The new FCAE will be one of the most provocative and technologically advanced engineering building in the country”

Terry Steelman: Design Principal, Ballinger of Philadelphia Architects
“This new facility will stimulate collaborative, multidisciplinary learning and research. It will lead to discoveries that we cannot even imagine today.”

President Dooley

“When the engineering disciplines combine, the sum is greater than its parts. URI Engineering is building the future.”

Dean Wright
URI CLASS OF 2020

GROUP I
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ELECOMP CAPSTONE 2019-2020
URI Class of 2020

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GROUP II
SPONSORING COMPANIES
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Welcome: It gives me great pleasure to welcome you all to the Annual Symposium of the ELECOMP Capstone Design Program. This year we are celebrating 12 Years of Excellence in Capstone Design for Electrical (ELE) & Computer (COMP) engineers. Our Program partners senior engineering students with industry sponsors to design, build, program and test solutions to real-world problems. We are excited to present 16 projects, by 51 seniors, at the mid-point of the 2-semester program, with the Summit on May 8th, '20. I have allocated 7-9 min./project for the oral “rocket” presentations. The depth and breadth of work in these projects is outstanding and I hope it will inspire you all to sponsor challenging, and innovative, capstone projects next year. We are very excited to be in the new Fascitelli Center for Advanced Engineering. More details on our program website: https://web.uri.edu/elecomp-capstone/elecomp-capstone-lab/

Capstone Bridge: The ELECOMP Capstone Bridge mirrors the well-known Wheatstone Bridge extremely well; see the back cover. All facets of our Program, together with our talented seniors, with diverse skills, form the two known arms of the bridge. The third known arm is the sponsoring company, their Technical Directors and the problem to be solved. Only when these three arms are in perfect balance, and collaborate in excellent harmony, success is achieved in the unknown arm: The Anticipated Best Outcome of the Sponsor’s problem. The economic impact for all the sponsors will run into many millions of dollars!

Together with all my senior capstone designers, I would like to thank sincerely the 15 companies who became the third arms this year; 4 are first time sponsors! Without their enthusiastic and generous support, it would be impossible to execute on all the facets of the program. Special thanks to all the Technical Directors for their time, efforts and dedication to mentor their teams. I look forward to your continued support. THANK YOU.

Consulting Technical Directors: Sincere thanks to Mike Smith, Jeremy Peacock, Alex DePetrillo and Brenden Smerbeck for consulting on many projects. Their expertise helped the teams make significant progress during the capstone laboratory session on Tuesday evenings.
7:30 – 8:40 am
• Breakfast
• Registration
• Viewing of Capstone Project Posters
  Location: Higgins Welcome Center:
  Hope Room and Anchor Rooms

8:40 – 9:00 am
Welcome
Professor Harish Sunak, Capstone Program Director
Location: Swan Hall Auditorium

9:00 – 10:12 am
Rocket Presentations I
Location: Swan Hall Auditorium

10:12 – 10:40 am
Break

10:40 – 11:53 am
Rocket Presentations II
Location: Swan Hall Auditorium

12:00 – 1:15 pm
Lunch
Location: Higgins Welcome Center, Hope Room

1:15 – 1:55 pm
Poster Session & Demonstrations
Location: Higgins Welcome Center, Hope & Anchor Rooms

2:00 pm
Announcement of Top 4 Teams
Location: Higgins Welcome Center, Hope Room

2:00 – 2:45 pm
Reception & Videos
Location: Higgins Welcome Center, Anchor Room

SAVE THE DATE!
ELECOMP CAPSTONE
SUMMIT
FRIDAY, MAY 8, 2020
## Rocket Presentations I

- **9:00 – 9:10 am**  
  Acumentrics Inc. *Fault Line*
- **9:11 – 9:19 am**  
  Acumentrics Inc. *Volta*
- **9:20 – 9:27 am**  
  Analogic Corporation
- **9:28 – 9:36 am**  
  Cambridge Technology Inc.
- **9:37 – 9:44 am**  
  eMoney Advisor LLC
- **9:45 – 9:54 am**  
  FM Approvals LLC
- **9:55 – 10:04 am**  
  General Dynamics Electric Boat
- **10:05 – 10:12 am**  
  Hexagon Manufacturing Intelligence
- **10:12 – 10:40 am**  
  BREAK

## Rocket Presentations II

- **10:40 – 10:48 am**  
  IGT Global Solutions
- **10:49 – 10:57 am**  
  Iradion Laser Inc.
- **10:58 – 11:07 am**  
  ON Semiconductor
- **11:08 – 11:16 am**  
  Phoenix Electric Corporation
- **11:17 – 11:25 am**  
  Taco Comfort Solutions
- **11:26 – 11:35 am**  
  Teknor Apex Company
- **11:36 – 11:44 am**  
  TSRgrow
- **11:45 – 11:53 am**  
  Vicor Corporation
GRADUATES FROM OUR ECBE DEPARTMENT

Brenden Smerbeck (ELECOMP Capstone 2017) Acumentrics Inc. 3rd year TD
Alex DePetrillo (ELECOMP Capstone 2018) 2nd year Consulting TD
Jeremy Peacock (ELECOMP Capstone; Double Major Expected 2020) 2nd year Consulting TD

Sandro Silva (2002) PEC 4th year TD
Mike Smith (2001) 4th year Consulting TD
Robert Davis (1997) ON Semiconductor 3rd year TD
Raymond Leland (1993) IGT Global Solutions 3rd Year TD
Frank Kolanko (1981) ON Semiconductor 2nd Year TD
Christopher J. Sanzo (1999) Vicor Corporation
Andreas Ladas (1993) Vicor Corporation
GRADUATES OF OTHER URI DEPARTMENTS

Jonathan O’Hare (1994) Hexagon 4th year TD
Jefferson Wright (2014) GD Electric Boat, 2nd Year TD

GRADUATES OF OTHER UNIVERSITIES

Michael Mielke Iradion Laser 3rd Year TD (University of Central Florida 2003)
Phil Manning Taco Comfort 3rd Year TD
Daniel Jaquez eMoney Advisor 3rd year TD (University of Texas 2005)
Gary Jutras eMoney Advisor 2nd Year TD (NEIT 1992)
Mark Lucas Cambridge Technology 2nd Year TD (Northeastern University)
Seetharam Sivam Cambridge Technology 2nd Year TD
Mikhail Sagal TSRgrow 2nd Year TD (Boston University 1996)
Robert Corvese 2nd Year TD IGT Global Solutions
Nicholas Costello Taco Comfort Solutions 2nd Year TD (Johnson & Wales University 2016)
Bob Kellicker Taco Comfort Solutions 2nd Year TD (Northeastern University 1990)
Yan Sun 2nd Year Consulting TD for GDEB (University of Maryland 2004)
Manbir Sodhi 2nd Year Consulting TD for Hexagon (University of Arizona 1991)
Elliot Young eMoney Advisor (Rhode Island College 2018)
Darius Strasel eMoney Advisor (Udemy Academy 2017)
Brendan O’Reilly Teknor Apex (McMaster University 1982)
Mickey Monarch Teknor Apex (Boston University 2008)
Ye Zhao Analogic Corporation (Northeastern University 2015)
Tim Prouty Analogic Corporation (Rensselaer Polytechnic Institute 1979)
Patrick Byrne FM Approvals
Gary Buker Cambridge Technology

Thank You Technical Directors for your support and mentoring engineers of the future!
You are an important component of The ELECOMP Capstone Bridge: see the back cover
PROJECT MOTIVATION:

All electronic devices require energy to operate – which can be derived from a voltage and current value. In these electronics, power consumption changes over time; appliances consume a varying amount of power depending on their intended usage. By analyzing power consumption, a system can uniquely identify specific device characteristics. Through learning this “power signature”, a system could identify abnormal device behavior and notify users to prevent catastrophic failure.

Due to the deployment of Acumentrics’ systems in secure environments, data collection will not occur in the field. Therefore, most cases of failure analysis occur upon the return of the system to the company, usually after system failure. 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, we hope to be able to predict electromechanical failures.

ANTICIPATED BEST OUTCOME (ABO):

The ABO 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. Should our team accomplish the ABO for one device, the ideal outcome would be a prototype that can perform the above action for multiple devices connected on the same line, with unique identification of each device based on its signature.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:

As Acumentrics’ products are built to last in normally inoperable environments, integrity is an absolute requirement. As the company extends its knowledge of power systems to autonomous power, the need for data analytics and understanding continues to grow. To have a deeper understanding of electrical devices and their power signatures, Acumentrics can not only improve its own products but also improve the longevity of devices connected to those products. Therefore, the economic impact is too large to accurately measure. For existing customers, the project would allow Acumentrics to better understand its devices’ points of failure and continue to improve the longevity of those devices.
ACCOMPLISHMENTS TO DATE:

**Appliance Selection:** A fan was selected as a target appliance due to its low-cost, easily induced electromechanical faults, and complex power load. Since the appliance has both real and complex power components, the unique power signature of the device will be more identifiable. Additionally, fault modes were identified to be inducible via both environmental factors and electrical power failures.

**Integrated Circuit (IC) Selection:** After thorough research, the analog ADE7880 IC and corresponding evaluation board 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.

**Prototype Assembly:** A functional prototype was designed, encompassing the evaluation board, current sense transformers and 3.3V power supply (Fig. 1), allowing us to sense the power data from the fan. The system is stored in an encasement with three connection receptacles: USB Type-B for computer connections, NEMA 5-15R single wall outlet input for the fan, and a C13 power socket that will feed electricity to the system from the wall (Fig. 2).

**Machine Learning (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 an RNN.

**ML Training Setup Formation:** A script was developed to train an RNN using TensorFlow. The process includes splitting the dataset (i.e. training, validation, and test), training the model on data windows from the training/validation datasets, and evaluating the model accuracy on the test dataset. As input, a user can define the batch size, number of epochs, and data window size.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

**Data Collection:** Using the ADE7880 LabView software, the power data from the microcontroller can be visualized. However, access to the underlying power data is limited. Thus, a method for the collection and storage of the power data must be implemented to train the ML model.

**ML Model Accuracy Improvement:** As with any ML application, the main focus of the model development is on improving its accuracy. For the given application, there are a variety of methods that can be utilized to enhance the accuracy of the ML model. These methods include model hyperparameter tweaking, generation of additional feature vectors, and varying the model layer structure.

**Inference System Design:** A system needs to be designed to enable efficient model inference (Fig. 3). The system must be capable of measuring power data, feeding the data to the ML model, and informing the user of the end result. As such, the planned implementation involves using a Raspberry Pi to both facilitate the IC communication and handle on-chip model processing (Fig. 4). Additionally, the Raspberry Pi will notify users of the model prediction via LEDs and cellular messages.

**SPI Communication Implementation:** Due to the lack of a pre-built library for the ADE7880, a library will be implemented that utilizes built-in SPI functions to communicate with the IC. Although the IC manufacturer provides adequate documentation of the protocol, the technical complexity of the implementation is difficult to assess.

**ML Model Export:** To utilize an ML model on a microprocessor, the model will need to be exported from TensorFlow to TensorFlow Lite and deployed onto the microprocessor. This process poses a variety of technical challenges, including ML model conversion, ML model deployment, and microprocessor software development.
** Fault Line – Power Signature Analysis for Fault Detection and Predictive Maintenance **

acumentrics.com

**Fig.1:** The functional prototype assembly

**Fig.2:** The functional block diagram
Fig. 3: ML inference process

Fig. 4: Communication flowchart for the ML inference system
PROJECT MOTIVATION:
Acumentrics is known for designing and building UPSs, 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 printed circuit boards with numerous responsibilities. With an automated testing system, the testing process becomes quicker, 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 of Project “Volta” is to eliminate that step by testing each board 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.

ANTICIPATED BEST OUTCOME (ABO):
The ABO would result in a functional prototype system that is capable of performing automated load tests of the 1U Blade’s DC/DC output board and charger board. The system must compare the observed characteristics of each board to values sensed by the testing system. These values will then be used to determine whether the board is acting as it should or is faulty. This system will not rely on any other systems within the 1U Blade and it will visually indicate to the operator the results of the test and data for analysis.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:
Acumentrics is a small company that designs and builds AC and DC power sources for secure environments, such as war zones. The economic impact, that our automatic test station will have for the company, is saving time and money by making sure that no faulty product is shipped out to the customer and ensuring that engineers do not have to disassemble the entire 1U Blade system to repair one board. The manufacturer will have our test kit and use it to make sure the printed circuit boards function properly. By having this, Acumentrics will have more time to spend on other products and operation of the company.
TECHNICAL ACCOMPLISHMENTS TO DATE:

High Voltage: The boards under test (Fig 2) require an input voltage of 200V. This high voltage requires the use of safety equipment during testing. Following research, we created a high voltage safety document to reference and determined the needed personal protective equipment which includes safety glasses, gloves, and an ESD mat. The testing environment (Fig 1) also shows the Device-under-Test (DUT) enclosure, safety barriers, and proper signage.

Test Environment: Equipment used in the automated testing environment includes a programmable DC load, data acquisition unit (DAQ), and both high and low voltage supplies, as seen in Fig 1. The DAQ contains a 20-channel multiplexer module (MUX) and 20-channel switch module. The switch module opens/closes relays to direct low voltage inputs to the boards. The MUX reads both the low voltage signals and the output voltage for validation during testing.

Manual Testing: It was required to construct cables for connecting the test equipment to the board, seen in Fig 1. It was essential to ensure an accurate gauge wire and use disconnects for a quick change between the board being tested. Manual testing was performed to determine how the system would be wired, how each board functions, and to troubleshoot the LabVIEW virtual interface. It was also decided that monitoring the output voltage from the board while varying the load using a constant current configuration would be the test method.

Flowcharts and Block Diagrams: Flowcharts for setting up the manual and automatic test and block diagrams as seen in (Fig 3) were made, as well as a block diagram for the LabVIEW virtual interface. These documents provide proper record and ease for anyone who wants to implement the automated test.

LabVIEW code: The DAQ and programmable load are communicated with using LabVIEW. A virtual interface (Fig 4) was designed that sends low and high voltage signals to the board. It also tells the programmable load to vary the constant current beginning at 0A. Then it uses the MUX to read the signals, as well as the output voltage to ensure the board is performing according to its specification. Additionally, the test program will notify the technician whether the board has passed/failed, or if there is any other error.

Automatic Testing: The steps for manually assembling the equipment and LabVIEW virtual interface were combined to achieve an automated output voltage test that is compatible with both the DC/DC output board and charger board.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Power Supply: For the automated test system, we decided on using a programmable high voltage power supply. A High-Performance Programmable AC Power Source has been ordered. In its place, we have been using the UPS provided by Acumentrics. The project is not held up, but when the power source does arrive our design will be completed to the point in which we intended.

Technical Difficulties: Occasionally, the boards under test or the equipment malfunctions. It takes time to receive and test additional boards, or to troubleshoot the errors within the system, thus preventing us from reaching the anticipated best outcome. It is essential that there are no errors like this and that the design is seamless so Acumentrics can use it without any complications.

Clean Design: The Anticipated Best Outcome has been met, but the final steps include cleaning up the LabVIEW virtual interface so it can be easily understood and used by an outside technician and ensure there are no errors with any of the hardware that may prevent accurate testing or smooth transition between the boards being tested.

Extended Best Outcome: Since the Anticipated Best Outcome is close to being reached, to advance the project, we have set a goal to use our system to test all of the boards within the UPS. This will require studying each board’s different specifications and then modifying any of the hardware and LabVIEW virtual interface. Additionally, we will modify LabVIEW to log data it is currently reading. In the end, our design should be compatible with and able to test any board within the UPS.
Volta – Automated Variable Load Testing of HV DC Output Boards

Fig.1: Test Environment

Fig.2: DC/DC Output and Charger Board
Fig. 3: DC/DC Output Board Block Diagram

Fig. 4: LabVIEW Load to Charger Board
TECHNICAL DIRECTORS:
Tim Prouty
Ye Zhao

TEAM MEMBERS: (L to R)
Luis Ibanez (C)
Rebecca Pham (E)

PROJECT MOTIVATION:
When working with performance-critical machines such as MRIs, unit shutdowns can be highly detrimental in regard to time, resources, and product reliability. Oftentimes, the cause of the shutdown is related to the gradient amplifier power stage - specifically, (1) the temperature of the insulated gate bipolar transistor (IGBT) surpasses acceptable thresholds or (2) exhaustion of the high-voltage capacitor banks supply. These issues can, and should, be avoided at all costs. If a machine operator is able to determine the feasibility of a current input waveform before actual application, then the chance of failure can be eliminated. Thus, having a user-friendly software that can model the operation, ensure completion of the task, notify users of predicted success/failure outcome, while accounting for present capability of the GA, is highly desirable. The motivation for this project is to increase the safety and reliability of MRI operations.

ANTICIPATED BEST OUTCOME (ABO):
The ABO will manifest itself as a complete deliverable of a fully-functional software package which can accurately model the electrical limitations & thermal behavior of their gradient amplifier systems. The software package will be developed using an encryptable, freely accessible, versatile programming language that can perform efficient computation. Proper coding practices and maintainability will be kept in mind during development. It will contain a user-friendly GUI with the ability to perform simulations that will predict failure and shutdown of the MRI gradient amplifier unit. A software user manual will be included.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:
Achievement of the Best Anticipated Outcome will help MRI installers, developers, and operators optimize use of Analogic gradient amplifiers (GA). This will reduce the unit failure rate during real operation and increase the overall system reliability and safety. More importantly, the proposed software would be beneficial to both operators and patients because it can minimize the operation risks including unit shut down, failures and any unexpected interruptions. Overall the implications will lead to: (1) Improved user experience and satisfaction, (2) Improved safety and reliability, (3) Proactive prevention of any unexpected results or failures, and (4) Augmented customer loyalty and relations.
TECHNICAL ACCOMPLISHMENTS TO DATE:

Programming Language Selection: Researched different programming languages to fulfill project needs. C++ due to efficient performance and compile-based nature. Managing the software at a lower level allows us to perform efficient computation on the large datasets that will be handled, and being compile-based will make incorporating encryption simpler in the future.

Prototype User Interface Creation: Created a prototype for the user-interface for software’s expectations and user-flow. Used to guide the design of the software’s frontend and backend.

Frontend Diagram: Designed a Frontend Diagram based on Unified Modeling Language (UML) concepts. Based the Diagram on the prototype interface and made additions and changes in parallel with designing the software’s Backend. Planning out the software design before implementation ensures fewer bugs encountered during development.

Backend Diagram: Designed a Backend UML Class Diagram that describes the way that the software will perform the simulation using the thermal and electrical models in an object-oriented fashion. Used Google’s Unit Test library to guide the backend implementation.

Review LTSpice Files: Understand how to effectively use LTSpice as an electronic circuit simulator (Fig. 3). LTSpice simulation results are the basis of C++ programs which model the thermal and electrical behaviour of the gradient amplifiers.

Thermal Model Development: Pseudocode, originally written in Pascal, was translated and used to create a basic C++ framework which describes the Gradient Amplifier (GA) thermal response to a variable user input. The thermal model predicts junction temperatures to predict failure due to temperatures exceeding thresholds.

Electrical Model Development: Investigated LTSpice files to derive mathematical equations describing the electrical relationship between multiple GA components. Pseudocode was developed and used to develop a rudimentary functioning C++ model of the Electrical Model. The electrical model predicts if user input waveforms will exceed power supply limits and go into automatic shutdown.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Research Graphing Solutions: Research will need to be conducted to determine a graphing solution that both works in the “Dear ImGui” framework and displays all the necessary information that will be desired of the plots provided by the program. A custom graphing solution may need to be developed to show all the variables a GA operator may want to know.

Finalize Software Architecture: Compile the User-interface, Frontend Design, and Backend Classes for the software’s architecture, linking together the dependencies between them.

Integrate and Debug Software: Using the final software architecture, implement the software using the pieces created while designing and testing the implementations for the frontend and backend, linking them together to provide a complete, user-friendly experience. This will involve starting a repository for proper version control and applying careful documentation practices to make sure that the software will be easily maintainable. Software will also need to be debugged on Windows 10 and possibly other operating systems.

Thermal Model Refinement: Must finalize C++ Thermal Model and integrate into software’s backend. Need to integrate into class structure, save simulation outcome, and plot relevant results for informative user display.

Electrical Model Refinement: Must finalize C++ Electrical Model and integrate into software’s backend. Bugs continue to be addressed to more accurately match LTSpice simulation results. Need to incorporate class structure, save program outcome, and plot relevant results for informative user display.

Increase Hardware Support: After finalizing implementation for the AG700 models, expand development to include support for additional Analogic products.

Create User Manual: Compile a succinct and informative user manual for GA operators to navigate the User Interface. Will include instructions on how to use the tool, interpret results, and documentations for any updates that Analogic may want to include in future versions.
Software Development of Thermal and Electrical Model for MRI Gradient Amplifiers

Fig.1: Expected User Flow

Fig.2: Configuration Menu Prototype
Fig. 3: Sample Input Waveform through X, Y, and Z axes, respectively

Fig. 4: Backend Structure
TECHNICAL DIRECTORS:
Mark Lucas
Seetharam Sivam
Gary Buker

TEAM MEMBERS: (L to R)
Travis Frink (C & E)
Nick Schmidt (E)
Rory Foley (E)

PROJECT MOTIVATION:
Cambridge Technology currently produces a laser polygon scan head for surface etching available to consumers. 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.

ANTICIPATED BEST OUTCOME (ABO):
On completion of the project, it is expected that the Scan Master Controller hardware system will be fully equipped to process and control the printing of raster images using a polygon-based laser scan head. This will be done completely in firmware modifying the SMCServer, Marking Engine, and Verilog logic components. A custom printed circuit board interface will be developed in order to interface the polygon scan head with the Scan Master Controller. Lastly, the graphical user interface software that goes along with the CT’s current controller, Scan Master Designer, will be updated to allow easier user configuration of the new polygon based system.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:
Due to the results of business acquisitions, the polygon scan heads currently produced by Cambridge Technology are interfaced with a controller produced by a competing company. The goal of this project is to modify a currently produced product line, the Scan Master Controller and Scan Master Designer laser scanning control solution, to replace this competitor’s controller. Doing so will allow Cambridge Technology’s customers to be able to use their polygon scan heads with a familiar controller interface. It is anticipated that this new feature of the Scan Master Controller, will generate $500k-$800k through additional system sales.
TECHNICAL ACCOMPLISHMENTS TO DATE:

Hardware Familiarity: The ScanMaster Controller uses the Xilinx Zynq-7020 at its core for the handling and processing of vector and raster data streams. Two ARM cores and memory mapped programmable logic accessible with ARM’s AXI Bus Technology are used to provide custom hardware access in Linux user programs. (Fig. 3) Efficiently making changes to this system has required an understanding of this technology.

Synthesis and Testing Environment Tools: The Vivado and Xilinx software development kit were used for the creation of the Polygon Scan head controller firmware. A workplace was configured on a machine that allowed the team to update the system while protecting version control and data integrity. (Fig. 2)

Legacy Code Documentation: Over 50,000 lines of code make up the software and firmware used to perform inter module communication and data processing in the system. A great deal of effort has been put into understanding the current software stack which consists of a combination of C, C++ and Verilog.

Single-Bit Resolution: Previously the system processed raster data with 8 bits of data used per pixel. To decrease the amount of internal bandwidth used and increase raster processing speed the amount of data used per pixel was changed to a single bit. (Fig. 1) Since in laser engraving the only data necessary is if the laser is on or off this can be represented as a single bit of digital logic.

Software Debugging using Serial Communication: To properly observe the functions of the Scanhead Master controller, we used a serial connector to communicate with the two onboard processors and step through the process of image etching. Combing through the dense code library of the scan head controller, we updated lines of code to make the controller run efficiently and work properly with the new polygon scan head.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Adjust Laser Fire for Timing Feedback: (Fig. 4) The polygon scan head device should be able to adjust the timing of the laser firing to account for the speed of the polygon system. The polygon system sends feedback to the controller alerting it of which facet of the polygon it is on and when it is up to speed. Using these feedback signals the controller should be able to correctly calculate the timing at which the laser should fire in order to keep the image quality in line.

Creating Hardware Interface of SMC: The control box for the polygon scan head has been designed already and the dimensions of the box should be large enough to accommodate the ScanMaster Controller. The scan head master controller does not perfectly link to the polygon scan head with easily managed cables so an adapter card will be designed to allow for proper interfacing with the scan head in order to keep wire management tight and easy to manage.

ScanScript Language Support: Users should be able to use Cambridge Technologies ScanScript language to control job settings, such as scan speed and resolution. Using this scripting language, the Scanhead master controller should be able to interface with the scanhead to put these settings into place and allow users greater control over their scan jobs.

Multiple Polygon Scan: The polygon scan head comes with multiple options for number of facets. Each option will operate similarly but the key of operation is that each line in the scan is timed so that it matches with a single facet of the polygon. The ScanMaster Controller should be coded to accommodate for every design of the scan head without, marking errors, timing delays or phantom pixels etched into the canvas.
Fig. 1: The data sent from ScanMaster Designer must pass through several layers of processing before ultimately controlling the galvos and laser output signal.

Fig. 2: The ScanMaster Controller (SMC) is setup for debugging with JTAG and Ethernet connections to a PC running ScanMaster Designer. Connections from the SMC and ScanMaster 1000 supply the Galvo-based scan head with control and power.
Fig.3: ScanMaster Designer has only 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 end point of control for the laser and polygon scan head.

Fig.4: 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 as well as raster images.
PROJECT MOTIVATION:

In the Agile process the “Definition of Ready” is used to ensure a unit of work is in a workable state with as little risk and delay as possible. A team agrees on a set of statements that must be true in order for the work to begin. There are no tools that currently walk a team through their agreements during the backlog refinement process. During the backlog refinement process there is a lot of discussion about each item, which is not captured in any form. When looking back at items that have already been planned, teams often need to rely on their memories, with details slipping through the cracks. The RU Ready application will automate the process of walking through a team’s definition of ready. It will provide a guide to discussing the aspects of a story and capture the important points of conversation around that story.

ANTICIPATED BEST OUTCOME (ABO):

By the completion of this project, the ABO will be an application that is capable of: Creating and editing a Team’s Definition of Ready (DoR); Connecting to Jira to retrieve backlog items; Presenting story information with the team’s DoR items; Recording and tracking discussion points and approvals from each participant related to Definition of Ready items; Signaling users when the team has approved the story against the DoR; Switching between DoR items and being able to view comments on those items; Saving the results of the discussion back to Jira.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:

The ABO would help each of the teams at the company to communicate about the work they do. By doing this, each team will think through each item of work before they start it, including breaking work into smaller pieces. Planning ahead tends to make teams much more consistent and reliable as they become better at determining their work capacity. There is no tool made specifically for coordinating the discussion of stories. If this application is determined to be useful it is possible that it can be adopted by a broader user base in the future.
TECHNICAL ACCOMPLISHMENTS TO DATE:

List of Teams: Developed React components in JavaScript capable of displaying a list of team’s information to the screen via a webpage Fig. 1. The frontend React components request the team information from a backend C# API capable of either producing a list of all teams or the information of a single specified team. The team information is stored locally as a .json file on the backend and incorporated into a local Redux store to be utilized by the frontend.

PBI Modeling: Developed a backend data model to represent a team’s definition of ready. A definition of ready is list of criteria used to determine a backlog items readiness to be added to a sprints task list Fig. 2. This data model can allow non-uniform definitions by supporting several types of definitions including simple Yes/No, selection from a list and free form text responses. The user can then use these types to create ready criteria populated with a description and an optional list of modifiers.

Code Maintainability: Reviewed and refactored the entire code base to conform to SOLID principles. Common patterns and code styles were agreed upon to allow the code base to remain functional, maintainable and uniform. Refactoring the application code to meet these standards will facilitate future development.

Configuring Definitions: Developed interactive React components on the frontend to guide the user through defining a team’s definitions of ready using the backend data model. Currently a repository has been populated with sample definitions of ready using several definitions shapes. A backend C# API was designed to retrieve this data from the repository and allow the frontend to display the definitions of ready for a team.

Database Integration: Local instances of Jira and Azure SQL have been installed and populated with sample backlog items and definitions of ready. API stubs have been developed to interface with these databases in order to retrieve data and update entries within the database.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Editing Backend Data: The current web app allows for the fetching and clearing of displayed data, but not the editing and changing of that data. Implementing the post and push API endpoints will be one of the final things needed to finish the configuration part of RUReady, as actual configuration will be possible.

Refinement Sessions: RUReady exists as a web application delivering a single page application to a client, as shown in Fig. 3. Within that context the two main functionalities are, defining a definition of ready, and running a refinement session to determine if backlog items are ready for the next sprint. The first functionality has been mostly completed while the second functionality is the main technical challenge in the semester ahead.

Cooperative Editing: One of the systems wanted for the Best Anticipated Outcome is the ability to have multiple users actively editing text and yet making independent selections recorded as individual users. This will likely require an external library that will need to be vetted to work with the eMoney internal systems.

Online Deployment: Currently the systems function without database integration and to non-live local versions of endpoints. One of the more important things we will be doing is linking to live pages and establishing end-to-end data flow, as shown in Fig. 4. This will allow us to cover all the skills and tools from the Best Anticipated Outcome.

Refinement Review: A want-to-have within the Best Anticipated Outcome is the ability to go back to previous refinement sessions to see the votes, comments, and other logged outputs. The users would also potentially be able to view some low-level analyses like the percentage of agreements over time.
Fig. 1: Screenshot of Teams list page populated with Team data

Fig. 2: Outline of Scrum iterative development process with emphasis on Sprint Planning
Fig. 3: Container diagram for the RUReady application

Fig. 4: Data and software flow diagram
PROJECT MOTIVATION:

FM Approvals tests and certifies gas detectors 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 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. The process is manual 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.

ANTICIPATED BEST OUTCOME (ABO):

The ABO is modifying the current manually operated system to a fully automated one. This system is filling the apparatus with a measured volume of test gas. After that, the automated system will expose the gas detector to the test gas. The gas detector will output a voltage related to the response time and passed along to the automated system for recording. Finally, a report with the reading will be generated with a pass/fail indicator reflecting the current form used by FM Approvals. These reports and test measurements will be saved for a period of two weeks.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:

The ABO of this project will allow FM Approvals, to reduce test time and allow for consistent, reliable, and repeatable results. These characteristics are difficult to obtain due to operator error and human reaction time as the manual system requires two people to operate. With an automated system, FM Approvals will offer more competitive proposals to their customers. FM Approvals will also expect savings of $15,000-20,000 per year. Lastly, the test apparatus may be incorporated in various gas detection standards in the future, as the reliable test data will be available.
TECHNICAL ACCOMPLISHMENTS TO DATE:

**Arduino:** Serving as the conductor of the operation, the Arduino allows for a repeatable and automated testing process. To replicate the current manual testing process, a finite state machine (FSM) had been implemented into the Arduino code. To describe the overall structure of the FSM, a flow chart had been created (Fig. 3). The FSM uses multiple states to control gas flow and allocate data from the gas detector under examination. The Arduino interprets the raw data into an array that is suitable for the GUI to work with.

**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 process that will be used for creating the test pass/fail report. The GUI also exports a csv file (with auto-generated file name) when done with the test run. The GUI also has a running stopwatch visual 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 2) in accordance with the derived flow chart and returned accurate test results to the GUI for processing.

**Pneumatic Knife Gate Valve:** To automate the test process, the choice of a pneumatic knife gate valve and smaller solenoid valves proved to be effective after individual tests. With these components working in unison, the flow of test gas to the lower chamber and then to the gas detector will be fully automated. (Fig. 2)

**Mounting Bracket:** To mount the solenoid valves associated with the pneumatic valve, a mounting bracket was developed to maintain a “clean” structure of the apparatus. This design has been 3D printed and implemented. (Fig. 2)

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

**GUI Refinement:** The GUI’s options for test related details need to be connected to the backend to ensure that this information will be included in the test report. The test report is another challenge, as it requires research to create a template, and design it in the likeness of FM’s test report. We will need to debug the form to make sure the data is accurately shown and that no data loss occurs.

**Database Creation:** The next step for the GUI is to implement a database where the test results will be stored over a period of two weeks. This will ensure that test values can be processed to fill out a template that includes a pass/fail indication as desired by FM Approvals. The csv file currently created by the GUI also needs to be debugged, so that it can be loaded into an SQLite tool to generate table entries.

**Arduino/Apparatus relationship:** Experimentation with data allocation has been executed with a current sourcing multimeter (Fig. 1). The next challenge is to run a test with an actual gas detector which will source current. Although this is a highly important task to be completed, it is a low priority at the moment, as working with test gas requires a controlled environment and a more complete system. Also, the development of a housing for the Arduino, power bus, and breadboard must be developed and 3D printed.

**Hardware Assembly:** In assembling the hardware and pneumatic fittings, it is crucial to ensure that there are no air or gas leaks. As of now, the hardware has been test fitted for a proof of concept, but the final assembly has not been completed. This final assembly will include using Teflon tape to ensure that all of the fittings are airtight. The solenoid mounting plate must also be refined in order to accommodate the smaller solenoid valves that will operate the pneumatic knife gate valve.
Fig.1: View of the current electronic components including the current source, relay module, power bus and power source.

Fig.2: View of the test apparatus with newly integrated components including the pneumatic knife gate valve, solenoid mounting plate, solenoid valves, and lower chamber.
Fig. 3: System Diagram including the Arduino, GUI, and test apparatus connections.

Fig. 4: Graphical User Interface showing data collection, test timer, and control buttons.
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. Furthermore, in addition to being able to effectively apply predictive maintenance to avoid unexpected equipment downtime, the Digital Twin will lower maintenance costs that may be incurred by preemptively replacing components far before the date when they would actually have to be replaced.

ANTICIPATED BEST OUTCOME (ABO):
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.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:
If successful, the Digital Twin project would serve as a proof of concept for GDEB, demonstrating that it could be used to aid in predictive maintenance on real-world products. Successful integration of the digital twin concept could reduce downtime incurred as a result of unplanned system failures. The ability to accurately determine when physical components will require expensive and time-consuming overhaul and maintenance will avoid critical naval assets being unexpectedly removed for maintenance. This system can also reduce the costs associated with expensive preemptive maintenance that would otherwise be done far in advance of when it is actually required.
Sensor Acquisition: The sensors the team decided on using were the Temperature and Humidity sensor, an accelerometer/gyroscope, and a Flow Meter sensor. Each of these sensors were carefully researched and tested for their practicality in predicting future breakage of certain aspects of the water pump.

Physical Asset: The pump that the team selected (Hayward PowerFlow Max) was chosen for its combination of the desired levels of cost, durability, performance, and support. The team arrived at Hayward’s offering after a competitive comparison of many other pumps in the field. This choice was vital. If the team had chosen a pump that was too durable, they would have difficulty provoking failures over the short duration of the project. If the pump was naturally prone to failures, they would be unable to determine if a given failure was due to intentional efforts or unrelated reasons behind the scenes. Furthermore, if the team made the wrong choice and had to change pumps later, they would end up wasting a significant amount of time, money, and work. After much deliberation, Hayward’s PowerFlo was selected as the best combination of all factors considered.

Database Development: One of the major components of the project required an easily accessible and secure database for save, store, view, and read data. Database schema has been implemented using Django to handle requests and responses including: sensor data, GUI queries, and ML queries.

GUI Development: The core of the GUI that displays the data from the procured sensors has been designed. After researching several frameworks, the team decided to use PyQT due to its ability to create stand-alone cross platform executables and stability.

Assembly of Remaining Sensors: After receiving a baseline of data, more sensors will need to be added on different parts of the water pump. Adding sensors to different parts of the pump contains finding a way to keep the sensors in place and protecting them from any water or leakage of water. In addition to adding more sensors, the team may need to order different types of sensors than those originally chosen.

Optimization of GUI: The core of the GUI is already designed; However, there are some features that still need to be implemented. Such as the visualization of sensor data and the remaining useful life of the water pump. We will also include a window that allows the user to see the current status of the mounted sensors. Therefore, the user can see whether the sensors are working properly and providing useful data.

Failure Testing: The team will use the remaining time in the project to conduct tests that will allow them to gather data on how various pump components progress to failure under multiple environmental factors that impede the pump’s normal function. By measuring the slow demise of the pump under different hostile conditions, the team will be able to use that data to develop a database that can predict the lifespan of the pump when given its real-world status. If the real-world pump is subjected to stress the Digital Twin model will be able to predict the impact on the lifespan of the real pump.

Data Analysis and Predictive Learning: With the database initialized, a simple Python program will communicate with the Django web-server to query live sensor data, portray the data into a human-readable graph, and translate the data into a machine learning algorithm to predict the remaining lifetime of the water pump. Ultimately, users will be able to easily determine how long the water pump will last, and what may be causing the decrease/malfunction from the live sensor readings.
Fig. 1: Sensor integration with a Raspberry Pi 4

Fig. 2: Overall Project Block Diagram

High-level Digital Twin Project Diagram
Real-time data flow and its desired process to be implemented and presented to users for an easy-to-use, human-readable format with accessible and reliable information.
Fig. 3: PowerFlo Matrix Water Pump / Installing Sensors

Fig. 4: Pump Reservoir Assembly
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.

ANTICIPATED BEST OUTCOME (ABO):

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. Stretch goals, or better than expected outcome, would include using camera systems already designed for the UR robot and having that system also capable of barcode reading and or OCR reading of labeled or marked parts.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:

A system that is 99% successful at identifying trained parts will contribute significantly to labor cost reduction for the inspection process since no data entry will be required by an operator at the time an inspection job is initiated. Although the present solution automates the physical loading of parts onto a CMM for inspection, it still requires data entry by an operator. This data entry is both prone to error as well as time-consuming since someone must be physically present at the system to enter the information. This functionality will solve this very apparent problem for our customers, and they will recognize the value-added in terms of both efficiency and traceability.
TECHNICAL ACCOMPLISHMENTS TO DATE:

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 IDS LE Camera in our design.

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.

Blender Algorithm Testing: An essential step in our design is to obtain image data on Blender by using the program’s camera function. This process is used to capture images of the object as the viewpoint is rotated at set degree intervals for each dimension. From this, we can also generate the appropriate outputs and labeling for each generated image, including object bounding box, classification, orientation, and mask information. The script is currently in use and we use the image data generated by Blender to perform training and testing on the existing neural network model.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Hardware System Design: Although we have acquired most of the hardware components we need for this project, and we have performed testing on individual components, the remaining task from the hardware aspect will be integrating all the components into one functional system that would cooperate with the trained neural network model.

Prototype Testing: Once the model has been fully trained on the entire dataset of provided objects, we will need to conduct tests to benchmark its effectiveness. Additionally, it is likely that the performance of our current design will be susceptible to change under different lighting conditions. Hence, we will have to conduct a few more testing under different lighting intensity conditions once we have everything integrated into one functional prototype.

Continued Training: We currently have a base trained model to perform object classification using the CAD models we were provided. This model was trained for a limited amount of time using transfer learning and its performance reflects that. Continued progress on this capstone project will certainly involve additional training and refinements of this model to improve accuracy and efficiency.

Orientation Detection: Currently, we are working to train models to perform Object Classification and Segmentation. However, another important computer vision task for this project involves determining the orientation of an object after it has been identified to evaluate if it has been loaded correctly into the drawer.

Uses and Limitations: After experimenting with the prototype, we will have the results of the performance under different lighting conditions, and we may use the results to formulate potential limitations with our design. In addition, we could also use the results to formalize the lighting conditions and image background in our design to deliver the best-anticipated outcome in the factory environment.
Fig. 1: Two Sample Drawer Layouts

Fig. 2: ResNet Model Layer Design
Fig. 3: Flowchart Detailing Training Process for ResNet Model

Fig. 4: Sample Output of Trained Model
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.

ANTICIPATED BEST OUTCOME (ABO):

The ABO is a functional prototype of a digital twin TouchPoint device. 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.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:

Achieving the anticipated best outcome for this project will result in IGT having greater insight into the overall health of their vast network of TouchPoint devices, which spans many states and countries. IGT has stated that maintenance of their TouchPoint fleet of terminals is an enormous cost to them which includes but is not limited to; penalties for the downtime of their devices, field service visits, as well as various other maintenance costs. By reducing these costs, the digital twin and predictive maintenance engine would have a significant positive economic impact for IGT as well as build consumer confidence in the long-term viability of their products.
TECHNICAL ACCOMPLISHMENTS TO DATE:

INA219 Current Sensor (Fig. 1): Used a current sensor to read the draw of the DC motors when they are active. The hypothesis behind using this sensor is that the motors will draw more current when the attached rollers are dirty after long-term use. This was supported by initial testing with the sensor that showed when using multiple play-slips to increase resistance the motors were drawing more current than when a single slip was read. The data from this sensor combined with that of the vibration sensor should provide valuable insight into when the terminals will experience a failure.

Minisense 100 Vibration Sensor (Fig. 2): Mounted a through-hole board with a vibration sensor to the TouchPoint terminal chassis using a screw that holds together the play-slip reader module. This allows for an accurate reading of how the terminal vibrates when the play-slip reader motor is active. The goal of this sensor being to distinguish if there is a difference in terminal movement when the rollers attached to the motor are clean and when they are dirty (near-failure) after long-term use. The sensor operates on the piezoelectric effect, producing a voltage in response to applied stress.

Plugins (Fig. 3): Developed several plugins for the telemetry-collection daemon, CollectD, such as a plugin to collect information from the CPU temperature sensors, to collect storage device health information, and a plugin to collect the terminal’s BIOS information. In addition to this, we have also developed a current sensor plugin which will notify the Digital Twin when the printer draws too much current, which can be a sign that a failure may occur in the near future.

Communication Between Arduino and TouchPoint Terminal (Fig. 4): After properly connecting the sensors to the Arduino, a method was needed to transfer the data from the Arduino back to the terminal so it could be processed. Since the Arduino is connected to the terminal via USB, we implemented a method utilizing the serial connection to get this data to the terminal. Once the data is transferred successfully from the Arduino to the terminal, the terminal is able to parse it.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Reading of Input Current and Voltage to Terminal: On the AC input side where the terminal plugs into the wall, we would like to be able to read the current being used by the terminal and the AC RMS voltage that the wall is supplying. We plan on accomplishing this by creating a box within which will be the relevant sensors will be placed. The box will act as an intermediary between the wall supply and the terminal, placed in series between the two. The terminal will plug into the outlet on the box which will be plugged into the wall. As of now we have a sensor selected to read the current (ACS712) but not one to read the voltage.

Analyzing Vibration Waveform: We need to find a way to distinguish between different vibrational waveforms on the terminal. Examples of what types of vibration the terminal can experience are; motor on, opening and closing of the LCD screen, physically moving the terminal, and applied shock by means of an intentional or unintentional impact. In order to provide useful data to the machine learning algorithm it will need to know the type of vibration that occurs.

Creation of the Digital Twin: We need to use all of the telemetry data we pull off the terminal to create a digital real-time representation of the physical device. We will be using Microsoft Azure as our platform and the data will be passed via the MQTT protocol.

Adding Additional Sensors: At the moment, there are tentative plans to add additional sensors such as those to detect temperature and humidity. We believe that there could be value in adding these sensors as they will provide the predictive maintenance engine with more useful data to anticipate a failure. Finding a way to seamlessly integrate these sensors with existing ones will be crucial.
Fig. 1: Motor current draw with varying numbers of play slips (resistance)

Fig. 2: Vibration sensor mounting on terminal
**Fig. 3: CollectD Data Flow**

**Fig. 4: Data Flow Between Sensors and Terminal**
**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 angle of the mirrors and their relative positions within their housings are imperative to the quality of the laser’s functionality, and must be aligned within a few microns of design dimensions to achieve optimal laser light performance. If mirrors are misaligned, power and reliability will be degraded, leading to a financial loss for Iradion. Additionally, the mirror surfaces cannot be touched in any way or they could be damaged. Even the slightest imperfection in the mirror surfaces could severely impact the performance of the laser. Therefore, creating an in-process inspection station that can evaluate the mirror assemblies both quickly and with no contact would ensure that the cost of laser production is kept at a minimum for Iradion.

**ANTICIPATED BEST OUTCOME (ABO):**

The ABO of this project would be to create a table top optical inspection station that will provide Iradion employees with a way to check if their mirror assemblies meet mechanical design criteria. The software will compare the scanned data to the mechanical model of the mirror assembly, and provide a Pass/Fail indicator based on the dimensions of the assembly as well as the position and angle of the mirrors. If the Fail indicator is displayed, an error report will be generated to provide the user with the dimensions and measurements that fall outside of the thresholds.

**IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:**

Meeting the Best Anticipated Outcome would save Iradion substantial time and resources in their laser production process. Currently, abnormalities in the mirror assemblies can only be observed once the laser is assembled. To correct the abnormalities or replace the faulty part, one must disassemble the laser, fix the part, clean the mirrors, and reassemble the laser. This is a lengthy process that can be avoided if the part is deemed faulty to begin with. Completion of the Best Anticipated Outcome would allow Iradion to grow substantially as a company and improve their laser production process to meet the growing market demand.
TECHNICAL ACCOMPLISHMENTS TO DATE:

3D Scanning Techniques: Many possible 3D scanners were researched. It was found that the most common technique for scanning highly reflective surfaces involves coating the mirror surface with a spray or powder, which is not a viable option since the mirror cannot be contacted in any way. A scan of the mirror was able to be acquired using a blue light scanner, but these types of scanners are well outside of the budget for this project.

CMM Technology: Coordinate Measuring Machines (CMMs) use a combination of touch probes, white-light scanning, and laser scanning to provide the utmost precise measurements. During the demo at Hexagon Manufacturing Intelligence, it was found that while CMMs are useful tools, a CMM cannot be utilized for the project since it is out of the given budget. It is also a much slower technique; it takes well over a minute to probe one mirror sub-assembly.

Graphical User Interface: The GUI allows the user to select one of three different types of mirrors. While the scan is underway, the expected values are loaded into the GUI. When the scan is complete, a .CSV file is created; consisting of the name of the measurement along with the measured value. These values are then imported into the GUI, and calculations are performed to determine the percent error and if the measurement is a pass or fail. The results are shown in Fig. 2.

Demos: Held several demos with 3D scanning companies. Some of the demos were in person, whereas for others the mirror sub-assembly was sent to the company through Iradion’s procedures. There was no guarantee that a 3D scanner could work for this application based upon consultation. Therefore, demos were a necessary step when determining whether or not a 3D scanner was viable.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Acquire Camera System: Find a Camera System that falls within the given budget of the project. A system that can change the focal length is preferred, while a liquid lens is also something to look into further. Ensuring that the mirror sub-assembly is fixtured to allow for a repeatable location is something that is also important.

Collect Data: Gather the necessary data for the four measurements - position, roll, pitch, and yaw. Creating a coordinate system will be another challenge that is faced. The use of a Raspberry Pi or Arduino has also not been ruled out. Ideally, this data will be able to be easily exported into a .CSV file and therefore imported directly into the GUI.

Algorithm Creation: As data is collected, algorithms will be needed to calculate the position of the mirror to the housing and the row, pitch, and yaw angles of the mirror. This will require further research into each angle respectively, and research into image processing software and how to extract data from it.

Modify GUI: With significantly less data than originally anticipated, the current full-screen application may not be the best option. The alternative here would be a fixed size application. Also, percent error is not going to be the best way to check for Pass/Fail, as there are now well-defined thresholds for each measurement. A better solution would be to check if the measured value falls within a specified range. Additional error and exception handling must also be implemented.

Determine Hardware Requirements: Purchase a computer that has the necessary system specifications needed. It must be able to run the scan, make measurements, export the data to a .CSV file, import the data into the GUI, and inform the user of Pass/Fail.
Automated Optical Inspection of Laser Components

Fig. 1: Laser Front Mirror Subassembly

Fig. 2: Graphical User Interface After Scan Has Completed
Fig. 3: Comparison Table of Measurement Systems

<table>
<thead>
<tr>
<th>Material Compatibility</th>
<th>Resolution</th>
<th>Envelope size</th>
<th>Equipment cost</th>
<th>Cycle Time</th>
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<td>Laser Scanner</td>
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<td>Excellent</td>
<td>Medium</td>
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<tr>
<td>CMM: Touch probe, white-light scanner, and camera</td>
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<td>Excellent</td>
<td>Very Small</td>
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<td>Good</td>
<td>Small - Medium</td>
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Fig. 4: High-Level State Diagram of Camera System
PROJECT MOTIVATION:

When an IC with an inductive load is turned off, the inductor will maintain its current. When the IC is turned off, voltage will start to rise on the output. The current through the inductor times the voltage will create power dissipation. Power times time is the Clamping Energy. The drivers have an absolute maximum rating and part of the prove out is taking data in the lab for this parameter. To do this, a circuit is set up with a large inductor and pulsed with a function generator. The energy value is recorded. This continues until the device fails. The abs max value from the previous setup is recorded as the data point. An automated system is needed to streamline this process. It will consist of a pulse width computer-controlled setup which monitors output current until damage occurs. The data is extracted and imported into excel for graphing.

ANTICIPATED BEST OUTCOME (ABO):

The ABO of the project is to take the existing output driver test board and fully automate it to measure the output energy capability of a device. This entails several goals. Code needs to be written to send a changing PWM signal to trigger the chip under test. Code also needs to be written to take the data collected on a Lecroy Oscilloscope to be displayed. A separate board needs to be created to support the PWM, the extraction of data, and display the result on the board. PADS PCB layout will be used to develop the PCB.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:

The current system is extremely tedious to use. By creating the automation system, employees will be free to work on other tasks instead of monitoring the test system. Additionally, the time the test takes to complete drops dramatically. This allows for a wider range of tests to be run on the IC to collect more data. Providing additional data for a highly sought customer parameter will satisfy the needs for more data than is presently available. Providing additional technical information on our integrated circuits will help the customer design in the right part for the application and increase our sales.
TECHNICAL ACCOMPLISHMENTS TO DATE:

Relay 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 (Fig. 1). 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 condition. This will force a large current through the system. If the system is 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.

Prototype Board Development: The automation system needs supporting hardware in order to function properly. The board incorporates the Arduino function generator, output switch, safety switch, and general purpose I/O all into a sleek design with supporting circuitry (Fig. 4).

GUI: The GUI allows the user to control the pulse widths sent by the Arduino. It can also read the Visual Basic data extraction files so that the data can be displayed on screen and then forwards it to the Arduino so it can be displayed.

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 and increment the amount of pulses and max allowable pulse width using our GUI.

OLED Displays: Two OLED Displays are programmed to display initial pulse width, increment amount, and max pulse width on one display and max energy, max current, and pulse width on the other (Fig. 2).

VBA Data Extraction: Initial automated data extraction from the oscilloscope (Fig. 3) has been achieved using Visual Basic and ActiveDSO (a software utility tool used for oscilloscope control). The Visual Basic program currently reads current and energy waveforms from the Oscilloscope and calculates the max values of each waveform.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

IC Temperature: For the most accurate data, the system needs to be evaluated over temperature. This feature will need to be integrated into the automation system. The diode located on the IC will have its voltage read across a temperature sweep in order to determine a dV/dT value. The diode will act like a thermometer in the tests, the voltage drop will be multiplied by this dV/dT value to determine the temperature of the part.

Test of ICs: The system is created to efficiently and accurately test ICs under a variety of inductive loads. It is also intended to be used with several different ICs. Several extended tests will be conducted to show that the system is fully operational.

High-Side Driver Operation: The current system is designed for low-side drivers, where the load is switched to ground. There are situations where the part will be a high-side driver, where the load is switched to power. It is important to have data on both situations, and the system will need to accommodate that feature.

Write Reports: The system will provide more accurate data about inductive clamping energy for ON Semiconductor to use. From this data, useful information can be obtained in order to produce more accurate methods for testing parts to give customers the best possible information. This will be compiled into a series of reports which ON Semiconductor will use.

Create System Independent of PC: Our goal is to create an easy-to-use all-in-one system without requiring too much setup. The challenge lies in the fact that our current system relies on a PC to run a VBA program for data extraction of the Oscilloscope and to run a GUI for pulse width selection. Ideally, we would like our system to run entirely on a pre-programmed Arduino microcontroller with push buttons on our system board for pulse width selection.
Power Output Driver Automated System for Integrated Circuits Over Time

Fig.1: Current IC test board for relay drivers

Fig.2: OLEDs displaying input and output information
Fig. 3: Waveforms from oscilloscope. Vout is the voltage at the output, Iout is the current through the output, Energy is the energy at the output, and IN1 is the voltage at the input.

Fig. 4: Block diagram of automation system
Recently there has been a large demand for systems that are immune to Electro-Magnetic Interference (EMI). Presently, PEC uses all copper wire in their annunciator systems for communication. These copper wires are susceptible to EMI which can lead to interruptions and errors. Our goal is to design an annunciator system that is immune to EMI and which is functionally equivalent to the electrical control circuit that is currently in use by PEC. The plan is for the design to be low cost, reliable, and scalable for use in many different applications. In order to do so, we will be using fiber optics to send signals back and forth between breakers and the annunciator systems since fiber optic cables are not susceptible to EMI.

**ANTICIPATED BEST OUTCOME (ABO):**

The ABO for this project is to have a working prototype of the continuity check board and annunciator board using multiple FPGA development boards. The prototype will be capable of monitoring the continuity of 12 signals on one board and communicating the status of each signal to the other board via a fiber optic interface. The continuity checks will also be configurable for normally open and normally closed circuits.

**IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:**

Achieving our best anticipated outcome means that PEC would have a more marketable product since it has the added benefit of being immune to EMI but would not cost much more than their current products. To get a system like this custom-made by a professional firm would currently go for thousands of dollars. We are striving to make our final product for just under $1000, which is well under the price range of what many of these firms would charge. Successfully achieving this would allow PEC to offer its customers a more robust system which is immune to EMI, all at a lower price point. Additionally, replacing copper wire in PEC systems would increase grid safety, which is of great importance to many private and public enterprises.
Programmed FPGA Modules: The first issue encountered was being able to program the FPGA modules using Vivado. The main issue was that the programmers ordered were incompatible with Vivado. The correct programmers were then ordered, which corrected this issue and uploaded a simple LED blink program.

Continuity Check Module: Created a module that monitored the continuity of 12-channels and reported their status. Each channel was configured to be normally closed or normally open. When continuity is invalid, it turns the indicator LED from green to red. This was successfully demonstrated in hardware.

Physical Loopback Using Aurora IP: Proved that data could be sent over fiber optic cables using a physical loopback and the Aurora IP reference design. Data was being randomly generated by the reference design.

Sent Data Between Two FPGA Boards (Fig. 3 and Fig. 4): Proved data transfer over fiber between the two FPGA boards with the aurora reference design programmed on both of them. To accomplish this, duplex transceivers were used as opposed to the bidirectional transceivers. Data was randomly generated by the reference design.

Custom Data Transfer: Modified the aurora reference design to send custom data over fiber between two FPGA boards. To accomplish this, a module needed to be written to send and receive through the AXI bus, which the Aurora IP uses to transfer data.

Test Bench for Continuity Check (Fig. 2): Created a test bench module to verify correct functionality of the continuity check module. Additionally, the Aurora IP was added to the design in order to send the status of continuity checks over fiber.

Schematic Capture: Generated schematics using a schematic design tool in CircuitMaker. Schematics are updated as hardware is successfully verified.

Complete the Functional Prototype: The best anticipated outcome is very close to being met, although there is still some troubleshooting that needs to be done on the current design. The functional prototype should be designed in such a way as to leave room for various stretch goals.

Serial Port Conversion: Add a serial port for configuration data. This will include configurations for normally closed and normally open continuity checks as well as for time delays on each channel. This will be done by implementing the MicroBlaze IP, a soft micro-processor core.

Test, Acknowledge, and Reset Buttons: Implement a module for each of the push buttons (Fig.1) that will be located on the front panel of the annunciator. The “acknowledge” button will silence the alarm and start a timer that will reset it at a later configurable time. The “test” button will test connections between “Input” and “Annunciator” by running through a set of blinking patterns using the LEDs. The “Reset” button will initiate a system reset.

Loss of Power Alarm: Create an alarm that will send out a signal before power is lost to any part of the system. The main challenge here will be storing enough power on the board in order to send the signal out before it loses all power.

Custom PCBs: A distant goal for this project is to provide a common PCB layout for both boards. Schematic capture is an ongoing part of this project that will contribute to this goal.

Try Alternate Transceivers: Switch to bidirectional transceivers instead of using duplex transceivers. This may help with cost reduction since only one fiber optic cable is needed for data transmit/receive as opposed to two cables.

Power Conversion: Procure an off-the-shelf module that will convert various DC input voltages to all of the voltages required for our system, including 12vdc, 24vdc, 48vdc, 125vdc, 24vac, and 120vac.
Fig.1: Best Anticipated Outcome Block Diagram (including wish list items)

Fig.2: Prototype of Input Board (left) and Annunciator Board (right) with yellow fiber-optic cable running between them.
Fig. 3: Input Side Block Diagram

Fig. 4: Annunciator Side Block Diagram
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PROJECT MOTIVATION:
In North America, the typical speed control signaling method for pumps and valves is a 0-10 Volt, 2-10 Volt, 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. By designing such a minimal cost, maximum benefit device, ELECOMP Team Taco would be providing Taco Comfort Solutions with a hardware and firmware solution typical of what is sought after every day in modern embedded systems development efforts, utilizing their skills in a directly tied to industry setting.

ANTICIPATED BEST OUTCOME (ABO):
Develop hardware and firmware to convert a 0-10 Volt control scheme to a PWM signal and convert a PWM signal to a 0-10 Volt control scheme. Develop the hardware to fit inside a currently produced Taco enclosure. Have a functional prototype ready for in lab alpha testing and possibly field alpha testing. In essence, a product which converts an input analog DC voltage to a PWM signal and converts an output PWM signal into an analog voltage back. This product will be programmable by Taco’s proprietary TacoBusLite protocol and must follow specific rules regarding the programming style and safety certifications.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:
With the development of this device, Taco would realize increased pump sales in the range of $350,000 to $400,000 annually. Because the device is cost optimized, much of this increase will be seen as profits. The device will also allow HVAC controllers to more effectively control the flow of water which will lead to cost savings for the end user and increased energy efficiency. As this product is deployed in the field and HVAC companies see the value and cost savings of PWM control, more companies will start to develop PWM controls, which will eliminate the need for this converter.
TECHNICAL ACCOMPLISHMENTS TO DATE:

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. (Fig. 4)

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 (Fig. 3).

Proposed ABO Firmware: Firmware which implements all the functions present in the originally proposed Best Anticipated Outcome (ABO). 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.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Printed Circuit Board: The printed circuit boards for the project are currently under development. Two boards are going to be 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 will be a 2-layer printed circuit board and will contain a 2 layer NFC antenna for the dynamic NFC tag. The production printed circuit boards will have very limited space available for components due to the way the existing enclosure is designed. Fitting the NFC antenna on-board will be especially challenging but should be possible while maintaining the cost-optimized nature of the device. (Fig. 1)

Production Ready Firmware: Because of the strides Team Taco has made in largely achieving the currently defined best anticipated outcome, the last major hurdle in achieving this goal is updating the firmware to production status, so that our device can be sold by Taco Comfort Solutions as one of their many products. (Fig. 2)

Serial Port Bootloading: Beginning our reach goals for the end of the year, one goal is to implement a firmware bootloader onto our device, which will use a serial communication protocol to update the firmware of the device without the need for an external In-Circuit-Debugger Tool. Furthermore, by allowing packet-based bootloading procedures, and finally updating the TacoBusLite interface, we may implement bootloading capabilities for ease of programming via the TacoBusLite GUI.

Near Field Communication (NFC): Our end reach goal will be to use our onboard NFC module to facilitate packet based wireless communication between the user computer, and the VPWMC. In doing so, we can not only then implement procedures to facilitate wireless bootloading of device firmware, but also energy harvesting capability, to have completely contactless firmware update capabilities for the VPWMC. Doing so will make field updates of firmware effortless and save Taco time and resources in the long run.
Fig. 1: Photo of current development board used to develop the device firmware, which will be further used as a schematic template for the design of the printed circuit boards.

Fig. 2: Firmware flow diagram for Taco VPWMC displaying startup procedures and main loop functionalities.
**Fig. 3:** Plot of 980 Hz, 72.86% duty cycle PWM input to Taco VPWMC and corresponding 980 Hz, 72.86% analog generation PWM output from VPWMC. Data obtained from Rigol DS1054Z series oscilloscope.

**Fig. 4:** System block diagram showing the macro-operations of each of the individual hardware circuits, and how they interact with one another.
PROJECT MOTIVATION:
Teknor Apex uses plastic extruders for its production. These extruders are made of barrels/zones, heaters, a cooling system, a screw, and a die. These extruders must heat raw materials upwards of 400°F and must remove that heat once at temperature, they then push the material out of a shaped die at the end. The methods of controlling these temperature zones have become fragmented and less accurate with the company’s growth. 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 an 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. This would help Teknor Apex determine exactly what temperature settings, heat up and cool down rates allow each product to run most efficiently on each production line.

ANTICIPATED BEST OUTCOME (ABO):
The ABO is a fully realized set of PLC code and HMI design for the extruder zone. A database to record and store temperature and alarm data needs to be created as well. Additionally, electrical schematics, Ladder Logic, Function Block diagrams, Data types, HMI Templates, and SQL scripting will all be needed. All design choices should consider scale-up and machine learning compatibility. Implementation should be achievable on multiple different types and ages of equipment and should be able to control the heating and cooling of a zone to within a degree. The user also needs to be able to efficiently wire multiple zones together.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:
This inefficiency costs Teknor Apex millions in overhead between wasted time, material, and energy. Furthermore, new opportunities in AI and machine learning stand to help the company become even more efficient than ever before, but require large amounts of data. This data must be structured and implemented in a standard way across the company in order to scale quickly and apply solutions globally. We seek to develop a standard method of controlling each zone such that the temperature is controlled to +/- 1°F. This would save the company millions and pave the way towards the greater efficiency and gains of Machine Learning.
TECHNICAL ACCOMPLISHMENTS TO DATE:

PLC Communication: Communication with the Programmable Logic Controller (PLC) (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.

Temperature Simulations: A simulation program was created using ladder logic and implement a PID loop. The simulation took the set point and the current temperature and the PID output how much to turn the heater 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 Function Block Diagram for the PID-E.

Server Computer Setup: The first part of setting up the testing apparatus included installing all of our necessary software onto a spare laptop. It will act as a central unit that will run all of our PLC testing software and allow us to work with and store our files from outside of campus

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.

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 (Fig. 1) to display valuable information to the operator. The interface had to be operator friendly using a well contrasting color schemes without confusing the operators.

Ignition Alarms: The Ignition interface has the ability to 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 a very crucial and necessary component with any operation.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

Temperature Integral: The next technical Challenge is to recreate what was done with the PID, PID-E, and Temp Integral command loop and apply that to the Pseudo Temperature Integral Control which is designed to be used for extruders. The simulation will also have to be updated to include heating and cooling for best results.

Testing Temperature Simulations: Once all the simulations have been completed, they will then be used to test the temperature control on the barrel. It will also be determined which kind of temperature control works best and the gains for the control loop.

Optimize Data Storage: To best fit the 10 GB restriction many of Teknor Apex’s databases face, we will aim to reduce the size of our recorded data to maximize the amount of data that can be stored while also keeping all important historical data.

Plastic Extruder Compatibility: As Teknor Apex has many different models of extruders in service in their facilities that follow a similar architecture to each other, we will first develop our solution on their most recent extruder processors and then port it down to work with their other extruder models.

Ignition Expandability: One of the end goals for the Ignition interface is the ability to be easily adapted to any other extruder set up. Depending on the size and number of zones of the extruder, Ignition needs to be set up for that exact extruder. The goal is for the interface to be easily adaptable and expandable to any size and number of extruders.

Ignition Interaction Scheme: Teknor Apex tasked us with changing the interface to be more user friendly with alarms and other various components, while still providing the familiar interface that is currently implemented.
Fig.1: A flow 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: Historian for a temperature zone.

Fig. 4: Barrel of an extruder and heaters that we will be working on and testing.
PROJECT MOTIVATION:

Today, data must be manually collected and compiled. Data points are taken anywhere between one inch to a foot apart. This is currently done by an employee manually collecting each data point over increasingly large areas. It is time consuming and labor intensive. There is no standard methodology or equipment to perform this testing and data collection. The goal of this project is to eliminate the need for human intervention. Any TSRgrow employee should be able to set up the sensor to start and be able to come back once it’s finished. The data should also be able to interact and align with TSRs’ current data visualization software. All new data needs to be used for customer interaction and preferably can represent light maps in three dimensions. These advancements in data collection will allow TSRgrow to be more productive and efficient which will lead to potentially more profit.

ANTICIPATED BEST OUTCOME (ABO):

To have automated data collection of PPF and PPFD from light fixtures. The method of collection will integrate robotics and a PAR sensor. Data collection must happen over a predefined grid area that can vary from 4’x4’ to 16’x24’ at heights from 6” to 72”. Also, the construction of a frame for accurately mounting fixtures for data collection. Finally, the creation of an application to aggregate, sort and store the information and create reports based on defined queries. This data must be entered into a GUI interface and that GUI interface must be able to be easily manufactured into lighting reports.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:

The best outcome will be to reduce current test time and to increase accuracy. This will enable employees who are currently in charge of testing to work on other projects for the benefit of the company. Faster tests and more accurate data will speed up and enhance proposal generation to customers. This should result in faster sales cycles and increase revenue. This testing methodology is likely to be adopted across the horticulture lighting industry as more stringent standards are developed around product marketing and sales. This test procedure has the ability to reduce company overhead and increase company revenue.
**TECHNICAL ACCOMPLISHMENTS TO DATE:**

**Sensor Identification:** For the first few weeks, we made technical calls to several companies to identify the best light sensor. We needed a sensor that has the ability to measure Photosynthetic Active Radiation and Photosynthetic Photon Flux Density. It needed to measure wavelengths from 380-800 nanometers and capture data. We have chosen to use the PLA-30 sensor. This sensor measures from 350-800 nm with a wavelength accuracy of .5 nm.

**Robotic Approach:** We also did copious amounts of research into methods of moving the sensor through the area where the data points need to be taken. We decided on a robotic approach to reduce manual labor. We initially believed we could use LEDs and diodes to accomplish both line following and color recognition. However, these methods proved inaccurate and difficult to put together. Instead, we used two different sensor arrays. We developed a line following robot that will accurately trace the area the sensor needs to cover. See Fig. 1.

**Robotic Sensor Array:** This robot uses an infrared sensor array in conjunction with an Arduino Uno. In addition to the line following sensor array, we are including a MD-TCS230 color sensor. This will enable the robot to stop at specific locations where the sensor takes readings. We are also using the Arduino MKR1000 wifi. This shield will enable communication between the PLA-30 and the Arduino. See Fig. 2.

**Light Fixture Mount:** We have also drawn up CAD figures of the light mounting system. We were able to obtain CAD files for each individual part from 80/20, which is the supplier for materials we will use for the mount, and construct them together in the desired orientation to have a virtual 3D representation of how the mount will be realized. See Fig. 3.

**REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:**

**Communication for Arduino:** One of our technical challenges is getting communication to our robot. Communication will need to run between one or possibly two Arduinos. It will need to communicate back to the windows machine when it has reached its desired position. The Windows Machine will communicate back to the Arduino to continue on its predetermined path.

**Communication for Windows Machine:** The Windows Machine will need to run a script to receive info on when the robot has arrived at a desired position and then signal the PLA-30 to start taking a reading. The opposite is needed as well, it will need to know when the sensor has completed its measurement and to send a “continue on path” signal to the robot.

**Communication for PLA-30:** The PLA-30 will need to be able to receive a signal to trigger a sensor reading. We then need to figure out a way to signal the completion of a reading and send that back to the Windows Machine and then on to the Arduino. This will require us to merge multiple code scripts carefully and in a clever way on the Windows Machine and Arduino. Our project sensor communication is detailed in the flowchart in Fig. 4.

**Robotic Control:** We need to incorporate our line following sensor array, color recognition sensor array, and the robot motor controls into one script. They need to all work at the same time in order to achieve the best anticipated outcome. We will also need to incorporate the PLA-30 into this control system to trigger the light sensor readings.

**Light Fixture Mount:** We also need to construct a way to hold lights. This needs to be strong enough to hold large lights and be adjustable. We have developed a CAD drawing of this structure but still need to build it.
Fig.1: Line following robot that will carry the PLA-30 light sensor around the measurement area.

Fig.2: This is the robot sensor array. This includes a MD-TCS230 color sensor and an IR line following sensor array.
**Fig. 3:** Light fixture mount CAD drawing. This will be used to mount and adjust the height of each light fixture.

**Fig. 4:** This flow chart details the sensor and computer communication.
Low Cost Desktop Design Evaluation System

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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.

ANTICIPATED BEST OUTCOME (ABO):
The ABO 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.

IMPLICATIONS OF ABO FOR COMPANY AND ECONOMIC IMPACT:
This evaluation unit would be a huge disruptor to the lab test market. If one looks at data acquisition products on the market, there is not a single unit dedicated to the low-cost evaluation of analog IC’s. This effort extends the Vicor test philosophy into the IC domain. Because the IC business is more standardized than the power supply module business, there may be opportunities for this class of evaluation unit outside of Vicor. The economic impact is indirect. Our tool will allow Vicor to service customers faster with new products and timely answers to field returns. In addition, both new product evaluation and product return service will not require the use of an expensive production tester. Taking a production tester off-line to do evaluation work is extraordinarily costly.
TECHNICAL ACCOMPLISHMENTS TO DATE:

Initial Research: Before being able to get started with component selection and construction there were many aspects of the project that required researching. Appropriate research helped to facilitate attaining a better grasp of the general concepts related to the project along with selecting the right components for a given job.

Embedded Systems: The Raspberry Pi 4 (RPi) and Arduino Due were chosen for this project after careful consideration, due to their low cost and sufficient computing power.

Communication Protocols: Multiple different communication protocols were necessary to interface the system together, such as UART (universal asynchronous receiver-transmitter) Serial between the Arduino and RPi, I2C (inter-integrated circuit) between the Arduino and DUT (device under test), and SPI (serial peripheral interface) between the Arduino and DAC (digital-to-analog converter) or ADC (analog-to-digital converter).

FSU Block Diagram: The hardware selected to control the team’s first functional FSU (force-sensing unit) circuit will support 2-channel communication between the FSU and the MUX card (Fig. 1). The FSU card design will be further developed to support 8 FSU channels to meet the project’s anticipated best outcome.

Component Selection: With the initial research came stipulations for each of our components to allow for the system to perform to expectations. To meet the design specifications, the use of the low dropout regulator LT1970 is applied in conjunction with additional MOSFETs and op-amps to increase reliability and efficiency, as shown in Fig. 4.

GUI Design: A block diagram was created to show what functions the GUI (graphical user interface) must perform (Fig. 2). A command-line user input script was developed that performs many of the functions we expect our GUI to perform, such as setting a desired voltage on the specified DAC channel, in preparation for a smooth transition to GUI development.

System Integration: Our team has established successful communication between the embedded systems and designed FSU test circuit. The embedded systems can correctly control various components that are integrated into the FSU circuit.

REMAINING TECHNICAL CHALLENGES FOR BEST ANTICIPATED OUTCOME:

GUI Development: The GUI design shown in Fig. 2 must be developed. With the system being controlled by a Raspberry Pi, it will require inputs made by the user to control system output. A GUI will allow for simple control and ease of reading the outputs from the tests done, providing a user-friendly experience.

PCB Fabrication: With the FSU circuit currently being utilized on a breadboard, it is not very usable in a final product. Once the final design of the FSU testing circuit is realized, it will be fabricated into a PCB (printed circuit board) to allow for more reliability and stability of the overall system.

Multiplexer (MUX) Card: The FSU is able to project a voltage and current onto the DUT. However, there is only a single output from the FSU, which is expected to test a large amount of pins on the DUT board. The integration of a MUX card is necessary here as it allows for distinct DUT pin selection and control, shown in Fig. 3.

System Scalability: Remaining cognizant of system scalability is key as multiple DUT pins will be tested simultaneously. While upscaling the FSU system, multiple FSU circuits will be placed on a single PCB with proper FSU-to-MUX integration for full test pin control. Sufficient connectors will be used and proper main board space will be allocated to accommodate the future integration of different purpose measurement cards.

Robust Design: Protection, stability, and efficiency are necessary features for making the system safer and industrially sturdier for the user, providing for smoother, more reliable and less-costly operation.
Fig. 1: Low-Cost Desktop Design Evaluation Board block diagram. Hardware shown on the FSU card is for supporting 2 channels.

Fig. 2: Initial GUI Design mockup. This block diagram details the functions the GUI should be able to perform and how it interacts with our FSU.
Fig. 3: Expanded diagram of MUX card. 8 channels, each consisting of Force Voltage/Current, Force Return, Sense Voltage/Current, and Sense Return.

Fig. 4: The low dropout (LDO) regulator circuit uses an LT1970A Power op-amp, FDS9934C MOSFET, and ADA4661 op-amp for adjustable current limiting.
Professor Sunak with Jack Murphy, ELECOMP Capstone Program Assistant, URI Class of 2022
The unknown resistance \( R_x \) is to be measured; resistances \( R_1 \), \( R_2 \) and \( R_3 \) are known and \( R_2 \) is adjustable. Only when the bridge is adjusted to be in PERFECT BALANCE, the measured voltage \( V_G \) is zero, and the unknown \( R_x \) is determined.

Now we can see the parallel with the 3 important aspects of the Capstone Bridge:

R1: ELECOMP Capstone Design Program
R2: ELE & COMP Seniors with diverse talents
R3: Sponsor’s Technical Director & Problem to be solved

When these aspects are in perfect balance and collaborate in excellent harmony, SUCCESS is achieved in the UNKNOWN (\( R_x \)): The Best Outcome of the Sponsor’s Problem