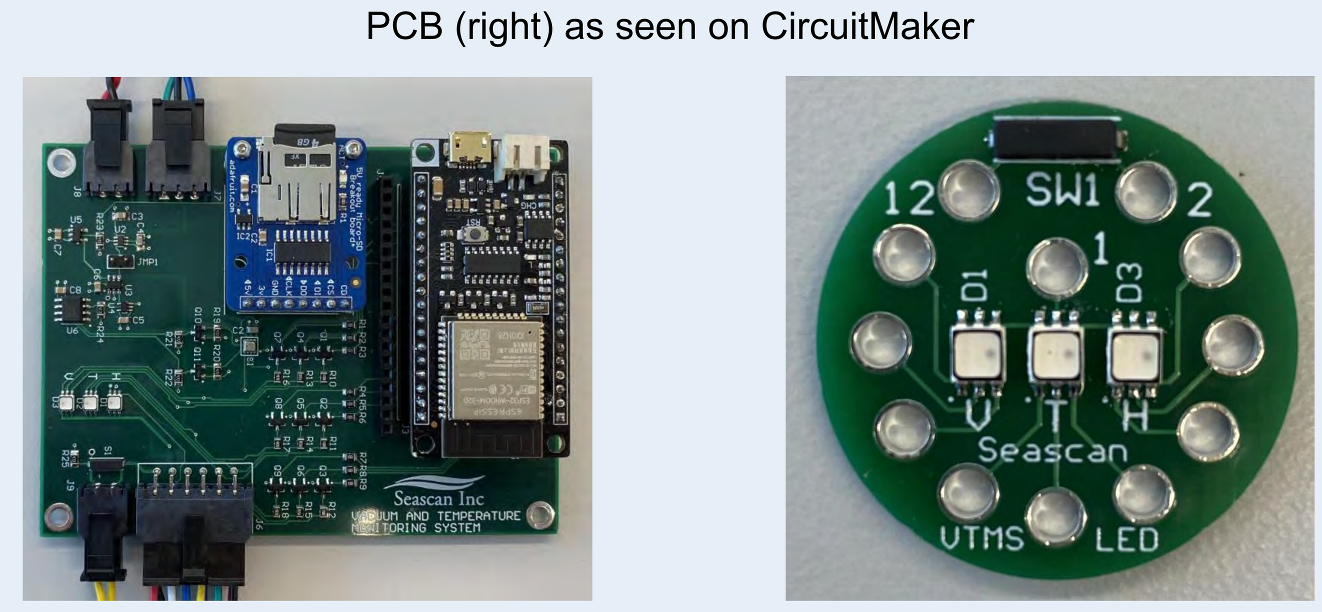

Fig. 3: The populated PCB of the main circuit (left) and the external LED circuit (right)

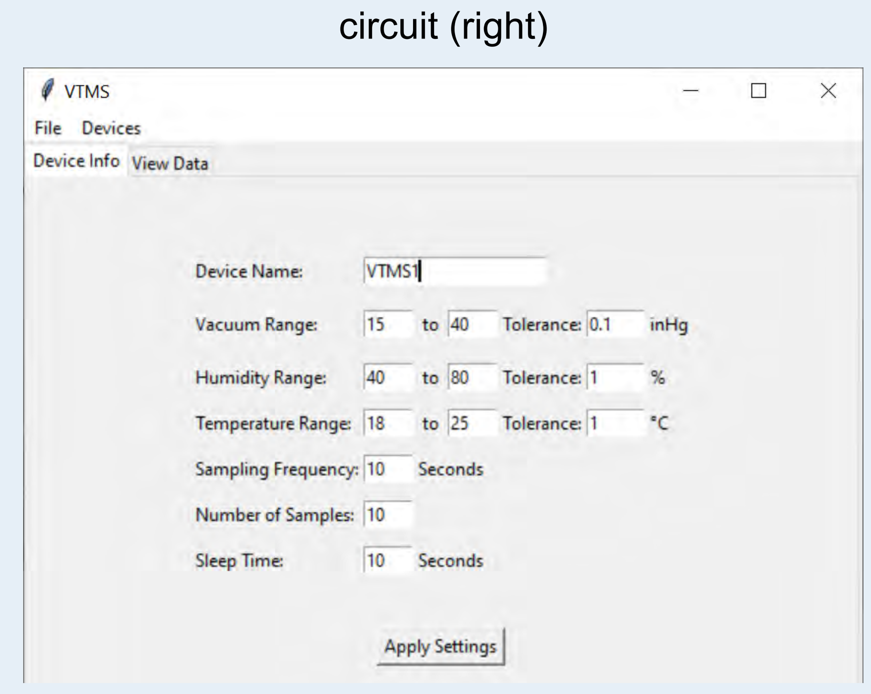

Fig. 4: The graphical user interface for the software. This allows the user to interact with a peripheral device in order to gather data.

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Data Collection Using IIoT

Industrial Internet of Things

supfina

Team Members: Nataly Cruz (ELE), Aaron Linares (ELE), Hungson Tran (CPE), Jason Yang (CPE)

Technical Directors: Mason Dumaine ('19) and James Lospaluto ('10) | Consulting Technical Directors: Jeremy Peacock

Project Motivation

Supfina Machine Company is one of the largest suppliers of abrasive finishing machines and attachments. Their machines improve the surface geometry of parts using a variety of abrasive media, with a focus on automotive parts and bearings. Recent developments in software technologies have created room for improvement in the machining industry. Supfina aims to stay on the cutting-edge and ahead of its competition by developing an IIoT data collection system for its machines. With IIoT facilitating data collection, this system will allow engineers to analyze trends more efficiently than before, detecting flaws and allowing workers to plan for downtime long before it starts. Our design makes use of modern hardware and software, with industrial grade sensors communicating via IO-link to transmit process data. Eventually, this data will be forwarded to the cloud-based storage system via the eWON Flexy data gateway, allowing it to be analyzed and viewed by customers and engineers at Supfina.

Key Accomplishments

Sensor Selection: The sensors selected for this project were flow rate, temperature/humidity, air consumption, vibration, and power consumption. To verify that the chosen power meter sensor was adequate, we consulted with a sales representative from Accuenergy, providing him with specifications and the intended use. We were then provided with various options but ultimately chose the power consumption meter capable of rated for 480V, 3 phase, 60 hz and the communication module is IO-link compatible. The air consumption sensor collects flow and temperature. The flow rate sensor is rated for water, oils and air, has IP67 rating, and is capable of measuring up to 100 bar. The temperature and humidity sensor detects various physical variables such as vibration, temperature, relative humidity and barometric pressure. Which reduces the costs of getting separate sensors to collect the variables separately.

Communication Protocols: In the industry there are a variety of communication protocols used for data transmission between hardware and servers. At Supfina Machine company the primary communication protocols implemented in their machines are EtherNet, IO-link, and analog. When searching for the sensors we primarily searched for IO-link enabled hardware. IO-link facilitates monitoring, diagnostic capabilities, and creates an easier to follow wiring system. As it requires less wiring due to transferring and receiving data over a single wire, being the M12 connector. Many IO-link enabled sensors can be connected to a master switch, which is then connected to the PLC via ethernet. Some sensors are not IOlink and use serial communication instead which requires extra hardware to be able to send the data to the PLC.

Eplan: Eplan is the software used at Supfina Machine for schematics. Supfina provided us with a variety of resources to help us learn to navigate and the software to be able to modify the schematics. Some of the resources included the "EPLAN electric P8 Reference Handbook", the beginners guide to eplan, and videos to follow along with the instructor. Eplan is a helpful software as it is similar to ladder logic which is what operators are familiar with to create the designed machines. The use of this software to create, and modify schematics helps increase the communication between engineers and manufacturers which inturn decreases the likelihood of mistakes. **(Figure 2)**

Hardware Design/Schematic Update: With guidance and help from our technical director the schematics were updated to include the new sensors and the connections necessary to provide power to the components, and communication between the sensors and the IO-link master, the master and the PLC, and the PLC to the eWON Flexy modem. **(Figure 3)**

Hardware Implementation: With help and direction from our technical director and the schematics, the sensors were connected using the appropriate wire gauge, and identifying the correct terminal blocks in the existing electrical cabinet. Along the process of connecting the sensors to their appropriate terminal block, there was a modification to the power supply that powered the power meter. We identified that there were two 24V DC supplies, one that was directly connected to the 480V supply, and another was derived from a 115V transformer that was connected to the 480V supply. On the schematic diagram we originally had the power meter being supplied from the 24V supply from the 115V transformer but decided to change it to the 24V power supply that was directly connected to the 480V supply. In addition, we had originally chosen a 5A circuit breaker for the power meter, but decided to use a 1A circuit breaker because the power meter datasheet suggested the 1A. **(Figure 4)**

Software Tools: The computer engineering members of our team **learned to use Java and the Eclipse IDE on a fundamental level.** We downloaded packages that allowed functionality with Amazon Web Services, and ran tests on Supfina's DynamoDB test code. The purpose of Eclipse was for HTML web development.

Introduction to PLC: Learning PLC was one of the crucial parts of the project. Being able to program in PLC allows the team to retrieve data from the sensors. Once the sensors are fully integrated into the machine, we will be able instruct our sensors with PLC Programming.

Web Development: To be able to access data effortlessly, a website was needed. Our computer engineers **learned web development concepts.** In addition to learning HTML and CSS, we learned more about the best practices for web development such as using the inspect tool to learn from existing websites and we were able to create a website.

Programmed scripts to process machine data: For the web server to function properly, the HTML required javascripts to manipulate data. The scripts will be used to display data sent from the machine. This was created to encourage consumers to better machine supervision, in case of malfunctions due to improper usage. The web server displays a data table along with a graphical representation. It also provides links to contact the company and their services.**(Figure 1)**

Java Programming with AWS: In order to be able to display data on the web server, the backend needs to be created. The program was created using Java. This allows us to access and obtain data being stored in the AWS database. Afterwards the data received is formatted as a .JSON and is sent to the web server to be presented in a table or graph.

Anticipated Best Outcome

The project's anticipated best outcome will be creating a functioning IIoT data collection system on existing Supfina machines in addition to a web-based system to display, organize and analyze process data which will allow Supfina to adjust, modify, and improve their machines.

Project Outcome

The Anticipated Best Outcome was not achieved

Figures

Figure (1): Temperature Graph

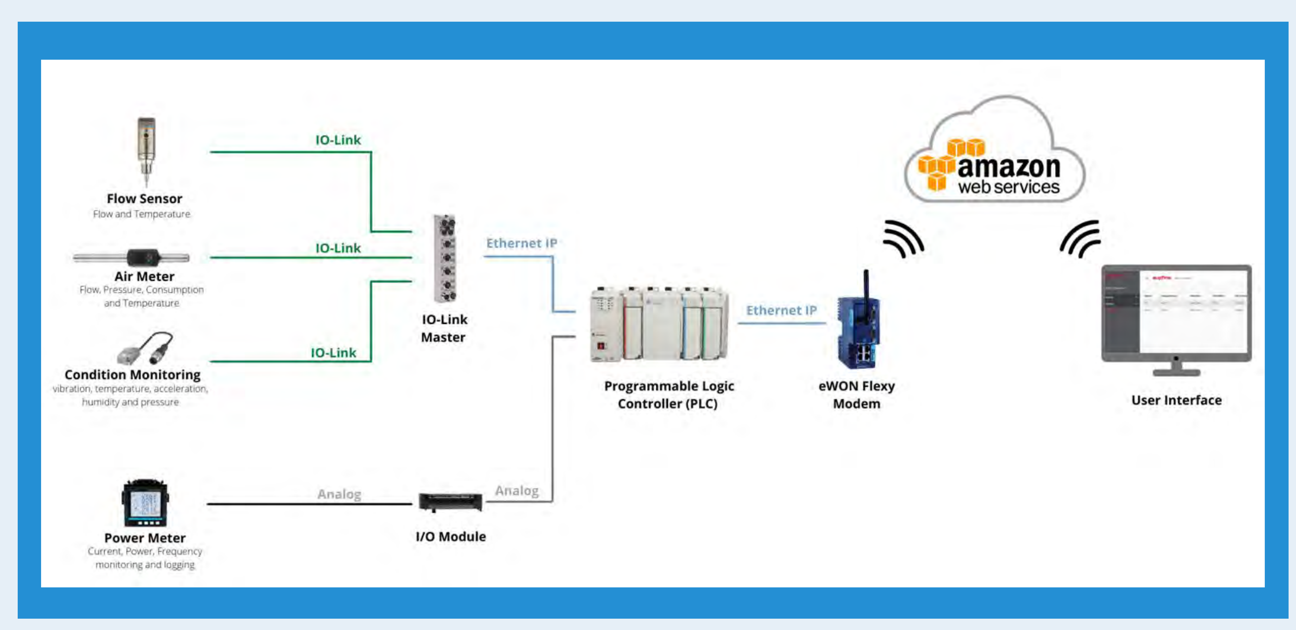
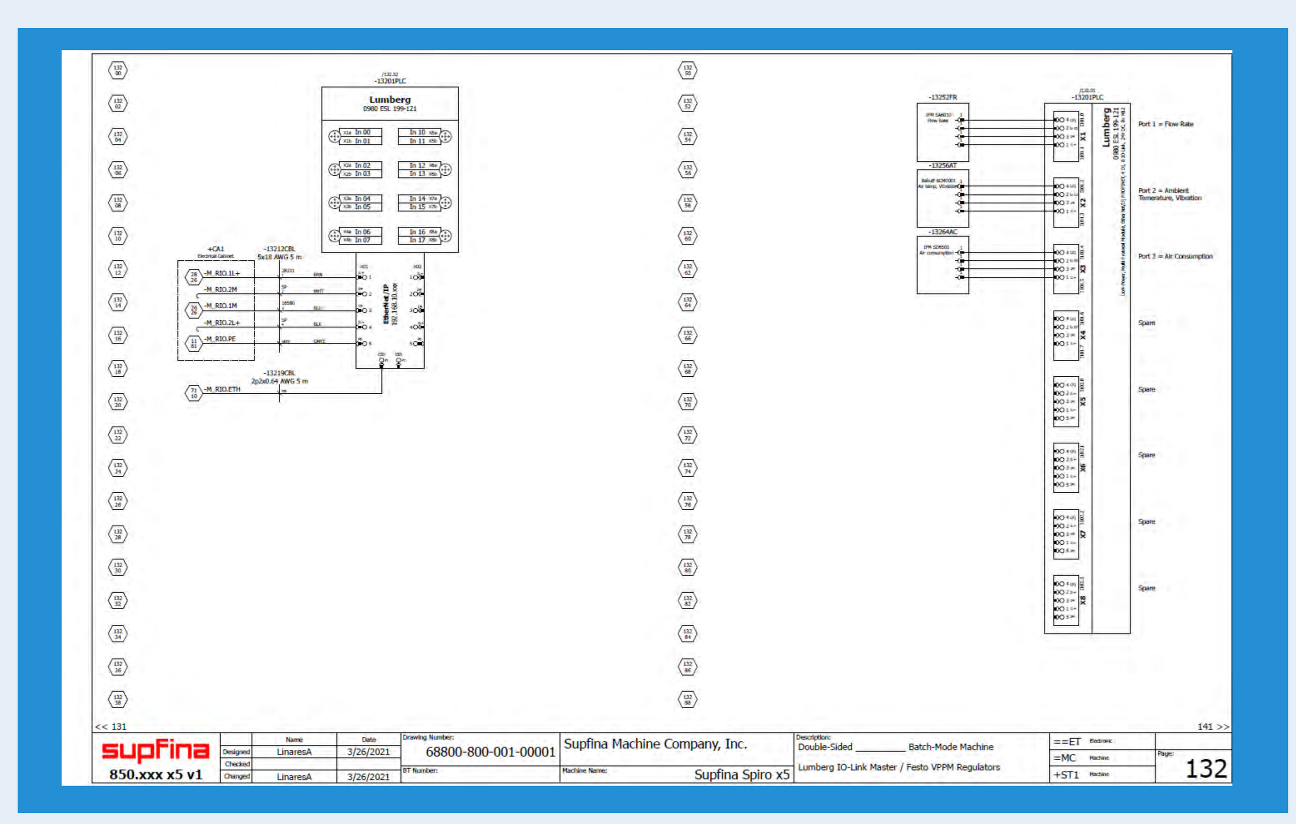


Figure (2): Block Diagram



Figure(3): Schematics

Figure(4): (L) Spiro F5 Machine (R) Nano Machine

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SPBBTR

SmartPlug Bluetooth Button Transmitter and Receiver

Team Members: Andrew Crawford (ELE), David Hwang (CPE), Kevin Kwan (ELE)

Taco Comfort Solutions
A Taco Group Company

Technical Directors: Phil Manning, Nick Costello, Mike Smith

Project Motivation

In certain parts of the world where there are water shortages like California, USA, there are mandatory requirements for on demand water heating. The average residence can waste up to 12,000 gallons of water per year waiting for running water to heat up to the desired hot temperature. Taco Comfort Solutions currently has a product called the SmartPlug® that can upgrade any recirculation pump to “Smart” operation. The project is to upgrade the current SmartPlug® so that it can be wirelessly activated via bluetooth with the push of a button when hot water is required. Manual activation of hot water recirculation increases the efficiency of water conservation even further by not having to rely on water usage patterns to assume when users might need hot water.

Key Accomplishments

Decide on a bluetooth microprocessor for the button and SmartPlug: The best option for a bluetooth processor is the nRF52840 by Nordic Semiconductor. It has the specifications that this project requires when it comes to range and frequency. It is bluetooth low energy which is perfect for the desired usage. This chip is used by a variety of vendors that implement it in their own products for ease of prototyping.

Acquired appropriate bluetooth modules: Adafruit Industries developed their own module called the nRF52840 feather express which implements the Nordic nRF52840 chip. Thanks to the MDBT42Q-U512KV2 chip by Raytac Corporation which contains the Nordic chip, Adafruit has been able to design a board that has a micro-USB for programming and other several components that make the board easy to test code. Adafruit also provides example codes relating to the bluetooth functionality of the nRF52840. The team has decided to choose this module for prototyping the code.

BLE Implementation: We made use of the Arduino IDE for the majority of the BLE implementation. Referencing the Arduino and the Adafruit library examples in order to pair the two modules. Usage of the callbacks were very helpful in coding both the Central and Peripheral modules; as the connection and disconnection tasks were performed in this way.

Central module: This module was coding to perform the task that the Button would perform. This module works to detect the advertised signal from the Peripheral module and pair to it. Acting only when a debounced button push is received from the user. After the module would begin to search for a specified signal to pair to. Once the button has been paired with the Peripheral module, acting as the SmartPlug, it would instruct the Peripheral module to begin their processes. See **Fig. 1**.

Peripheral module: The partner module of the Central module, acting as the Smartplug. This module is constantly advertising it’s UUID in order for the two modules to pair with one another. Setting up characteristics for the button, this allows for the use of a characteristic write to be performed. Making it possible for the paired modules to communicate with one another. See **Fig. 2**.

Testing the modules: Testing the modules together, took any attempts with much trial and error. Pairing the two modules together is a quite quick step in the testing. The team was able to make a simple connection between the two modules. Issues arose when we were looking to send a specified debounce signal through our designated characteristics. We attempted to perform a characteristic write from the Central to the Peripheral. We were able to resolve this issue when we discovered that permissions were required for the write to be performed. See **Fig. 3**.

Designed the PCB for the button: Since the modules worked the way the project intended, it is clear that the nRF52840 was the right processor for the job. When it comes to designing a standalone PCB for the button, the MDBT42Q-U512KV2 will be used and the other components will be implemented. The other components required for the standalone PCB to work include capacitors for decoupling, reset switch, LEDs for troubleshooting, a micro-USB for bootloading and programming, and a voltage relay for power and filtering. All components are surface mounted. See **Fig. 4**.

Anticipated Best Outcome

A new version of the current SmartPlug® in its prototype stage of development that includes a redesigned PCB within the current enclosure and updated firmware to interact with a remote button through bluetooth to control the hot water recirculation pump. The hardware and firmware for the button separate from the SmartPlug® is developed. The whole system will include other functions such as a learning algorithm and programmable timer for automatic recirculation on top of manual activation.

Project Outcome

The outcome of this project includes a prototype of the SmartPlug equipped with an Adafruit nRF52840 bluetooth module and a prototype of the SmartButton with a custom PCB. The team has met the anticipated best outcome that was set.

Figures

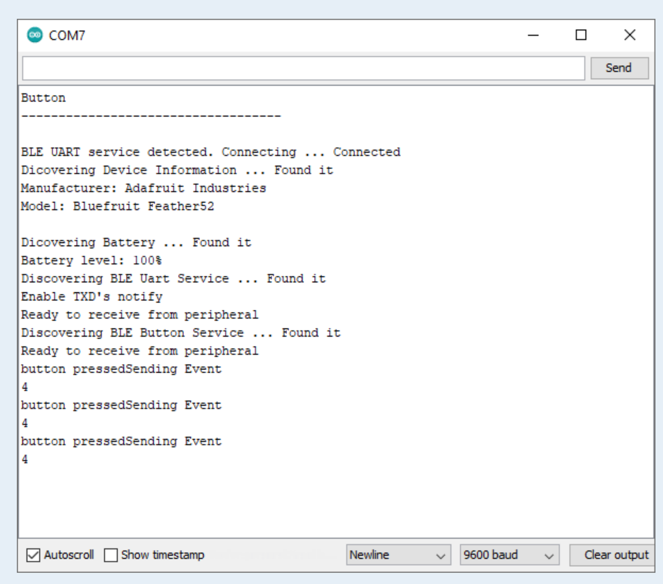


Figure 1: Central Module Serial Monitor: The serial monitor in arduino gives the user information about what the module is doing in the IDE. The top portion of the code indicates the module has connected to the peripheral module. The last 6 lines indicate the button on this module has been pressed 3 times.

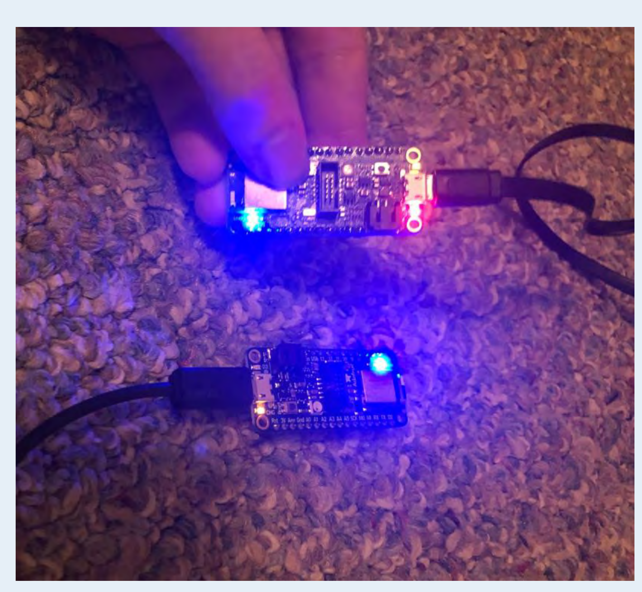


Figure 3: Central Module (TOP) and Peripheral Module (Bottom): When the blue LED is blinking on both modules, this indicates that neither of them are connected to the other. When it is a steady blue light, this means that they are connected. The red LED was used in troubleshooting for the button press in the central module. When the button is pressed the red LED will remain on for about 5 seconds to indicate the debounce function which prevents the user from pressing the button too many times in an instance.

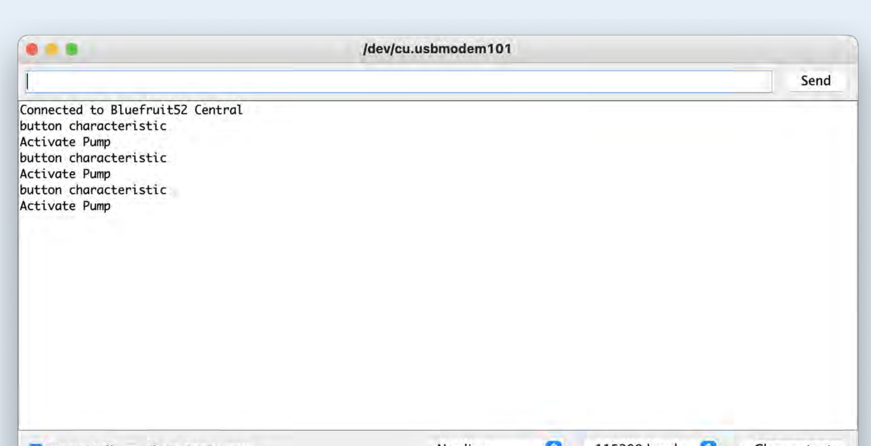
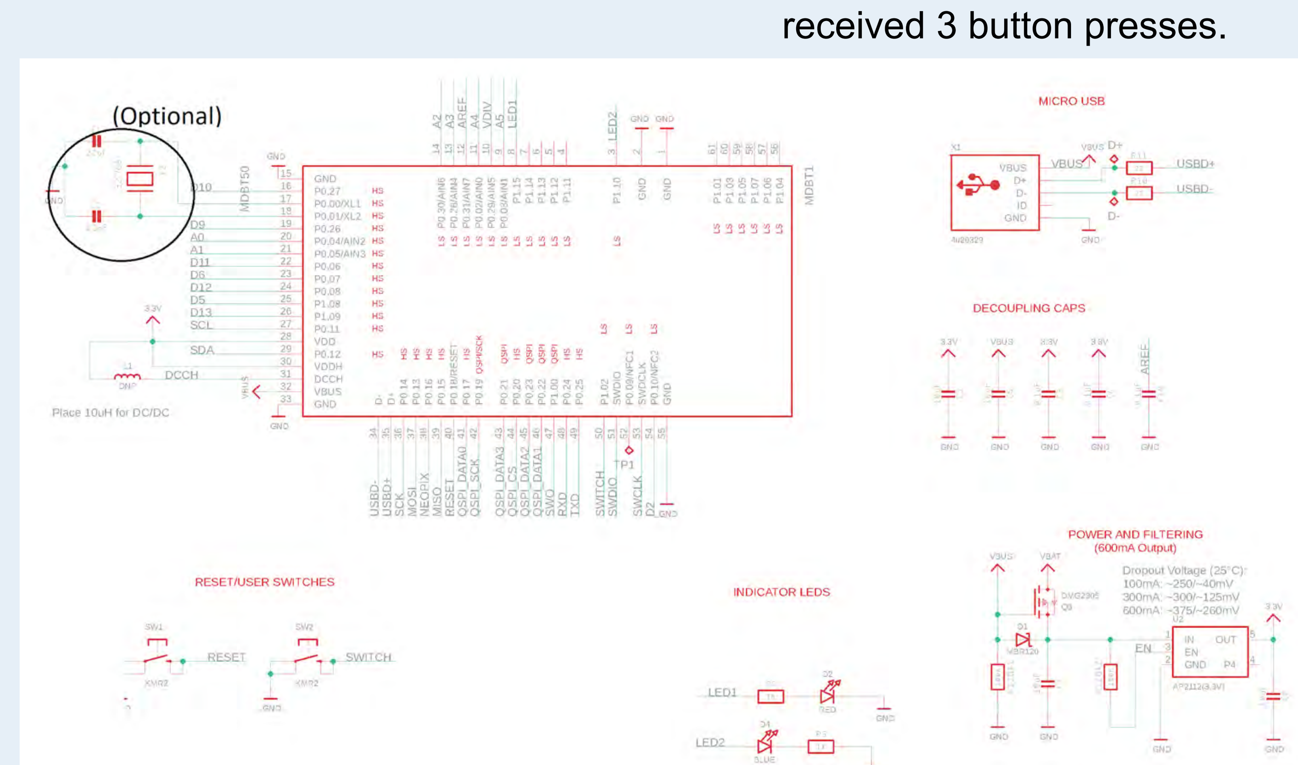


Figure 2: Peripheral Module Serial Monitor: The serial monitor for the peripheral indicates that it has received a signal from the central module that the button has been pressed. This will then activate the pump function which sends a signal to the pin that performs this function. This module was in sync with the module in Fig 1 which is why it has received 3 button presses.



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ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone

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FRIDAY, MAY 7, 2021

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THINK BIG WE DO™

BLE-TSTAT

Two-Wire Bluetooth Thermostat Adapter

Team Members: Tyler Aceto (ELE), Eric Berlo (ELE), Johann Karl-Muller (CPE)

Taco Comfort Solutions™
A Taco Group Company

Technical Directors: Evan Cornell, Jack Kang, Robert Kellicker | Consulting Technical Director: Mike Smith

Project Motivation

Hydronic heating systems are controlled by thermostats located throughout the home, wired directly to an electronic controller at the heating unit. Older thermostats operate similar to a mechanical switch; when the system calls for heat, a connection is made between two wires, and the unit is powered on. With emerging technology, programmable "smart" thermostats have become increasingly more popular in the marketplace. These thermostats require a third (common) wire for power supply and proper operation. Most of the time when a homeowner is looking to upgrade to a smart thermostat, it is necessary to run new thermostat cable from the unit to each zone, increasing costs and challenges in installation. This is undesirable for the homeowner and the installer. The motivation for this project is to allow for convenient installations of smart thermostats to existing two-wire thermostat configurations, with minimal installation effort and no need for routing new wires.

Key Accomplishments

Design Concept: The design involved implementing a device able to detect a thermostat heat call signal and transmit it via Bluetooth to the heating unit, using power from the existing thermostat wires. The overall design concept is described by the block diagram in **Fig. 1**.

Component Selection:

Microcontroller: nRF52805 by Nordic Semiconductor was chosen due to its price, BLE capabilities and Taco's relationship with Nordic.

Power Management: A 4-diode bridge rectifier followed by a low-dropout voltage regulator (LDO) was designed for AC-DC conversion. The MCP1792 was selected based on cost and the $55V_{in}$ to $3.3V_{out}$ design specifications. The SOT-223 package with heat sink was chosen for temperature control. To ensure stability, 10uF/50V and 2.2uF/10V ceramic capacitors were selected for the input and output respectively.

Heat Signal: A FOD817 optocoupler was selected to isolate the AC heat call signal from the DC MCU input. A diode and a 100kΩ current limiting resistor for the input and a 100kΩ pull-up resistor on the collector of the optocoupler were selected. Both resistors are sized for 1/4W power consumption.

Prototype Simulation & Design: A breadboard prototype was created using mostly through-hole components. The 24VAC input was produced via an isolation transformer connected to a Variac transformer for safely isolating earth ground. A resistor was used to simulate the MCU current load during BLE communication. Oscilloscope readings of ±20% nominal voltage were tested in the lab to ensure LDO stability.

PCB Design: Altium Circuit Maker was used for the schematic, **Fig. 2**, and PCB layout. Board specifications and design rules were based on OSH Park 2-layer board guidelines. Circuitry for proper MCU operation was determined via the nRF52805's data sheet. The antenna was based on a template for an AN043 Inverted F Antenna (IFA) designed by Audun Andersen from Texas Instruments to have an impedance of 50Ω at 2.45 GHz.

Firmware Development: Firmware for BLE communication was developed using Segger Embedded Studio and nRF5_SDK examples provided by Nordic Semiconductor. The main service transmits a bluetooth signal to the central unit to indicate when the thermostat heat state changes. A bootloader was created for initiating a buttonless Device Firmware Update (DFU) service for wireless update capabilities. The firmware was designed and tested on the nRF52_SDK and confirmed via Nordic's phone application nRF Connect, shown in **Fig. 4**. It was then adapted and developed for nRF52805 by adjusting certain aspects to accept the S112 SoftDevice. Adjustments included changing the preprocessor definitions, memory segments and section placement macros with the correct flash and RAM sizes. New files needed to be patched into the SDK to support the nRF52805 as well as adjusting the post build command associated with generating the settings for the main service.

Alpha Testing: The fabricated PCB, **Fig. 3**, was tested with the transformer power supply setup previously described for the breadboard prototype. The firmware was uploaded to the PCB via the nRF52_SDK using a plug-of-nails connector. More capacitance was needed on the DC side of the board for stability when uploading the firmware. The service failed to show on the nRF connect app, indicating that there are some issues with either the antenna or firmware that need to be solved.

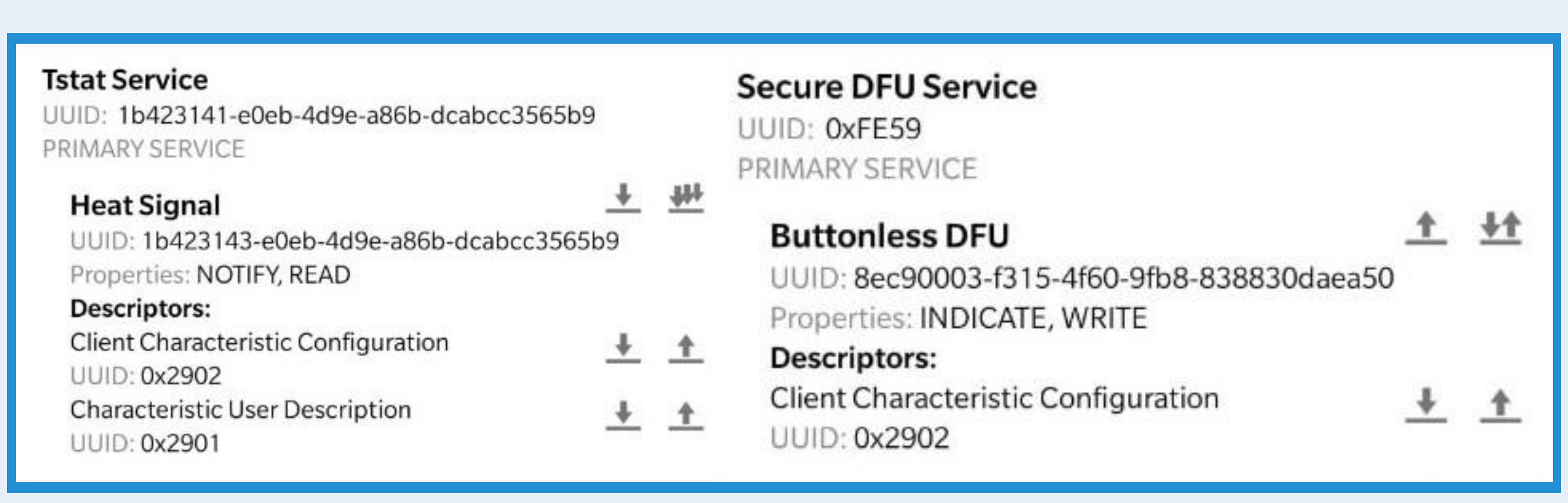

Fig. 4: nRF connect application showing the Tstat heat signal and Device Firmware Update services being transmitted using the nRF52 development kit.

Anticipated Best Outcome

The anticipated best outcome of this design is to develop the hardware to bring power via two existing thermostat wires from an electronic zone controller to a programmable thermostat, pass the heating call signal from a smart thermostat to a microcontroller, and develop firmware to transmit a Bluetooth Low-Energy (BLE) signal from the microcontroller to a hydronic heating unit when the thermostat call state changes. Once all design specifications are met, fabricate a prototype PCB that is functional and ready for lab testing and possible field testing. The device should be cost effective to maximize production and sized efficiently to simplify the installation process.

Project Outcome

The hardware and firmware were completed and demonstrated to be working on a breadboard prototype and the nRF52 software development kit. The PCB prototype needed hardware modifications and had issues with showing services on the nRF Connect application. Although the design concept is complete, further firmware debugging needs to be done.

Figures

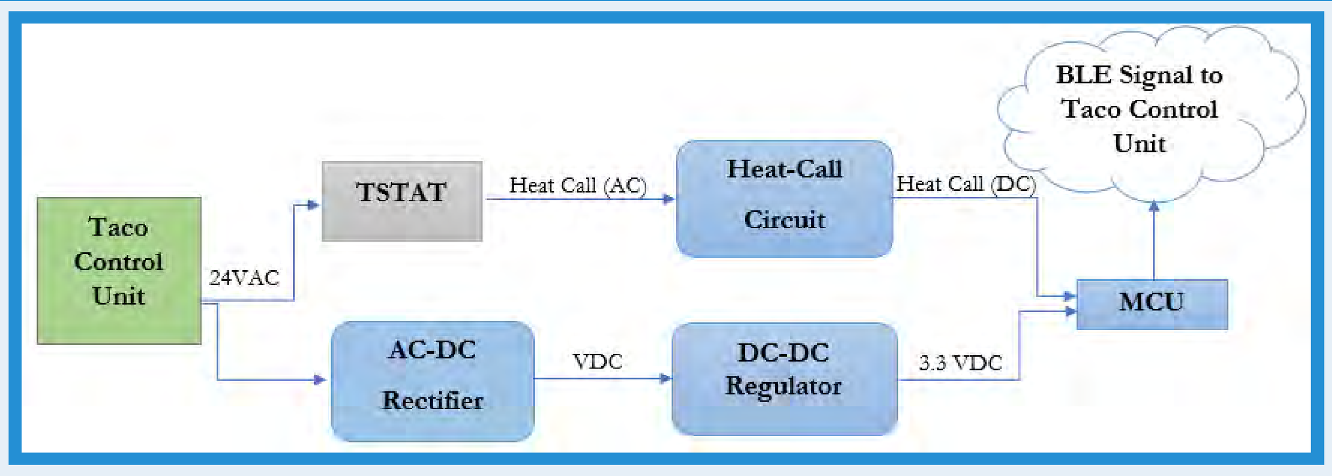

Fig. 1: Block diagram of the overall design.

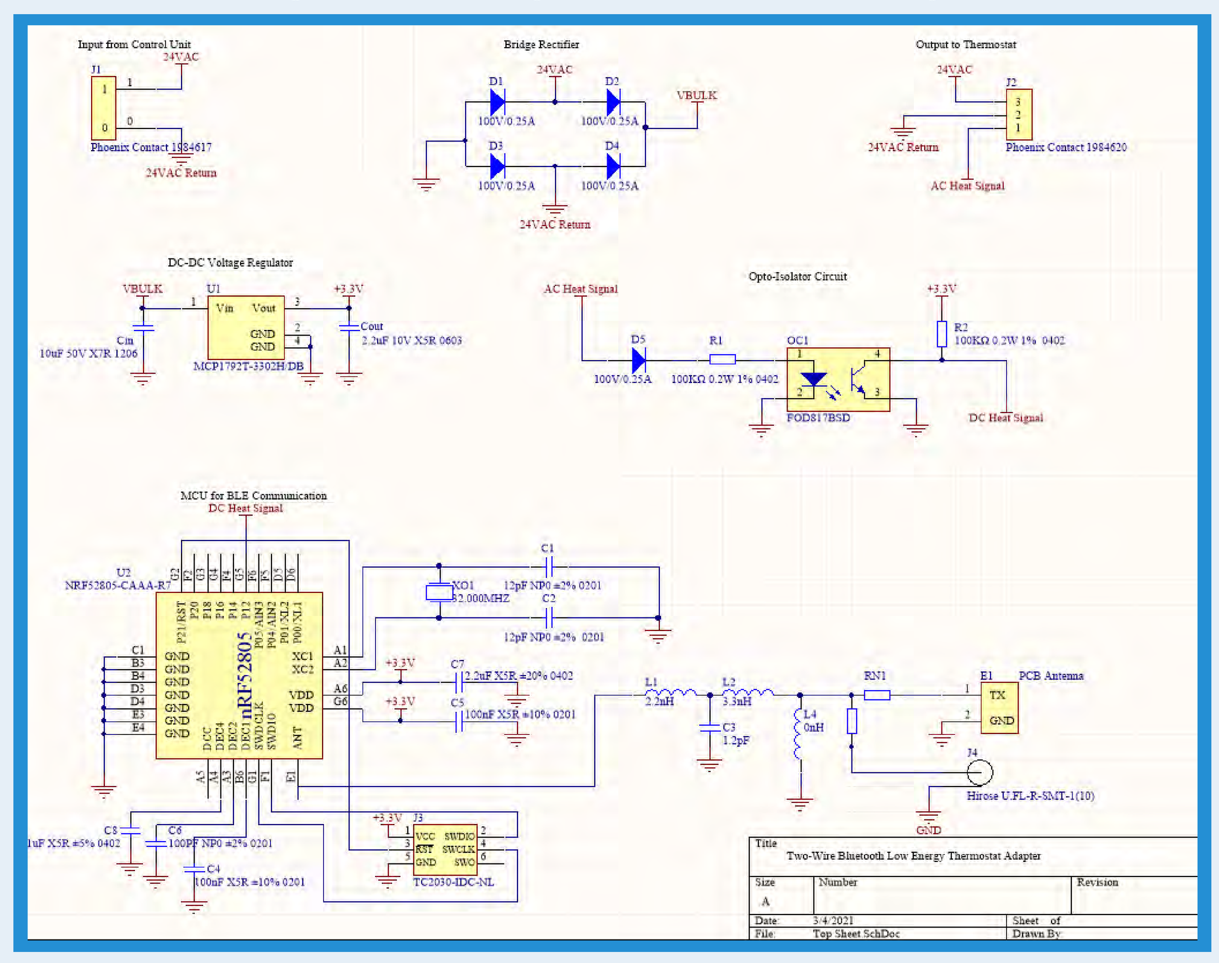

Fig. 2: Schematic showing the components and circuits for the design.

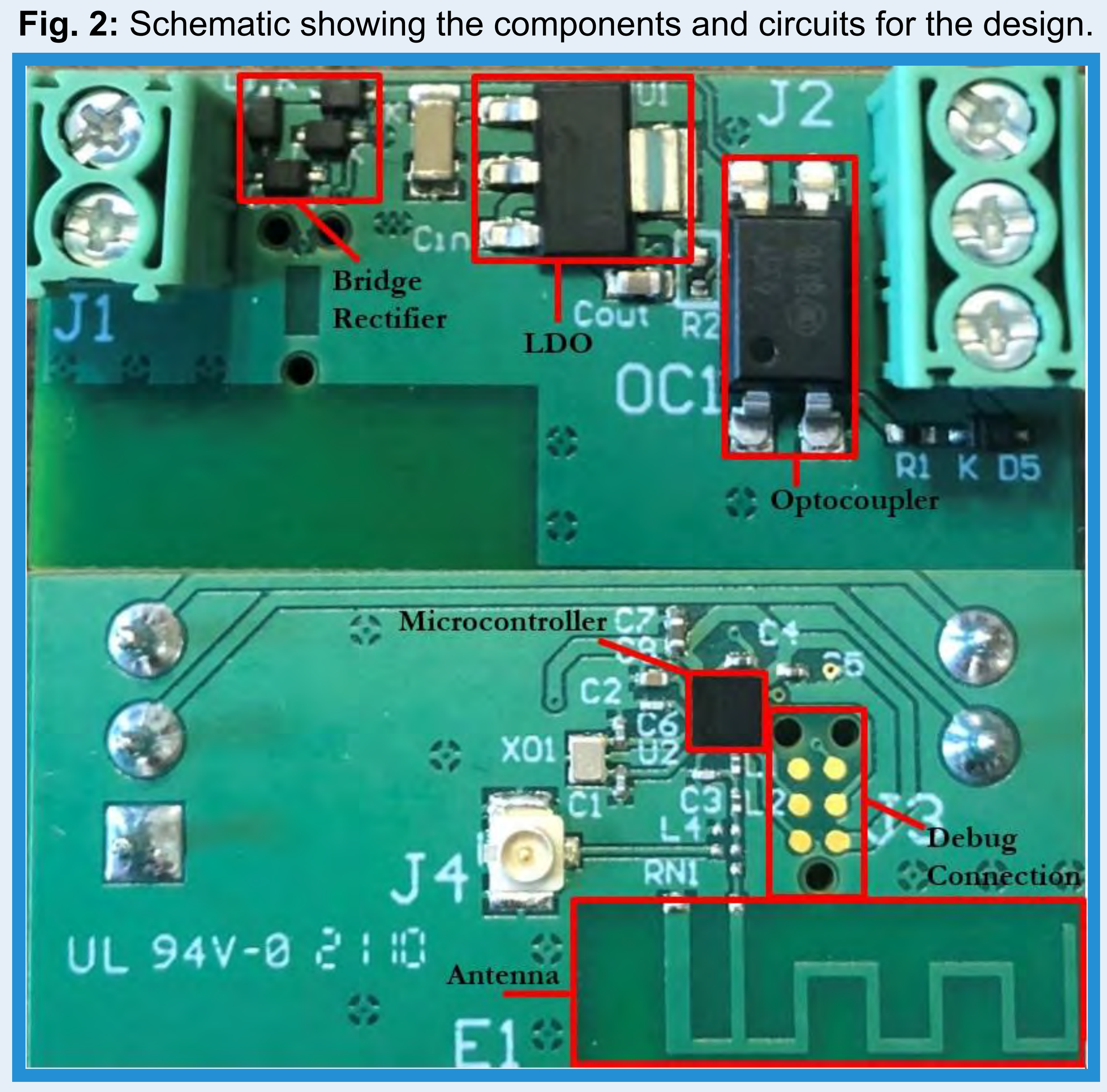

Fig. 3: PCB prototype. Top layer: connectors, power management, and optocoupler circuits. Bottom layer: MCU, antenna, and debug connector.

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone

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Hardware Checker

Verification for Probe Test Fixtures

VICOR

Team Members: Daniel Hartnett (ELE), Garrett Barker (ELE)

Technical Directors: Al Binder, Nathan Shake | Consulting Technical Director: Mike Smith

Project Motivation

The motivation behind this project is to support and expedite internal and outside testing and troubleshooting for the probe cards, as well as reduce development time for new and improved probe cards. This tester will be able to understand which passive or active components of a probe card are faulty and or need replacing. The hardware checker also allows test development engineers to confirm that the testing program itself is not suffering from any major problems, but instead the components of the probe card itself. This will enable engineers to quickly test the entire probe card before needing to test the silicon wafers of the card. A hardware checker will also help with contract manufacturers, saving time and money allowing troubleshooting to be done on site without the explicit need for an engineer to be flown out to visit, something incredibly time and money consuming for both parties

Anticipated Best Outcome

The Anticipated Best Outcome is to create multiple hardware checkers that will be able to rigorously test each of their intended probe cards in order to confirm hardware functionality and completeness. The P013, P014, and P037 cards will be priority number one but extensive work and testing will also be done on the code for the P055 cards. The code for these cards will contain significant portions of the pins and pathways on the main page, driver page, and timing page of the schematics, being marked accordingly. These codes will then test multiple cards of the intended variants to ensure correctness of both the code itself and cards.

Key Accomplishments

Software Coding of P014, P013, and P037 Hardware Checkers: Referenced the Schematics to write test paths everywhere possible to verify all components on the PCBs will function properly. Tests were written for each page, a main page, a timing page, and a driver page. The tests are separated to distinguish components, one test being dedicated to the pin connections, another verifies the relay connections, and another tests the capacitors functionality. For any buffers on the schematics, made sure the correct output is being recorded. For the drivers, tests were done to make sure the high and low sides of each driver are functioning properly. Testing has been conducted on multiple cards with tweaks and adjustments made accordingly depending on the Hardware Checker. Completed all possible tests, compiled and ran code with no errors or failures. The functional block diagram of the Hardware checker can be seen in **Fig 2**.

Updated Nomenclature: Used a new updated Naming Convention for debugging purposes.

Hardware Testing of P014, P013, and P037 Hardware Checkers: Setting up the tester and assembling and disassembling the probe cards. Learned to use the voltmeter to verify voltage, current, or capacitance is present between components or pins on the probe card. Live testing of the P014 Probe cards, attaching the resistor ring to the corresponding HW checker PCB, shown in **Fig 1**. Removing the resistor ring to attach the ground ring which is used to get rid of all the unneeded resistance for later tests. Debugged any issues present with capacitors and their ramp currents, or relays using the ETS RAIDE tool. Tested every board to verify all are functioning.

Software Coding of Needle Checker: New project to verify the needles on all pins 1-70 on the ring board. Connected the pins to three connectors labeled C1, C2, and C3 which can be seen on the hardware in **Fig 3**. Tests were written to measure the resistance and capacitance between the pins which would verify the proper connections were being made. The connectors were used during the capacitance tests where pop ups were coded to tell the user to short a block of pins to get the capacitance of the pins when open and when close. This allowed for a more accurate cap value by taking the difference of the shorted pins from the open pins. The pop ups also allowed for a better test flow where there was no need to dump out of the program and rerun to go from C1 to C2 and so on.

Hardware Testing of the Needle Checker: Compile and run the program and the test would run through all the resistance tests. It tests the capacitance measurements while all connectors are open and then it will pause and a pop up will tell the user to insert the yellow shorting block into C1, then continue testing the capacitance measurements for C1 while shorted. It will test C2 open before the next pop up telling the user to short C2. The same process will occur and go through C3 and once it completes all 3 connectors it has tested all 70 pins and the test is done. It will reveal all the data results making sure all values were within the correct ranges. The functional block diagram of the Needle checker can be seen in **Fig 4** which will provide a clearer picture of how the test works.

Software Coding of Probe Interface Board: Completed a bonus goal of writing a program to test the interface board to ensure that it is working properly. Referencing the schematic, tests were written to verify every APU, DCH, MAT, and CBIT while using pop ups to make sure the correct connector is connected, as well as tests to verify the voltage supplies and TMU pins are correct.

Project Outcome

The Anticipated Best Outcome of the project was achieved and even exceeded. As a bonus, the Needle Checker and Probe Interface checkers were completed and tested as well.

Figures

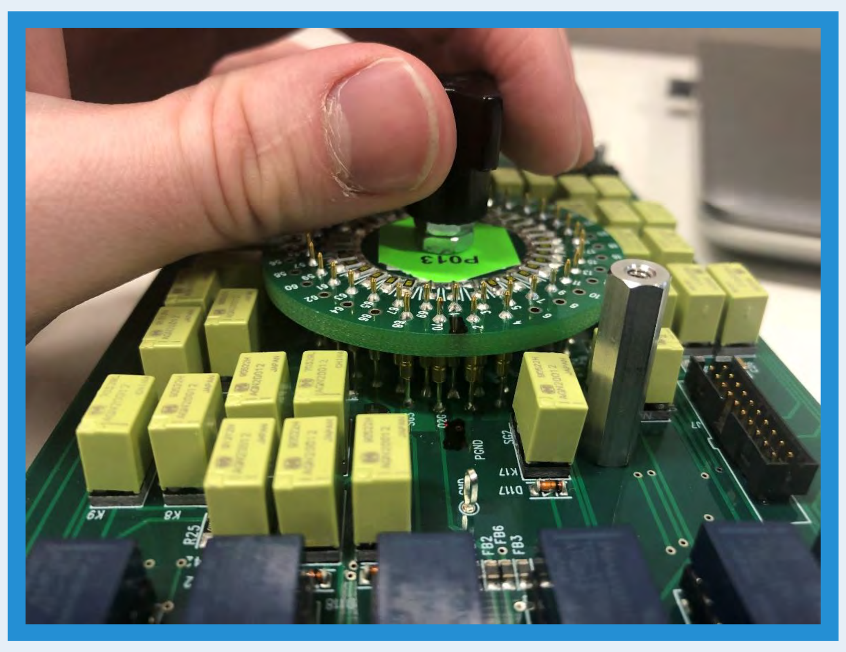

Fig 1: Resistor Ring being guided onto PCB. It has a black mark on both the board and the ring to help assist in properly aligning the pins to avoid bending/breaking any.

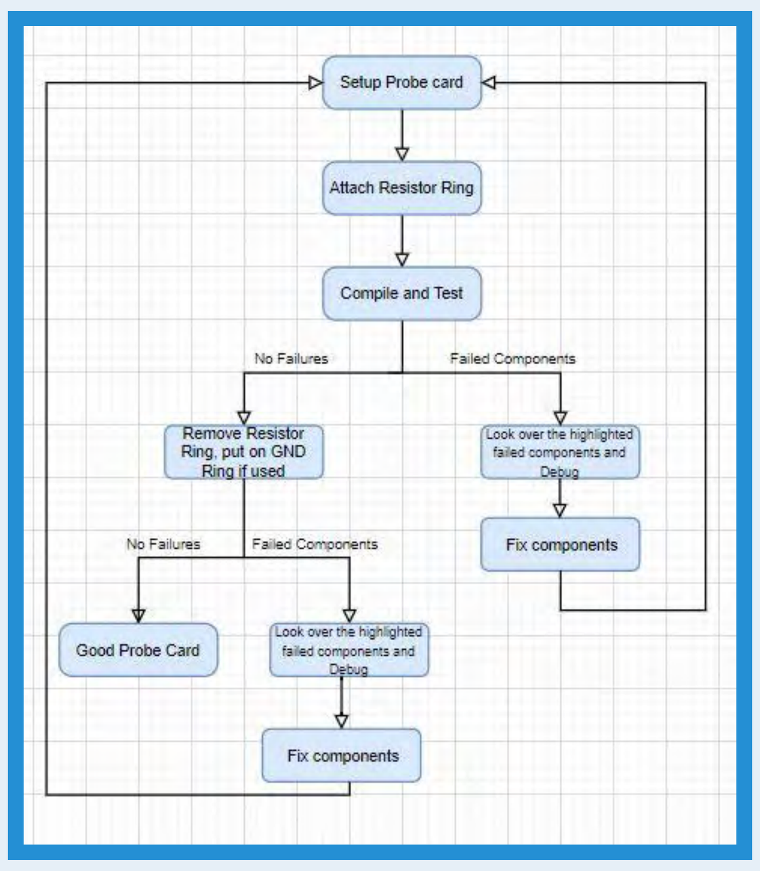

Fig 2: Functional Block Diagram of Hardware Checker

Fig 4: Functional Block Diagram of Needle Checker

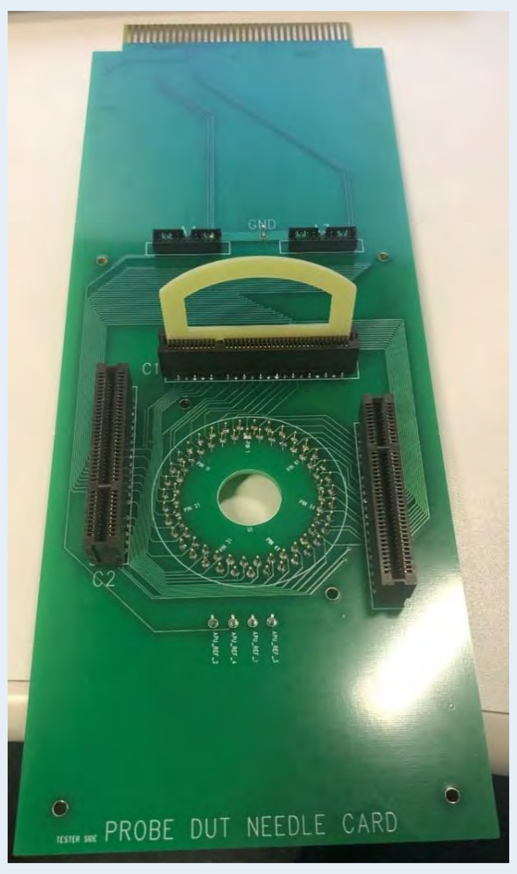

Fig 3: Needle Checker Board with C1 Shorted. The yellow block is inserted into each connector when instructed to by the pop-up windows in the program.

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Plate Reader

xcore.ai License Plate Camera and Reader

XMOS®

Team Members: Kyle Nannig (ELE), Steven Anzivino (CPE)

Technical Director: Andrew Cavanaugh ('08) | Consulting Technical Director: Najib Ishaq, Alex DePetrillo

Project Motivation

Complex computing devices have continually served to automate any processes that can be described by patterns. With the recent trend in 'intelligent' devices it makes sense for computing to be done as efficiently as possible at the source. XMOS' newest chip, xcore.ai, is perfectly suited for moving the processing demand of a neural network off of company servers and onto local devices.

The market for Artificial Intelligence Internet of Things (AIoT) devices is extremely large and growing extremely fast. By providing a technology that enables these devices to operate with low energy consumption, and regard for end-user privacy the xcore.ai platform will be well positioned to be the first choice for the AIoT manufacturers in the coming years. This project uses a camera, DSP, and machine learning to create a prototype that solves several complex problems with a simple chip.

Key Accomplishments

Testing of Xcore development kit: Throughout the entirety of this project many facets of the Xcore development process were tested and reviewed. Posing questions to the technical director allowed XMOS to determine many likely problems that engineers buying their products would have when attempting to implement their hardware. The full scope of the project allows XMOS insight into determining the most common features expected for modern AI devices.

Network selection and training: The project decided to go with a convolutional neural net **Fig4**. ideal for image processing tasks. We went with a relatively large network for increased accuracy and ability to detect characters even at extreme angles and in questionable lighting. The network was trained to specialize at the license plate detection problem, and training sets were adapted to prepare the network for the specific characters it would encounter. Pruning the network was especially important due to limit the size taken up on the microcontroller.

Plate identification algorithm optimization: Through applying signal processing techniques the incoming image had to be modified to allow the neural net the optimal chance to identify the characters within it. **Fig2.** Techniques such as blurring, dilation and binarization where all experimented with and employed. As the character segmentation was not done with a neural network, height and ratio thresholds used to identify which contours were characters had to be experimented with until ideal values were found.

Wi-Fi and camera integration: A SPI 2-megapixel Arducam camera **Fig1** was chosen due to its ease of integration with the Xcore microprocessor, low-light sensitivity, and low power and memory consumption. Test examples were run, and the camera was successfully integrated. Ensured functionality of onboard Wi-Fi device through execution of throughput test.

Network quantization: In order to run neural networks on microprocessors they must be converted to TensorFlow Lite **Fig3** and quantized to reduce their size. Int-8 quantitation compressed the file size by as much as 75% and was helpful in fitting a large neural network onto a small microprocessor memory. In order to do this quantization, representative datasets had to be assembled that would indicate to the compression algorithm the dynamic range of the data set. Furthermore, XMOS' own optimization algorithm known as "Xforming" was applied to allow for efficiency and compatibility on XMOS devices.

Network deployment: In order to run the neural network on the microprocessor a model runner was generated. The model runner was then exported to the chip. In order to fit the large neural network on the chip the external memory, or DDR, was used. As this was the largest network ever to be put on the Xcore.ai, heap size allocation was properly modified. C code was then used to control the intertile transfer of information from the camera, through the neural network, and back to be reported.

Prototype assembly: The explorer board, SPI camera, and battery were combined into a prototype. **Fig1.** The hardware was placed in a waterproof case to allow it to sit outside in weathered conditions. The cameras connections were soldered to proper ports on the explorer board. The case has a clear top to allow the prototype to be used as a demonstration piece. Estimation of power usage was done, and a battery was selected to enable approximately 7 hours of power.

Wrote custom functions for image processing: Created a set of program files to organize and enable image manipulation on images that will be provided by the camera attached to the board. At this time this has proved much more difficult than expected. Numerous programming problems causing slowdowns and the general complexity of reading images for processing has caused time to be spent without usable material.

Worked towards a more effective contouring algorithm: Associated with removing the dependency on OpenCV, time was spent learning and experimenting with contouring algorithms. The possibility of utilizing our own contouring algorithms for image processing purposes was investigated.

Combining initialization and dependencies between programs: Utilizing two programs written by XMOS, one to transmit data over Wi-Fi, another to process images created a single program that combines their individual functionalities. The combined program compiles but does not yet transmit processed data over Wi-Fi.

Anticipated Best Outcome

The ABO is a fully functional prototype that can accurately report license plate numbers in a variety of lighting and motion conditions. An enclosure with XMOS hardware, camera and a power supply that can survive inclement weather conditions would be ideal. The images captured by the camera need to be as clear or clearer than those used in the ML training data sets. Firmware for the xcore.ai chip, which should be able to start in parallel with the electrical design should include basic data acquisition, image processing, and a neural network for interpreting the images. The results of the inference should be made available via some backhaul method.

Project Outcome

The Anticipated Best Outcome was not achieved due to the developmental nature of the associated technology.

Figures

Fig1. Prototype with SPI camera, explorer board, portable battery. Contained in waterproof box

Fig2. Example of image processing and segmentation

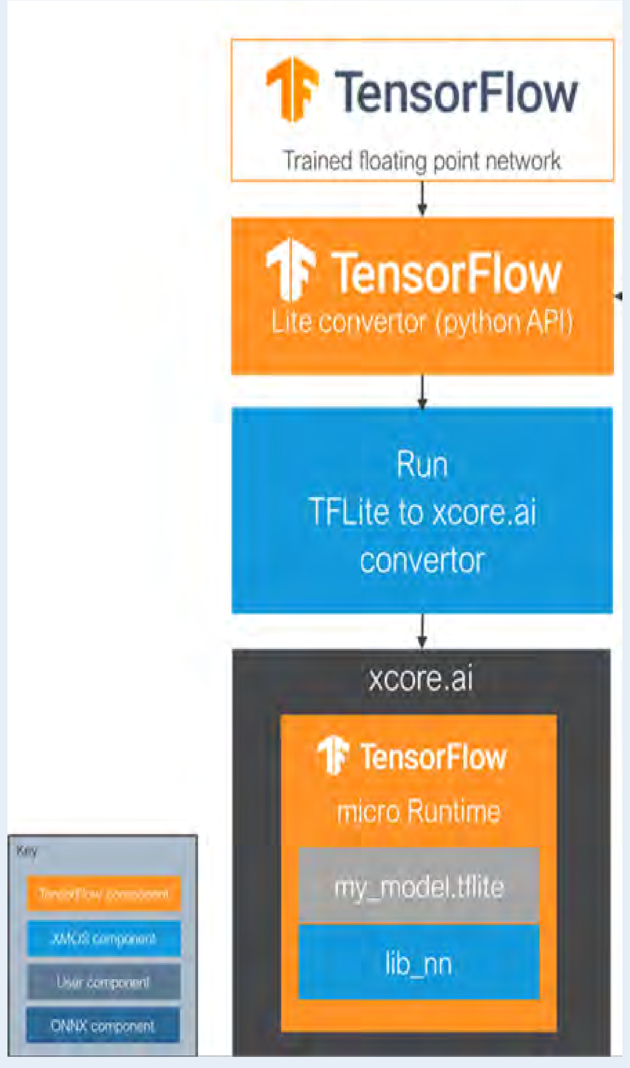

Fig3. Model conversion

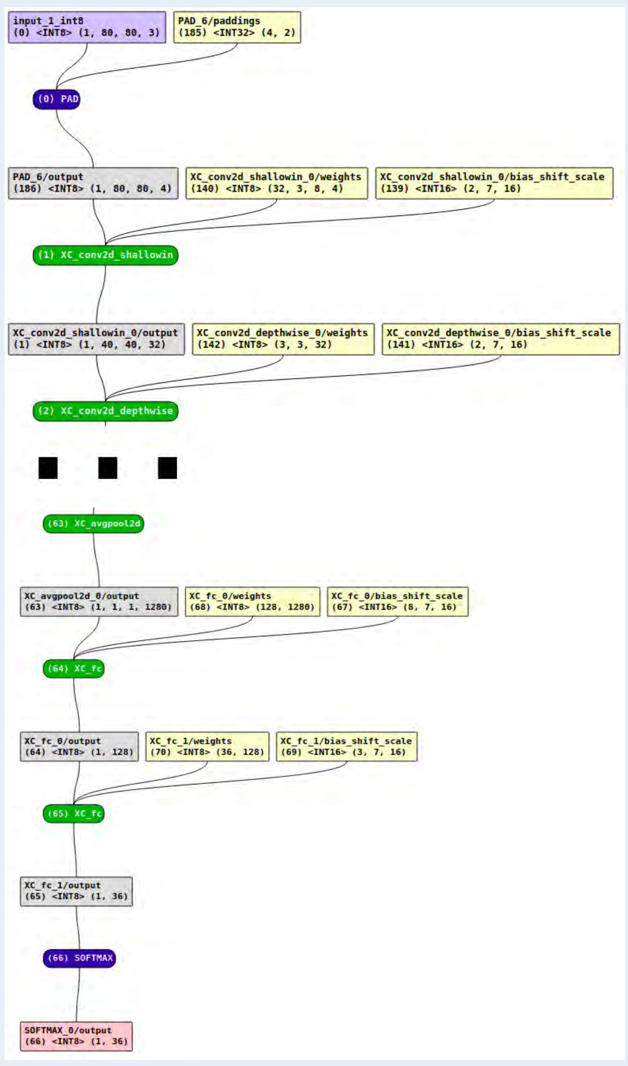

Fig4. Neural network visualization

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859 ELECOMP Website: uri.edu/elecomp-capstone

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Torque Measurement

Printer Real-Time Torque Measurement

Team Members: Christopher Medeiros (CPE), Moboye Dié (ELE), Jose Valdez (ELE)

Technical Director: Matthew Corvese ('16) | Consulting Technical Director: Alex DePetrillo ('18)

Project Motivation

Many Zebra mobile printer customers use a wide range of media. These media may come from a variety of different sources of which some are not Zebra manufactured media. Typically, adhesives on these media are not well controlled or documented. Zebra often runs into torque issues with some of these media causing our printers to stall (unable to feed media). Zebra currently does not have a way to measure the system torque while printing a label, they can only do it while feeding blank media. Zebra discovered that when printing on certain media the front sides of the labels tend to stick to the printhead. These sticking issues are caused by the chemical reactions produced when the printhead heats the media to turn it black. They would like to be able to print a label on a given printer and measure the torque required to move each print line. This would provide peak values and incorporate printhead sticking as well as the adhesive variation.

Anticipated Best Outcome

- Interface the torque transducer, printer, and external stepper motor driver to one device that will sync the torque output with each step signal sent from the printer.
- A known label would be sent to the printer to initiate the test and an image of the label will be used as a background of the output for the torque graph which will provide a visual aid for torque output vs label content.
- A GUI will be developed to control the test and provide graphical output of the data.
- The test should be able to be completed by a test technician with ease.

Key Accomplishments

Sync Speed Excel (Hybrid Vs Platen): The team created an excel sheet that takes care of the synchronization process of the printers platen to the hybrid motor based on the customers input parameters of their printers. These parameters include full steps per line, platen diameter, microsteps, speed, and DPI. This excel sheet will later be replicated in C code as the prototype software is created.

Integrated Circuit (IC) Selection: We selected the STM32F767ZI Nucleo-144 board to be the center of control for the entirety of our combined systems. Those systems are DRV8424RGER stepper motor driver, and the TPS56339 buck converter/regulator along with digital potentiometer MCP42010 that will allow accurate voltage manipulation. As far as the STM selection, picking one with enough GPIO pins as well as ethernet for the GUI was a big part of our choice making. The buck converter and the motor driver IC's will also handle the voltage and current control, respectively, commanded through the microcontroller board.

Prototype Assembly: Starting with the DRV8424RGER, CircuitMaker was used to create a symbol as well as a footprint for PCB purposes. The next, we assembled a circuit with both the buck converter and the digital potentiometer. This circuit will feed voltage into the motor driver board (**Figure 1, Figure 2**). The voltage and current range that will be supplied to the DRV8424RGER is 9-16V and 200mA-1.5A respectively.

Voltage Control: A new digital potentiometer (MCP42010) was utilized with the buck converter and interfaced to the STM32 MCU under a SPI connection. The C code was developed to give us control of the necessary resistance that the buck converter needs to see for obtainment of the desired supply voltage the VM pin of the motor driver receives.

Current Control: Our prototype has adjustable current control configured by using one of the STM32 PWM timers. The desired current that the motor would be running at can be set through the STM32 software and the PWM duty cycle will change accordingly to achieve that current. This PWM signal is fed into the VREF pin of the DRV8424 development board then is internally automatically scaled by the driver.

Input Capture: Input signals simulated under the use of a signal generator as a representation of the printer were used. TIMER2 input capture was chosen to accurately read incoming signals from the printer by the STM32. The input capture timer was set to 7MHz clock frequency using a 32bit auto-reload register. Input signals rising edges between 500Hz and 4kHz were well captured and their period/frequency were measured. These measured values were stored in a 32bit variable to then be used in TIMER5 using PWM mode 1 to replicate or scale the output signal according to the selected stepping mode (**Figure 3**).

Sync Speed (Excel to C conversion): Using the previously created Excel sheet as a reference, Team Zebra successfully created functions in C code through the STM32CubeIDE software that replicate exactly what we wanted to achieve. The software will automatically detect a variable change given by the user, and adjust the Hybrid PPS rate by outputting the correct PWM output and most accurate stepping mode that matches the input captured step rate accordingly.

PWM Output Testing: With the help of the input capture period/frequency measurement, a PWM output signal was generated to replicate the incoming step signal input (**Figure 3**). The different scaled microstepping signals of up to 256th-stepping were thoroughly tested. Using these microstepping signals and the motor driver (DRV8424), stepping modes from Full-stepping to 16th-stepping were achieved, resulting in a very accurate output frequency and duty cycle.

Label Printing: Using the given test fixture (**Figure 4**), signals were pulled out of the printer and fed into our prototype setup. From there, the software was reconfigured to accept these as inputs. When the printing process begins, our software sends a PWM signal to the hybrid motor which drives the platen causing the label to feed through. This results in a label being printed with accurate and adjustable resolution.

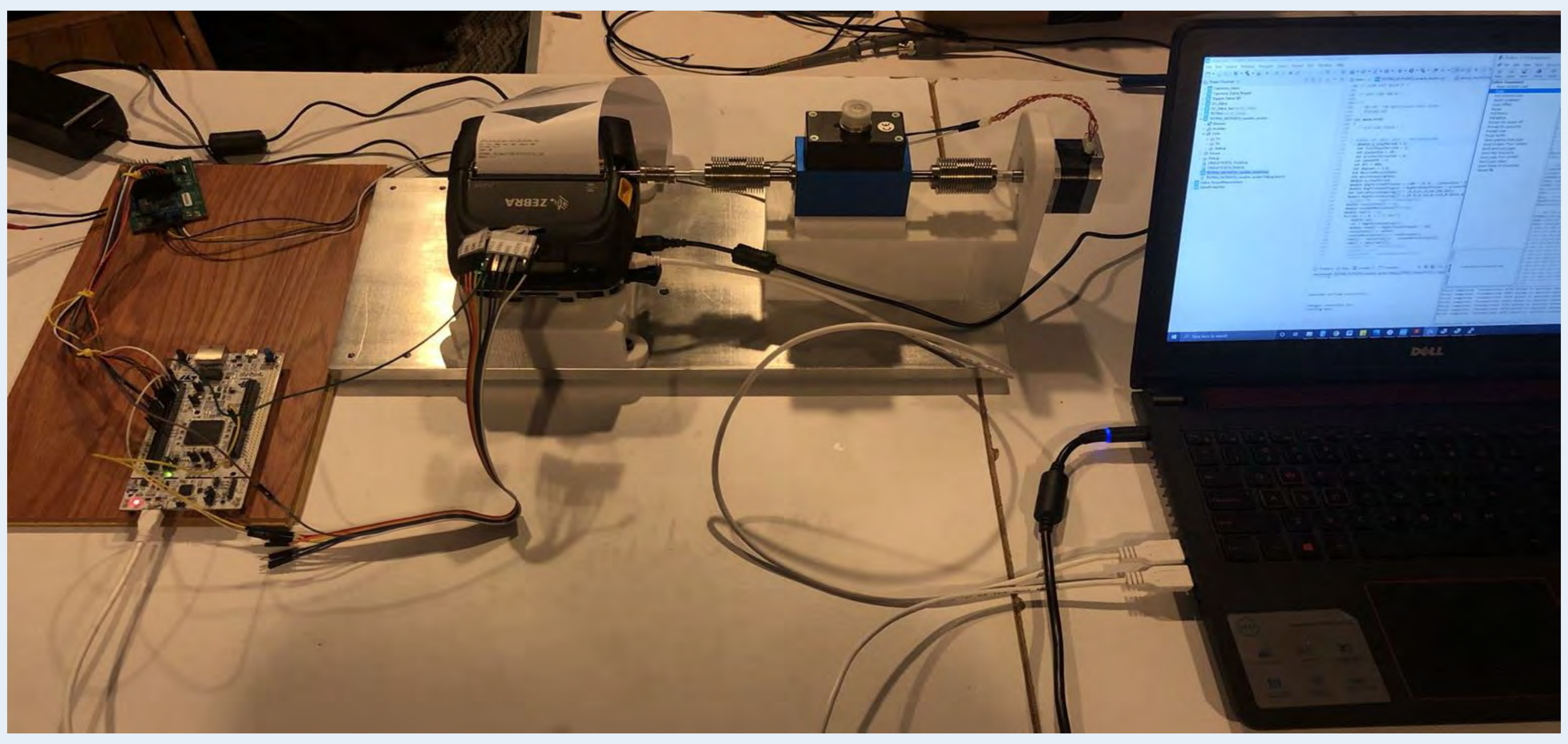

Fig. 4: New Test Bed Setup

Project Outcome

The Anticipated Best Outcome was not achieved. We have designed and created a working prototype that is able to accurately print a label in some stepping modes which is ready to be interfaced with the torque transducer and data acquisition unit for obtaining platen torque measurements.

Figures

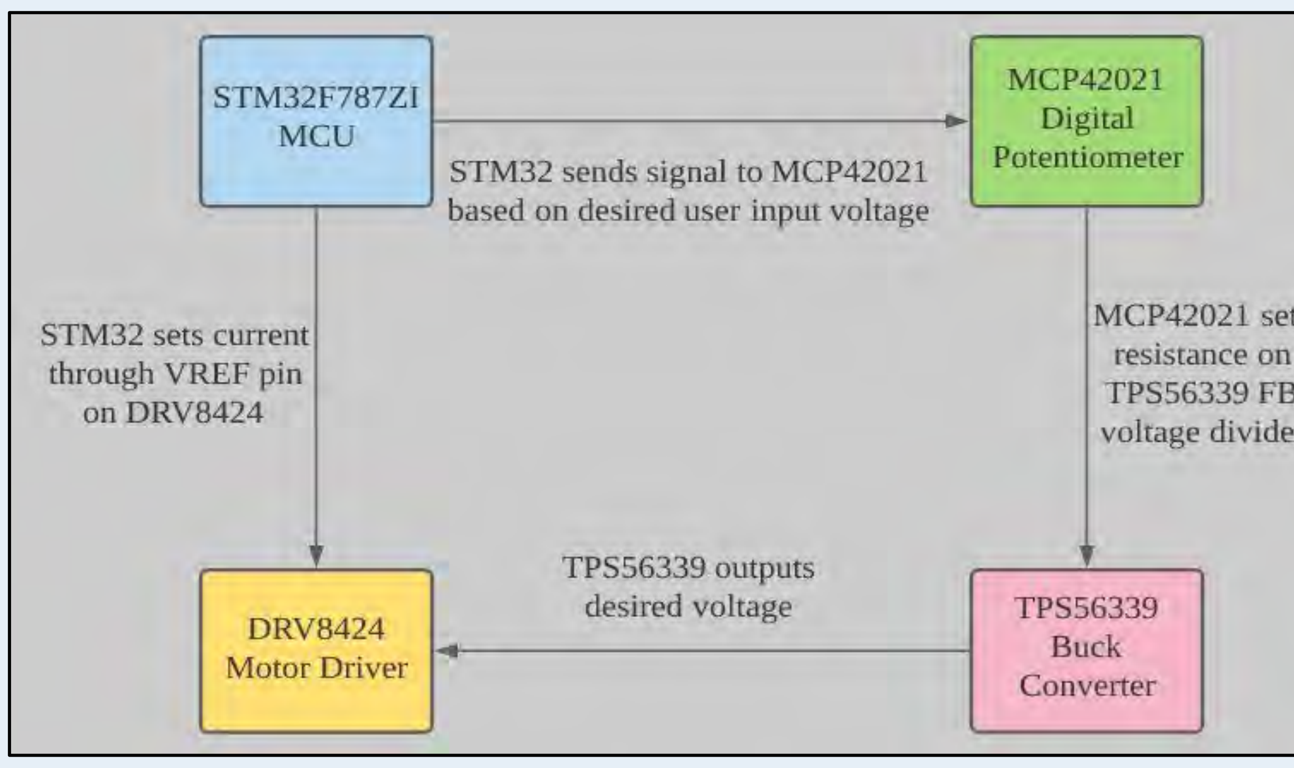

Fig. 1: Voltage Boost and Current Control Prototype Flow Chart

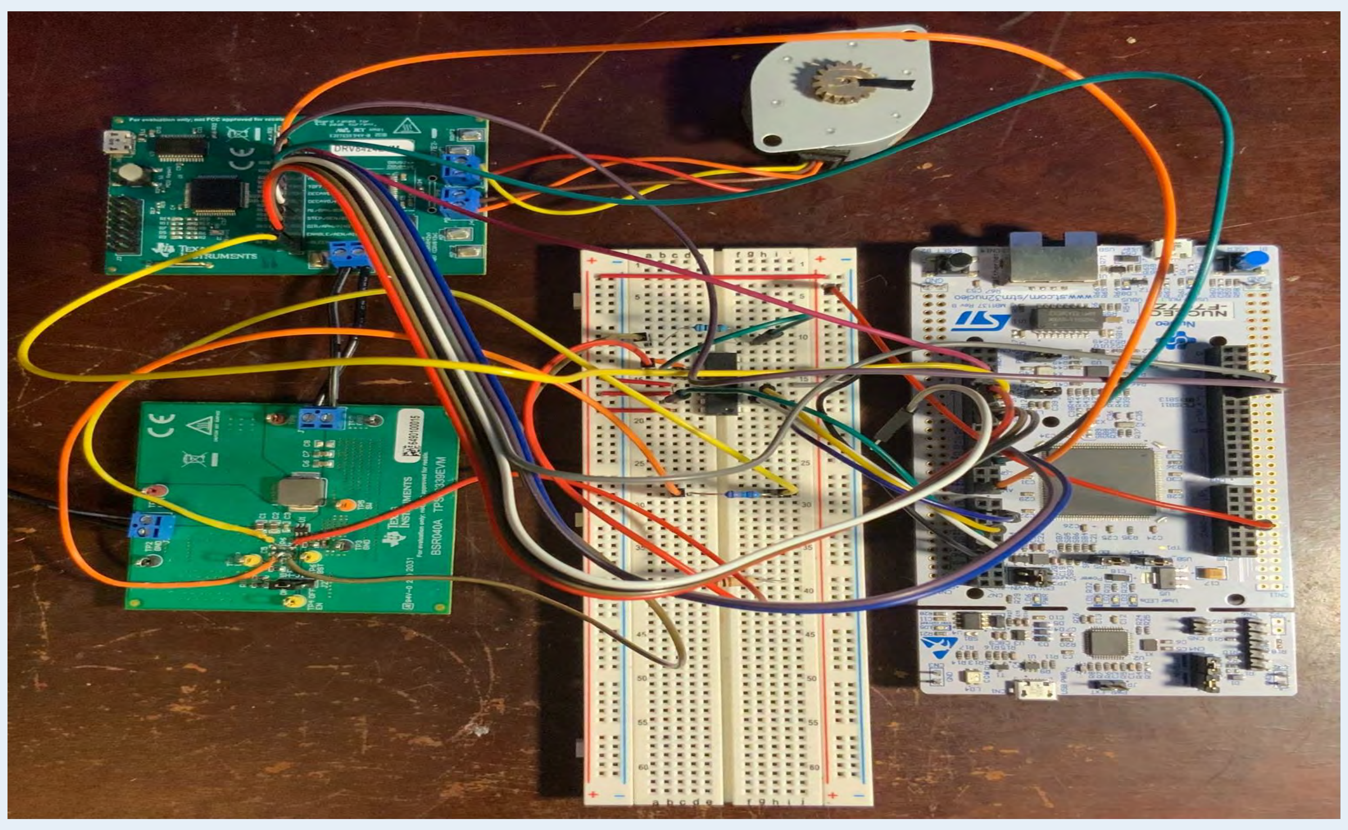

Fig. 2: Final Prototype

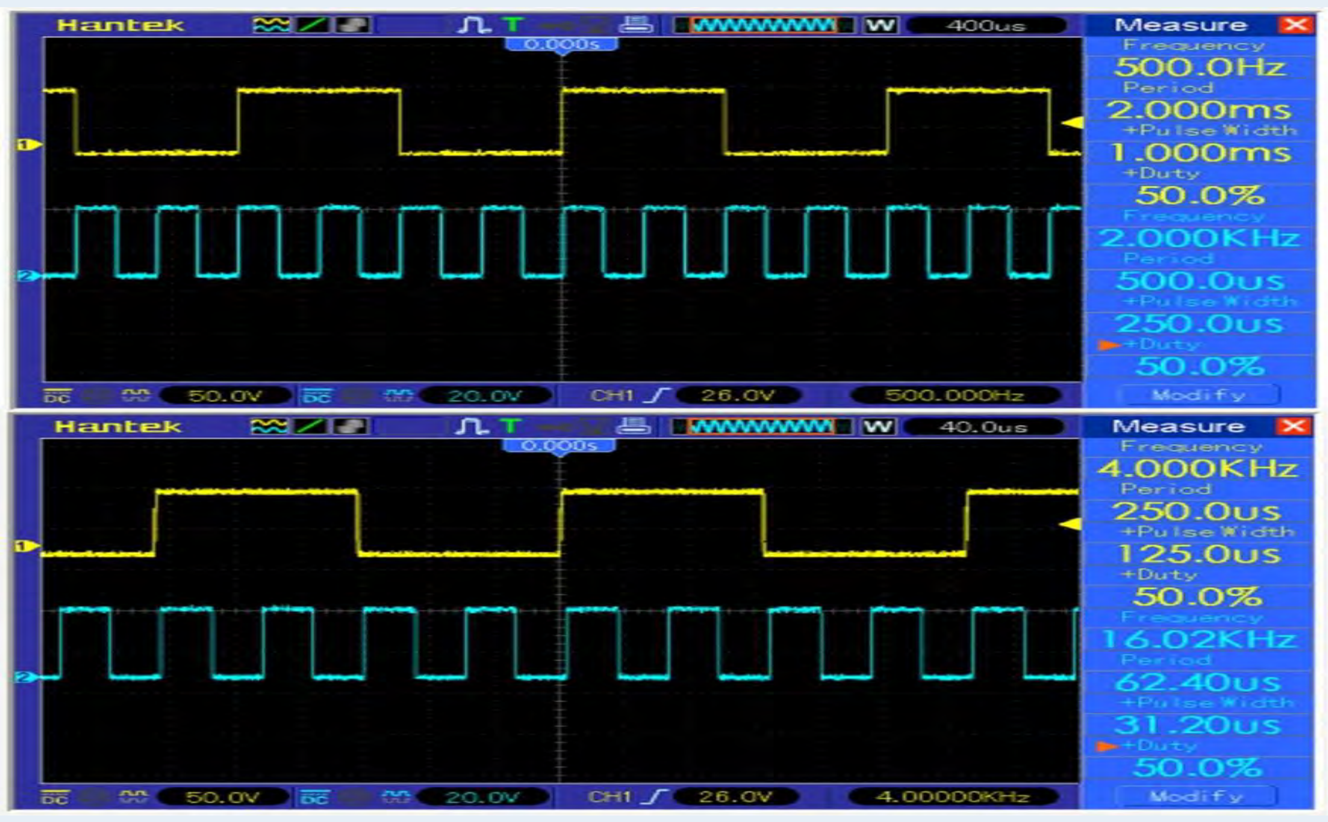

Fig. 3: Input Capture (500Hz & 400kHz) vs. Output PWM Signal (¼ Step)

ELECOMP Capstone Program Director: Professor Harish R D Sunak

email: sunak@ele.uri.edu telephone: 401-874-5859

ELECOMP Website: uri.edu/elecomp-capstone