



FaultLine

Power Signature Analysis for Fault Detection and Predictive Maintenance



Team Members: Daniel Forman (CPE), Brianna MacDonald (CPE), Dominick Barata (ELE), Lucas Halkidis (ELE), Eydis Embla Ludviksdottir (ELE)

Technical Director: Brenden Smerbeck ('17)

PROJECT MOTIVATION

All electronic devices require power to operate, a value which can be derived from voltage and current. Power consumption varies over time depending on the intended action to be performed by the device. By analyzing the power consumption, one can identify specific electrical characteristics in a device over time. Learning this unique 'power signature' allows the user the ability to identify abnormal device behavior and can be used to prevent catastrophic failure. Due to the deployment of Acumentrics' systems in secure environments, data collection cannot occur in the field. Therefore, failure analysis occurs upon the return of the system to the company. Similar to earthquake prediction - accomplished by analyzing characteristics at notable fault lines - the goal of the project is to be proactive instead of reactive. By leveraging machine learning, our team hopes to be able to predict electromechanical failures.

KEY ACCOMPLISHMENTS

Appliance Selection: A fan was selected as our target appliance due to its low-cost, easily inducible electromechanical faults, and complex power load. Since the appliance has both real and complex power components, the power signature of the device will be more unique.

Fault Mode Induction: In order to train the ML model it was necessary to induce unique fault modes into the target appliance. Over the course of the two semesters, our team induced three fault modes within the target appliance. First one increasing the load to the motor where five quarters were attached to one blade. Second decreasing the load where a single blade was removed from the fan. The last one was burning the motor by holding the blades still for thirty seconds, repeated for 20 iterations.

Integrated Circuit (IC) Selection: After thorough research, the analog ADE7880 IC was selected for its functionality, compatibility, and accuracy. With advanced power analysis features and single/poly-phase data acquisition, the chip was an ideal choice for its high precision energy monitoring calculations that are necessary to determine unique power signatures.

ML Model Selection: A Recurrent Neural Network (RNN) was selected for our application to enable effective training on the power data. RNNs are capable of learning relationships within temporal data; given an input data series, the model is capable of learning the effect of previous entries on the currently processed value. For power data, the underlying characteristics of the signature can be understood by a RNN. However, instead of training on temporal data, the input can be converted to the frequency domain with Fast Fourier Transforms. By converting domains, the total amount of input data is decreased without negatively affecting the accuracy. To train on the non-temporal data, an alternative model was utilized, an Artificial Neural Network.

ML Training Setup Formation: A process was developed to train an ML model with the ADE7880 data. The process includes visualizing the input data, preparing the input data for the model, facilitation of the training process (via TensorFlow), and evaluation of the resulting trained model (Fig. 3).

Development of the Data Collection Unit (DCU): In order to initially achieve the ABO, a system was designed to read and collect data from the ADE7880; the system utilizes the evaluation board, current sense transformers, and 3.3V power supply to calculate power data from the fan analog inputs (Fig. 2). However, the system was unable to properly collect and log ADE7880 data.

Implementation of the ADE7880 Communication (ADEC) Library: To communicate between the ADE7880 and the Raspberry Pi, an IC communication library was developed; the library utilizes the Linux kernel spidev library to send and receive SPI transactions at rates of 2.5 MHz. The library API provides the functionality to read/write to ADE7880 registers, lock/unlock the Digital Signal Processor of the ADE7880, save/load a set of pre-defined calibration registers to/from a CSV, and collect data from a set of pre-defined register values.

Development of the Fault Detection Unit (FDU): Due to the shortcomings of the DCU, an improved system, the FDU, was developed. The system had two major goals: real-time data collection and real-time inference. To achieve these goals, the DCU's evaluation board was adapted into a custom PCB. This board provides the capability to not only feed the appliance's analog inputs to the ADE7880 but also providing a Raspberry Pi interface to read the register data (Fig. 1). Depending on the set mode, the Raspberry Pi can append the data to an output CSV or feed it to an embedded ML model. The resulting fault prediction is then displayed on a set of LEDs (Fig. 4).

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome is:

- A functional prototype capable of modeling a single connected device and detecting abnormalities in behavior
- The system must be non-intrusive and rely solely on the power signature of the connected device
- The system must be capable of real-time data collection as well as real-time model inference.

PROJECT OUTCOME

The Anticipated Best Outcome was achieved

FIGURES

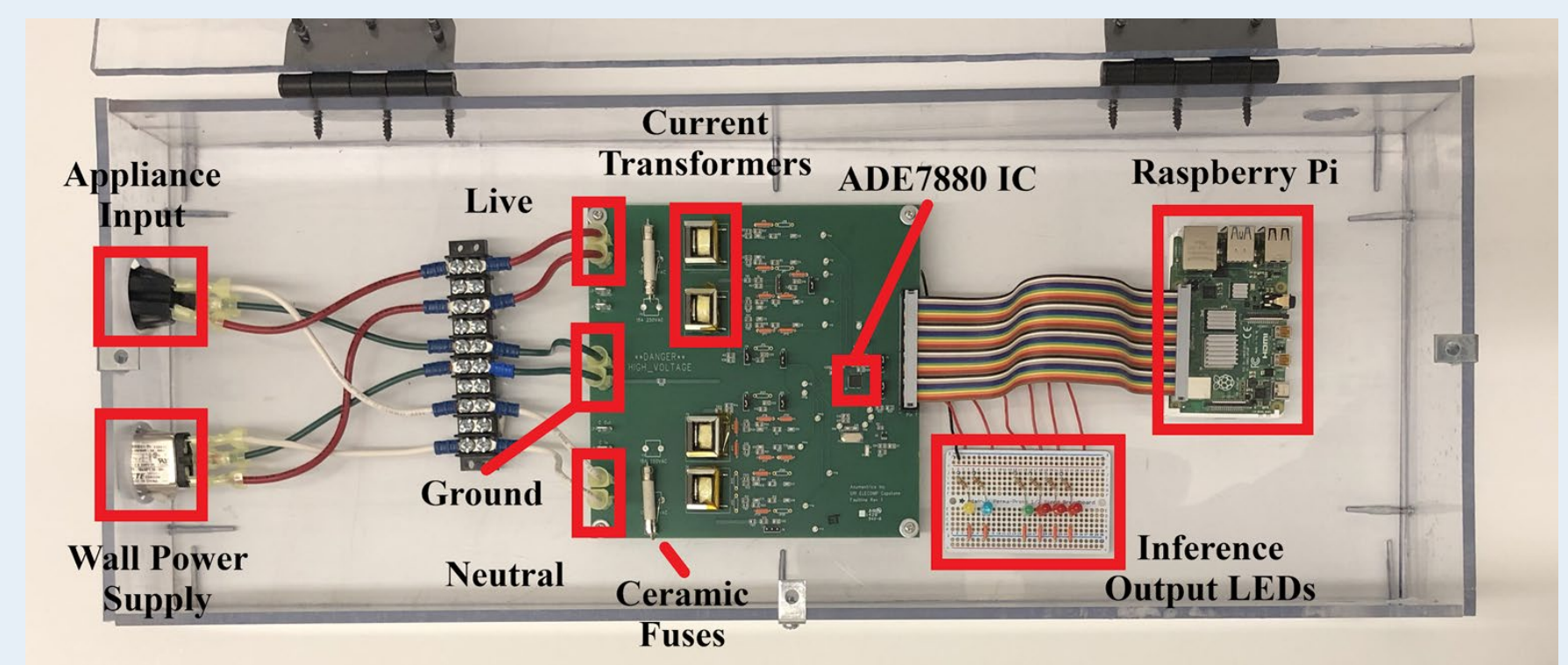


Fig.1: Fault Detection Unit Assembly

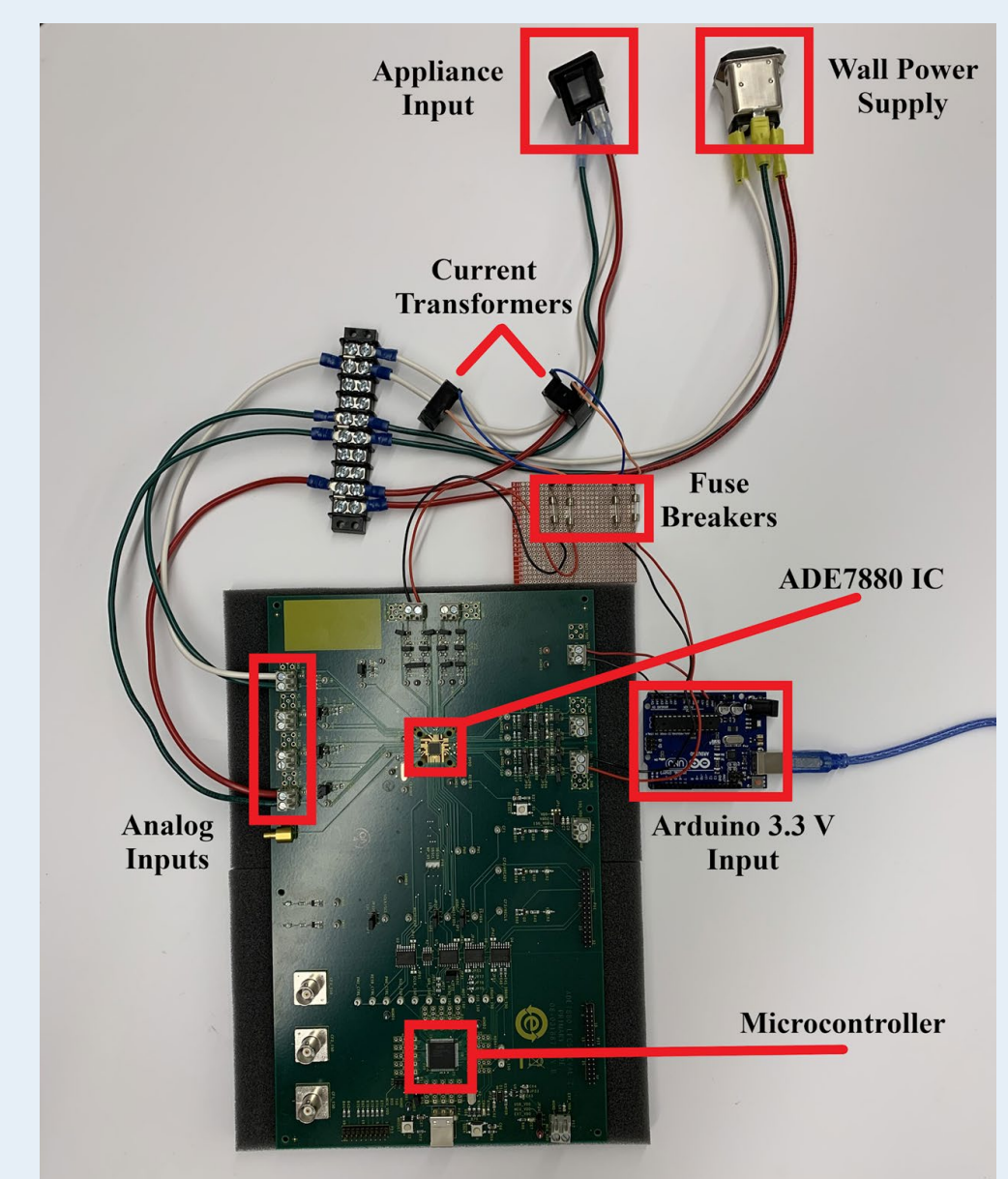


Fig.2: Data Collection Unit Assembly

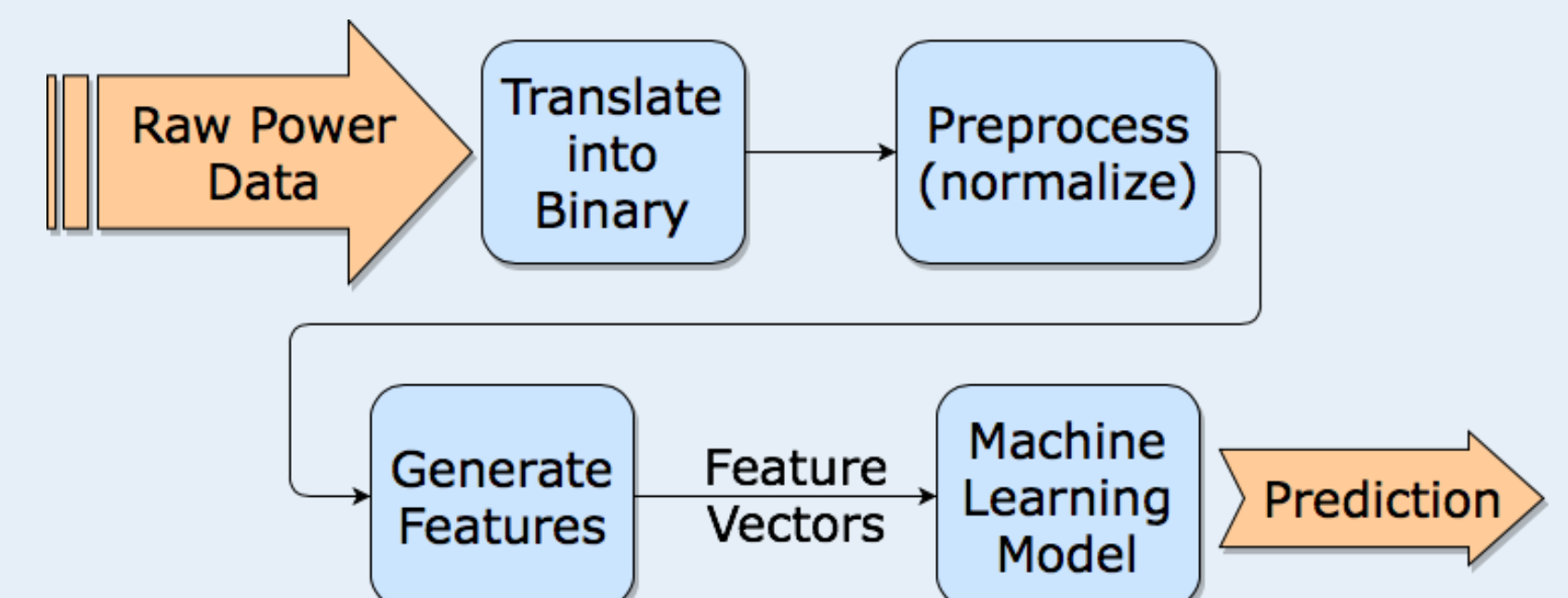


Fig.3: Machine Learning Inference Process

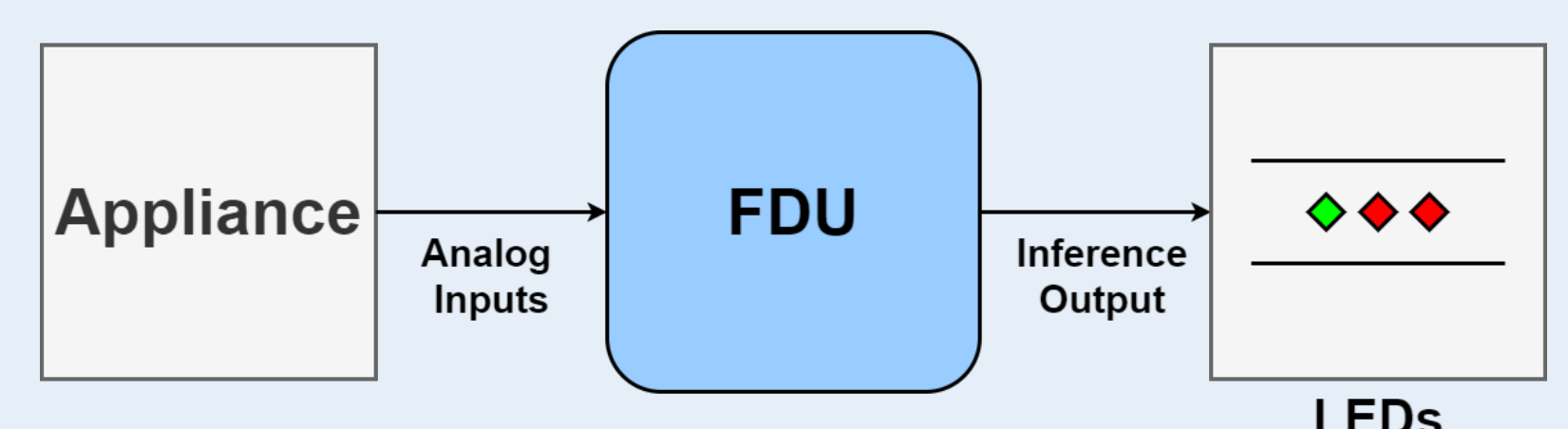


Fig.4: FDU System Overview



Automated Variable Load Testing of HV DC Output Boards

Team Members: Hannah Ditto (ELE), Darol Groeneveldt (ELE), Kyle Connell (ELE)

Technical Director: Brenden Smerbeck ('17)



PROJECT MOTIVATION

Acumentrics is known for designing and building uninterruptible power supplies (UPS), which have the ability to support a wide array of input sources while providing clean and reliable output power. The motivation in creating an automated testing system comes from the 1U Blade Series UPS being a complex piece of power equipment. The 1U Blade has high power density and allows users to chain multiple units together. It is composed of over a dozen different circuit boards with numerous responsibilities. With an automated testing system, the testing process becomes more efficient, thus saving Acumentrics time and money. If a faulty board is discovered, the system would normally have to be disassembled before replacing the board. The end goal is to eliminate that step by testing a small selection of boards separate from the unit to see if it can accept any input source, condition and clean the signal, and convert the signal to the required output signal.

KEY ACCOMPLISHMENTS

Safe Testing Environment: We spent time integrating safety equipment into our testing with LabVIEW. In addition to personal protective equipment, a DUT enclosure, grounding rod, safety barriers, and warning signs were purchased to create a safe testing environment in accordance with OSHA and NFPA regulations. The DUT enclosure (**Fig. 2**) ensures that power is cut when the container is opened. The programmable test equipment in (**Fig. 1**) that was decided upon was a Preen single-phase power supply, a Keysight data acquisition system with a 20 channel multiplexer, and a 20 channel switch module, a BK Precision DC electronic load, and a Tekpower DC power supply.

Constructed Cables: We spent time at the Acumentrics facility constructing cables to connect the boards to devices for testing. An important part of this was to make sure the wire gauge was appropriate to handle the amount of current flowing through. We wanted the system to be as organized, compact, and universal as possible. We labeled all of the wires and added quick disconnects to them to make our system compatible with testing other boards and to make sure it is easy to transition from one board to the next.

Manual Testing: Manual testing is required before using the LabVIEW program. Beginning with the DC/DC Output and Charger boards we were able to determine how we wanted the LabVIEW program to work. We spent a large amount of time collecting data and studying the boards when running manual tests. There were many times we had to troubleshoot to determine if the board was broken or if there was an issue with our cables/hardware.

LabVIEW Testing: After manually collecting data, we were able to achieve programs that run through automated tests for each board. This consists of the DC board, Charger board, and preliminary programs for the DC Front End board. The LabVIEW programs initialize the testing equipment (**Fig. 3**) and runs through a current loop that constantly raises depending on the board being tested.

LabVIEW Convenience: Along with automation, a User Interface (UI) was designed to enhance the test engineer's ability to monitor data as well as the state of tests. LEDs can be witnessed in the UI to signify the user whether the current test is running, passed or failed. In addition to this, work was done on each individual VI to condense the block diagrams using sub-VIs, allowing for an easier flow of information and editing. A master VI was created to call to other VIs depending on the board being tested, so the test engineer only needs to go to one place to access all testable boards.

AC and DC solid-state relays: The relays are powered by 5V from the benchtop voltage source. The positive voltage is connected to the switch channels within the DAQ to control which relay is being used. The positive end of the high voltage power supply is connected to each of the relays and then to the DUT enclosure interlock. From the interlock, each board can be connected to their matching cables for testing. We performed a manual test on the DC/DC Output board to verify the enclosure works as designed. When the lid is opened, the circuit is not complete, and the power is cut. Two relays (**Fig. 2**) were required because only one can be used at a time and is only AC or DC. Since AC and DC boards are being tested, two different relays were required for complete compatibility.

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome (ABO) and Extended Best Outcome was to create a functional prototype system that is capable of performing automated load tests of the DC/DC Output board, Charger board, DC Front End board, and PFC module. The system must compare the characteristics of each board to values sensed by the testing system. This is done by using a data logging function in LabVIEW. These values are then used to determine whether the board is acting as it should or not. This system will not rely on the 1U Blade and will visually indicate to the operator the results of the test.

PROJECT OUTCOME

The Anticipated Best Outcome was achieved.

FIGURES



Fig.1: Automated Testing Equipment



Fig.2: Wiring on DUT Enclosure

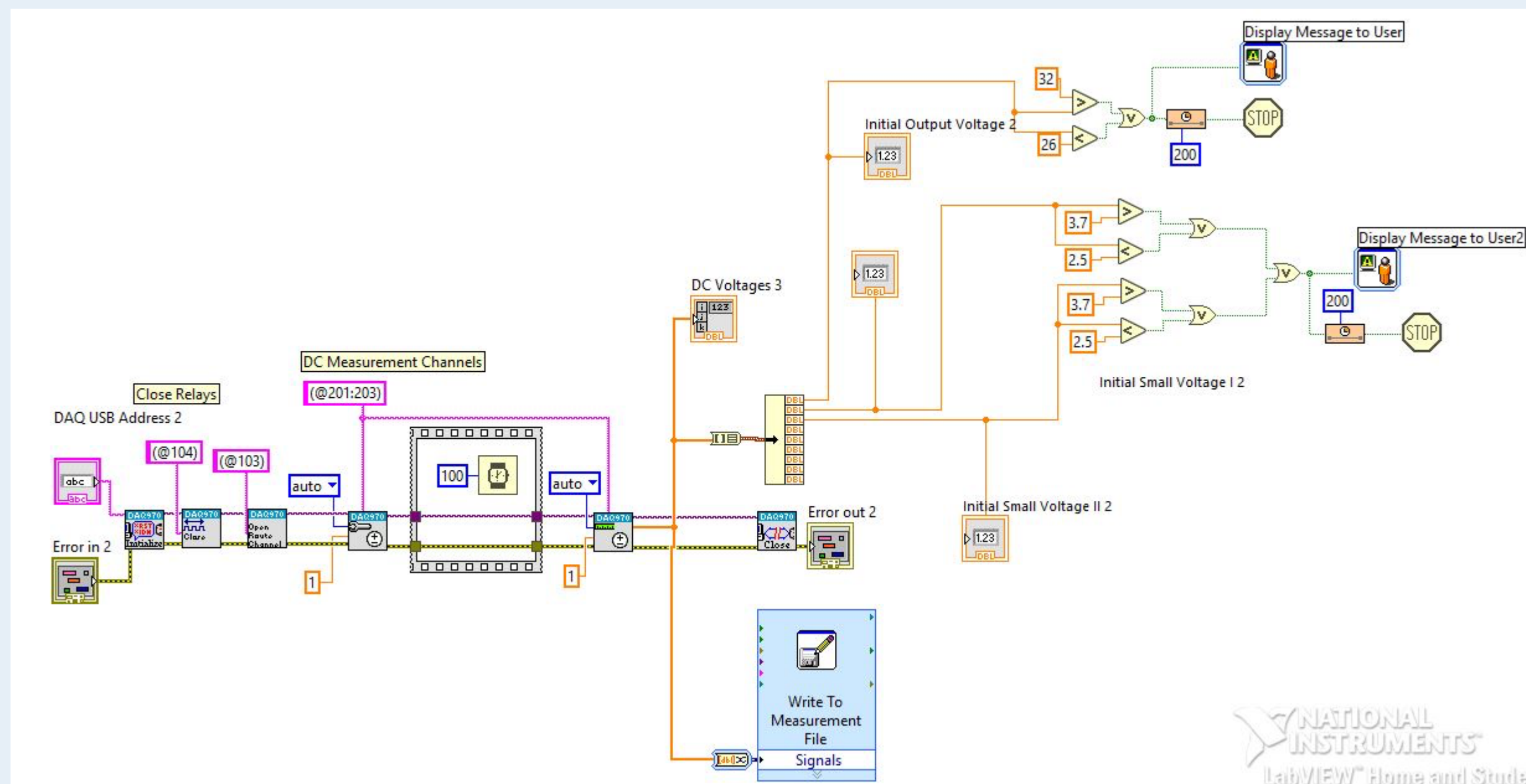


Fig.3: DAQ Initialization



Software Development of Thermal & Electrical Model for MRI Gradient Amplifiers

Team Members: Luis Ibanez (CPE), Rebecca Pham (ELE)

Technical Directors: Phil Houle, Tim Prouty, Ye Zhao

PROJECT MOTIVATION

A major business focus for Analogic Corporation is the production of gradient amplifiers (GA), which generate both the current and power required to operate MRI machines. When working with performance-critical machines such as MRIs, unit shutdowns can be highly detrimental in regards to time, resources, and product reliability. Oftentimes, the cause of the shutdown is related to the gradient amplifier power stage - specifically the temperature of the insulated gate bipolar transistor (IGBT) or depletion of the high-voltage capacitor banks. If operators were able to simulate specific input waveforms prior to run-time, and be notified of imminent issues and concerns, the potential for system failure and its negative effects can be eliminated. Thus, having a user-friendly software that can model both the electrical and thermal behaviors of the GA, and ensure completion of the task, is highly desirable. Ultimately, the motivation for this project is to supplement customer demand and reinforce the safety and reliability of the gradient amplifiers.

KEY ACCOMPLISHMENTS

Project Foundation

Language Selection: C++ was the selected language of choice for the software project due to the need for high performance and easily encrypted code. C++, being a lower level, compiled language handles both of these requirements elegantly.

GUI Library Selection: Choosing C++ required finding a suitable GUI library to display the application with. The open source Dear ImGui library was selected for being lightweight and simple to integrate into the project, along with providing all the functionalities necessary to implement the requirements of the software.

Electrical Model: Fig. 1 is a high-level flowchart detailing the computational processes involved for the electrical model. The electrical model is accessible by users through the graphical user interface, and accepts user-inputted PWL command signals which are then put through a linear interpolating function. The C++ program performs calculations to determine relevant values such as load current, load voltage, output voltage, and available voltage. Upon completion, it notify users of predicted system failure, time of expected failures, or simulation success.

Thermal Model: The thermal model is also accessible through the graphical user interface, and accepts user-inputted PWL command signals. Using team derived and compiled mathematical equations describing the thermal behavior of the AG700 GA, calculations for cold plate temperature, junction temperature, and overall IGBT junction temperatures are performed. The C++ model outputs expected temperature rise, potential threshold breach, time of simulation failure, or simulation success. A flowchart detailing these computations is shown in Fig. 1.

Full Software Integration

Multithreaded I/O: Due to the large file sizes that the program will be taking as user input, an algorithm for handling the input and output data was designed in order to efficiently read and write the information needed and produced by the models. This algorithm uses multithreading to simultaneously read input information, perform computations on that information, and write the results to a file.

Modular Architecture Design: Compatibility with Analogic's other GA products was kept in mind when designing the software architecture, which led to a modular implementation of the gradient amplifier models. The class hierarchy derived from this planning will make maintaining and adding features to the software much simpler in the long run.

Model Integration: Due to the modular nature of the software's simulation implementation, integrating the models of the AG700 involved only slightly modifying the data structures used for multithreading synchronization to account for the fact that the models must adhere to sampling frequency laws.

User Features

Plot & Report Generation: Plotting of both the input data and results from each simulation is handled by a custom-plot implementation made for Dear ImGui. Plotting is handled independently from the simulation computations, leading to a higher performance, quicker-to-completion simulation.

Documentation: Informative documentation and comments have been continually added to the program in order to allow for easy understanding and smooth transition for any future work. In addition, a repository has been created to maintain thorough records of development as well as a user help guide

ANTICIPATED BEST OUTCOME

The Best Anticipated Outcome will manifest itself as a complete deliverable of a fully-functional software package which can accurately model the electrical limitations & thermal behavior of the gradient amplifier systems. The software package should be developed using a secure, freely accessible, versatile programming language that can perform efficient computation, with proper coding practices and maintainability being kept in mind during development. It will contain a user-friendly GUI and be able to perform simulations that will be used to predict failure and shutdown of the MRI gradient amplifier unit. An additional software user manual will be supplied.

PROJECT OUTCOME

The Anticipated Project Outcome was achieved.

An operable software package with the aforementioned capabilities will be delivered to Analogic.

FIGURES

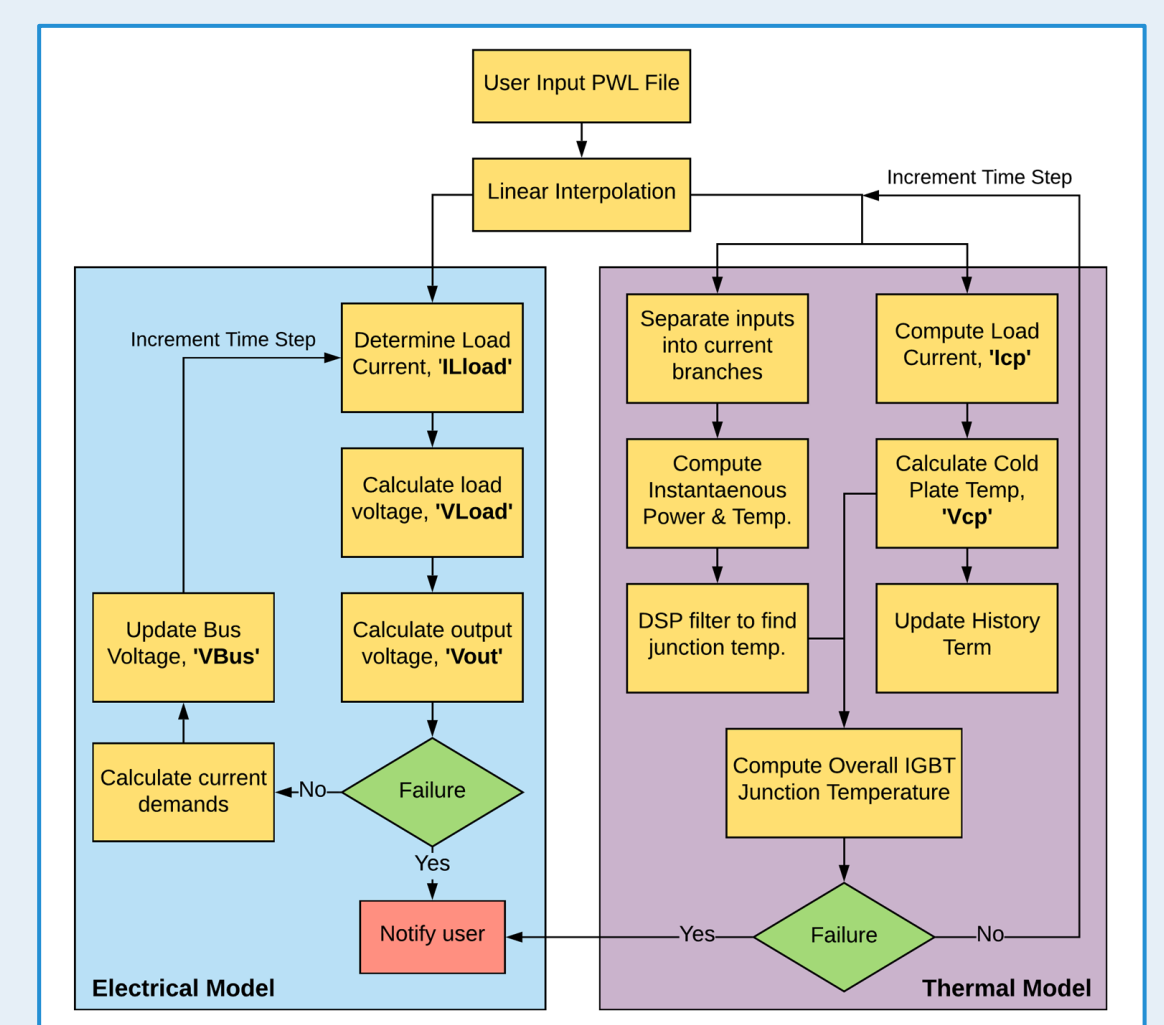


Fig. 1: Flowchart for Electrical and Thermal Model C++ programs

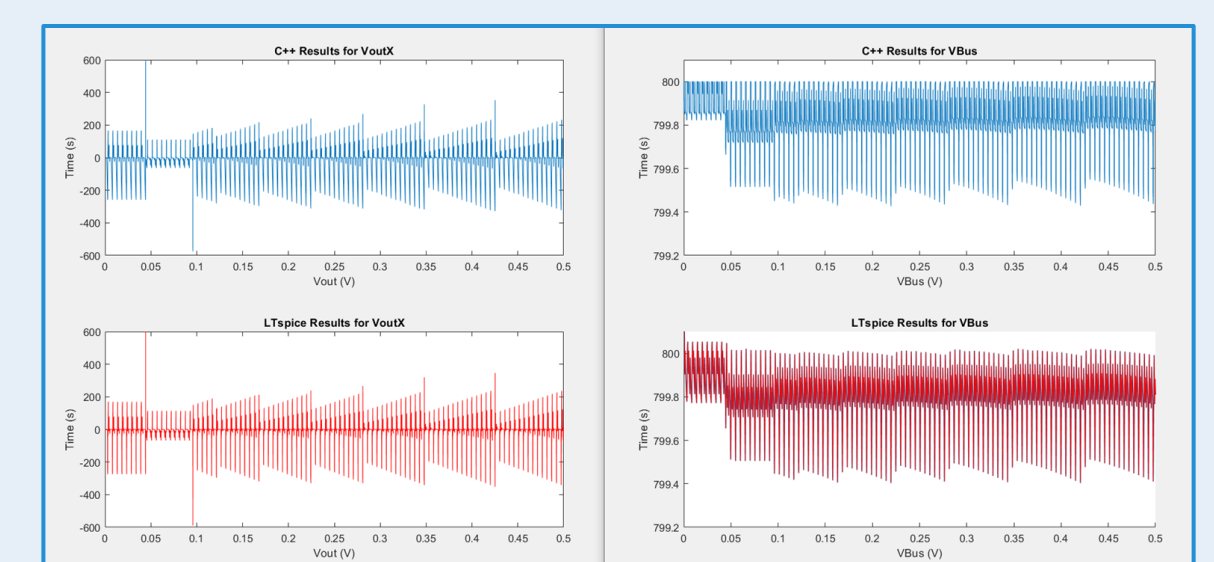


Fig. 2: Verification for Output Voltage (Vout) and Bus Voltage (VBus); C++ vs. LTSpice results

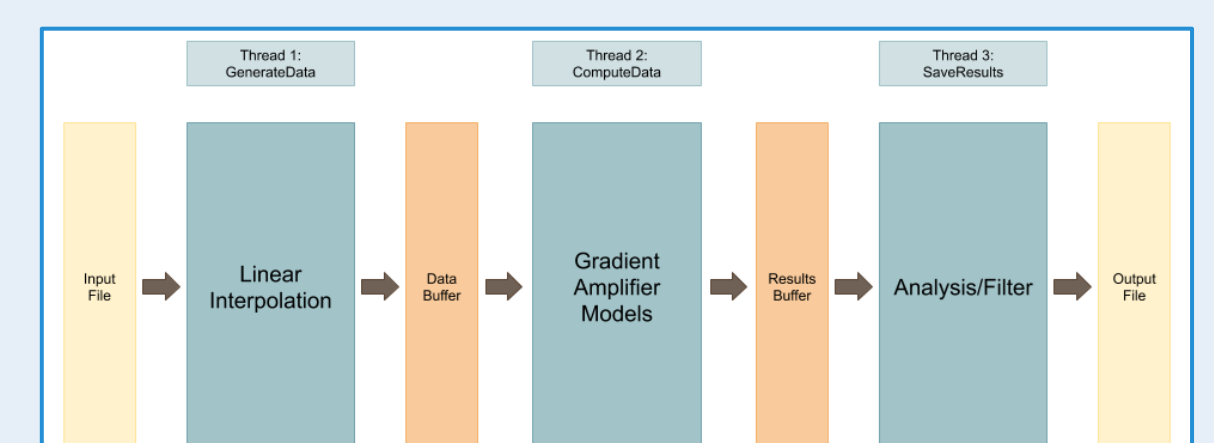


Fig. 3: Multithreaded I/O Design



Fig. 4: Main Graphical User Interface of Application



Polygon Scan Head Integration

Integration of a Polygon based laser scanning head into an existing controller platform

Team Members: Nick Schmidt (ELE), Travis Frink (ELE/CPE), Rory Foley (ELE)



Technical Directors: Mark Lucas, Seethram Sivam

PROJECT MOTIVATION

As part of its product line, Cambridge Technology produces a polygon-based laser scanning head. However, the system that controls its inputs and outputs is produced by an outside, competing company. Adapting Cambridge Technology's existing laser scanning controller to support polygon scan heads will provide a significant economic advantage to the company and create greater continuity for its customers. The advantage of using a polygon scan head lies in its ability to process raster-type images at high speeds. The current scan head controller is capable of scanning raster images, but it faces mechanical limitations in how fast its individual mechanically controlled mirrors, or galvanometers, can position the laser. The target technology uses mirrors affixed to a disc with several flat, mirrored faces rotating at a constant rate, which will replace the galvanometer for one axis. This will ultimately allow significantly faster raster scanning and improved resolution of the system.

KEY ACCOMPLISHMENTS

- **System Familiarity:** The ScanMaster Controller uses the Xilinx Zynq-7020 at its core to process and compute raster and vector data coming from ScanMaster Designer [Fig. 3]. Becoming familiar with the system first required learning the Xilinx SoC platform and development tools. This included understanding how the hardware and software components of the system function and communicate.
- **Code Familiarity:** Once the Zynq system and development tools were understood familiarity with Cambridge Technology's current code base was required to begin development. Consisting of over 50,000 lines of C, C++, and Verilog, components of interest had to be identified and investigated to determine the best ways to integrate polygon scan head functionality into the system.
- **1-bit per pixel processing:** Previously the system had a resolution of 8 bits per pixel allowing varying pixel intensity for raster images. Changing to a 1-bit per pixel data format was a requirement for the system to enable scanning rates fast enough to keep up with the new polygon scan head. Even with this change, the system is still able to emulate variable pixel intensity using dithering techniques.
- **I/O board:** A new input/output board was developed to take the place of the board that was in the control box when we received it [Fig. 2]. This was done using the old PCB layout as a baseline to design a board that would allow us to use parts from the control box we received to provide a functional, clean-looking prototype to our technical directors. The board provides the wiring needed to connect the SMC to the scan head, power, and various other circuitry. All of the external connectors are directly mounted on this PCB.
- **Polygon Speed Control:** Prior to a fixed software implementation the polygon scan head required basic control to enable the system, set its speed mode, and wait for its speed synchronization. Using Cambridge Technology's ScanScript language these preliminary functions were implemented and used to debug functionality such as laser timing.
- **Laser Timing:** In order to properly position raster images scanned from the system a delay was added to the laser firing based on the polygon rotation rate and workspace dimensions [Fig. 4]. After determining laser timing analytically the resulting function was implemented in the SMC software to allow the passing of the delay to the system firmware where the delay is executed. The system hardware was also changed to detect facet transitions in the polygon to properly delay the raster scanning stream and fire in synchronization for each raster line.
- **Polygon scan head integration:** The hardware, firmware, and software of the system had to be modified to enable control of the new polygon system. Using the facet signals from the polygon scan head the laser timing calculations were implemented to properly scan the image.
- **Polygon error correction:** During manufacturing errors may be introduced in the polygon facets that will cause deviations in the laser path that will differ per facet. These errors can be corrected for by adding per facet corrections in the software. These correction values called wobble and delay cause offsets in the y and x direction respectively for each facet. Once determined by the user these correction values can be set by the user using ScanScript.
- **ScanScript integration:** Cambridge Technology's ScanScript language is a custom scripting language designed to allow low-level control of the ScanMaster Controller and related devices. By adding additional ScanScript functions to the system users are now able to control various components of the polygon scan head. These include enabling the polygon, setting its speed and waiting for its speed synchronization. ScanScript is also used to set per facet error correction values for the polygon.

ANTICIPATED BEST OUTCOME

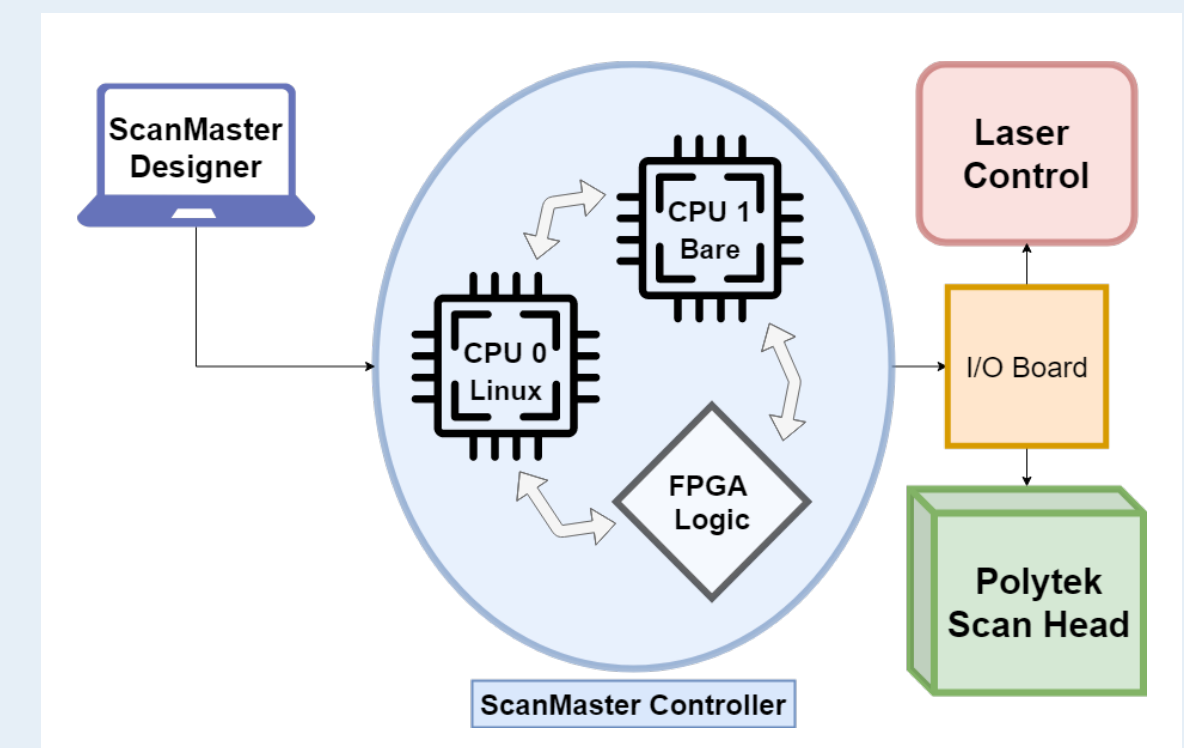
As of April 26th 2020 the anticipated best outcome for the project was met. The polygon-based scan head is now able to scan images while being controlled by the ScanMaster Controller. A user is now able to use Cambridge Technology's ScanMaster Designer software to import images, connect to the controller, and set scanning parameters using the ScanScript language. This functioning prototype is delivered as a closed-box system that only requires a typical power cable, two cables to the scan head, and an ethernet cable to the user PC. This system will be further refined to create a marketable product package for Cambridge Technology's customers.

PROJECT OUTCOME

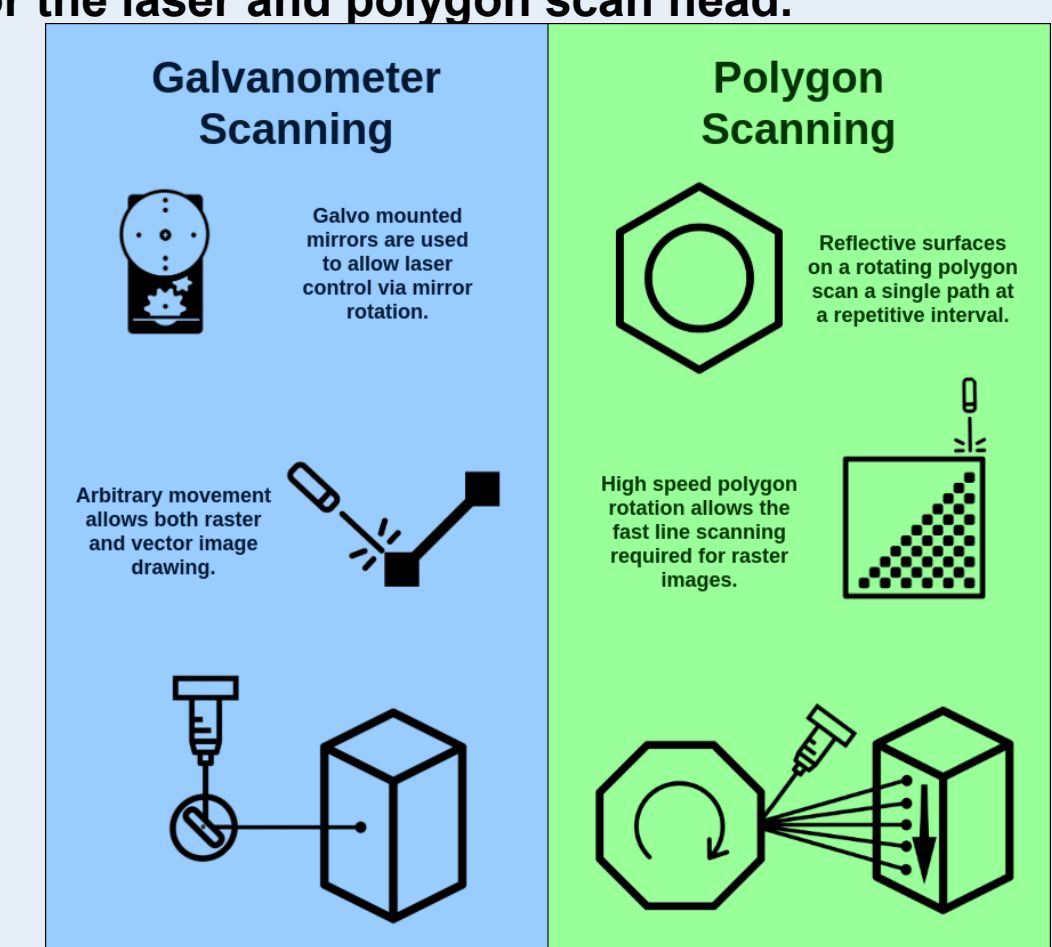
The Anticipated Best Outcome was achieved.

We were able to deliver a functional prototype to our technical directors that will be further refined to produce a professional product to market to customers.

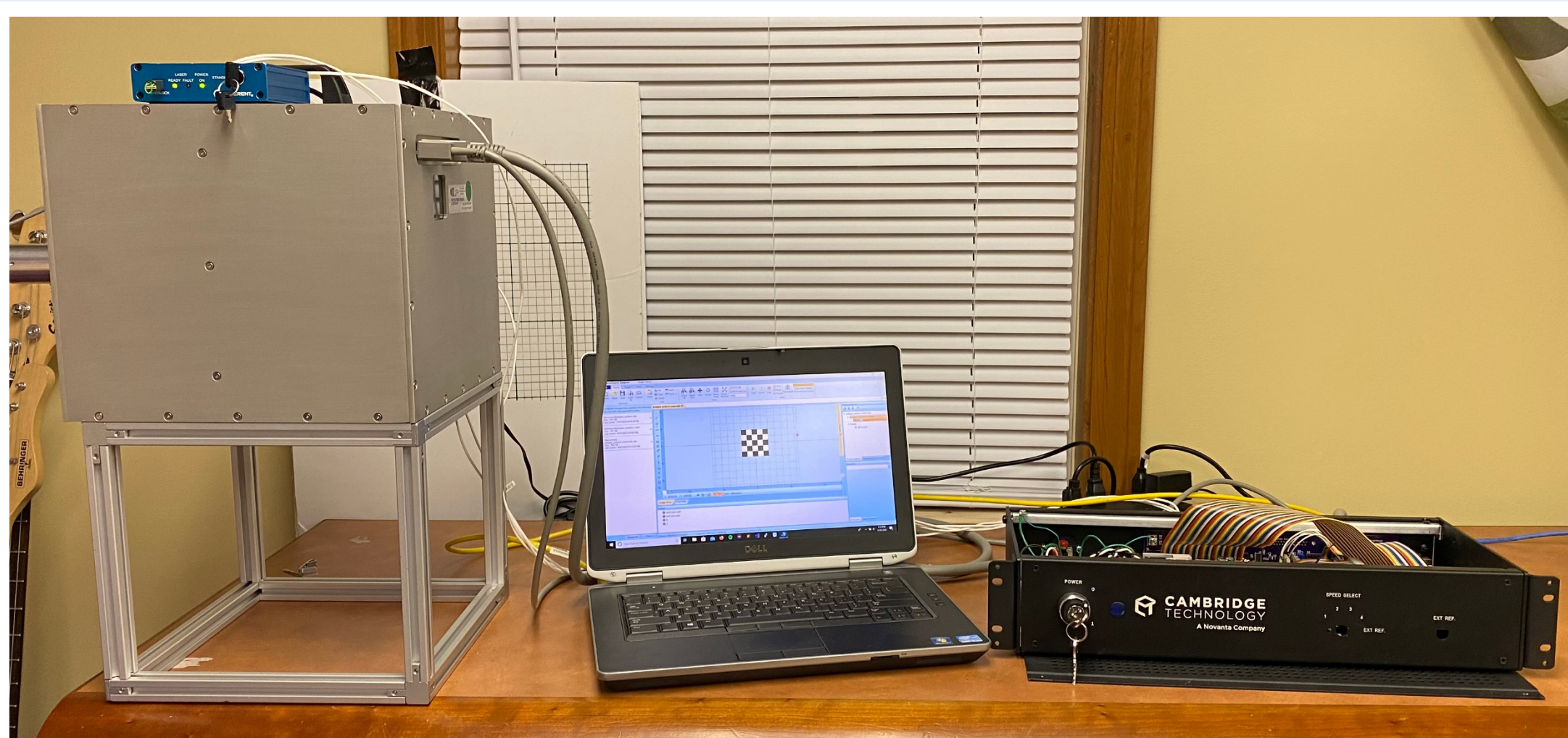
FIGURES



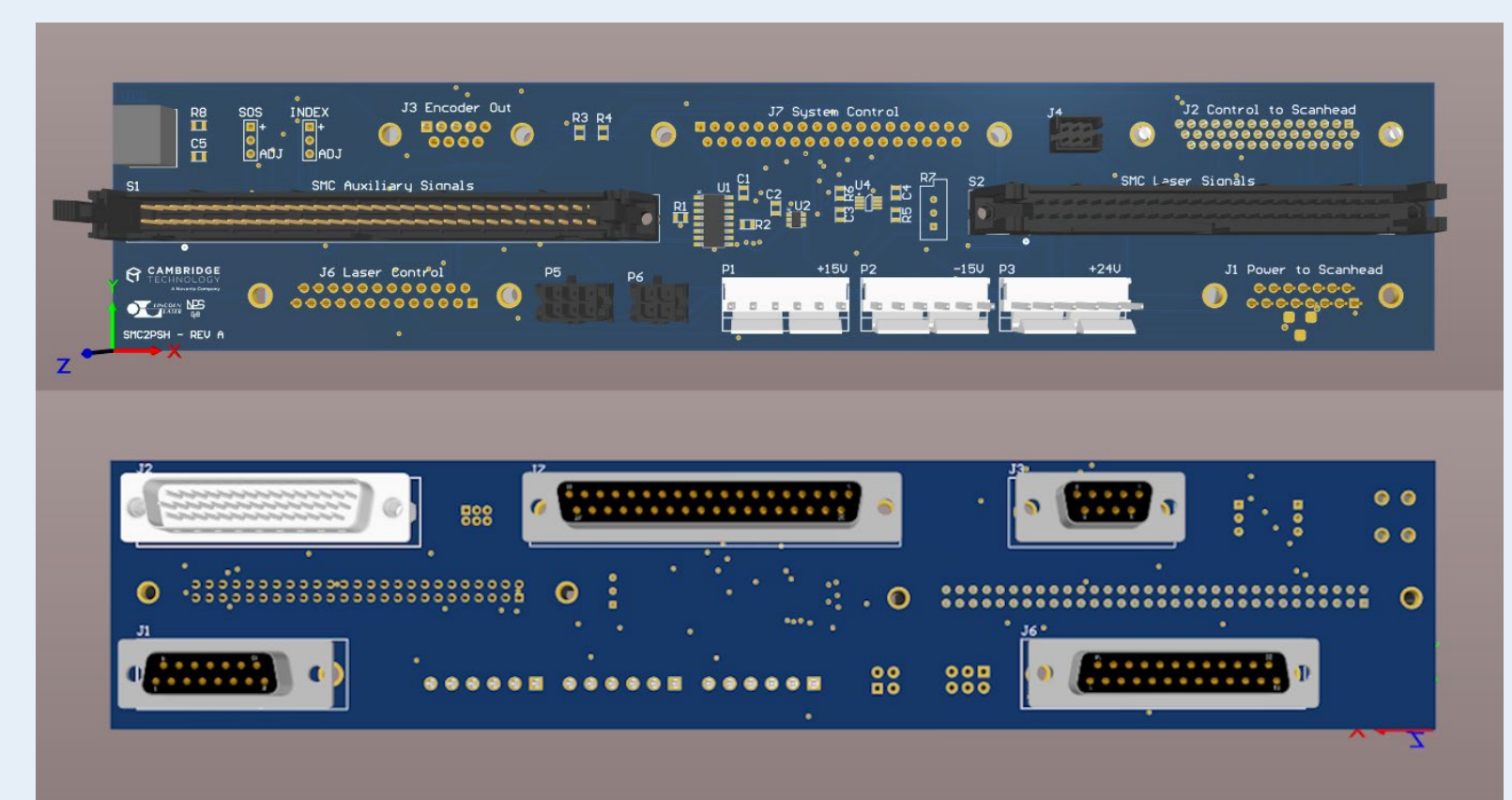
ScanMaster Designer has a single TCP connection between itself and the SMC while the two ARM cores and programmable logic on the SMC are capable of communication among each other. The programmable logic on the Zynq system provides the endpoint of control for the laser and polygon scan head.



Both galvo and polygon-based scanning systems are capable of rendering raster images, but polygon-based scanners are capable of doing so at much higher speeds. On the other hand, fully galvo based scanners can scan vector images as well as raster images.



The new Polygon scan head setup. Shown left is the polygon scan head on top of a T-slot mount. In the center is a laptop running ScanMaster Designer. On the Right is the control box including the new I/O board.



A 3D render of the I/O PCB using Altium Designer. This PCB enables interaction with the Polygon scan head using the ScanMaster Controller.



RUReady

Cooperative Backlog Refinement Software for Agile Development

Team Members: Patrick Hurney (CPE), HopeRose Puroll (CPE & CSC)



Technical Directors: Daniel Jaquez, Gary Jutras, Darius Strasel, Elliot Young | Consulting Technical Director: Brenden Smerbeck ('17)

PROJECT MOTIVATION

In the Agile process, developers use a set of acceptance criteria called a "Definition of Ready" (DoR) to ensure a task is in a state that is both workable and poses little risk of delayed completion. A team agrees on this set of standards that all tasks must meet before it is included in a sprint. Currently, there is no tool that will walk a team through comparing their work items to this DoR during the backlog refinement process. Most teams follow manual checklists and the use of verbal consent from participants. During the backlog refinement process, there is a lot of discussion about each item that is not captured in any form. There are many times when team members want to recall key points from these discussions, but they must rely on their imperfect memory for details. The RU Ready application will automate much of the process of walking through a team's DoR.

KEY ACCOMPLISHMENTS

Jira Controller: The Jira controller verifies that a user either has been authenticated through Jira and has allowed RUReady to make asynchronous API calls on their behalf. If a user is not authenticated, the controller redirects the web page to Jira for the user to input their credential and saves their token information in session for future use

Frontend API Link: Front end API calls for a list of teams via a Redux and React framework as shown in Fig. 3. This connects to the Teams API, discussed below and shown in Fig. 4.

Teams API: The Teams list controller verifies that the user has Jira tokens in session and either redirects them to sign in if that is not or forwards the request to the Team's service. This service first forwards the appropriate CRUD request to the repository which packages the contents in Http to be forwarded to Jira. Upon return from Jira and the repository, the data is then processed in the service to comply with data models before being converted to JSON and sent back to the Teams controller and then ultimately back to the front end to be rendered Fig. 4. Because there is no way to directly get a list of teams for a user, the team's service works through several Jira API calls to completely compile a list of teams. A complete list of teams is used to determine a complete list of roles that are in turn used to determine a complete list of users. This is then compared to session information and information from previous calls are combined to create a functional list.

Team Rendering: Front end data mappers from Json to Team list were implemented to parse the files received from the backend Teams API, referenced previously. This linked the JSON file to individual teams which were contained within a page that renders a list of Teams Fig. 1, to account for any members on multiple teams. This was styled with both inline and individual CSS files.

DoR API: The DoR controller has endpoints for Get, Post, and Delete REST actions. These requests are then forwarded to the DoR service. The service forwards Get and Delete requests immediately and does validation checking on Post body before forwarding the request to the repository. The repository creates, deletes, reads and writes JSON files to the file system to store a team's DoR information. Upon return from the repository, the service then verifies that a DoR is present and either returns a default or formats the DoR to be sent back to the front end to be rendered Fig. 4.

Criterion/DoR Rendering: Front end API calls for a list of criteria functioned similarly to those done for the Teams list, but the link to the backend varied since in these instances the front end was actually able to update the data and send API requests directly. These changes required their own frontend data mapper from JSON to the DoR criterion, and like the Teams page, there needed to be a page that renders a list of criteria Fig. 2. The page contained card components that render a single criterion, with each type of criterion being rendered in a slightly different way to represent the different information contained within. This was styled with external CSS.

Front End Actions: The frontend links to the backend, referenced previously, works using Redux Data modeling and transfer, using action creators, processors, gateways, and data storage. This is a bit beyond what is shown in Fig 3 and Fig. 4 but is an important part of how the program actually functions.

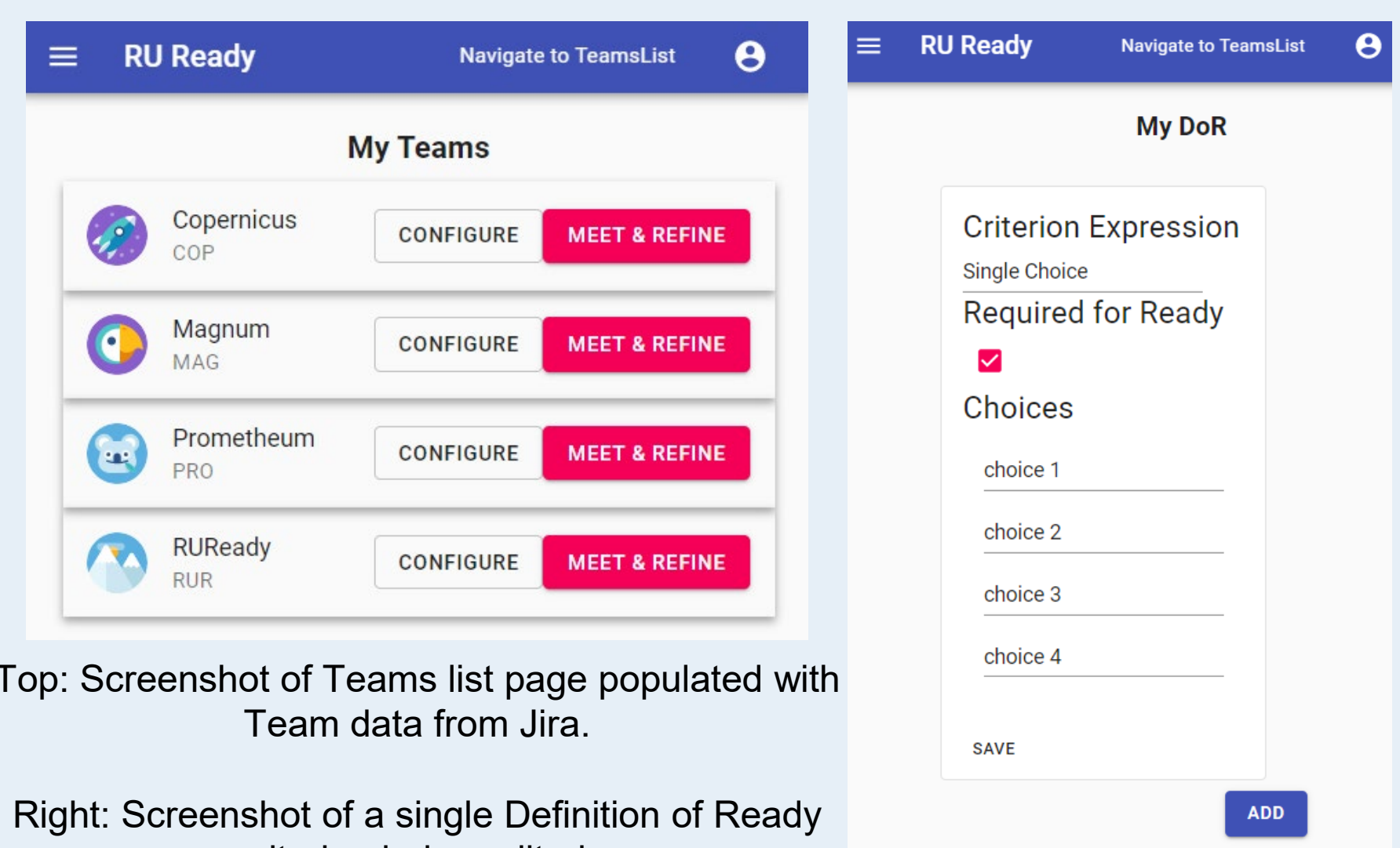
ANTICIPATED BEST OUTCOME

The anticipated best outcome for this project has evolved since the Symposium. We have chosen to focus on the development of the definition of ready, allowing the creation, editing, and deletion of the DoR criterion. We aimed to integrate with Jira to retrieve a list of teams. To create a container page for the DoR configuration. To implement DoR creation and deletion via linking through Redux store actions and features. And finally to allow the editing and reorganizing of the DoR. All these things link to the backend through a complex network of React, Redux, and C# API calls.

PROJECT OUTCOME

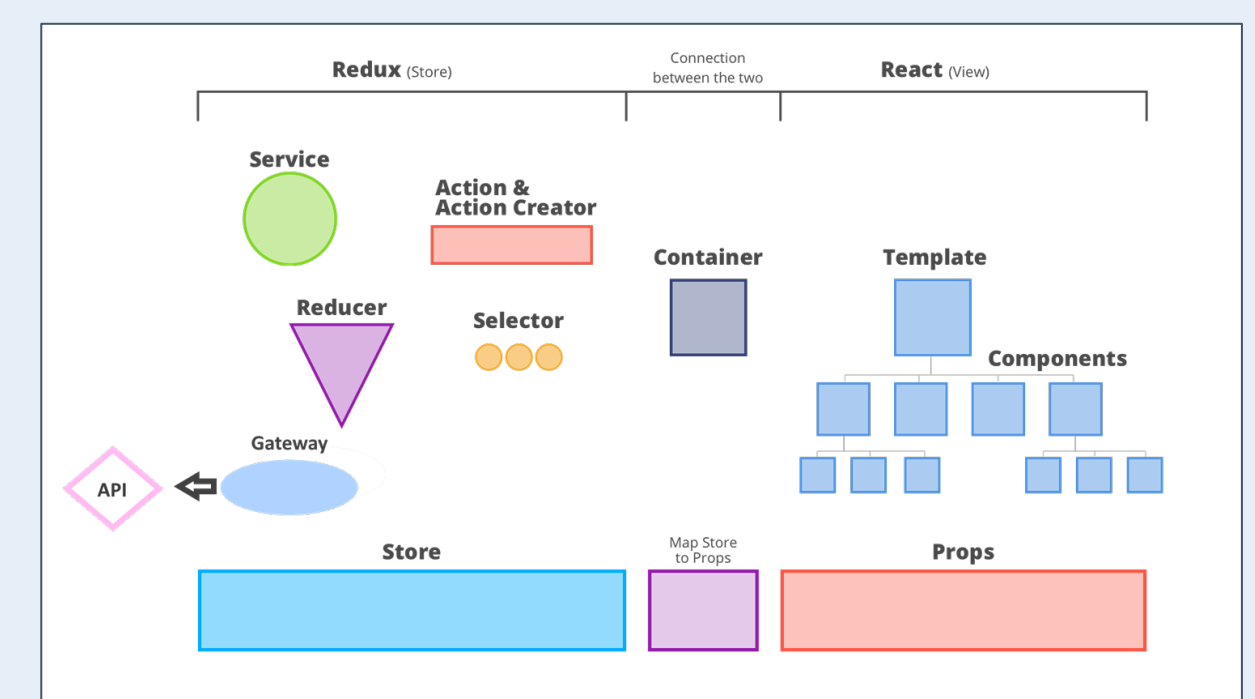
Updated Best Anticipated Outcome Achieved. Initial goals were out of scope, but once updated the work was completed.

FIGURES

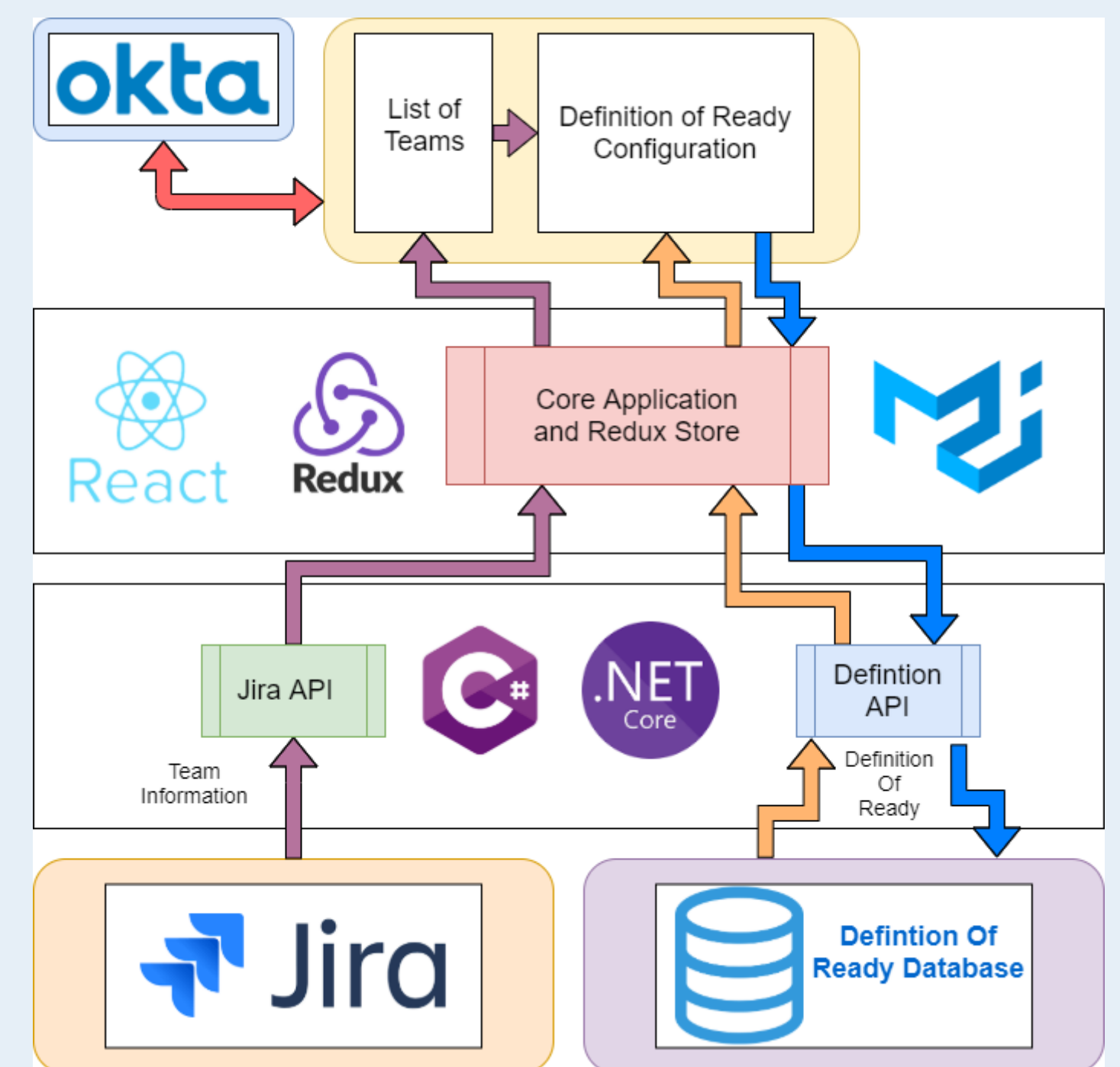


Top: Screenshot of Teams list page populated with Team data from Jira.

Right: Screenshot of a single Definition of Ready criterion being edited.



React and Redux architecture, with link to external C# API



Data and software flow diagram



Automated Response Time Measurement for Gas Detection Equipment

Team Members: Andrew Phillips (ELE), Andrew Ramirez (CPE), Andrew Vose (ELE), Jane Trapala (CPE)



Technical Director: Patrick Byrne

PROJECT MOTIVATION

FM Approvals tests and certifies gas detectors that are used for the protection of personnel and property by detecting the presence of either combustible or toxic gases, to several national and international standards. These standards all require measuring the response time of the gas detectors when presented with a specific gas. This is done by exposing the detector, initially in clean air, to a step change of a known quantity of a specific test gas. The output of the gas detector must reach 50% of the final reading within 20 seconds and 90% of the final reading within 60 seconds, according to FM's own response/recovery report.

This process is being done manually with the current test apparatus. It is time consuming and requires two people, therefore making it challenging to create repeatable data. The motivation of the project is to automate this test apparatus to save time and improve the repeatability of the results.

KEY ACCOMPLISHMENTS

Arduino:

Serving as the conductor of the operation, the Arduino creates a repeatable and automated testing process. To replicate the manual testing process in an automated manner, a finite state machine (FSM) had been implemented into the Arduino code. To describe the overall structure of the FSM, a flow chart has been created (Fig. 1). The FSM uses multiple states to control gas flow and allocate data from the gas detector under examination. The Arduino sorts the raw data into an array that is suitable for an FM Approvals employee to work with. The Arduino also sends signals to the relays, allowing the solenoid valves to open and close at the appropriate times.

Graphical User Interface (GUI):

The GUI has working components to start the process and graph the test results in real time. It contains options for the user to enter the information related to the test that will be used for creating the test pass/fail report. The GUI also exports a csv and/or a xlsx file, based on user input (with auto-generated file name) when done with the test run. The GUI also has a running stopwatch to verify the timing of the test. (Fig. 4)

System Test:

The establishment of communication between the Arduino and GUI had been verified through various tests. The Arduino successfully controlled the components (Figure 3) in accordance with the derived flow chart and returned accurate test results to the GUI for processing. This achievement was an extraordinary benchmark for the team, being that the hardware had finally been able to work in harmony with the software.

Automated Valves:

To automate the test process, a pneumatic knife gate valve and smaller solenoid valves were chosen. The pneumatic knife gate valve was chosen to control the flow of gas out of the lower chamber and up to the gas detector. The solenoid valves were chosen to control the flow of test gas into the lower chamber, as well as supply compressed air to operate the pneumatic valve. With these components working in unison, controlling the flow of test gas to the lower chamber and then to the gas detector proved to be far more efficient in comparison to an electric valve. The pneumatic valve has a much faster cycle time, meaning that it can open and close much quicker. This is a key feature to the design, ensuring that the test gas will flow at a constant rate, up to the gas detector, as soon as the valve is opened. The choice of a pneumatic knife gate valve and smaller solenoid valves proved to be effective after individual tests. (Fig. 3)

Printed Circuit Board:

To control the hardware using the software, a schematic and PCB was designed. The design allows for consolidation of all of the components into a neat, small board with easy-to-use terminal connections. This board holds all of the electronics needed to operate the solenoid valves, including relays, an Arduino Nano, snubber diodes, the BME280 breakout board, and circuitry to read the 4-20 mA output of the gas detector. (Fig. 2)

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome is a system with the following features:

- Automated system for filling the apparatus with test gas.
- Automated system for exposing the gas detector to the test gas.
- Integrated data acquisition system to record the response time of the gas detector.

PROJECT OUTCOME

The Anticipated Best Outcome was achieved and exceeded by including a small form factor and stopwatch into the design.

FIGURES

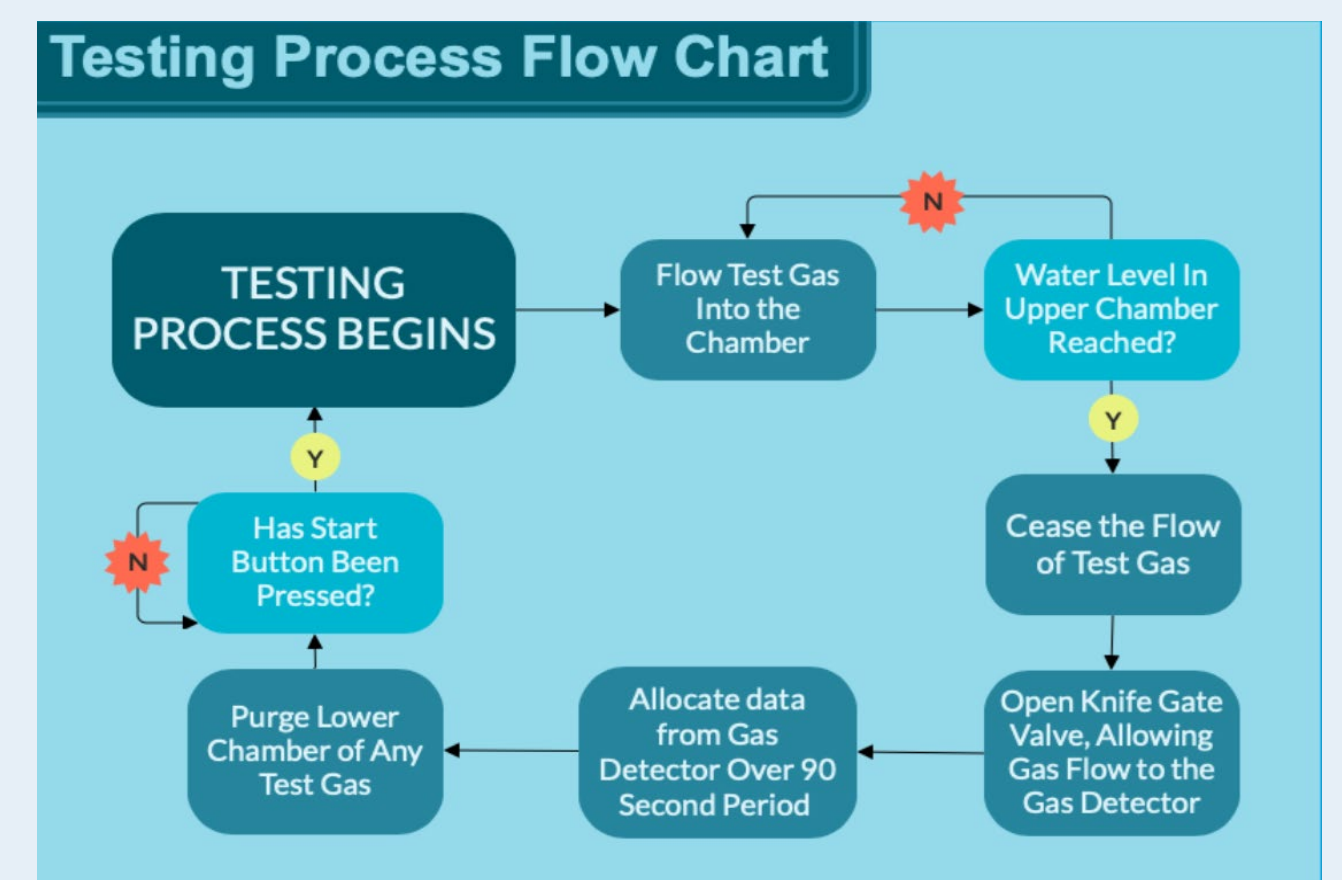


Fig.1 - System Diagram including the Arduino, GUI, and test apparatus connections.

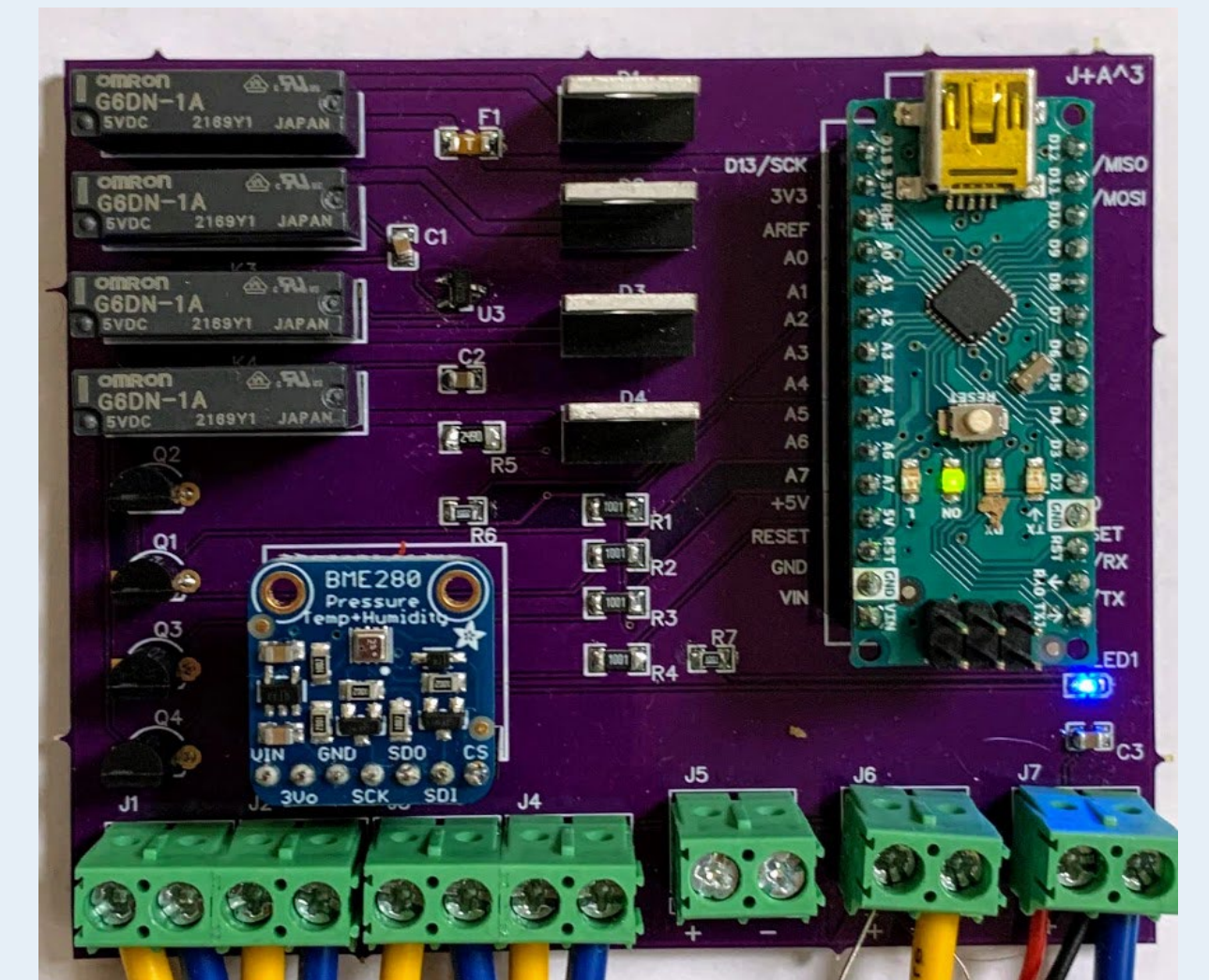


Fig.2 - Printed Circuit Board

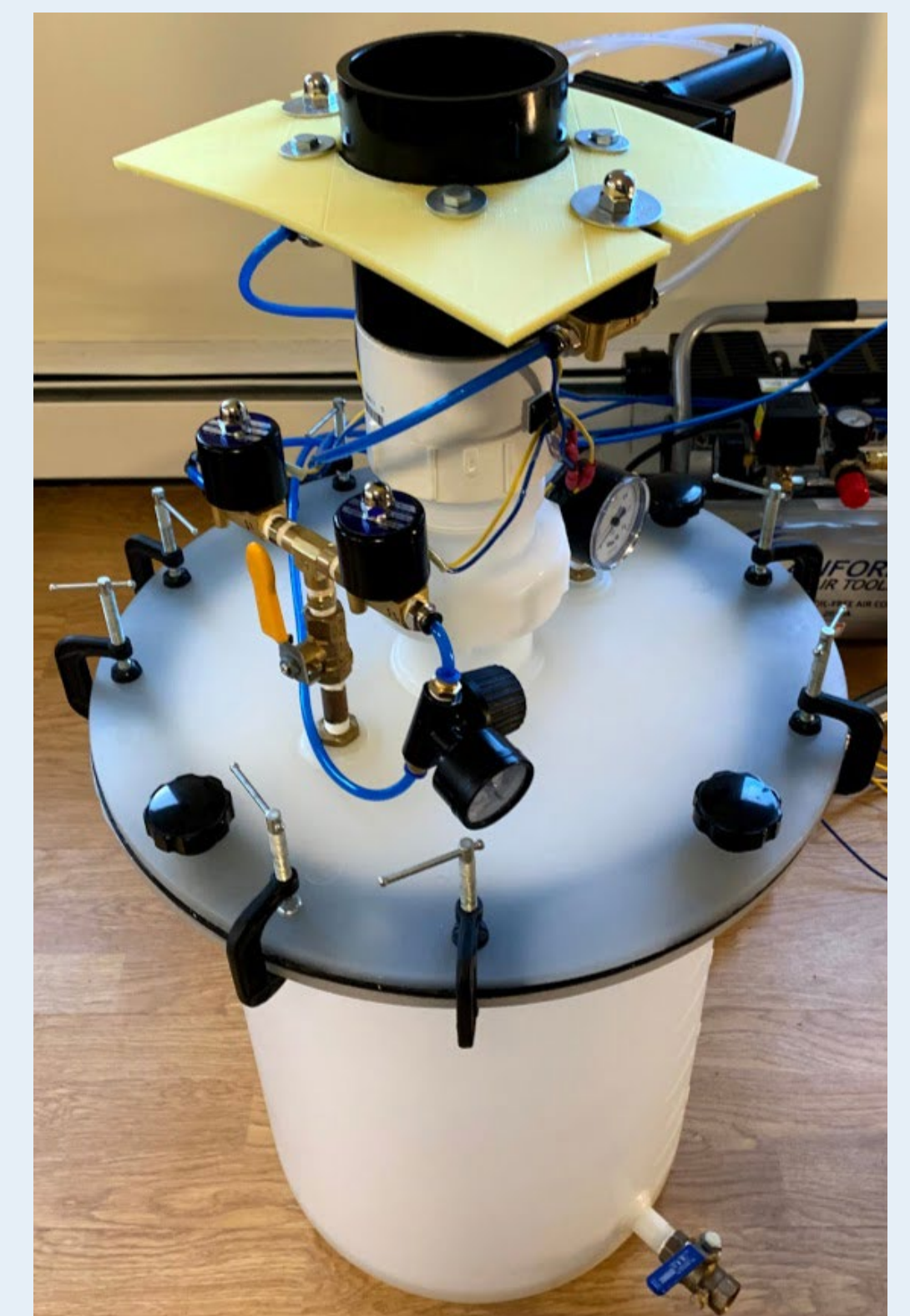


Fig.3 - View of the test apparatus with newly integrated components



Fig.4 - Graphical User Interface



Digital Twin

Digital component replication and predictive maintenance

Team Members: Charles Humphries (CPE), Hennjer Alcantara (CPE), Amy Drake (ELE), Zachary Zezeus (ELE)

Technical Directors: Jefferson T. Wright, Denny Moore

GENERAL DYNAMICS
Electric Boat

PROJECT MOTIVATION

The idea behind the “Digital Twin” is to create a software representation of a physical component that will give insight into the physical component’s reliability due to changing environmental factors. The information provided will be updated in real-time, showing the impact of changing environmental factors on predicted reliability to the user, as well as logging this data so that it can be used to establish a trendline of wear that will be used to determine lifespan. Armed with that information, engineers can use the digital twin to predict the reliability, and maintenance requirements of the physical component, ensuring that the physical component does not break down unexpectedly.

KEY ACCOMPLISHMENTS

Raspberry Pi Dependencies: For the project to properly function, the Raspberry Pi required proper installation of dependencies such as Python libraries, virtual environments, GUI dependencies and proper GPIO and database libraries to connect sensors and database necessities.

Water Pump Assembly: The “Water Pump Assembly” includes the pump, associated piping, and the water reservoir. The pump has been located at ground level for maximum effectiveness, and PVC piping was installed to connect the pump to the water reservoir. The PVC piping is installed to prevent water from draining out of the reservoir in the event of a pump failure, so that the system is passively safe. Shown in **Fig 4**.

Sensor Installation and Testing: The following sensors were installed on the water pump setup: DHT-11 Temperature and Humidity, 2 MPU Gy-512 Accelerometer Gyroscopic Modules with a built-in AD converter, GR-105 water flow sensor with a flow range of 5-150L/min, and a waterproof temperature sensor. The location of each sensor is shown in **Fig. 3**.

Data analysis: Proper installation of sensors led to testing data and realizing average operational datasets. Within the process of experimentation, the project can analyze data live, from data inserted previously into the database, or from randomly generated data that simulates that of a operational water pump.

Database Created and IoT: Remotely accessible database created utilizing PostgreSQL and EleplantSQL. This utilizes the AWS service and data queries such as SELECT and INSERT can be created with the use of Python with proper library dependencies installed (psycopg2). This completes our software design backend shown in **Fig 1**.

Live Analysis Tool: Successfully created a Python code to detect sensor data and present operational temperature, humidity, and water flow rates to the user. The analysis tool also alerts the user if specific thresholds are reached that portray a failing, or soon-to-be failing water pump. This is mainly successful through manual data analysis and inserting manual data thresholds based on time increments of data readings.

Data Prediction: Through the use of Python libraries included within Jupyter Notebook, we were able to predict the outcome of some data values - namely our temperature. We were able to calculate the mean and standard deviation of the temperature readings from our DHT-11 temperature sensor, however we noticed a flaw within our data readings. Our data reflects the powering on and off of the Raspberry Pi - there are major fluctuations within data readings that clearly indicate when the Raspberry Pi has shut down. Calculations include all data, which causes inaccuracy within predictions.

Graphical User Interface(GUI): A GUI is provided so the user can view the current, historical and predicted status of the hardware. A good GUI makes the entire system more user friendly and allows detailed information (such both past and predicted trends) to be cleanly and accurately conveyed to the user so that it can be appreciated at a glance.

Fail Testing: In order to develop an accurate model of the pump’s performance under a variety of circumstances and due to several variables, the pump needed to be tested as it proceeded to the point of failure. Data would then be gathered on the pump’s performance and the conditions that drove it to fail, to develop an accurate model of the pump’s durability under those conditions.

Documentation: The project is backed with an ample amount of data to easily view, duplicate, and follow for future project development in order to successfully achieve the ABO. Good technical documentation is vital to ensure that a project can be well understood by entire teams, repeated as necessary, and optimized and improved on over the course of its existence.

ANTICIPATED BEST OUTCOME

The ABO of this project is a digital twin prototype that can monitor the state of a given physical component and use the gathered information to mirror that component in software. This digital twin will be able to monitor and predict the state of the physical system based on the impact of various environmental factors and present that information to human operators. The system will present the information to the user in an easy to read graphical user interface (GUI), which will display current status, historical trends, and predicted reliability based on extrapolation of that information.

PROJECT OUTCOME

The Anticipated Best Outcome was not yet achieved. We have acquired a large amount of data and tested it against our data prediction algorithm, but a new dataset may be necessary for greater accuracy in data prediction.

FIGURES

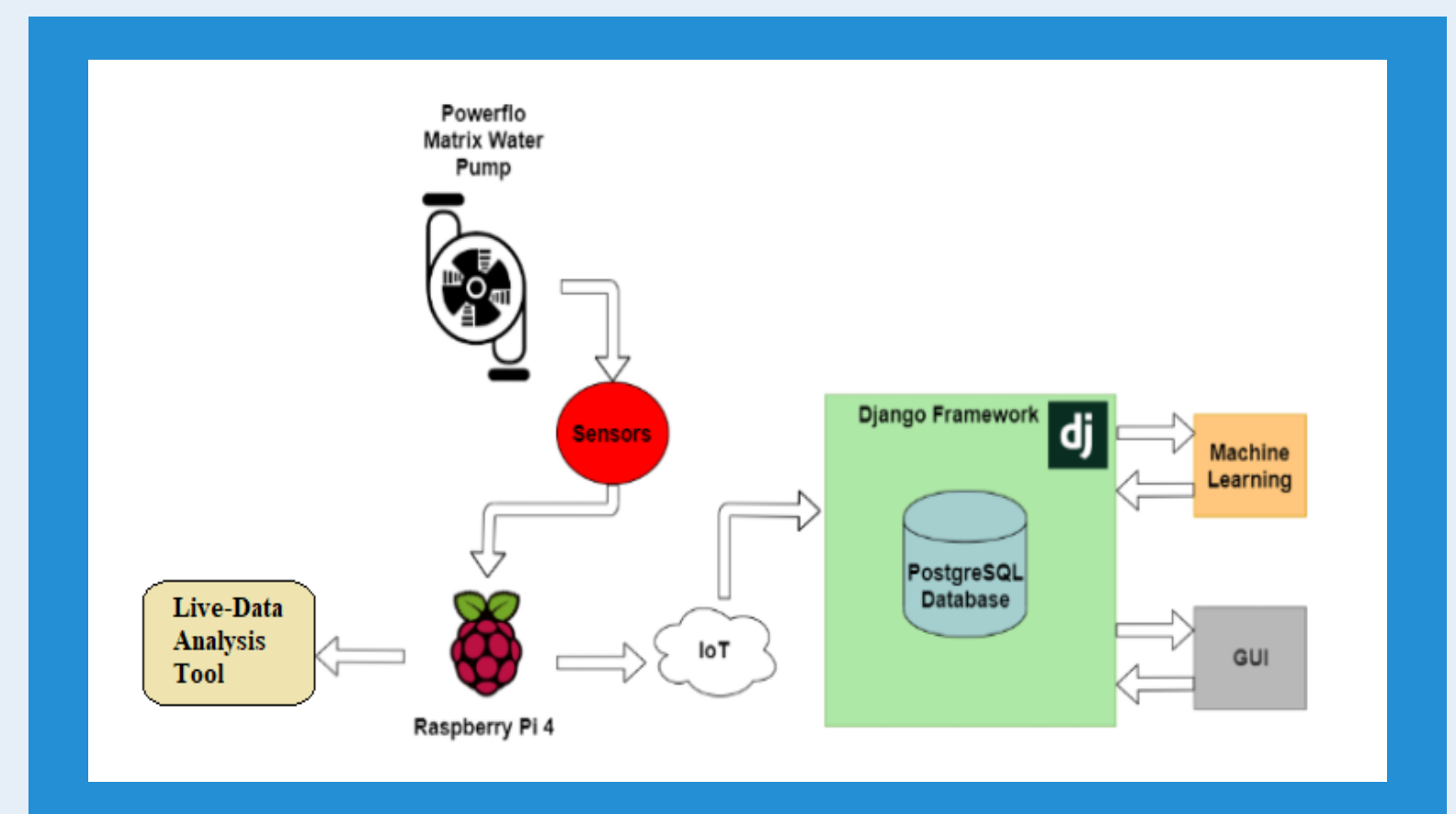


Fig 1: System Block Diagram



Fig 2: Water Pump Setup

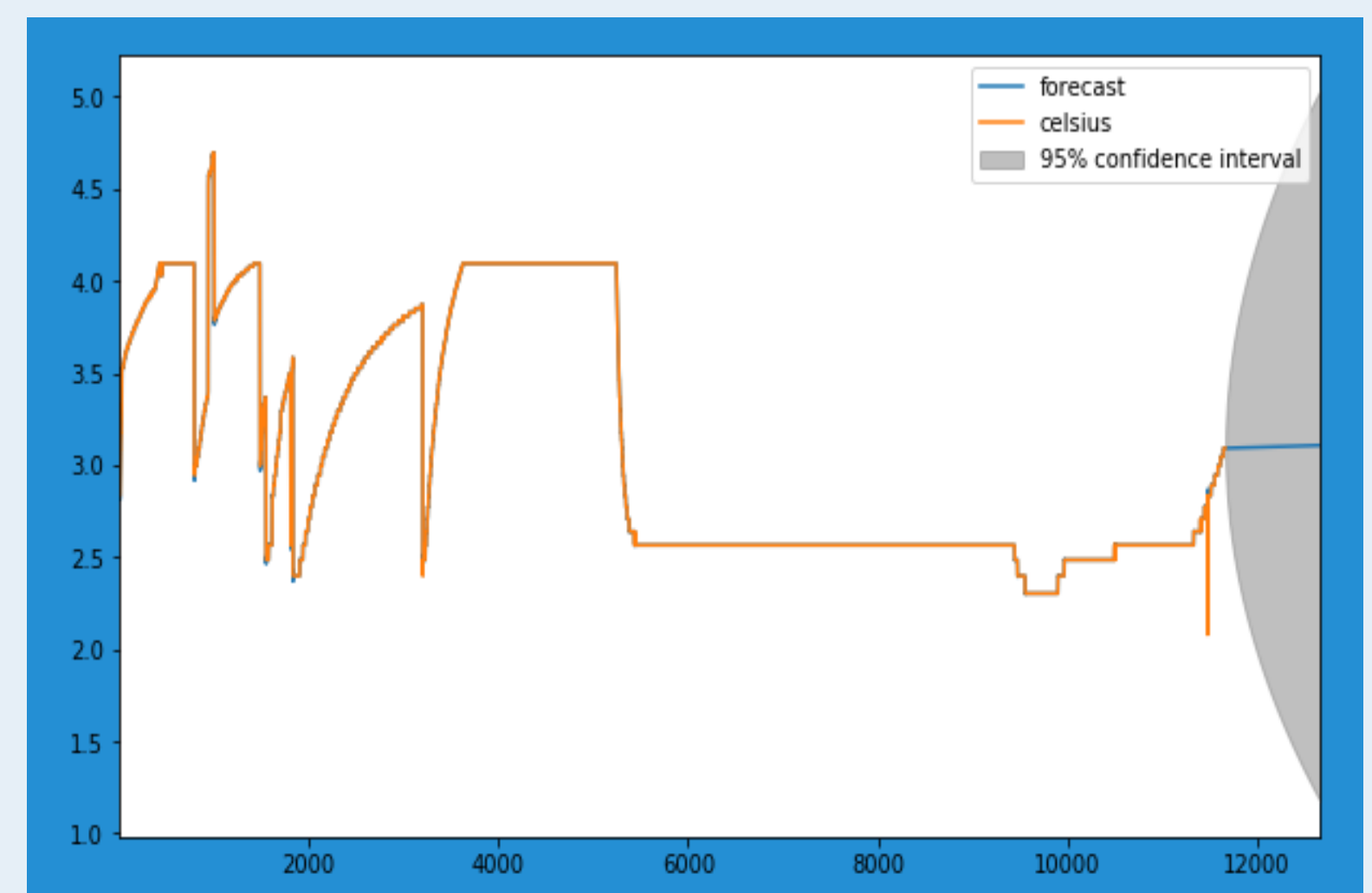


Fig 3: Data Prediction



Part Identification and Post-Processing Using a Collaborative Robot

Team Members: Luke Watkins (CPE), Long Zou (ELE)



Technical Directors: Mr. Jonathan O'Hare and Dr. Manbir Singh Sodhi

PROJECT MOTIVATION

One of the rapidly growing areas in manufacturing is automation. Companies today need to be globally competitive and thus must be able to justify highly skilled labor through the efficiency of their operation. To this end, collaborative robots (COBOTs) as well as other automated machinery, must be effectively integrated into each production process and work as independently of human intervention as possible. One such production process in virtually every manufacturing operation is the inspection or measurement process. Coordinate measuring machines (CMMs) have long been used to assist in providing critical measurement data to provide the necessary feedback to control all the other processes responsible for producing the product. Although CMMs are already computer automated and somewhat intelligent in their own operation, they still often rely on human operators to make decisions to prepare parts for inspection as well as analyze the results for corrective action. Hence, we will implement a vision system in our design which consists of Raspberry Pi camera and trained Machine Learning model. Altogether, they serve as an intelligent vision system that will automate the inspection process, and ultimately improve this arduous procedure.

KEY ACCOMPLISHMENTS

Research and Project Planning

Much of the beginning of the project involved research into what would be the best approach to tackling a series of different problems. Topics included Background Detection with Object Segmentation, Object Classification and Instance Segmentation, Object Orientation Detection, generating data for training and testing using real and simulated objects and images, and research into hardware components.

Initial Hardware Component Selection

A crucial part of the hardware component for this project is a high-quality that is capable of capturing clear image data, and allows object recognition system to locate, identify, and recognize the object in the image. Initial research for types of cameras includes Time of Flight (ToF) 3D cameras, embedded vision cameras, and 2D industrial cameras. Due to the usability and effectiveness in actual implementation, we decided to use Raspberry Pi Camera in our design.

Edge Detection In Images

An essential step in our design is to obtain an image of the drawer and be able to determine if one or more objects are present. The methods used attempt to distinguish the object by recognizing the edges which bound it. This process is tested on images of different objects under different lighting conditions and with different orientations of the viewpoint to determine reliability. From this information, we can also generate the appropriate outputs and labeling for each generated image, including object bounding box and mask information, which can be used to help classify the object. For this task, multiple algorithms were tested on a large subset of images to determine which was the most effective.

Foreground/Background Segmentation

Creating a script that given an image can return a bitmask of the same dimensions labeling the foreground and background of the image. This also aids in object segmentation as non-overlapping objects in an image will be separate and distinct in the scene. These objects can then be passed separately into the model for classification.

Build an Adaptive Linux Testing Environment

Examined the performance of the current testing system and research alternative methodologies to benchmark the performance against the current testing system; built a Linux testing system using a raspberry pi and multiple high-quality programmable cameras; developed an algorithm that would automatically capture image data within a given time; compared and contrasted the quality of image data of different testing systems.

Image Data Processing

Improved background mask performance and implementing multi-object segmentation; created single image slices and properly formatted them to be input into ML models; researched different methods to generate a mask for objects directly on the Linux system.

Integrating Hardware and Software

Built a script to generate JSON object using the model output to be sent to COBOT; researched methods to establish a connection between local Linux system and cloud drive, store large sets of image data onto a cloud drive; developed a method to combine all components together as a final prototype.

ANTICIPATED BEST OUTCOME

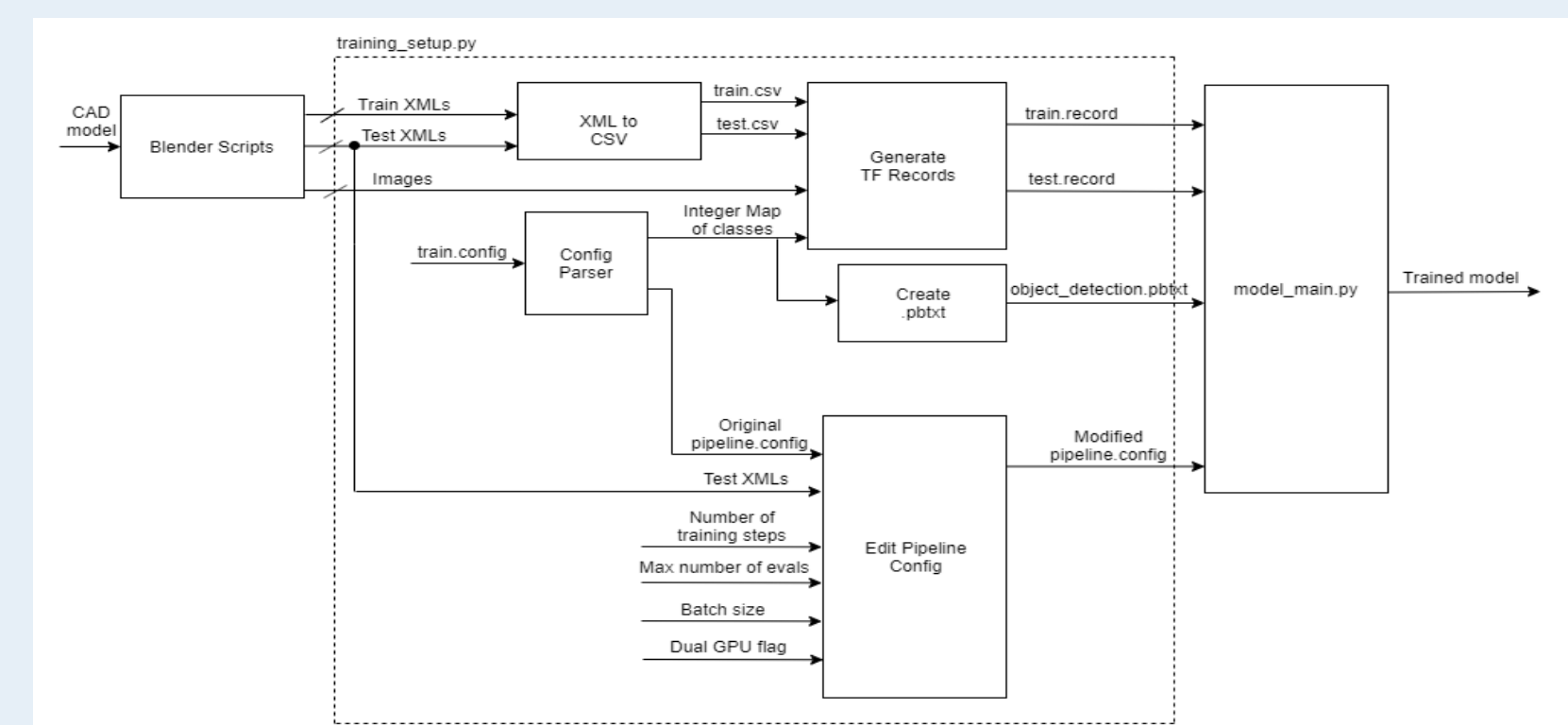
- A part recognition method that is reliable and fast enough for the inspection process, easy to teach for new parts and able to be easily integrated with existing hardware.
- The integration of the part recognition method must also be demonstrated to handle the various error conditions previously described which are typical for the inspection process.

PROJECT OUTCOME

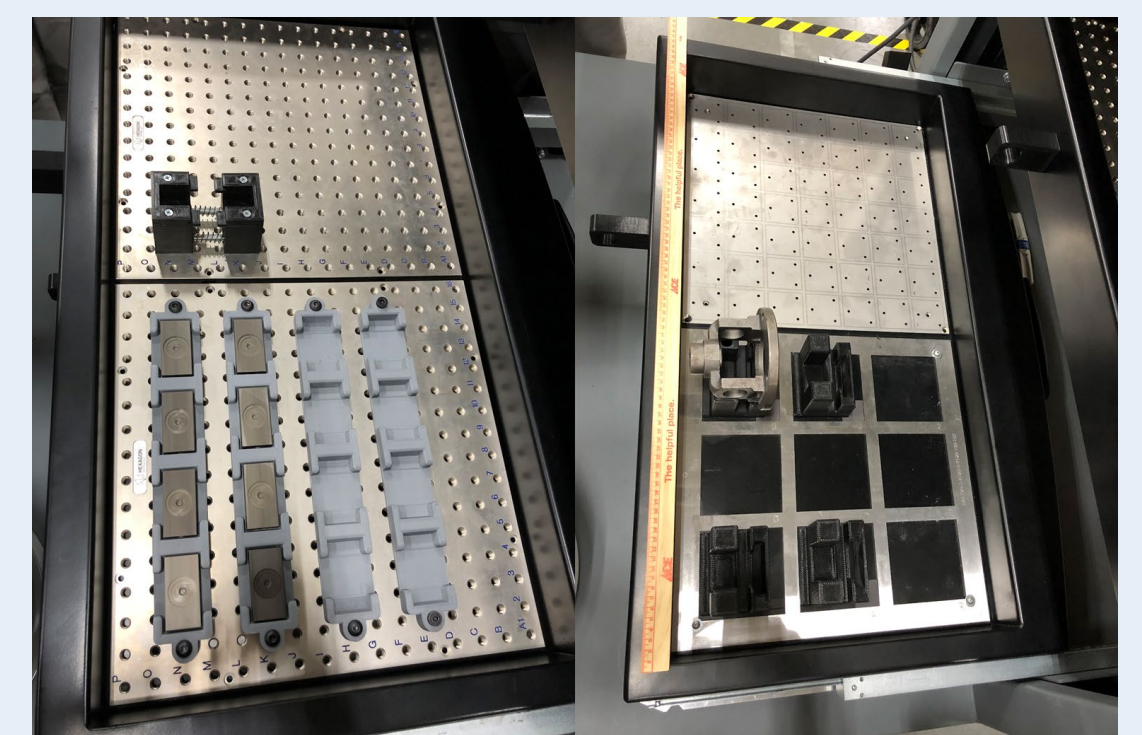
The Anticipated Best Outcome was achieved.

The trained Machine Learning model is capable of identifying the correct objects on an average above 95% of the time.

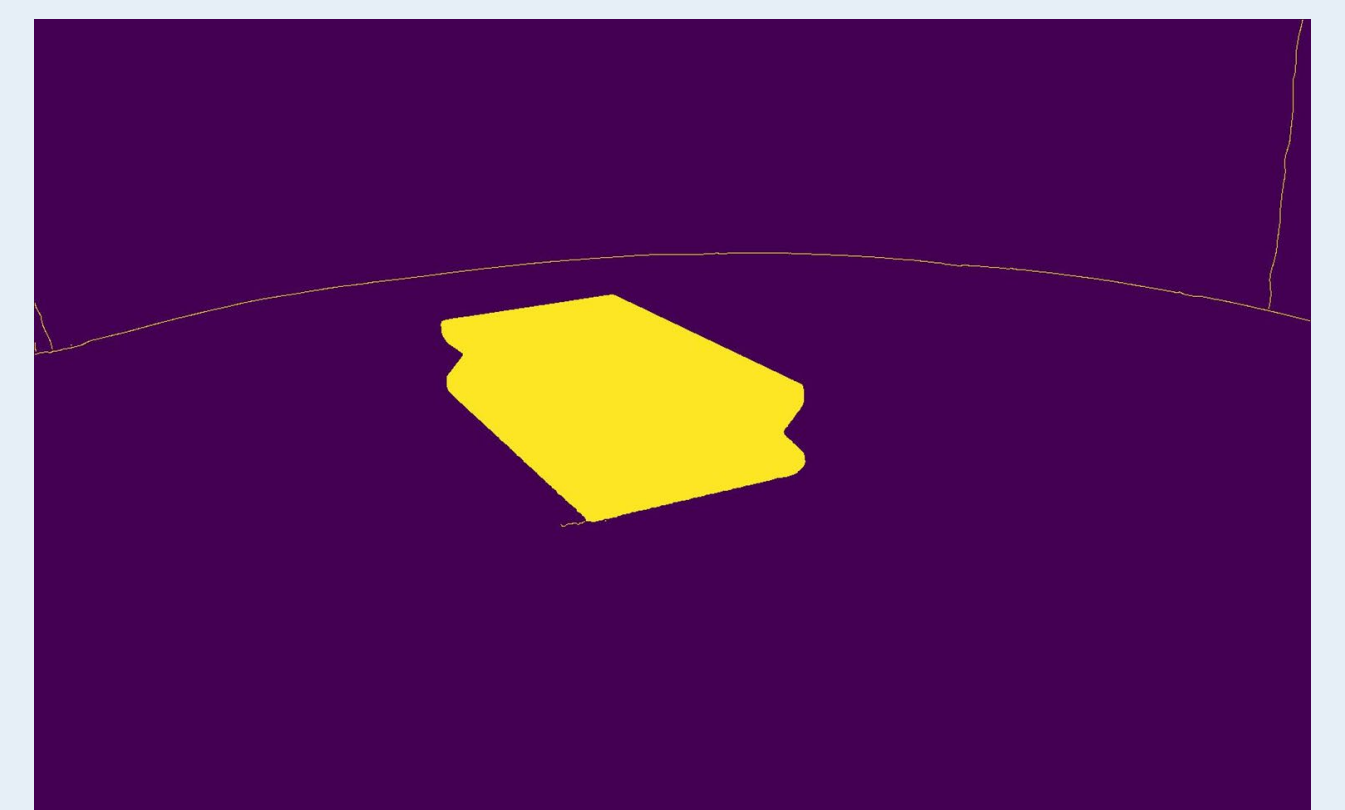
FIGURES



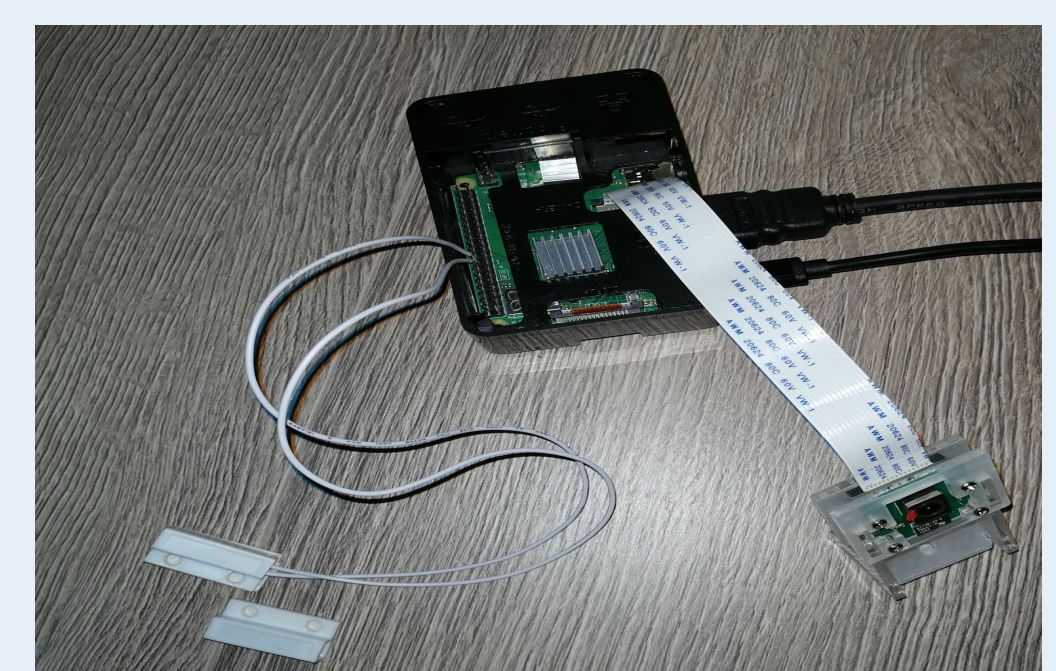
Flowchart Detailing Training Process for ResNet Model



Two Sample Drawer Layouts



Example Part After object detection





TouchPoint Companions

Modeling Digital Twins



Team Members: Sean Creamer (CPE), Ryan Hultquist (ELE), David Delgado (ELE)

Technical Directors: Robert Corvese, Raymond Leland

PROJECT MOTIVATION

TouchPoint terminals are lottery-based devices that process online wagers. These devices range from point of sales devices to self-service devices. These devices typically stay deployed in the field for many years and need to be serviced in order to keep them running for the duration of a contract. The motivation behind this project is to create a functional digital twin of a TouchPoint terminal device. This will allow IGT to collect live telemetry from the physical TouchPoint terminal devices in the field and have the ability to proactively fix devices that exhibit slight abnormalities in the data before they stop functioning completely. Devices that are down cost IGT not only in missed ticket sales but also in having to pay the contractee out for the time the device was down. Being able to predict when a device will fail and fixing it before it does will result in major savings.

KEY ACCOMPLISHMENTS

Design and Build of Interface Box

We put together what we as a team are referring to as an "interface box" which will house the majority of the sensor components used for collecting telemetry off of the terminal, as well as the Arduino microcontroller for handling all of the data. The interface box also contains a standard NEMA wall-plug power connector that can be used to plug in the terminal itself.

Improve Vibration Sensing Performance

At the conclusion of the fall semester (post-symposium) it was decided that the current way we were measuring vibrations on the device would be inadequate for the kind of data we were looking to collect. Due to its size, and possible mounting positions, the previous sensor was not able to collect significant data on the amplitude of the vibrations when the terminal was running. It was replaced with sensors that can mount flat on the gearbox of the terminal which allows us to get the most accurate reading possible of the vibrations in the terminal.

Connected the MQTT broker on the terminal to the broker on AWS

The local MQTT broker on the terminal was originally being used to collect all the telemetry on the terminal. To create a digital twin, we needed to find a way to bridge the connection from the local broker to the MQTT broker on the AWS side. After this was completed, any data that was getting posted locally is now not only inside the local MQTT broker but is also forwarded to the broker on the AWS side for the digital twin.

Proof of Concept

At inception, the base assumption for this project was that the play-slip reader would draw more current when its rollers were clean versus when they were dirty. For the first semester we simulated this by using multiple play slips to mimic more resistance in the reader. While this was a simple solution it was not ideal. For this semester, we obtained a second play-slip reader in which dirty rollers were installed. After testing both the clean and dirty readers with identical play slips we found that our initial hypothesis was indeed proven true and the dirty reader did draw more current. See figure 2 for more details.

High Level Document

For this project, we put together a high-level document. One thing IGT wants to do is build upon our progress. The document is sufficient enough to transfer knowledge of everything one needs to know about the project to keep working on it. It contains information of everyone associated with the project, risks, constraints, every piece of hardware used, software documentation, etc.

Schematics

Along the entirety of the project, we have had to make schematics. Just like how we made progress and changes to the project, we also had to make changes to these schematics. These schematics make it easier to see what you need to do and following them ensures you do not make mistakes. We made tons of schematics and flow charts for both the hardware and software sides. The hardware ones to help us wire all the sensors together and the software ones so that we knew how everything needed to flow. One very important schematic was the wiring of the whole project. This goes back to how documentation and schematics are important because this diagram was so detailed that someone outside of the project was able to help and make connectors for us. All he had to do was follow the diagram and he knew exactly what we needed.

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome is a functional prototype of a digital twin TouchPoint device by the completion of the ELECOMP Capstone program in May 2020. The prototype device will make use of the telemetry that is currently collected from the TouchPoint terminals and additional sensors to show a true representation of a digital twin.

Ideally the digital twin will be able to interface with a predictive maintenance engine. The predictive maintenance engine will then be able to use the gathered telemetry to anticipate a failure and solve the problems outlined in the Project Motivation.

PROJECT OUTCOME

The Anticipated Best Outcome was not achieved.

The device is very near completion for a future team to work on.

FIGURES

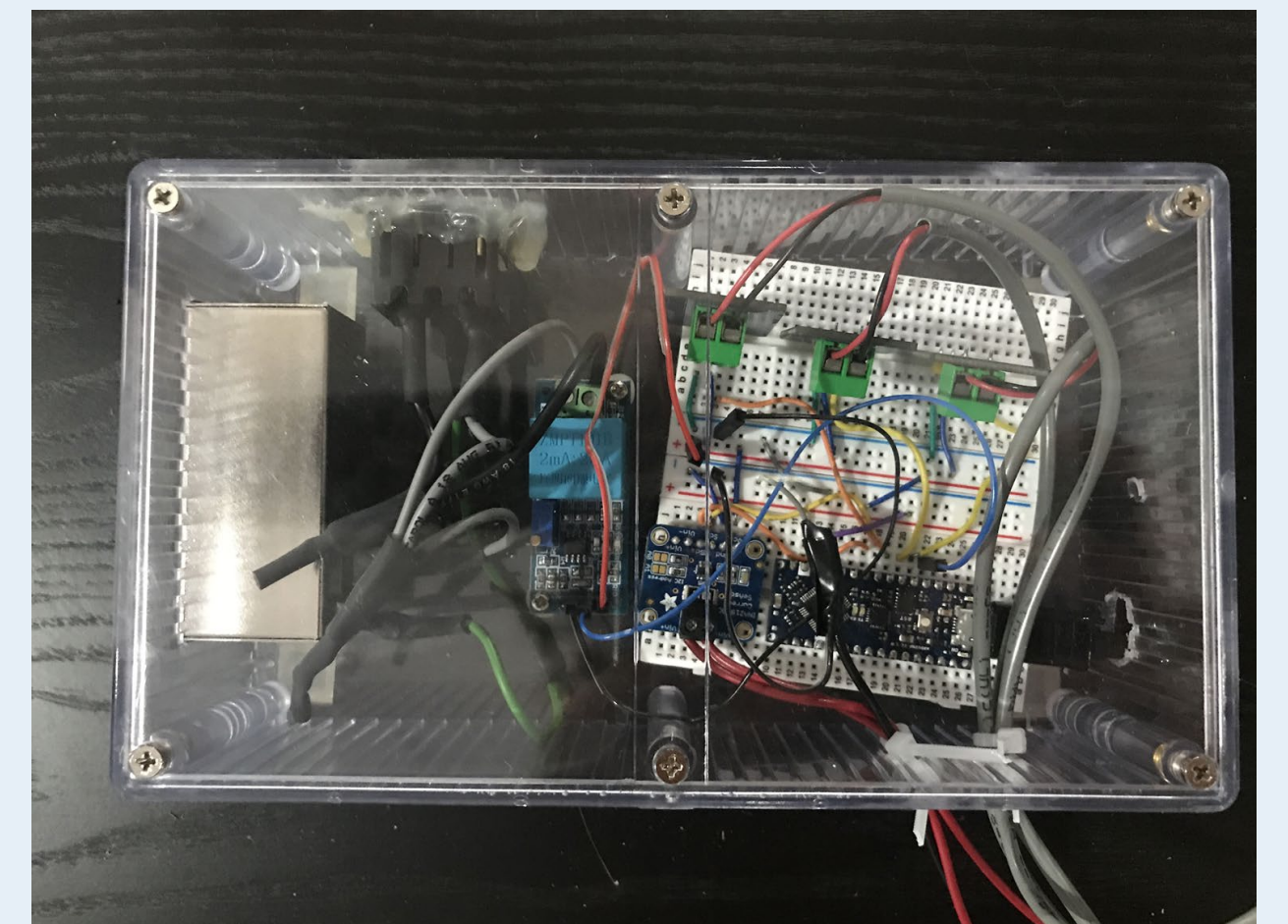


Fig 1: Image of interface box with internal components.

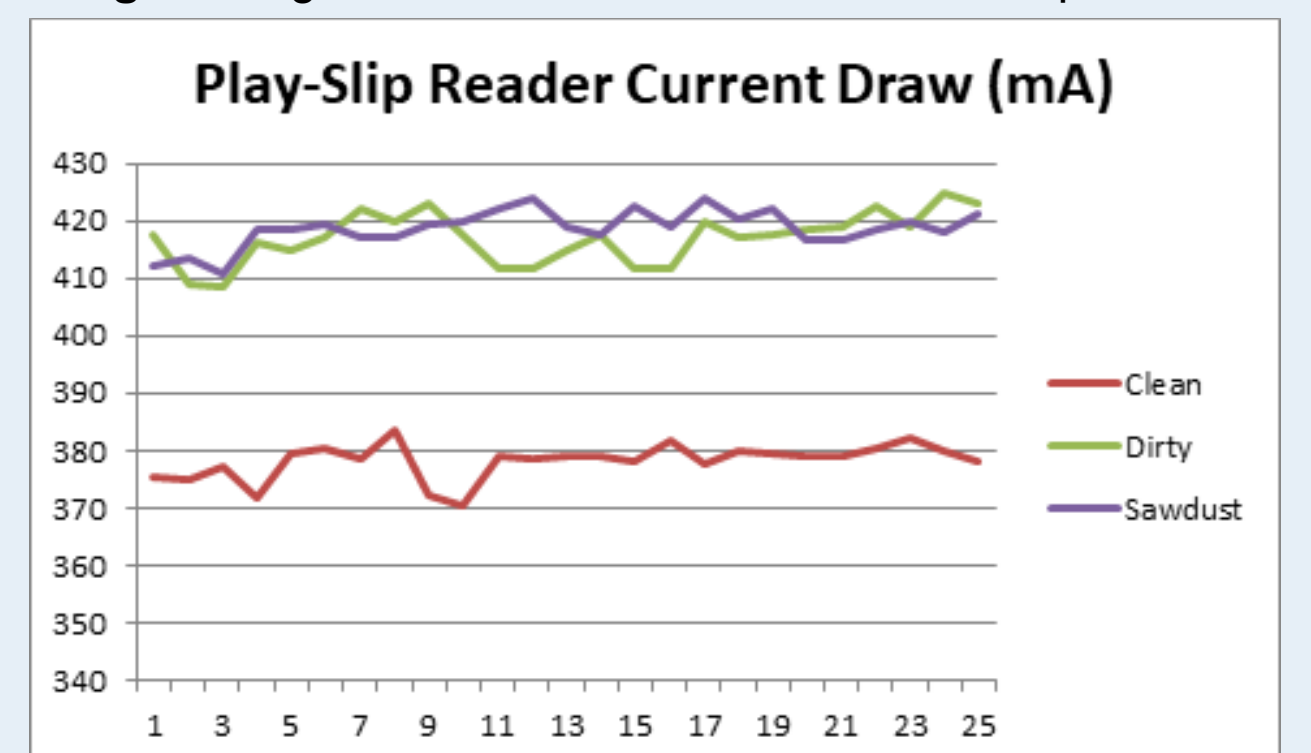


Fig 2: Current draw of play-slip reader when clean, dirty, and dirtied with sawdust.

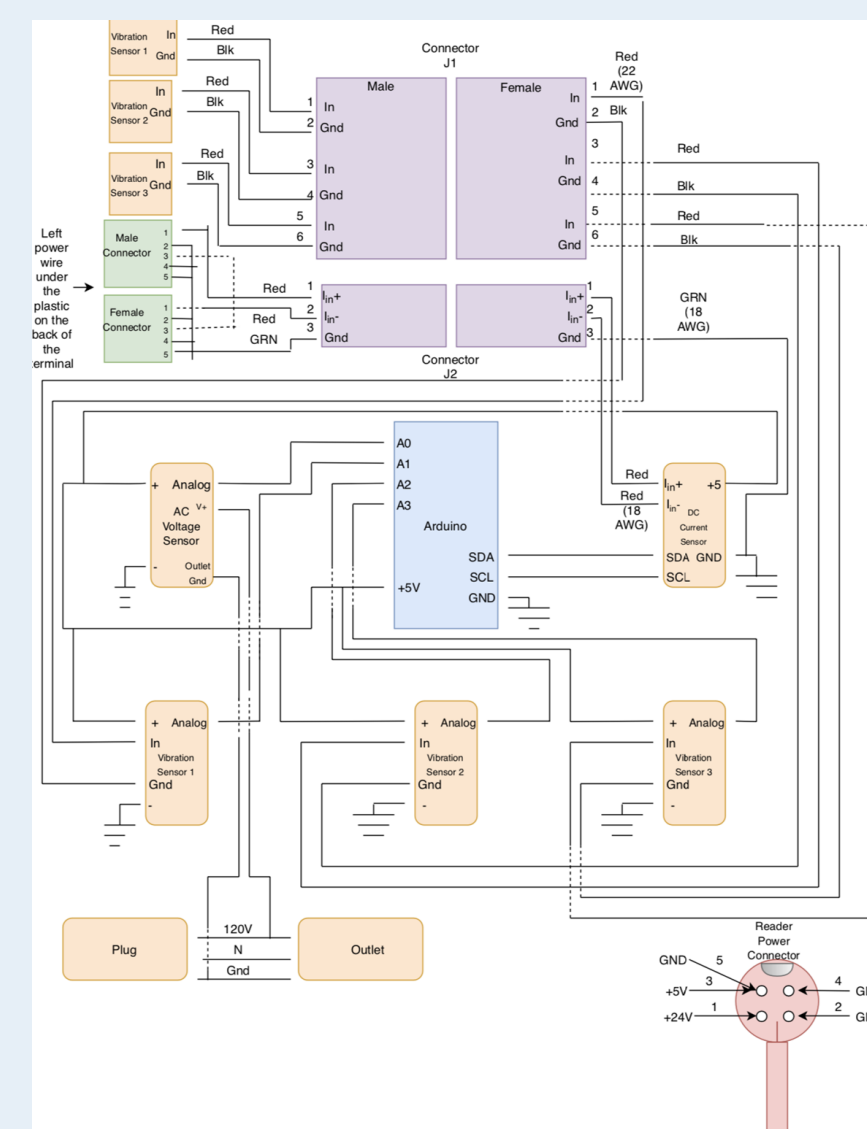


Fig 3: Schematic/wiring diagram of all components used to collect telemetry.

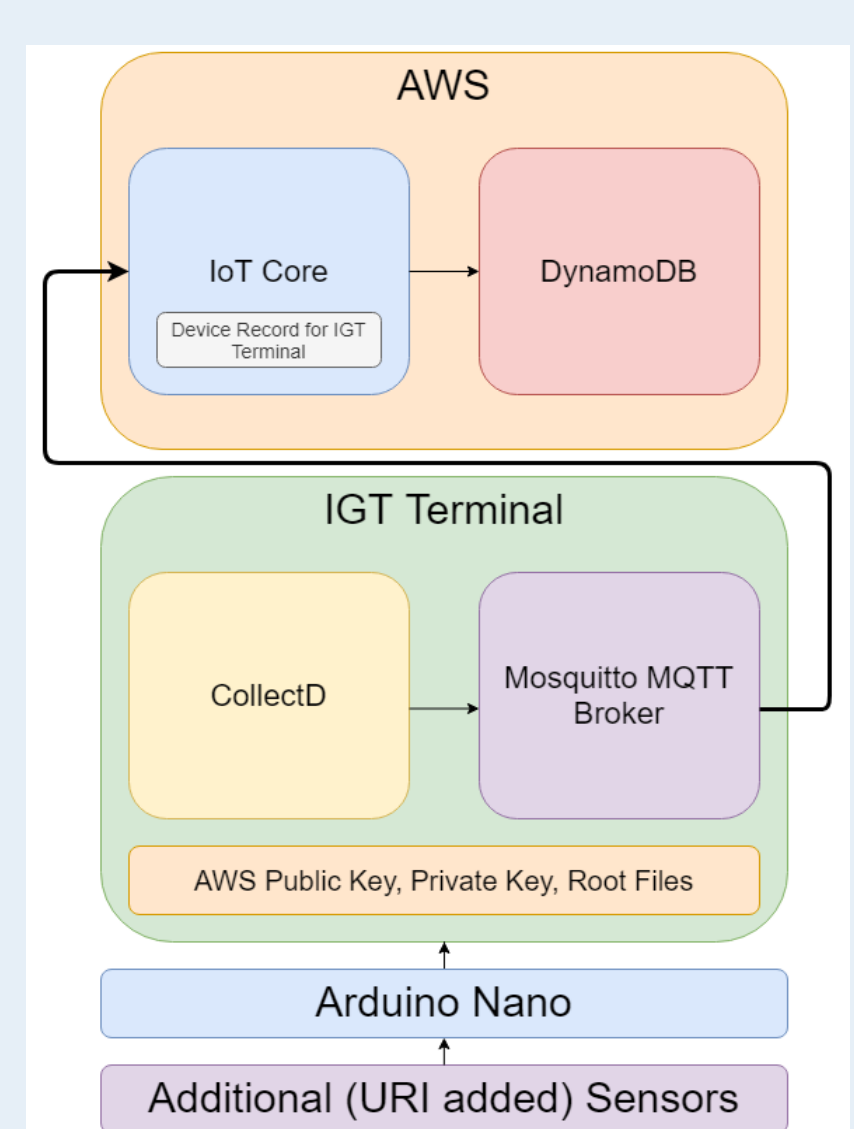


Figure 4: Depicts flow of data when it is collected by the sensors to the point it reaches Amazon Web Services.



Optocheck

Automated Optical Inspection of Laser Components

Team Members: Katherine Alberg (ELE), Bryce Goode (ELE), Joseph Morris (CPE)

Technical Director: Dr. Michael Mielke | Consulting Technical Director: Jeremy Peacock



PROJECT MOTIVATION

In a laser, mirrors are positioned on opposite ends of an energized medium in order to form a laser resonator that is capable of producing a beam of light. The mirrors are vital to the function of the laser, and both must be within specified design dimensions to achieve optimal laser light performance. If the mirror dimensions are not correct, then the performance of the laser as a whole will suffer. Additionally, the mirror surfaces cannot be touched in any way or they could be damaged, since imperfections in the mirror surfaces could gravely impact the performance of the laser, which would lead to a financial loss for Iradion. In order to make sure the cost of laser production is kept at a minimum for Iradion, they need a way to quickly and accurately check the dimensions of each mirror assembly, which can be done with an in-process inspection station that can evaluate the mirror assemblies both quickly and with no contact.

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome of this project was to use a camera system and a linear stage to create a table top optical inspection station that can provide Iradion employees with a way to check if their mirror assemblies meet mechanical design criteria. The system would compare the scanned data to the mechanical model of the mirror assembly, and provide a pass or fail indicator to show if the mirror assembly meets the desired criteria. An error report would be generated if the part fails, in order to provide the user with information on the dimensions and measurements that fall outside of the thresholds.

KEY ACCOMPLISHMENTS

- 3D Scanner:** No amount of research could identify which 3D scanner would be the best within our budget. The message from the companies we have contacted has been clear: it is not easy or even possible to scan a reflective surface without using a spray or powder. For our project, we cannot make any contact with the mirror assembly, shown in Fig. 1, let alone cover it with a spray or powder. The scanners that could work without a spray or powder were far outside our budget.
- Software and GUI:** After speaking with Phil Chin, he persuaded us to use C# in our programming, as that is what is used in Iradion's software. A Graphical User Interface, or GUI, shown in Fig. 2, was created for this project. It can take data from a scan, compare them with the expected values, and display a pass or fail indicator. Additional tabs were added to show more information about the scan. The software has been adapted to automatically move the camera with the stepper motors, and trigger the camera.
- Camera System:** Our Camera System consists of the ThorLabs CS505MU camera, along with the ThorLabs MVL50TM23 lens, as shown in Fig. 4. This is then connected via Micro USB B to USB 3.0 A cable to the PC. This camera system is controlled entirely via our custom software. Used the spec sheet for the camera to determine requirements for a PC.
- CNC Router:** Since the camera system we chose has a field of view smaller than the top surface area of the mirror-sub assembly, we need a moving stage for the camera system to move on to capture the entire top-view of the mirror-sub assembly. We selected BobsCNC E3 CNC Router Kit, shown in Fig. 3, due to its compatibility with Arduino and its relatively small size, which is perfect for a table-top inspection station.
- GRBL, Arduino, and G Code:** Grbl is a highly-functional, open-source software for controlling machine motion. Fortunately, it can be flashed onto an Arduino Uno easily with the CNC Arduino shield that came with the CNC router kit. This shield also has drivers for the stepper motors that came with the kit, so they were meant to work together. Geographic Code, or G Code, is a programming language for motion. It can encompass all three axis, and is simple enough to learn. The Universal G Code Sender is software that can visualize and send G Code to the Grbl-flashed Arduino and control the motors accordingly. It has been proven that through the Universal G Code Sender, or UGS, commands can be given to control the motors. However, it is not needed for this project, as lines of G Code sent through the Arduino Serial Monitor are enough to control the stepper motors. Fortunately, there is a way to communicate with the Arduino Serial Monitor via C#. Additionally, there is also a way to take a text file containing G Code and turn it into an array of strings. With these ideas combined, it was possible to automate the stepper motor control process.
- Image Processing:** Matlab will be used for the image processing side of the project. Matlab has all of the toolboxes necessary to get the measurements we need, and can be easily implemented into our C# code. The image processing and computer vision tool boxes will be used in our application, in order to access certain Matlab functions that will allow us to make measurements, adjust contrast, detect pixels, and much more. Additionally, the camera should be able to export pictures directly into Matlab for processing, which will make the whole process go smoother.

PROJECT OUTCOME

The Anticipated Best Outcome was not achieved. While falling short on image processing, software that is capable of triggering the camera and its movement on the CNC router was successfully designed.

FIGURES

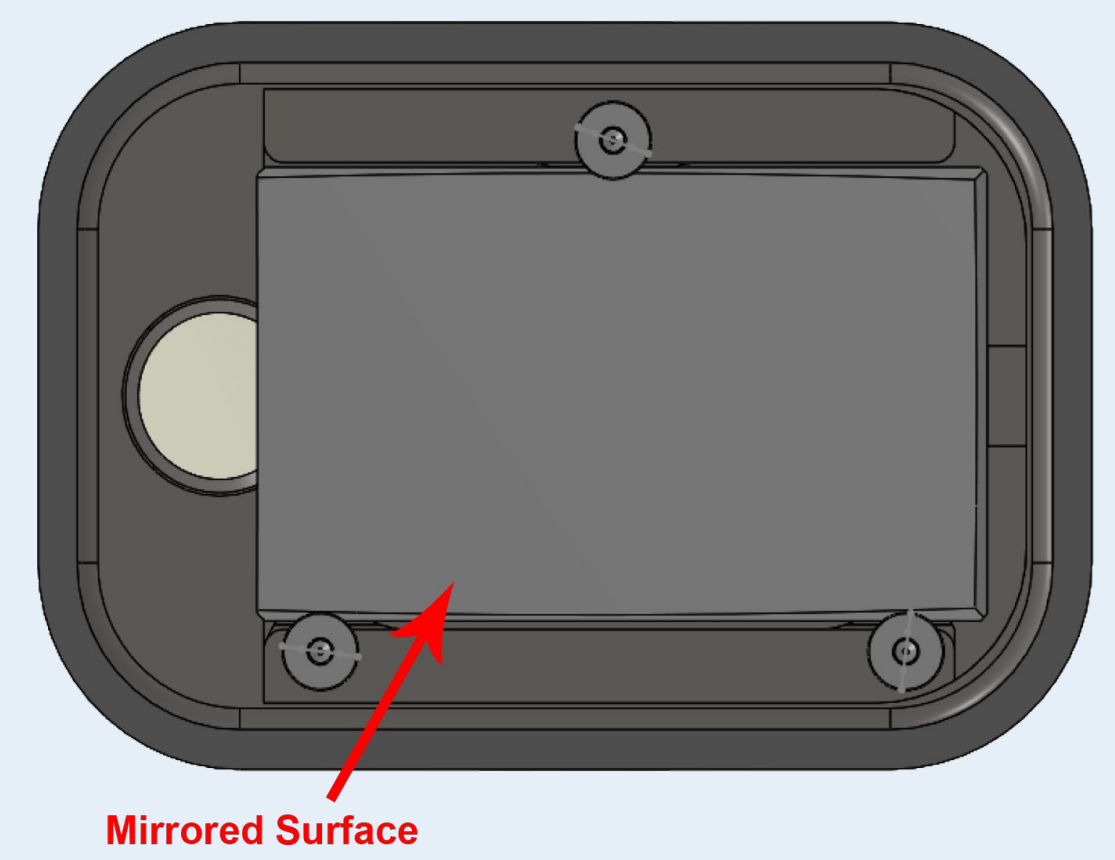


Fig.1: Laser Mirror Subassembly, the part we are trying to analyze

Name	Expected Value	Measured Value	Pass/Fail
Position	>8.83 mm and <8.93 mm	8.86 mm	Pass
Roll	>-1° and <1°	0.45°	Pass
Pitch	>-0.06° and <0.06°	0.07°	Fail
Yaw	>-0.06° and <0.06°	-0.03°	Pass

Fig.2: Graphical User Interface After Scan Has Completed

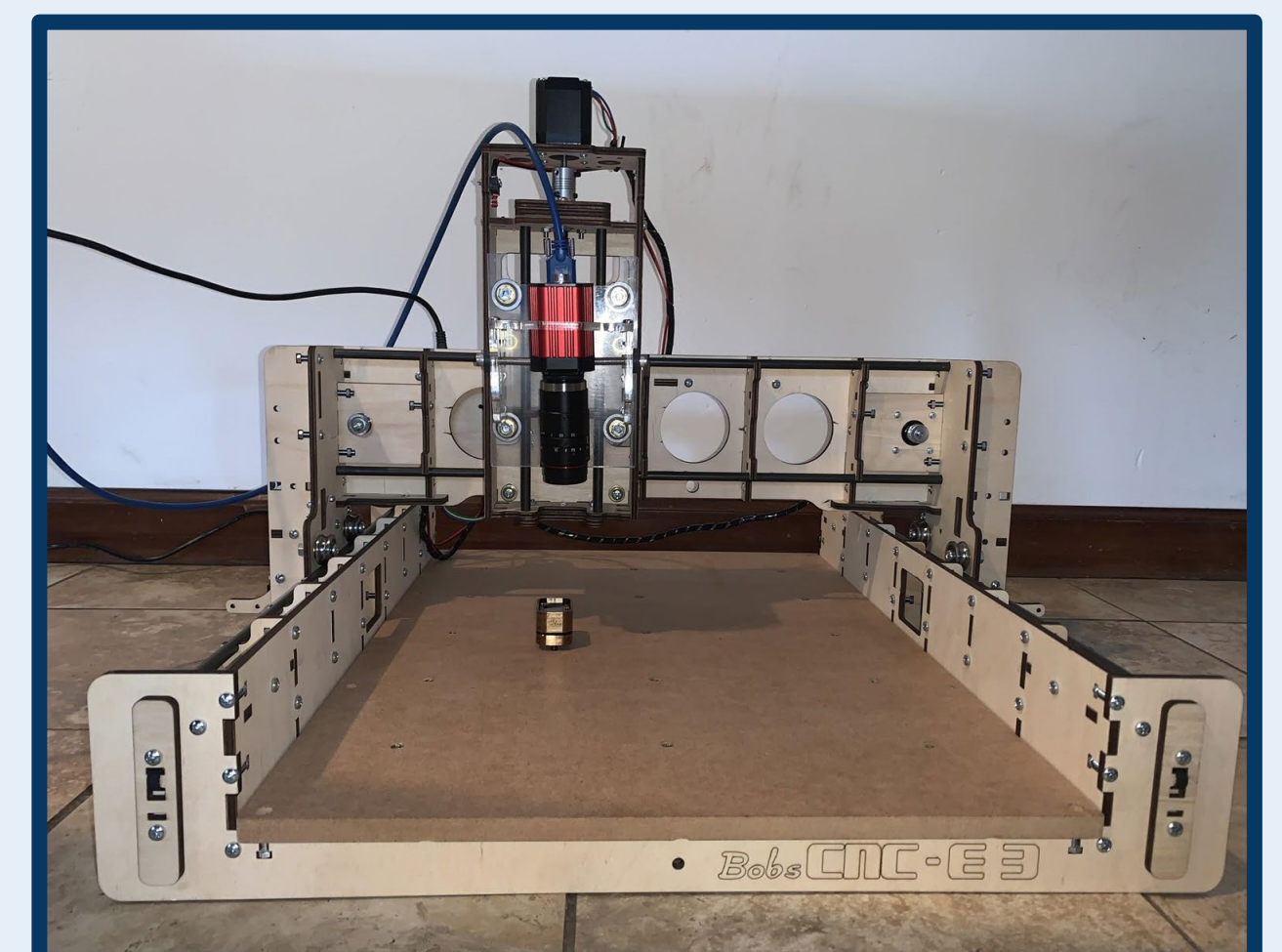


Fig.3: CNC Router Hardware



Fig.4: CS505MU Camera with MVL50TM23 Lens



PODAS

Power Output Driver Automated System for Integrated Circuits over Time

Team Members: Nicholas Amore (ELE), Alex Cressman (CPE), Robert Robinson (ELE), Luke Thoden (CPE)



ON Semiconductor

Technical Directors: Frank Kolanko & Robert Davis

PROJECT MOTIVATION

When a driver integrated circuit with an inductive load is turned off, the system will try to maintain the current using the energy stored in the inductor. Since the driver is turned off, the voltage will begin to change on the output pin. The current created through the inductor with the voltage will create power dissipation in the IC. That power multiplied by time is the Clamping Energy. Drivers have a maximum rating specified for Clamping Energy. Part of testing is taking data in the lab for this parameter. To do this, a circuit is set up with a large inductor and a function generator that controls the pulse width. A pulse is sent, the circuit is excited, and the energy value is recorded. The pulse width is increased, and the subsequent value is recorded. This continues until the device fails. An automated test system is needed to streamline this process.

KEY ACCOMPLISHMENTS

Output Switch: The ICs under test have multiple outputs. In order to fully automate this test, the system needs to be able to test each output individually. Using a relay, each output can be selected without requiring the user to manually change which is under test.

Safety Switch: The IC under test fails in a short. This will force a large current through the system. If left in this state for an extended period of time, it runs the risk of damaging the system. The safety switch acts as a disconnect from the power supply, preventing damage to the system.

Temperature Sensor: As the part is tested, there is more power dissipated with each increasing pulse. This raises the temperature of the part. By using delays between pulses, the overall temperature will continue to increase. This will result in premature failures due to temperature and provide poor data. To address this issue, a temperature sensor is used which takes advantage of thermal characteristics of the body diode to monitor die temperature during the test.

Fail Detection: In order for the system to safely test every output of the device, it must be able to determine when an output has failed, so it can iterate to the next one. By taking advantage of the voltage characteristics of the part when it is being tested, the Arduino can easily monitor outputs to determine whether to continue testing the part or move to the next output.

High-Side Driver Operation: The parts being tested are not only low-side but also high-side drivers. Our system needs to be able to handle the differences between both styles of this part. The fail detection and temperature sensor are the same conceptually, but are implemented differently for high-side. The other features work the same for both high and low-side. All the user must do is push a button to configure the system. This and the previous accomplishments are illustrated in Fig. 1.

PCB Development: The automation system needs supporting hardware in order to function properly. The final board incorporates all the features that have been developed along with supporting circuitry into a sleek design as seen in Fig. 3. The final board had a drastic reduction in size from the prototype allowing for a cleaner workspace.

Pulse Width Control: Automation of varying length pulse widths has been achieved using an Arduino. The user is currently able to adjust initial pulse width, set the increment between pulses, and change max allowable pulse width using push buttons.

OLED Displays: Two OLED Displays show programming and test results. The programming OLED displays initial pulse width, increment amount, and max pulse width. The test results OLED displays test configuration, current pulse width, and test status. Both OLED screens can be seen in Fig. 2.

Oscilloscope Data Extraction: Automated data extraction from the Oscilloscope has been achieved using Oscilloscope built-in autosave feature. This feature collects all the signals displayed on the screen and exports it as a CSV file.

Python Application: To analyze the files saved by the Oscilloscope, the user is provided with a Capstone Flash Drive which contains a Python Application and the necessary folders and libraries required to run it. The application displays the CSV file names and the peak values of that file where the device fails. The GUI displays the maximum current and energy values of the entire test and allows the user to graph any of the CSV files. An example of what the user would see can be found in Fig. 4.

User Manual: The user manual was created to assist anyone looking to run the system. It provides the user with a list of necessary materials required to set up the system, as well as, step by step instructions for setting up both boards, the Oscilloscope and how to use the Python Application.

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome of the project is to take the existing test board and fully automate it to measure the Clamping Energy of a device. The delivered product needs to be a fully developed system that can iterate through every output of an IC, detect failures, monitor temperature, and extract data from the oscilloscope. The data needs to be presented clearly and provide the user rapid feedback. The system should be simple to use, and independent of a PC. The user should be able to walk up to the system and run the relevant tests with no hassle.

PROJECT OUTCOME

The Anticipated Best Outcome was achieved.

We also included several additional key features to improve the function of the automated system.

FIGURES

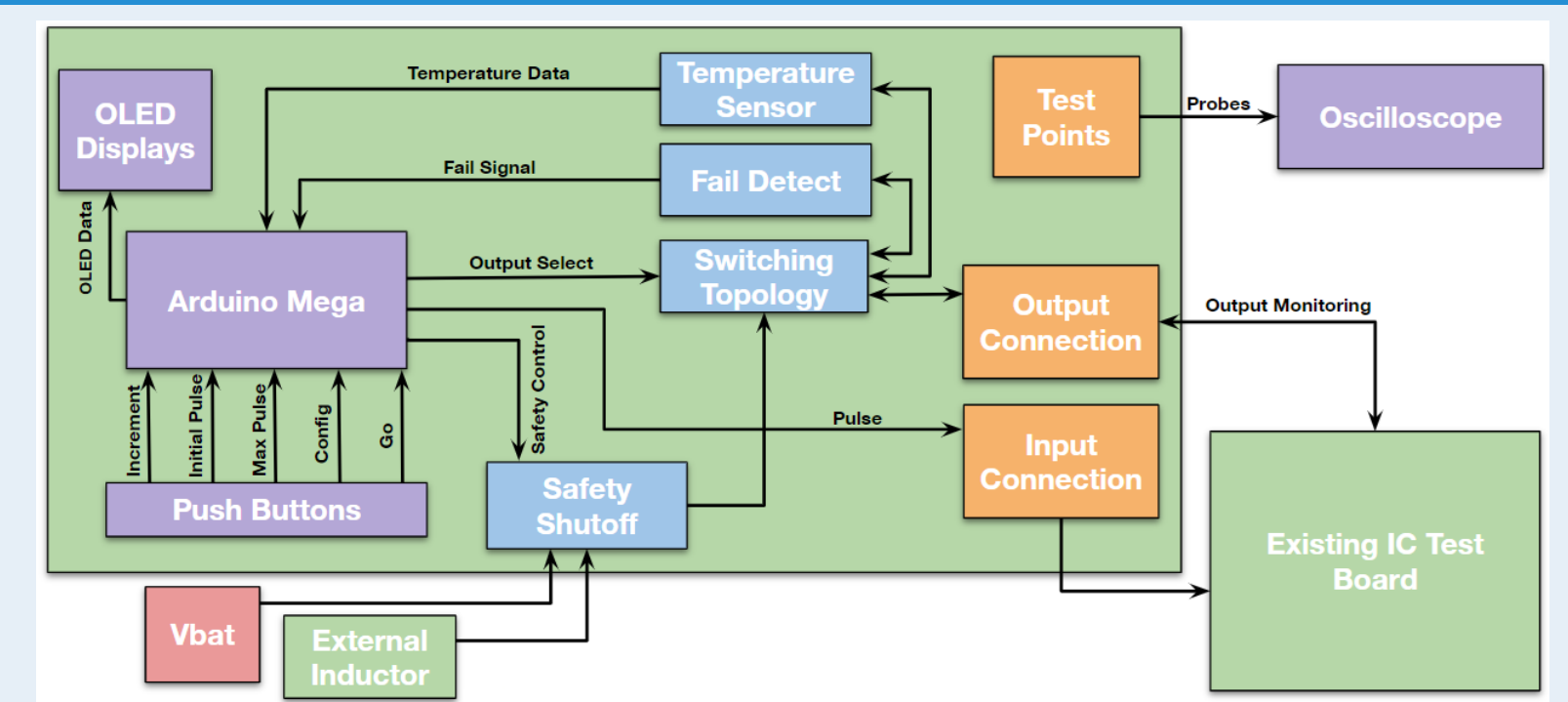


Fig. 1: Block Diagram of PODAS System with all Relevant Features.

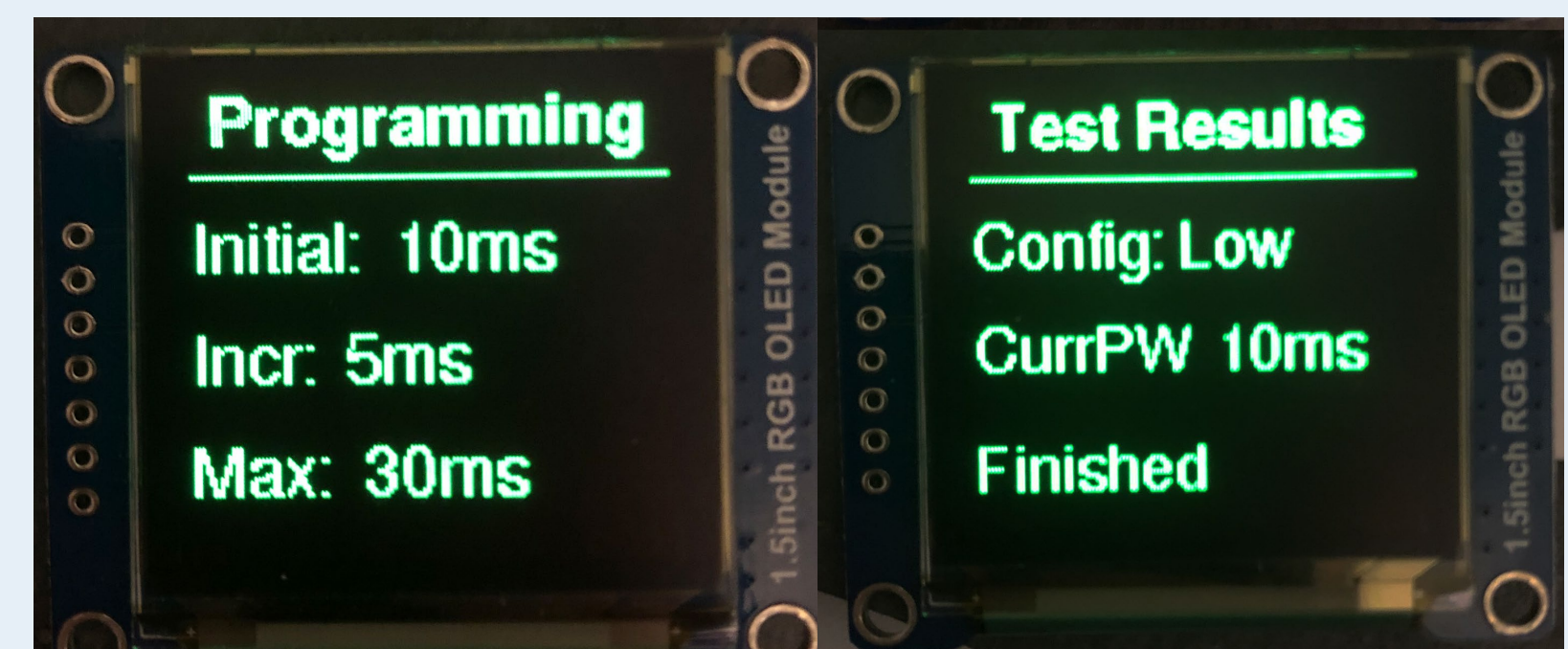


Fig. 2: OLEDs Displaying Input and Output Information.

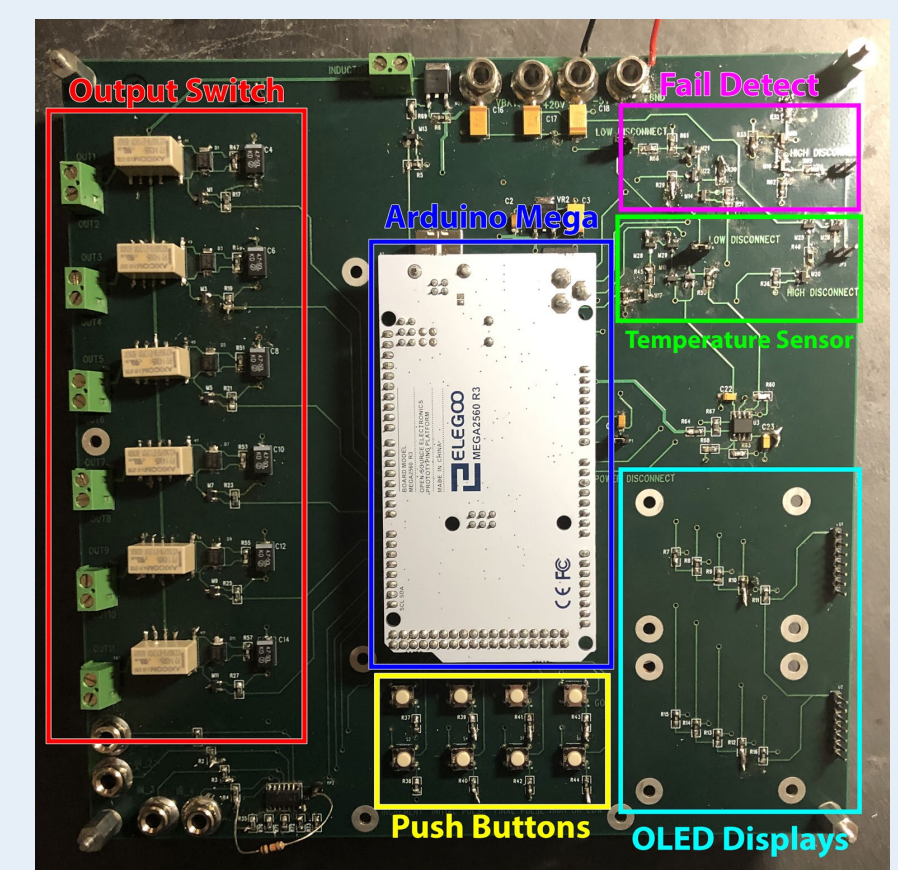


Fig. 3: Fully Assembled Final PCB.

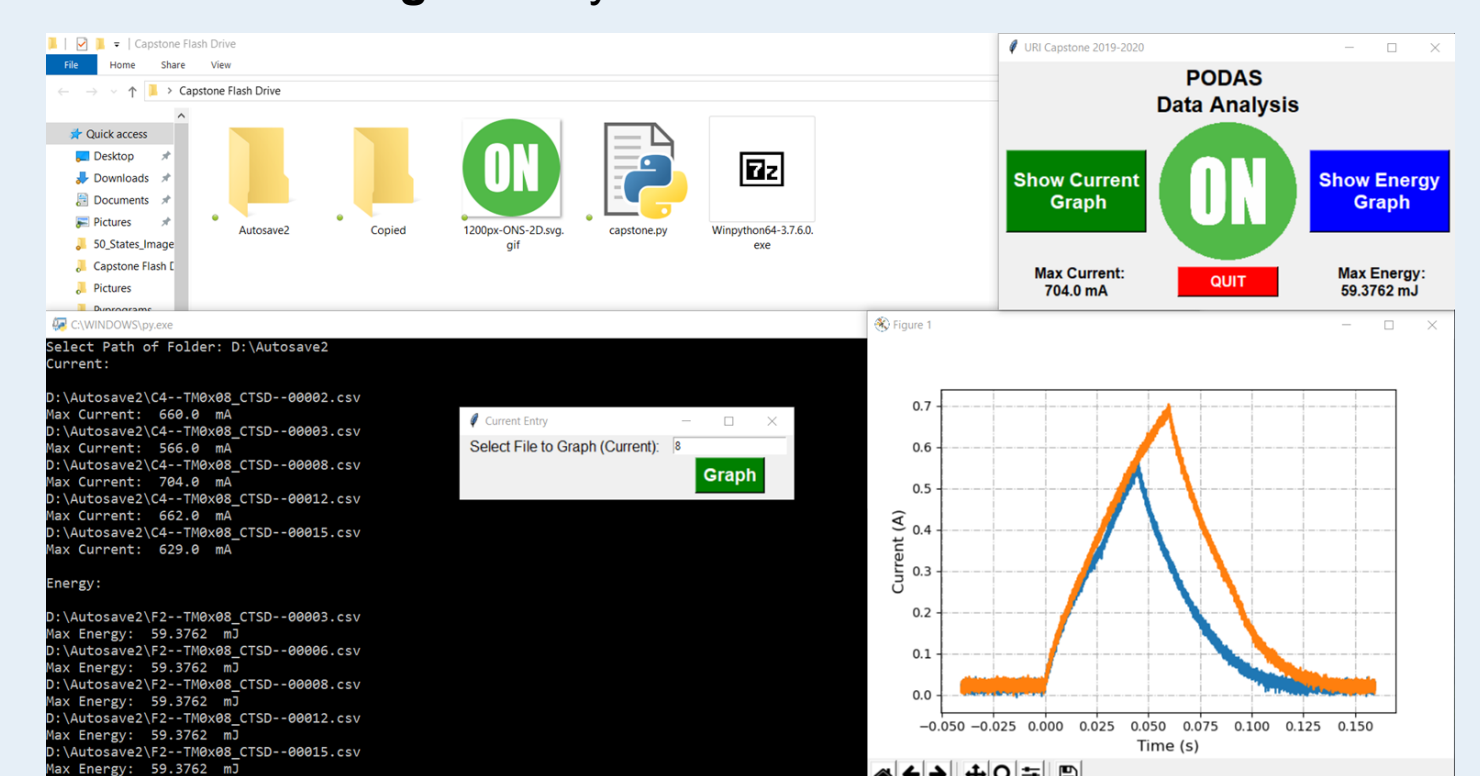


Fig. 4: Data Analysis Software.



Fiber Optic Annunciator

A power control system annunciator immune to electromagnetic interference.



Team Members: Maxwell Tyree (ELE), Seth Botelho (ELE), Ethan Ribb (ELE)

Technical Directors: Sandro Silva, Mike Smith

PROJECT MOTIVATION

The power distribution market has a high demand for systems that are immune to Electro-Magnetic Interference(EMI). Currently, Phoenix Electrical Corporation is using traditional Copper Wire systems for their annunciator systems. These copper wire systems are susceptible to EMI which can lead to false positives and unnecessary downtime, both of which waste a companies money and time. Our Goal is to design an annunciator system that is immune to EMI, while still maintaining functional equivalence to PECs current copper wire annunciator systems. The plan is for this system to be easily configurable, reliable, low cost, and adaptable for application in many different industry standards. In order to achieve this we will be using fiber optic cables for communication between our annunciator and input boards since fiber optic cables are immune to EMI.

KEY ACCOMPLISHMENTS

Development Board Selection: Since the focus of this project is to create a functional prototype of an annunciator system, all work is done on development boards. We selected a Trenz Artix-7 FPGA module and associated carrier board, which features plenty of I/O and an SFP cage for a fiber optic transceiver.

Communication Over Fiber: The first major task was to prove that communication between two FPGAs was possible using SFP transceivers. For this we selected the Aurora 8B10B IP from Xilinx, and started with the reference design. After learning how the IP worked, we were able to use it to send custom data over the gigabit link.

Continuity Check Module: Created a module for the key feature of an annunciator, the continuity checks. This module will test the state of 12 switches, and return a logic value representing their validity. Each channel may be configured to be "normally open" or "normally closed", depending on their desired application.

Programmable Delays: A common feature on annunciators is a programmable delay on each continuity check channel, which serves to filter out false alarms. This delay can be configured to be up to one minute, with a millisecond resolution, depending on the desired application.

LED Display with Input Buttons: A display module serves to take in input from three pushbuttons, while displaying the status of the continuity check channel on a set of 24 LEDs, 12 green and 12 red. Each pushbutton mimics common inputs found on traditional annunciators, such as "Test", "Reset", and "Acknowledge".

Breakout Boards for Switches and LEDs: To assist with testing of the system in hardware, two different PCBs were designed as breakout boards for switches and LEDs needed by each board. The signal collecting "input board", features 12 SPST switches for emulating breakers monitored by the continuity checks. The annunciator board features the 24 LEDs and 3 push buttons required for the display module.

MicroBlaze Core for Serial Port Configuration: We have modified the Vivado MicroBlaze reference design in order to create a basis for serial port configuration. Currently the design has been modified to be able to take in data from the serial port then reprint the data back to the serial port. Additionally we have created a custom constraints file for our FPGA boards and the Microblaze reference design.

Custom IP Packaged as an AXI Peripheral: The annunciator board codes have been packaged as custom IP for use in Vivado with a MicroBlaze core. This was an important step toward finalizing some of the features of our digital system design, and makes it possible to use custom VHDL codes with Vivado's block diagrams.

Test of all Features in Hardware: Tests of every completed feature have been conducted in hardware using our Trenz development boards. The full test setup includes a duplex fiber optic link between each FPGA board, with the continuity check data being streamed from the input board to the annunciator board, and displayed on our custom display PCB.

Schematics of Hardware for Completed Features: Schematic capture was done as various components and modules were proven to integrate well within the overall design. This was a slow process and was worked on bit by bit all year long.

DC/DC Converter Selection: Since a product like this would need to be a versatile tool that can work with various input voltages, which may be country or grid specific, three converters were chosen. One AC/DC two DC/DC converters were selected and cover a wide range of voltages with the ability to step down to 3.3V in order to power the FPGAs.

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome for this project is to have a fully functional prototype that is equivalent to traditional annunciator systems using 2 FPGA development boards and Fiber Optics. Our system will be capable of monitoring 12 signals being fed into our Input board, and then communicating their continuity status via fiber optic cables to our annunciator board which will display their valid/invalid status to our LEDs. The system will be able to be configured to normally open and normally closed.

PROJECT OUTCOME

The Anticipated Best Outcome was achieved, and the project is ready to be continued by next year's team.

FIGURES

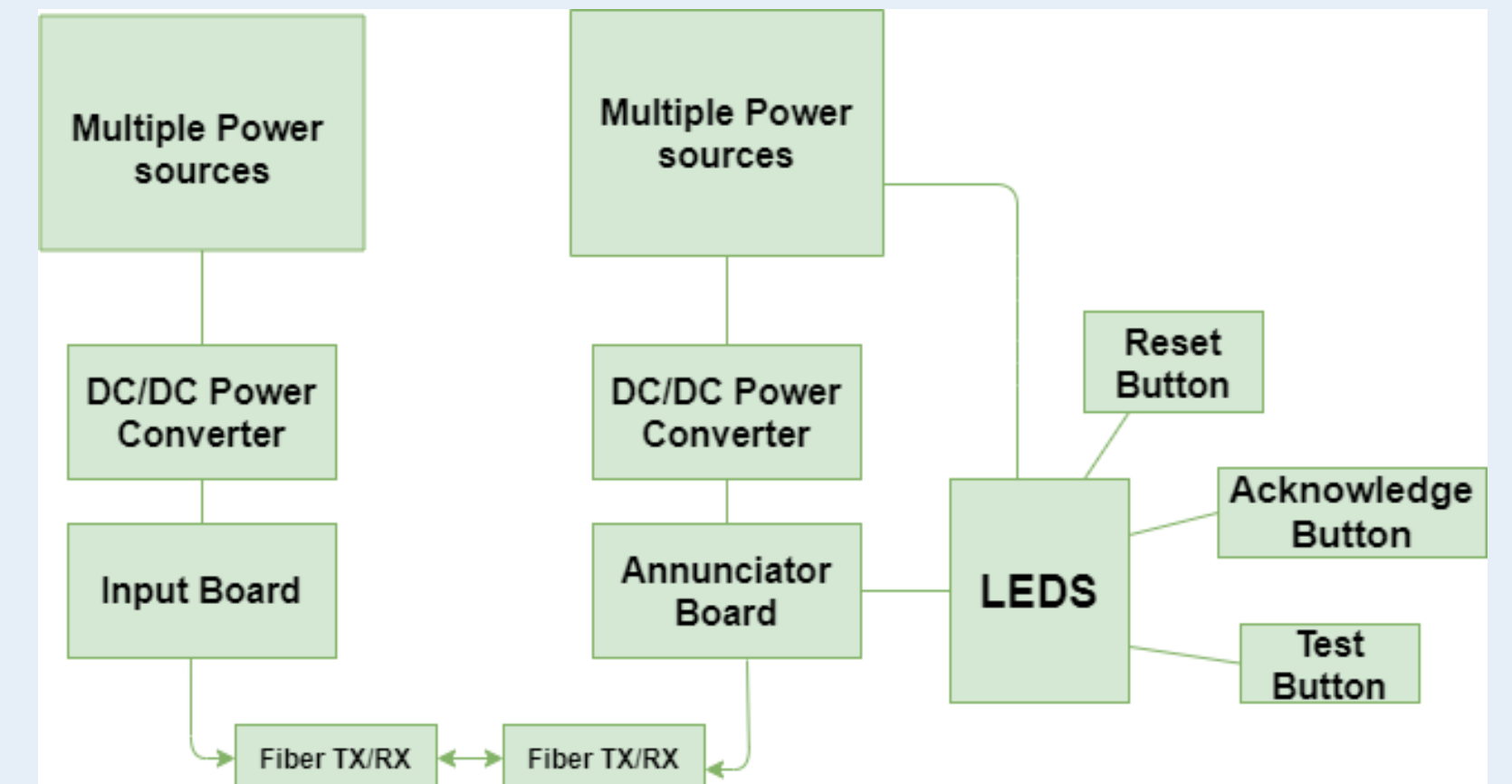


Fig 1: Functional Block Diagram of our entire annunciator prototype.

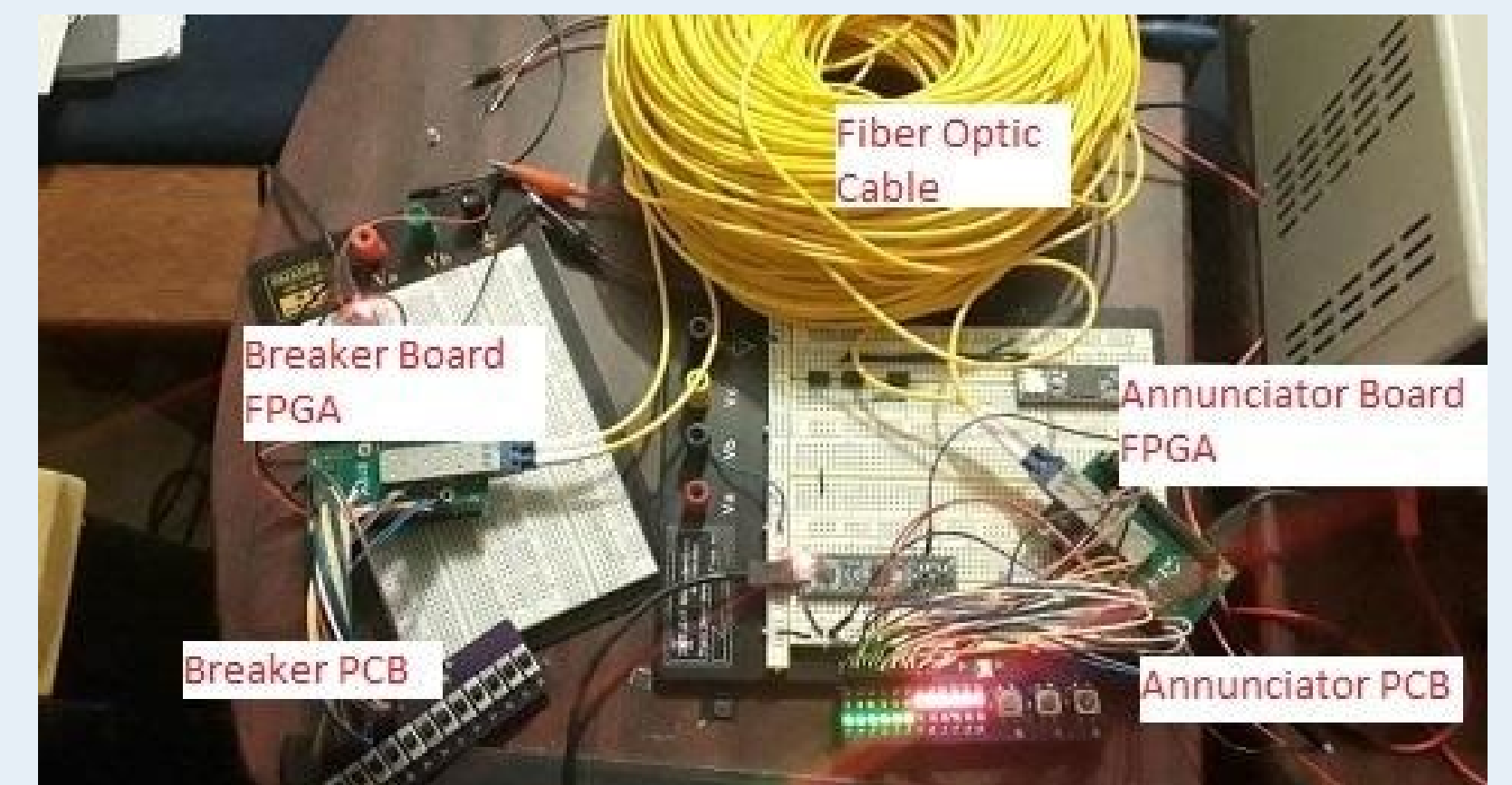


Fig 2: Picture of our Current Functional Prototype.

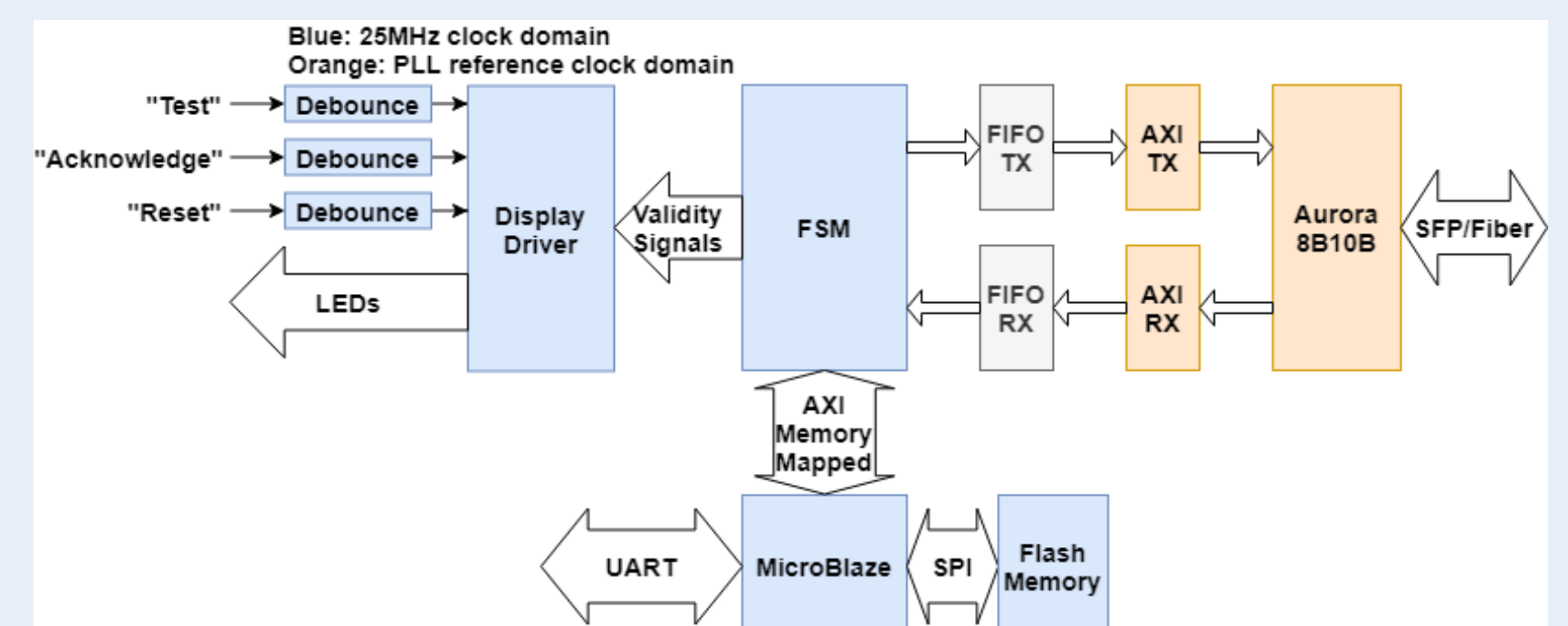


Fig 3: Functional block diagram of our annunciator board, including the planned UART configuration feature.

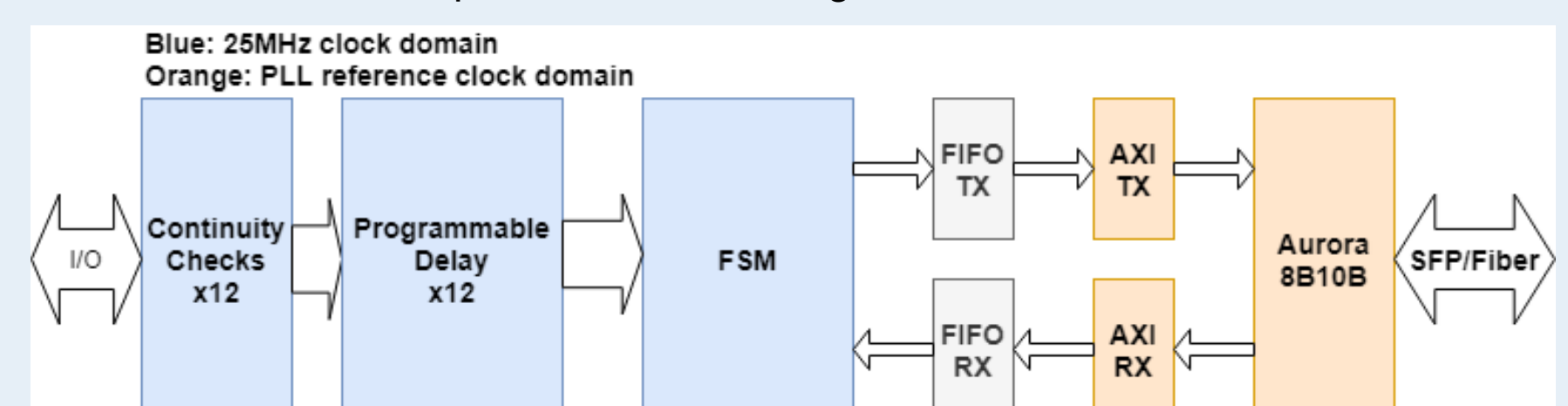


Fig 4: Functional block diagram of our input board.



Voltage to PWM Converter

A Translational Controller Between American-Design Boilers and European-Design Pumps

Team Members: Timothy Boyd (CPE and ELE), Paul Crisafulli (ELE), Christopher Volcy (ELE)



Technical Directors: Robert Kellicker, Phillip Manning, Nicholas Costello | **Consulting Technical Director:** Mike Smith

PROJECT MOTIVATION

In North America, the typical speed control signaling method for pumps and valves is a 0-10 V, 2-10 V, or 4-20 mA control scheme. Taco International currently has a pump that is controlled with a pulse width modulation (PWM) signal. To take advantage of this pump in North America, Taco Comfort Solutions proposes developing a voltage to PWM converter module, which is capable of performing the proper control scheme transformation. In doing this, Taco Comfort Solutions will be enabling itself to reap the cost saving benefits of using such pumps, at a minimal cost to upgrade.

KEY ACCOMPLISHMENTS

Development Hardware: The hardware for the VPWMC involves multiple points of design which heighten the ability of the microcontroller to produce certain signals and work over certain communication protocols. The baseline hardware for the device involves the processor linked to a special active filter - gain stage pair, allowing the 5V microprocessor to produce up to 10V analog signals without the use of a specialized DAC or digital potentiometer.

PWM to Analog Voltage: One major challenge of this project was the generation of 10V analog from the microcontroller. Our solution to this problem was to implement an active filter which removes all frequency components of the PWM signal, leaving only the DC component. We achieve control of this level via an input PWM mimicking routine.

Proposed BAO Firmware: Firmware which implements all of the functions present in the originally proposed Best Anticipated Outcome (BAO). In doing this, we have implemented bi-directional Analog Signal to Pulse Width Modulation conversion across three different modes of voltage or current signal inputs.

Power On Safety Diagnostics: Additionally to the originally proposed BAO Firmware, we have implemented important power on safety diagnostics procedures similar to those found in the IEC 60730 application safety certification. In doing so, Taco can easily verify that a VPWMC device is working properly and ensure the safety of the end user.

Production Line Testing: We have also implemented production line testing via Taco Comfort Solutions' proprietary cyclical redundancy check based communication protocol: TacoBusLite. In doing so, Taco can not only write device specific Serial Numbers to the device with the ease of a comprehensive Graphical User Interface, but also control the inputs and outputs to the device remotely in order to verify that the device is working correctly before it is sent off to the end user.

Near Field Communication (NFC): An important reach goal was to implement an interface for Near Field Communication on the device. Using the STMicroelectronics ST25DV chip, and an onboard PCB antenna, Team Taco provided this capability, along with writing comprehensive firmware which can be expanded into desired functionality by Taco Comfort Solutions. Doing this has opened the door for this technology to be used in many future Taco products.

Printed Circuit Board: The printed circuit boards for the project have been received and tested. Two boards have been produced; a development board which has additional I/O and is larger, and then a small production style board which will fit in the provided Taco enclosure. The production style board is a 2-layer printed circuit board and contains a 2-layer NFC antenna for the dynamic NFC tag. The production printed circuit boards have very limited space available for components due to the way the existing enclosure is designed. We managed to fit the NFC antenna well and have verified that the design enables such communication. (Figures 1 and 2)

Production Ready Firmware: The last goal of Team Taco was updating the firmware of the VPWMC to eliminate transient bugs and fortify the existing processes against noise and other concerns. Through Alpha testing, Team Taco was able to find and eliminate a few crucial errors, which allowed us to expand into a newer, more capable processor family, and ensure clean signal analysis and production. After more discussed desirables, Team Taco finally completed the production ready firmware revision 2.1.5, meaning Taco can now go through the process of selling this device.

Bootloading Compatibility: One of the stretch goals provided by Taco on this project was to begin and attempt to finally implement the capability to program the VPWMC without use of an external debugger device. With desire to do this wirelessly via the NFC module onboard, crucial steps were taken by Team Taco to expand the interface into the module, and build out functions which lay the groundwork for such an interface, rarely seen on the market, to be implemented on not just this, but many of Taco's future products.

ANTICIPATED BEST OUTCOME

- Device which possesses the following capabilities or traits
- Conversion of input analog signal to output PWM and input PWM signal to output analog, thus performing the two-way translation.
 - Power on safety diagnostics based on those found in IEC 60730 Class B
 - Production line testing via Taco's proprietary packet-based protocol TacoBusLite
 - Hardware developed to fit a previously designed Taco enclosure and built on a PCB
 - Device ready for production as one of Taco Comfort Solutions' many products

PROJECT OUTCOME

The Anticipated Best Outcome was achieved.

Team Taco was able to excell past our goals for this project, achieving the Anticipated Best Outcome by the end of Fall Semester, and achieving our Extended Outcome Goals in the Spring.

FIGURES

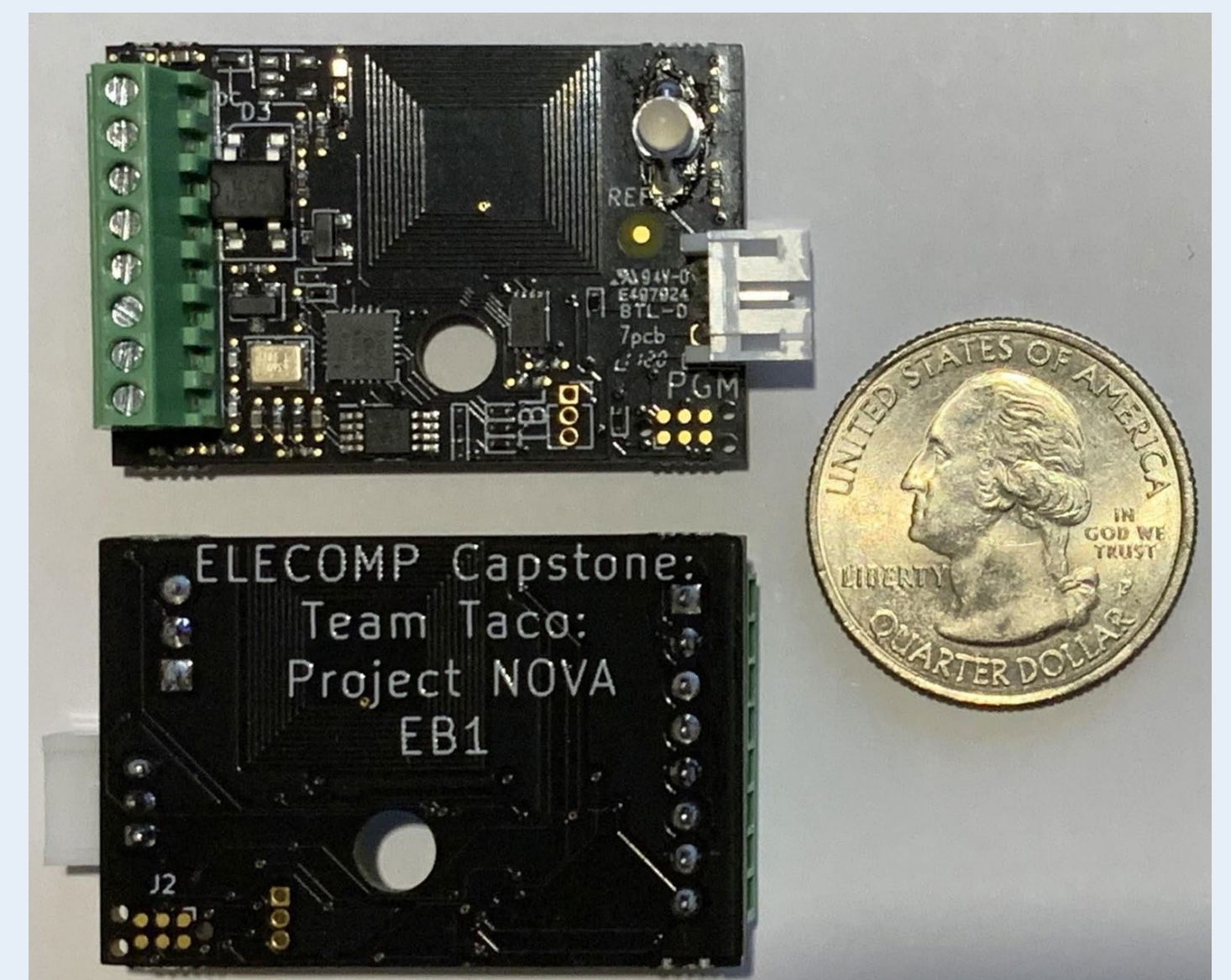


Figure 1 - Photo of the Revision 2.0 VPWMC production boards with U.S. quarter for scale

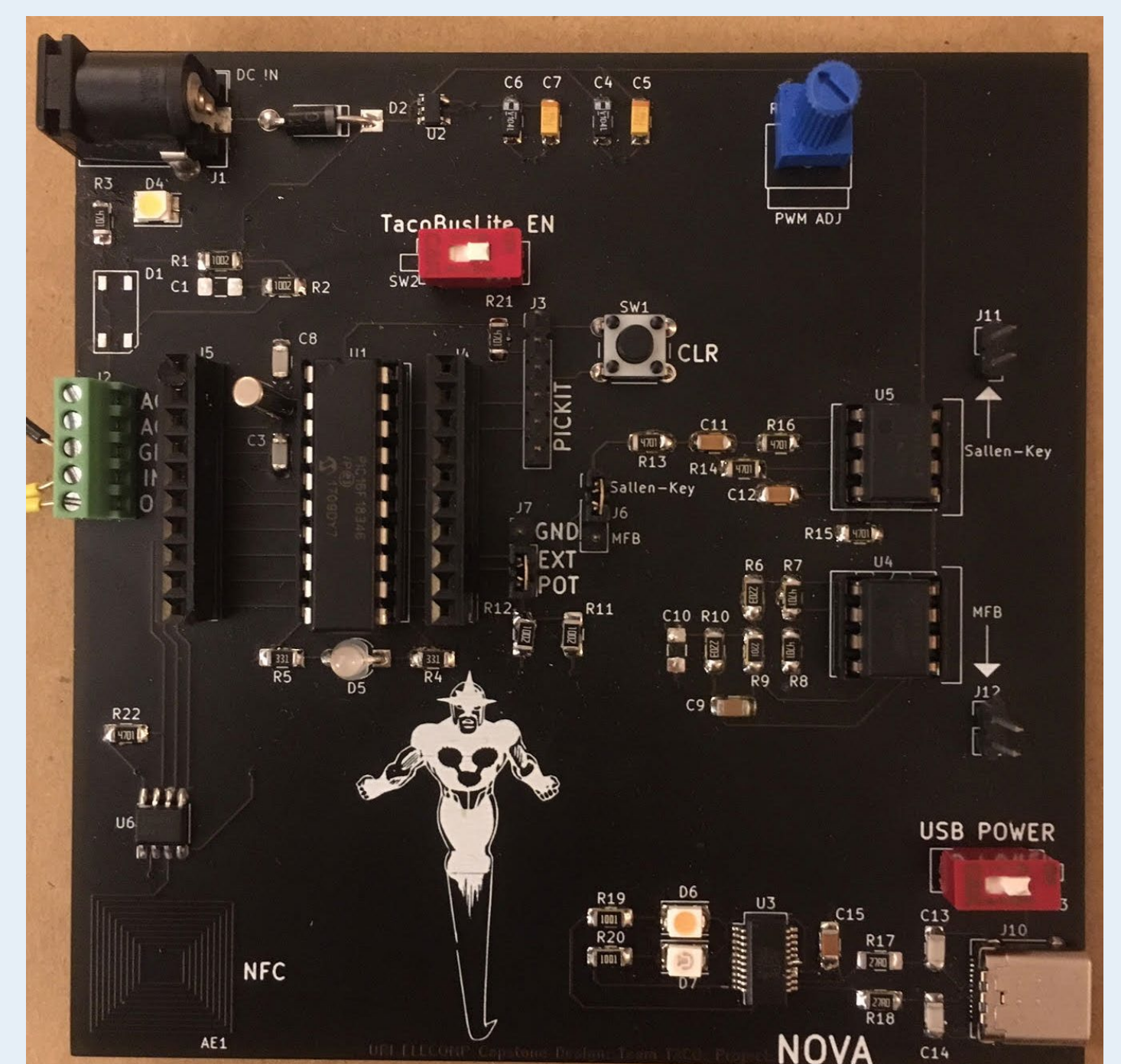


Figure 2 - Photo of the Revision 1.0 VPWMC development hardware used to facilitate alpha testing for the VPWMC



Extruder Zone Heating and Cooling Control with PLC

Team Members: Stefano Petrarca 1 (CPE), Ryan Wilkes 2 (CPE), Brian Beauvais 3 (ELE), Samuel Darkow 4 (ELE)

Technical Directors: Mickey Monarch and Brendan O'Reilly



PROJECT MOTIVATION

Teknor Apex produces plastic using extruders. The extruders consist of various components like zones, heaters, cooling system, and a die. The extruder heats raw plastic compounds to a temperature up to 400° F. The extruder then pushes the material through a die to be cut to specifications. The method of controlling the temperature zones have become dated and much less accurate over time compared to newer extruders today. Maintaining control over the temperature of each zone is important for product quality and electrical efficiency where a +/- 10° F difference makes quality control more difficult, produces off-grade product from burning of product and poor mix quality and costs money. We seek to develop a standard method of controlling each zone, dropping the difference to +/- 1° F of all the extruders in use, new or old. This would help Teknor Apex optimize temperature settings to run more efficiently on each production line.

KEY ACCOMPLISHMENTS

PLC Communication: Communication with the PLC (Programmable Logic Controller) (Fig. 2) was established by creating a static IP and updating the firmware over ethernet. The connection with the PLC was made through an ethernet switch, making a small local network. The PLC was then given a static IP on the URI Wi-Fi for remoting in more

PID and PIDE Simulations: A simulation program was created using ladder logic and implemented a PID loop. The simulation took the set point and the current temperature and the PID output how much to turn the heat on which was then proportional to the current temperature. The simulation will then be applied to the barrel (Fig. 4). The same thing was done in the Function Block Diagram for the PID-E.

Pseudo Temperature Integral Control: Implementing P_TempIntg and P_HeatCool in function block diagram to automatically set the gains and be controlled manually. The simulations could be flipped between automatic and manual control of the control variable.

Server Computer Setup: A spare computer was set up to act as a central remote networking server computer. It was installed with the Rockwell Studio 5000 and Inductive Automation Ignition server software that we needed to complete our project. This was set up and equipped with the means for us and our TD's to collaborate on our progress and store it in a central location that we would be able to remotely access from anywhere outside of campus. (Fig. 1)

Zone Tag History Graphs: One aspect of our data collection is to have an interface that is easy to see patterns and events on (Fig. 3). An Ignition tool was made so that it would read a SQL database for a zone's data and display trends in an easy to view and interactive graph and table for each zone in an extruder.

Automated Zone History Report Publishing: Ignition scripts that trigger whenever a new job order or plastic batch is started would compile the data from the last batch and is able to save the report as a PDF or send it over email.

Ignition Interface: This task involved creating a user-friendly interface through Rockwell's Ignition. This in conjunction with the PLC allowed communication to each other to display valuable information to the operator. The interface had to be operator friendly using well contrasting color schemes without confusing the operators.

Ignition Revamp: This task came at the end of the semester when we consulted our TDs. The task involved revamping the Ignition main screen to more easily identify specific changes to it. This task also involved revamping how the zones acquired data from the PLC. The data was also created neatly for use with Teknor Apex. This allowed for work to be done on the main screen to easily expand the zones if need be. This would work for extruders of various sizes in Ignition.

Ignition Alarms: The Ignition interface can include various alarms for the operators to take notice to. The more necessary alarms like overheating were put into place first, with easy expandability in mind for the rest of the alarms. These alarms are a very crucial and necessary component with any operation.

Test Bench: The barrel was stood up on steel plates to allow access to its water inlet and outlet. It was also prepped for heating and insulation. A water pump used for cooling was connected and tested.

Wire Diagrams: Some simple wiring diagrams were created in AutoCAD to represent some of the components we would have used. After uploading the basic wiring diagrams into AutoCAD, they were modified to represent our setup.

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome was four control loops implemented in ladder logic and a HMI design for an extruder zone. A database to record and store temperatures and alarms written in python. Additionally, electrical schematics, Ladder Logic, Data types, HMI Templates, Ignition and Python scripting were necessary. All design choices were for one zone but considered scale up and machine learning compatibility. Implementation should be achievable on different models and ages of equipment. It should also be able to control the heating and cooling of a zone to within one-degree Fahrenheit. The user also needs to be able to wire multiple zones together efficiently.

PROJECT OUTCOME

We did not meet the Anticipated Best Outcome because we were not able to fully realize the test bench. This did not allow us to acquire real data to be further processed.

FIGURES

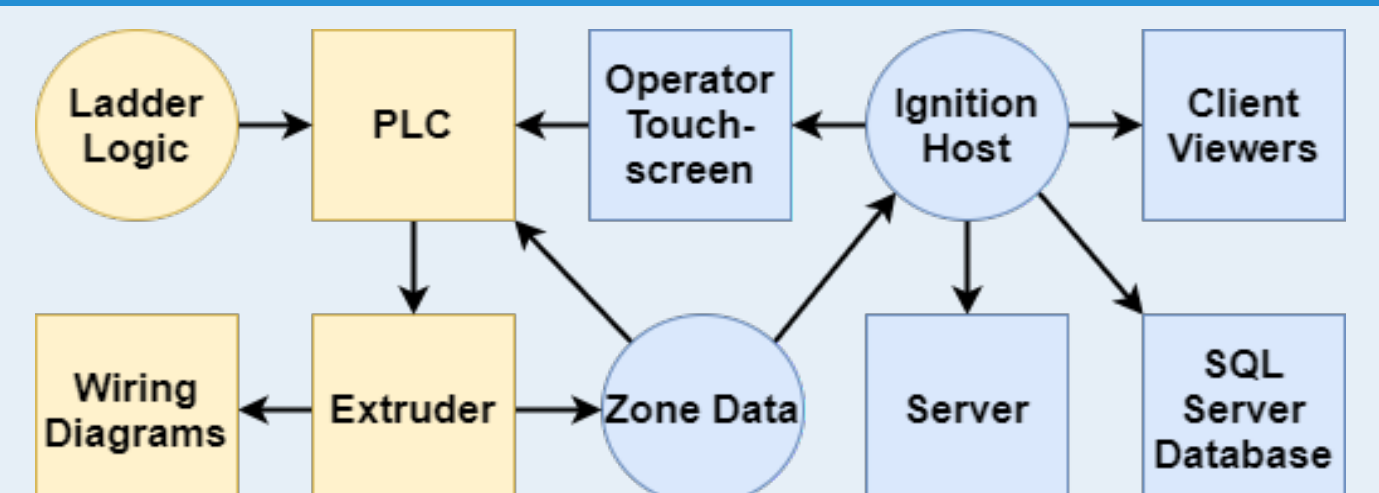


Fig. 1 - A block diagram of how the parts of the system function together.



Fig. 2 - Programmable Logic Controller with, from left to right, the Processor and the Ethernet card.

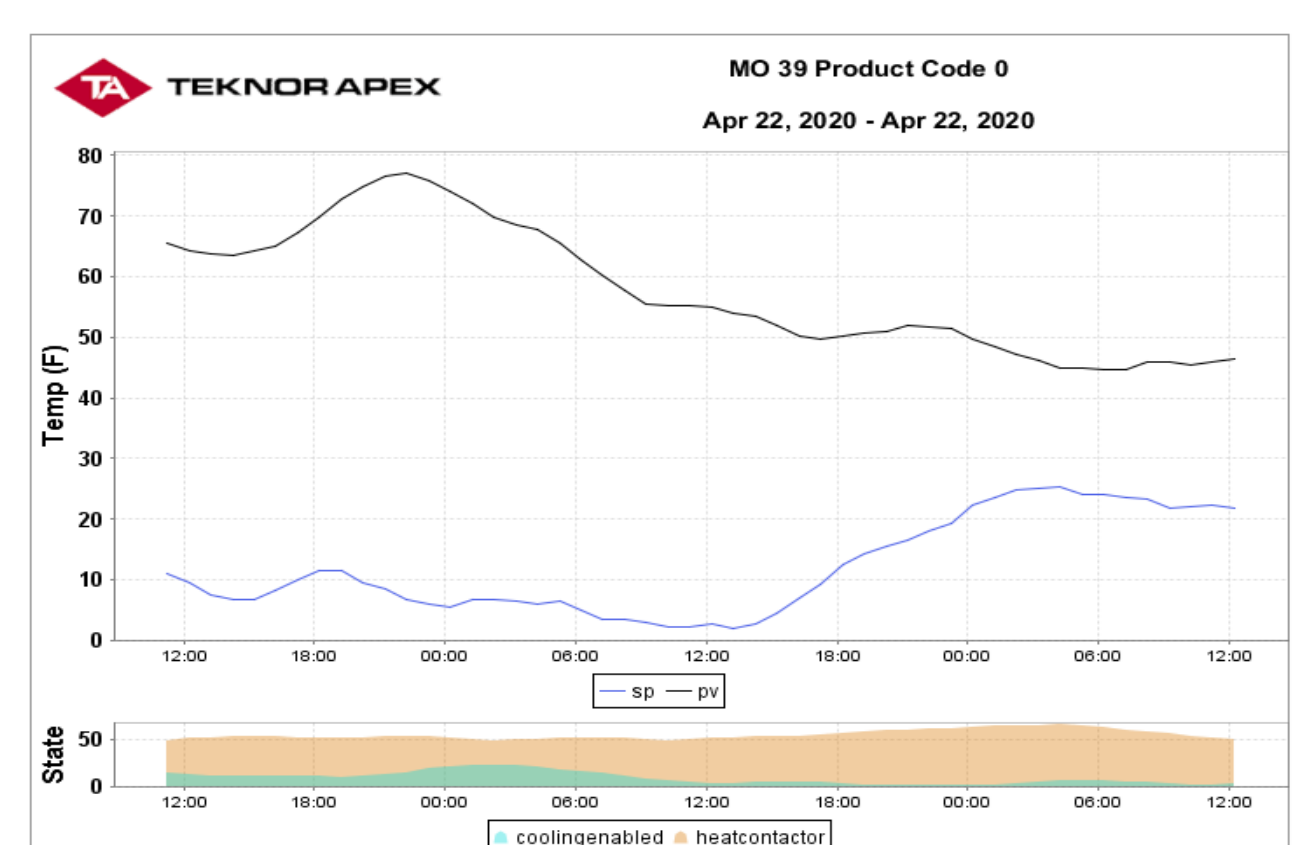


Fig. 3 - Historical Graph for a temperature zone.



Fig. 4 - Zone with attached cooling system.



Automated Spectral Data Acquisition and Analyzer

Team Members: Robin Hall (ELE), William Guo (CPE), Ruairi Heslin (ELE)

Technical Director: Mikhail Sagal



PROJECT MOTIVATION

Currently, desired data must be manually collected and compiled. Taking this data is time consuming and labor intensive. This is done by an employee collecting each data point with a PLA-30 over increasingly large areas. There is no standard methodology or equipment to perform this testing and data collection automatically. The goal of this project is to eliminate the need for human intervention. Any TSRgrow Employee should be able to set up our prototype/product to start a test and be able to come back once it's finished. The data will also be able to interact and align with TSRs' current data visualization software. The data collection will be automatic and can be used for customer interaction and can represent light/heat maps which show the efficiency of PAR getting to the plant canopy from the fixtures. These advancements in data collection will allow TSRgrow to be more productive and efficient which will lead to more profit.

KEY ACCOMPLISHMENTS

We created a robot as seen in **Fig. 1** that is capable of following a specified grid and stops to take light or PAR(Photosynthetic Active Radiation) readings at certain predetermined locations. The robot is capable of accurately carrying the PLA-30 light sensor. It stops at desired locations as seen in **Fig. 2** and triggers the PLA to take a light reading. Once the reading is complete, the PLA triggers the robot to move to the next point. This allows for accurate and repeatable measurements.

The Line following robot consists of two arduinos, one UNO and one MKR-1000. They are connected via two cables, these are then connected to the PLA-30 by being physically the platform for the PLA but also via the WiFi page hosted by the MKR-1000 board. The two cables connecting the MKR and UNO allows the two boards to send and receive signals between each other which then can be utilized by their individual program to perform task stop as adjusting the status of robot on webpage. The PLA program **Fig. 3** we've adjusted, waits for signals from our MKR board and takes automated measurements when specified. The program also allows users to input all testing related dimensions, such as positions of LED lights or number of expected data points. The program also allows for all collected data and testing dimensions that were entered by the user to be exported into a .csv file which then can be used to create heat maps or data sheets which represent the PAR and specific wavelengths at each test point.

We tested this grid system on printed mats seen in **Fig. 4** and it proved to be very successful. We were able to make these mats in photoshop and implement 90 degree turns. These printed mats feature 1/2 inch thick lines for the robot to follow and 1/2 inch thick lines, which are perpendicular to the pathway, to mark sensor points. The printed grid mats will be placed underneath a light fixture to accurately test the efficiency of the fixture and deliver the correct wavelengths of light to the correct place on the canopy of plants. For smaller fixtures we will need a smaller grid area for our robot to test and a larger fixture calls for a larger grid and so on. The robot will be placed on the grid and powered on, it will then be given initial test info, and then finally follow the path and carry out its test sequence. After it has completed the whole test sequence it will save the data to be examined. We are able to repeat light measurements on the same grid and get high quality results. Printing these grids allows for the whole test set up to be moved, taken down, and manually adjusted. Our system eliminates the need for human interference. Once the robot is started, it can take all the measurements necessary for any given light fixture. This allows TSR employees to work on other tasks instead of manually performing these tests.

Lastly we created a fixture mount prototype. We have both a prototype and cad files representing a desired final product. This was deemed not an essential portion of the test due to the fact that TSR already has a method for mounting light fixtures and fell to the backburner when we encountered the COVID-19 crisis. However this prototype mount would be capable of holding any fixture TSRgrow may need to test and be able to adjust vertically to any desired height. This would be done using a ceiling mounted piece with a guide which allows a sliding portion to be lifted/lowered into place.

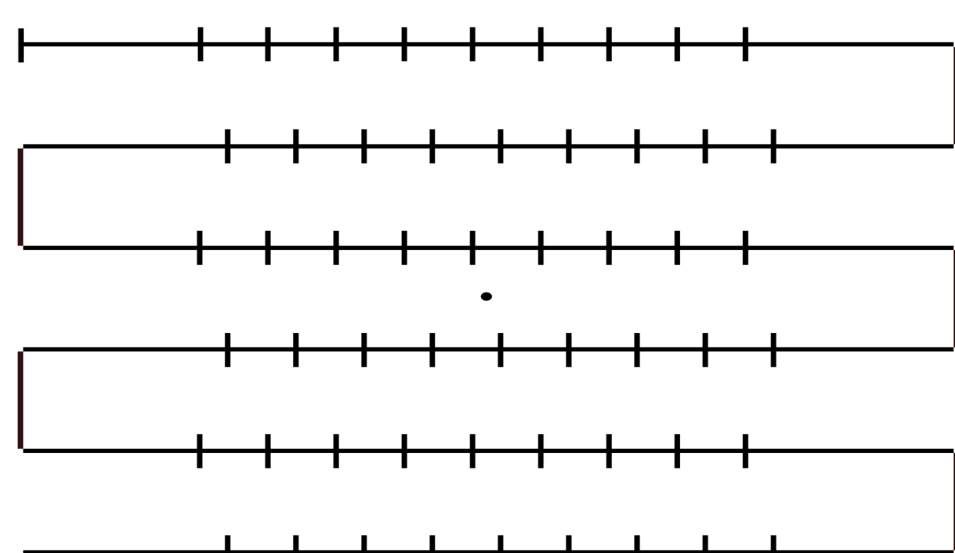


Fig. 4 One of the finalized mats that the Robot will complete a test on.

ANTICIPATED BEST OUTCOME

To have automated data collection of PPF and PPFD from light fixtures. Data collection must happen over a predefined grid area that can vary from 4'x4' to 16'x24' at heights from 6" to 72". A grid set up needed to be created that complements the created system and works in TSRgrows facility. Finally, the creation of an application to aggregate, sort and store the information and create reports based on defined queries. This data will be entered into a GUI interface that controls all aspects of the light testing system. It must aggregate data in a way that can be easily manufactured into lighting reports.

PROJECT OUTCOME

The Anticipated Best Outcome was Achieved.

We created an automated test apparatus using robotics and a PAR sensor, the PLA-30. Wireless communication between an Arduino Uno and MKR-1000 enabled the robot and PLA to communicate and take light data. We developed printable grids that can be used to test any light fixture.

FIGURES

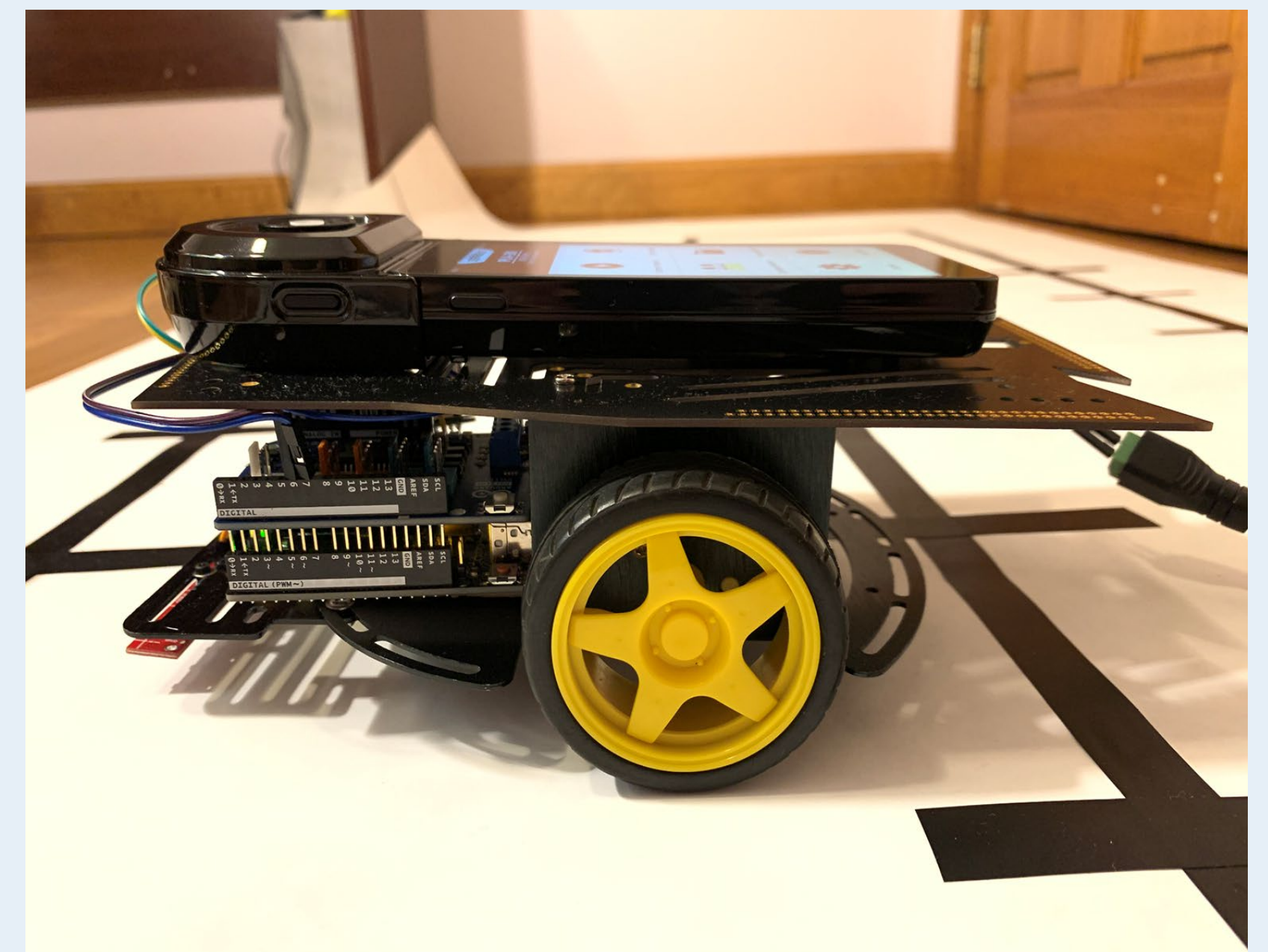


Fig. 1: Completed Robot composed of Arduino Uno, MKR-1000 and an Everfine PLA-30

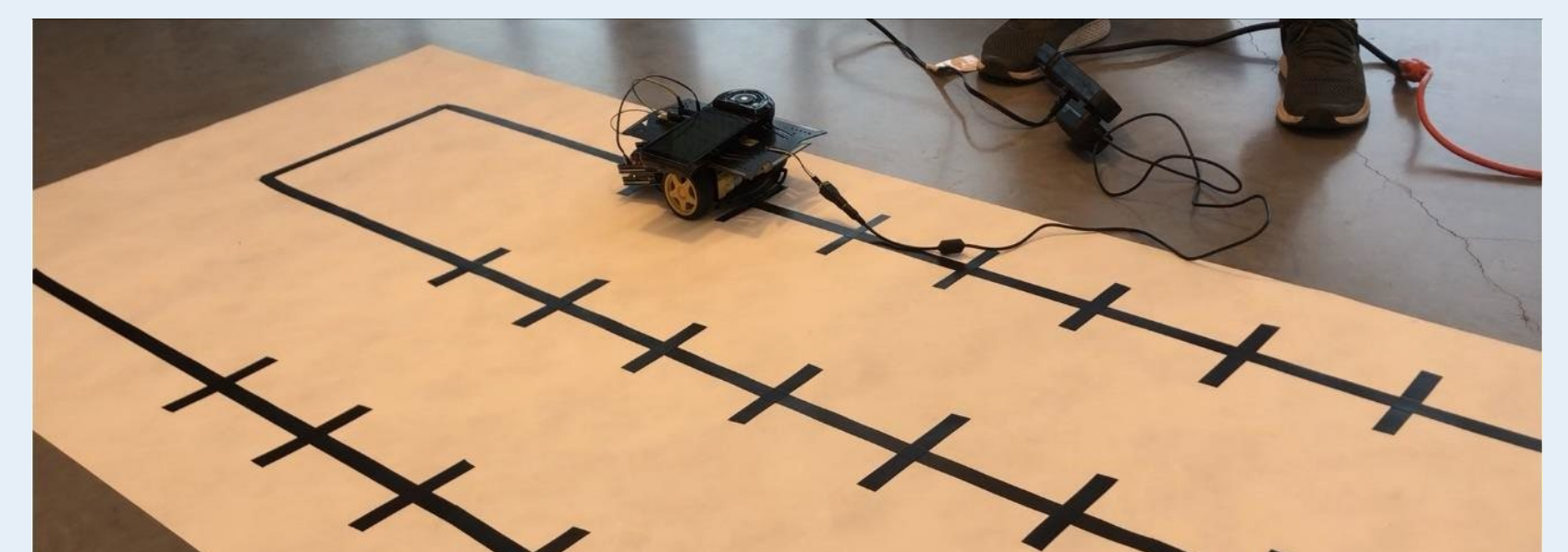


Fig. 2: Robot in middle of a test sequence, Stopped taking a reading at desired data point.

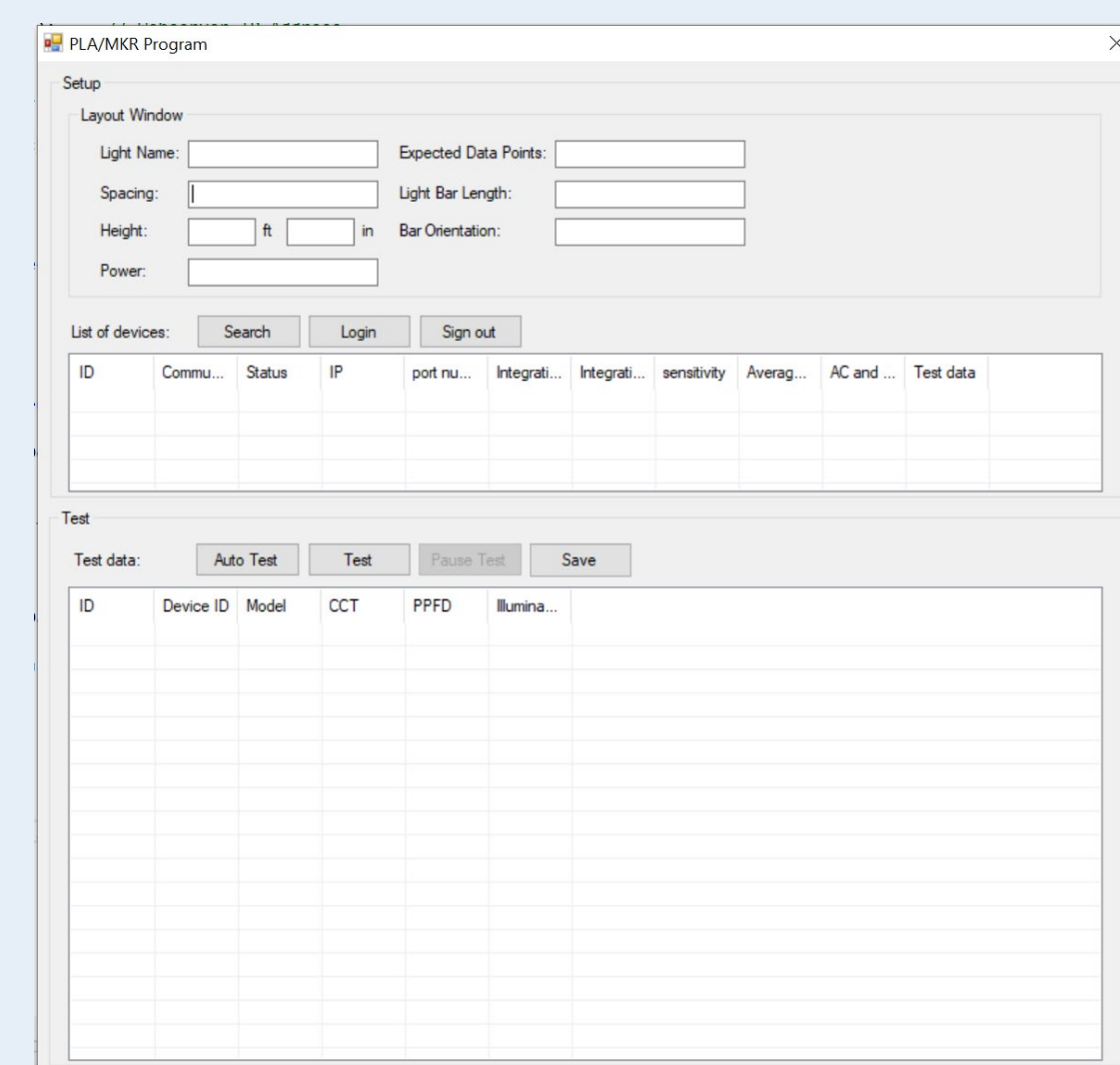


Fig. 3 PLA-30 Program to handle taking PAR readings and stopping/going on path again.



Low-Cost Desktop Design Evaluation System

Team Members: Brady Peacock (CPE), James Gannon (ELE), Nathan Shake (ELE)



Technical Directors: Chris J. Sanzo, Andreas Ladas, Al Binder

PROJECT MOTIVATION

Engineering Lab Bench Equipment is expensive, bulky, and poorly suited to rapid evaluation of new mixed signal silicon. Because of these qualities, equipment is often shared and/or takes up valuable lab real estate. If multiple development programs are urgently needed, equipment must be taken from one setup to another; creating opportunities for error.

Furthermore, digital communication on traditional lab bench equipment requires knowledge of communication language and instruction set for each piece. Often, even a simple meter or bench supply is not interchangeable. And the protocol for communicating can be very slow – making datalogging very time consuming.

Our project goal is to make low-cost, small, portable, self-contained systems that only require a keyboard and monitor to complete a full product characterization over temperature. Clearly, such a system will have limitations for number of resources, current capacity, voltage rating, accuracy, etc.

KEY ACCOMPLISHMENTS

Component Selection: Researched and selected various IC's and switching regulators to be integrated into the first desktop FSU system prototype that were compliant with predefined design specifications. Various tests were performed on selected components to prove their usability and functionality.

Communication Protocols: Having had no prior experience with any sort of communication protocols, over the course of this project we had to learn and master three. We first had to learn I2C in order to control the DUT board. Next, we learned the Serial communication protocol in order to establish a connection between the Arduino Due and Raspberry Pi. Finally, the DAC and ADC were controlled by SPI.

Embedded Systems: With a heavy use of both the Raspberry Pi and Arduino Due in this project, there was a lot to learn about embedded systems in general. We learned how powerful these devices can be, as well as where their limitations may lie. With no prior experience, we had to master our control and expertise of these devices.

Design Tool Proficiencies: The final product cannot be produced or understood without first building a model or simulating the design in the virtual world. While building core knowledge in the structure of the project's circuit topology, competencies were developed in LTSpice, PCB design with Altium tools using CircuitMaker, and initially building and verifying ideas with equations.

Schematic Design: The schematics of both the Final FSU PCB as well as the MUX card (for future system integration) were made and improved upon, following a hierarchical design approach.

PCB Design: With guidance from the team's Technical Directors, a Dual (two-channel) FSU PCB was designed. The design process consisted of cross-referencing LTSpice simulations with board schematics, and .pcb files in CircuitMaker, board layout, making improvements during design reviews, producing a BOM and ordering the board. Many key design skills were learned in the areas of copper parasitics, kelvin sensing principles, circuit protection and analog circuit fundamentals.

Final FSU Prototype: The FSU system is capable of forcing and sensing current and voltage at precision across a Device Under Test (DUT), for up to 48-pin IC's. The custom 2-channel FSU PCBs were designed from scratch in CircuitMaker, while the 2-channel FSU prototype board is a one-plug system that utilizes few off the shelf components with circuit protection. The concept behind the prototype is that it will greatly reduce the cost and time factors involved in the IC testing process.

Software and Hardware Documentation: A software library for all files used to control the system is documented and available on a project GitHub repository, while the hardware documentation is still being produced.

API: Our system comes with a fully-fledged and well-documented API, to make the user experience smoother and more efficient. This API performs all the basic functions of our system, allowing the user to use the API functions as building blocks to create any test they desire in an easy manner. This API also takes care of error handling, prohibiting one to access an out of range voltage or current, for example.

Measurement Scripts: The product will be delivered with two sample measurement scripts. These scripts perform the following tests on the DUT: measure a comparator threshold voltage going either up or down, and measuring a pull-down voltage/resistor. The user may modify these scripts in any way, or ideally use them as an example to go off of when creating their own scripts and/or tests.

MUX Card Design: A MUX card design has been created in CircuitMaker for future integration into the FSU system. Implementation of this MUX card design will allow for scalable force/sense system capabilities and overall project expandability. Its reconfigurable design allows for utility in integrating either 4 FSUs, or 2 FSUs and 2 sense modules.

ANTICIPATED BEST OUTCOME

The Anticipated Best Outcome would be a BOM and a demonstrated prototype for a sub-\$5000, portable evaluation unit that meets or exceeds all specifications. It would also have clear documentation, a well-maintained firmware/software library and a high level of robustness for shipping either with or without the thermal chamber. Ideally, the desktop evaluation unit should offer a sustainable and scalable design as to accommodate the integration of additional modular hardware and measurement cards with clean pin hookups.

PROJECT OUTCOME

The Anticipated Best Outcome was achieved during this project. We were tasked with building an objective set of hardware and performing measurement tests to achieve results within project specifications. We were able to build a 2-channel force/sense unit that interfaces with a 48-to-1 MUX in order to individually select each pin on the DUT, and we were able to perform a comparator threshold test and a pull-down resistance test with desirable results, however we were not able to put the two together in order to achieve said results using said hardware due to some unforeseen hardware issues and time constraints. After discussing with the Technical Directors, we still consider this outcome to be a success, and ultimately consider the ABO to have been achieved under these circumstances.

FIGURES

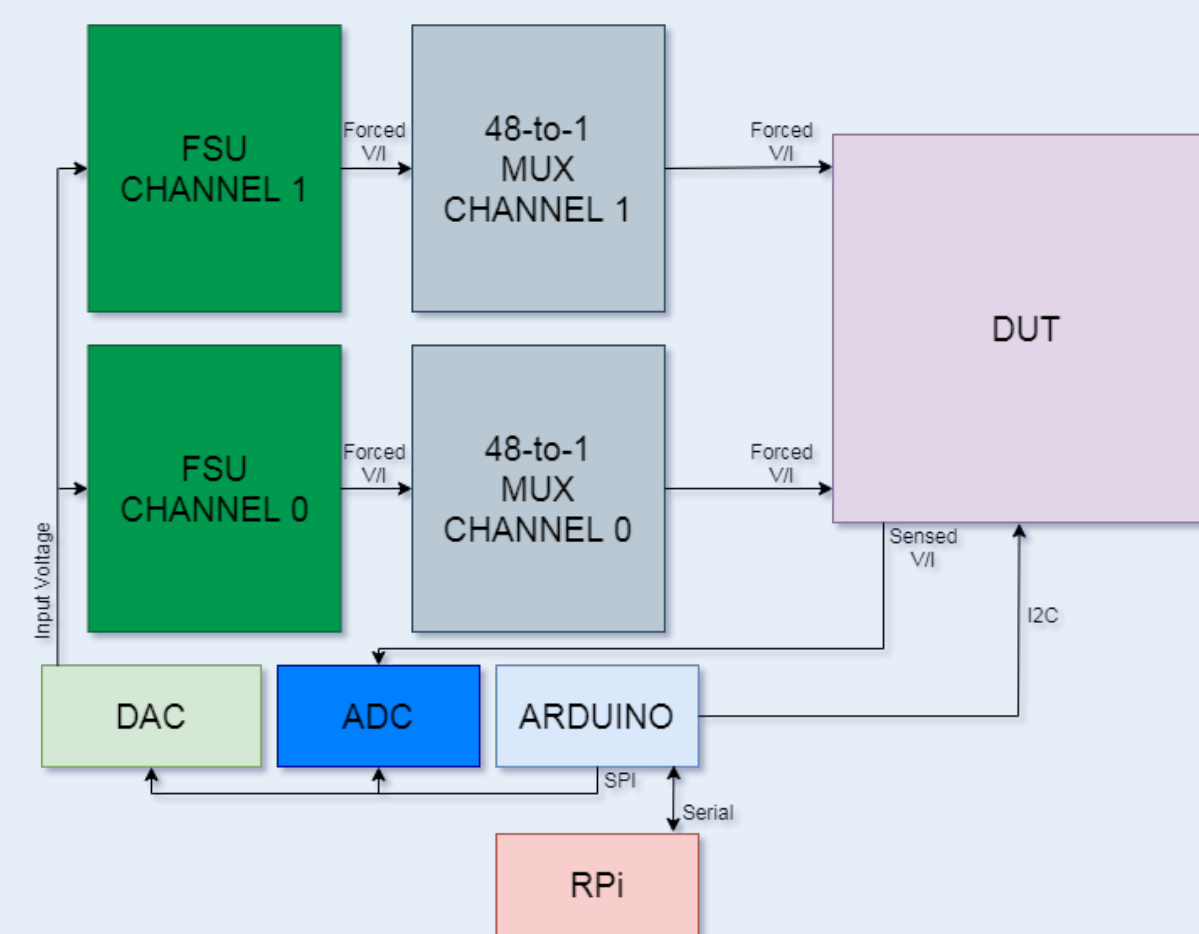


Figure 1: Block diagram of FSU system interfaced with external DUT and Raspberry Pi

Figure 2: Fabricated PCB for 2-Channel FSU board

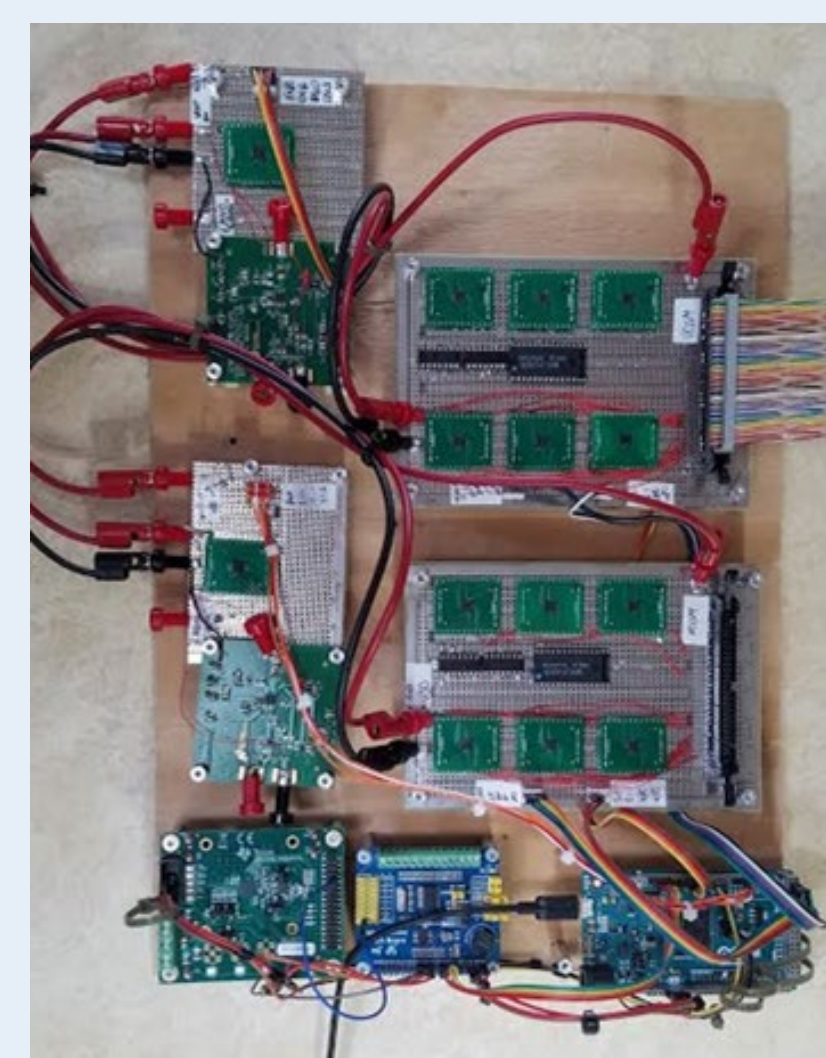
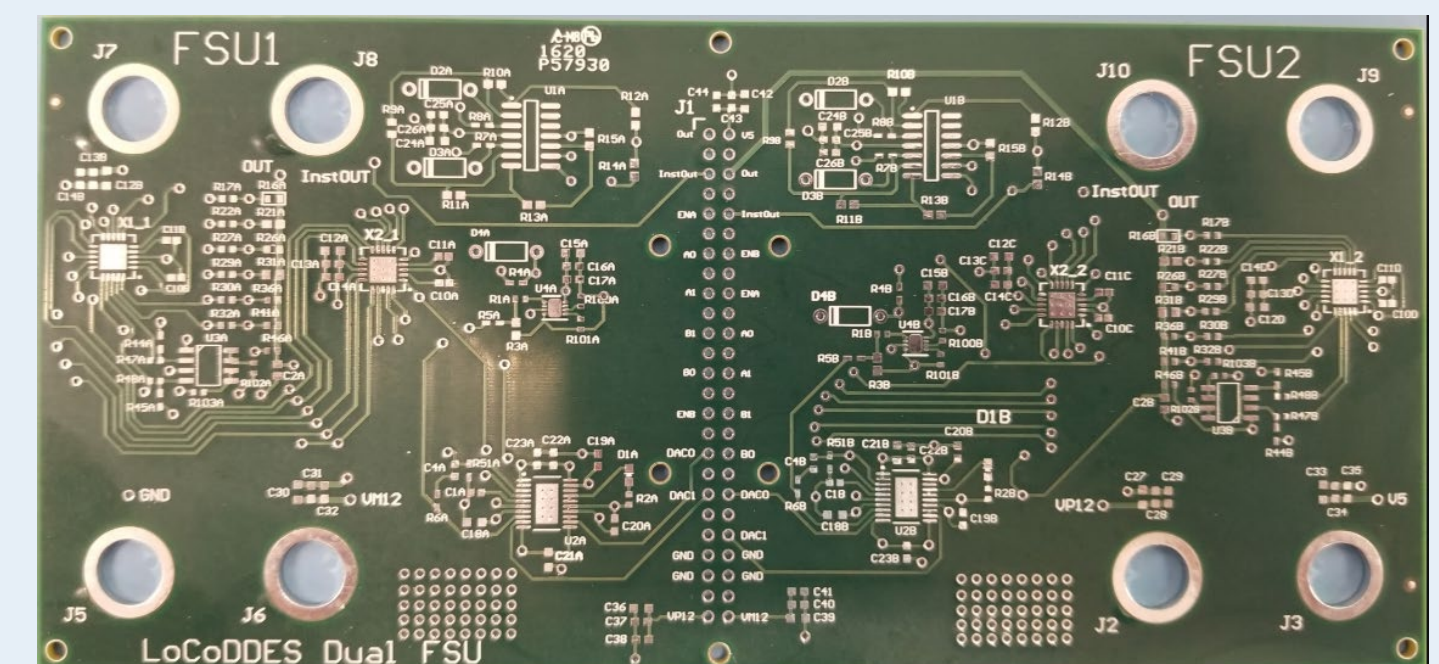


Figure 3: Physical version of the block diagram in Figure 1. Not in picture: RPi, DUT

Figure 4: MUX card schematic layer design showcasing the ability to select and communicate with all 48 pins on the DUT with only a 4-signal input DEMUX. Each of the 6 Maxim Integrated MUX ICs to the right of the DEMUX can handle 8 selective outputs (6 x 8 = 48 pins)

