Sanmina Vikings
Senior Design Lab Product Manual
CU Boulder ECEN Capstone 2023

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1. Revision history for this document

1.0.0 (September 8, 2022): Product overview finished
1.0.1 (September 16, 2022): Engineering and Marketing requirements written up along with use cases and design constraints. Some edits made to product overview section (elevator pitch)
1.0.2(September 30, 2022): Functional Decomposition + Systems Diagrams
1.0.3(October 7th, 2022): Addition of Budget and Schedule, with revisions on other topics
2.0 (November 11th,2022) : Major revisions and general updates to reflect new goals and plan
3.0 (March 24, 2023): Budget updated with all purchases up to this date, integration tests added, construction and testing of submodules section added, acceptance testing added, phase 2 descriptions and missing PDR descriptions added. Power Budget edited.
4.0 (May 5th, 2023): Final Product Manual Update. New sections added and made edits to previous sections

2. Product Overview

2.1. Project info

2.1.1. Project title

Sanmina Automated Coupon Tester

2.1.2. Product title

Sanmina Automated Coupon Tester

2.1.3. Sponsor

Sanmina Corporation

2.1.4. The technical advisor

Eric Bogatin

2.1.5. Your supervisor

Brian Nelson

2.1.6. Team name

Sanmina Vikings

2.1.7. Team members, roles, responsibilities

Team Member	Roles	Responsibilities
Matthew Teta	Primary: Project Manager/Team Lead Secondary: Firmware + Hardware	● Makes sure software and hardware processes are in sync ● Plans and maintains progress on the project (manual editor) ● Assists in Firmware/Hardware design if necessary ● Responsible for the GUI of the project
Iskandar Shoyusupov	Primary: Software Lead Secondary: Embedded Systems	● Makes sure updates and progress is updated in GitHub, and all code is kept safe in a git repository ● Responsible for development, maintenance, testing of all code ● Assists with embedded design ● Financial management for the team
Abdulrahman Alduaij	Primary: Firmware/Electrical Lead Secondary: Hardware/PCB	● Designs and maintains firmware/analog solutions for the project ● Responsible for testing of firmware and making sure power resources are considered in implementation ● Assists with hardware design
Shambaditya Tarafder	Primary: Communications Manager Secondary: Hardware/Software	● Computer vision head ● Development of PCB microcontroller and embedded code development ● Manages time conflicts and figures out scheduling ● Assists in either hardware or software projects ● Upholds communication with sponsor and plans all meetings between team members and sponsor
Logan Van Grinsven	Primary: Hardware/PCB/Mechanical Lead Secondary: Firmware/Electrical	● Responsible for overall physical architecture and integration. ● Design PCB components ● Design mechanical components ● Assemble mechanical components ● Assists with firmware/electrical systems

2.2. Elevator pitch

The Samina automated PCB coupon tester is an autonomous system that when given a test coupon will automatically position a TDR testing probe on each of the single ended test pad locations to measure the impedance of the PCB fabrication process and compare the value to the expected value. This will allow Sanmina to save labor hours and money by speeding up the procedure for the validation of the board manufacturing processes. Through the use of image processing and computer vision, automation can be ensured for up to 100 PCB test coupons in a row with minimal human interaction.

2.3. The problem our product solves

Currently, Sanmina employees must manually measure thousands of test pads on hundreds of coupons for just a single manufacturing order. This procedure costs them a lot of money in labor hours and causes it to take longer for PCB's to get into the hands of their customers. This product provides significant improvement for this large scale manual TDR testing. The automated coupon tester solution allows for the consumer to be capable of processing thousands of boards with minimal intervention.

2.3.1. How our product fits into this overall solution

The product is a physical test platform and associated software interface which only requires operators to load and unload PCB coupons, automating the rest of the manual steps. The product automates identification of board identifiers, identification of pad/via test probe locations, TDR probe positioning, TDR measurements collection, processing, and export.

2.3.2. Our vision of what our product will do when you are done

The product is broken up into two user-facing components. The first of which is the physical test platform. This test platform will have a lever which an operator will use to load or unload the test coupon (DUT). The test platform also has a flying gantry holding a camera, single ended TDR probe, and a z-axis distance sensor. Lastly, the test platform houses some lights which aid in the imaging of the DUTs.

The other piece of the product is the user interface (GUI) which is responsible for command and control of the test platform, data processing, and procedure sequencing. The GUI will allow the operator to prepare the system for measurements, view and verify the data from the TDR as well as from the computer vision software system.

A user will be able to scan the first coupon of a given type (there are ~100 similar coupons for the same MO all testes in series), confirm and adjust the test points through the software, and press run to cause it to take the measurements. The scanning phase is when the camera moves in a line above the coupon to gather high quality images of it. The measurement phase is when the machine positions itself on each test location and collects measurements in series.

2.3.3. Who is the customer

The factory personnel working at the Sanmina Corporation.The end product of which will make the work of the personnel more streamlined.

2.3.4. Why is this product of value

In the current system used by Samina, impedance measurements are done manually. These manual measurements are time consuming and tedious. This is where our product comes in to supply an automatic system with the goal of delivering consistent results, and saving the client's time by freeing the test technician's burden of manually testing.

3. Requirements

3.1. Marketing requirements

Number	Marketing Requirement	Importance	Acceptance Test Notes
1	Auto image scanning of DUT's	High	Check that the product can read a coupon and associate the text with the appropriate fields for many test coupons as provided by customer
2	Automated creation of impedance test reports per lot measurement using TDR	High	The test report generated should contain all the necessary information regarding the test being performed. This includes an impedance graph and pass fail criteria.
4	Automatic result and measurement database cataloging for PCB fabricator access	Med	Use sample data to check if the .csv files are accurately saved in the correct directory and format.
5	The probe lifetime shall be greater than 10,000 touch downs.	Med-High	If we use COTS pins for the probe then we can use the manufacturer lifetime specification
6	Test time within 120 seconds, ideally below 60	Medium	With a functional product, we verify the time a measurement is taken with the target time.
7	Different operation modes, one automated mode where measurement results are stored for later viewing. Another mode that will let the operator step through a test of one coupon at a time with viewing of waveforms.	Medium	Test the same PCB coupon in the two different modes, and check if the results are the same.
8	Measured waveforms need to be displayed in an auto-scaled sense to include both incident and reflected rising edges at a reasonable resolution to see discontinuities. Operator needs to be able to scale the vertical axis similar to an oscilloscope	Low	Data plots are compared with current customer solution to plotting the data from the TDR
9	Automated tester's infeed with up to 100 coupons of various sizes	Low-Medium	Test different sets of PCB coupons with varying sizes, colors, and thicknesses. See Engineering Requirements.

10	Support Via spacing of 100 mil (imperial)	Medium	Test with coupons with 100 mil spacing between the vias.
11	Safe operation with E-Stop	High	Ensure that interference with the device does not risk harm to the device or the operator. Proper fail safes such as an emergency stop are implemented. Temperature of control board tested for overheating.
12	GUI for displaying the associated data-points , the result of the TDR test and the start of the entire automation process	High	The operator should be able to enter the parameters for the given coupon. After the testing is complete, they should be able to take a look at the data points/graphs generated to verify the performance of the machine and the validity of the DUT.
13	Visual cohesion	High	The product should look presentable with cables routed, electronics hidden, and labels visible. This ensures safety and ease of use.
14	ESD Protection	Extremely High	The product MUST be ESD safe to protect it from users touching the machine.

3.2. What are the killer apps

- Correct and consistent alignment of the probe and DUT probe locations.
- Correct TDR measurements of impedance.
- Correct and reliable association of text read from the coupon and the identifying fields for export.
- A GUI for easy test operation control and result interface.

3.3. Who are the intended end users and how will they use the product?

Sanmina production floor employees are the intended end user and they will use this machine by loading 1 coupon at a time and starting the machine. Once the machine has finished its testing the technician will review the generated report and approve its measurements. The technician will also change out the probes on the machine for insured accuracy and safety every 10,000 probe tests.

3.4. Are there any specific safety concerns in the use of the product?

There exists some safety concerns regarding the user performing unintended interactions with the product. Additionally there is the concern of ESD breaking the TDR.

3.5. Use case 1 (automatic impedance measurements)

1. The product is set on a workshop table.
2. The ON/OFF button on the product is turned ON.
3. The user connects the appropriate USB cables to the operating computer. One USB cable is connected to the TDR, and another cable is connected to the microcontroller.
4. The apparatus is powered and connected to a computer but no measurements or movements are made. This is the product's idle mode.
5. The user opens the lever and positions one coupon inside of the test platform and then it clamps the coupons in place.
6. The user sets up the software by entering in information about the job number and the single-ended measurements to complete for each coupon in the MO.
7. The user confirms the configuration and pushes the button to begin the automated test.
8. The gantry head flies over once to image the coupon.
9. The coupon’s product details (visible in the coupon image) are transferred into text format, and the pin locations of the coupon are calculated using the image.
10. The coupon text details are used to retrieve the coupon's measurement specifications from the operating computer.
11. Using the calculated pin locations the operating computer orders a gantry to move the probe to the correct location and to measure the impedance of the traces on the coupon.
12. A buffer containing the impedance over the distance of the cable and PCB trace is saved to the computer. The impedance results of a single test are processed and compared to the nominal value and acceptance criteria entered in step 6.
13. The machine finishes with the coupon, showing overall pass/fail criteria.
14. The user unloads the coupon by opening the clamp.
15. The user then loads the next (similar) coupon and hits the run button again. The job information and the test pad locations is saved so nothing has to be entered for consecutive boards.

16. The machine repeats steps 8-13 until all coupons in the job have been measured.

3.6. Use case 2 (manual impedance measurements)

1. The user goes through step 1 to 15 from the above use case.
2. In step 11 from use case 1 the user can order a manual checkup on the latest measurement.
3. The mechanical system retracts from the testing probes and stops at the ordered connections.
4. The operating computer shows a labeled TDR plot of the current impedance measurement buffer in Ohms vs. nanoseconds.
5. After the checkup is complete the user can order the continuation of the automatic impedance testing through an option on the operating computer.
6. The system continues where it stopped in use case 1.

3.7. Use case 3 (safety and error termination)

1. At any point in the process the user can terminate the process by pressing a button on the apparatus
2. Press the E-stop button.
3. All mechanical parts of the apparatus halt and hold current position, as to not cause any damage or worsen a potential issue.
4. Previously measured impedance tests are saved, and coupons with unfinished measurements are labeled unfinished in the database.
5. System returns to idle until a new order is made.

3.8. Design Constraints based on the customer requests

- The apparatus excluding the operating computer should fit in a 25” x 25” tabletop workshop area.
- Capable of testing 1 coupon at a time without human interference.
- Capable of testing any number of sequential coupons with the same footprint and test pad locations with only human intervention to swap the coupons between tests.
- The probe lifetime shall be greater than 10,000 touch downs.
- Test one board within 120 seconds, ideally below 60
- Up to Two 110 VAC 15A power feeds
- Must support probe pitch of 100 mils.

3.9. Engineering requirements

Marketing Requirements	Engineering Requirements	Justifications	Integration Tests
2,6	Three motors move a "flying" head with x,y,z and rotation about the z axis control fast enough to test in under 20 sec	Must be capable of moving test head and DUT's	Given that a coupon is positioned properly in the mechanism, the head will reliably align precisely to each probe site.
1	Camera module which can accurately resolve feature size of <= 0.1millimeters with minimal distortion.	Needed for output format	Check that the product can read a coupon and associate the text with the appropriate fields for many test coupons as provided by customer
5,6	A 50 Ohm impedance matched single-ended probe capable of 10000 touchdowns and minimal measurement interference.	Ensure accurate measurements for 2 pin requirements	Probe is compared to COTS probe with 35 ps rise time & calibrated TDR machine to determine its' transparency and performance.
2,4,7	Software to perform analysis of measured impedance results against pass/fail criteria that consists of +/- ohm acceptance range specific to test instructions entered by the user. The software also should be capable of adding the results and measurements into a database in the form of CSV files for PCB fabricator access.	Engineering professionals who will utilize the automated system will need all data measured to be outputted in easily accessible format (CSV), this requires proprietary software solutions.	Comparison of provided example test data and automated test data to make sure data formats match up against one another.
7,11	Rigid frame that encloses systems with access doors.	Keeps the device sturdy and ensures operator safety.	A user cannot accidentally stick appendages into the machine and get hurt.
6,1,2,9	Clamp for holding DUTs (device under test)	DUTs will have varying sizes and will need to be clamped in place and aligned to datums to ensure tests can be reliably performed automatically.	Through the performance of TDR tests revealing abnormal or non abnormal data, we will be able to tell if the DUTs are improperly aligned.

1	PC/software program capable of processing images and finding text and vias on captured image data	The minimum customer requirements specify that the coupons need to be automatically identified in order to minimize human intervention.	Running computer vision programs and analyzing results. Picking a number arbitrarily, we should have a failure rate no less than 95%.
7,11	Emergency stop that cuts power to the mechanical system, and sends a signal to the operating computer to stop the current process	Safety of operator and ability to use manual mode	Non movement of mechanical components (especially stepper motors), unless forced by operator
8	Graphical user interface (GUI) & associated back-end SW that is used to select the current process and view labeled TDR plot (ohms vs nanoseconds) data for manual measurement	Required for intuitive use by operator	GUI will need be tested for reliability (all functionality being present in control of machine), and for ease of use which can be cleared by technology advisors
1,6,7	Power system does not require more than 2 120V standard wall outlets.	Provides necessary current and power for proper device operation	Using oscilloscope readings to check for proper current flow for the device. MCU potentially will be capable for reporting on inadequate supply
7,11	Devices must be UL certified.	For safety of the operator and the TDR, all metal parts must be connected to earth ground and the coupon platform must consist of a dissipative surface to prevent ESD events on the TDR probe tips.	A DMM can be used to verify that all components are connected to earth ground. The dissipative mat should measure 10±3MΩ across 1 inch.

4. Functional Decomposition

Level 0: Automated TDR System

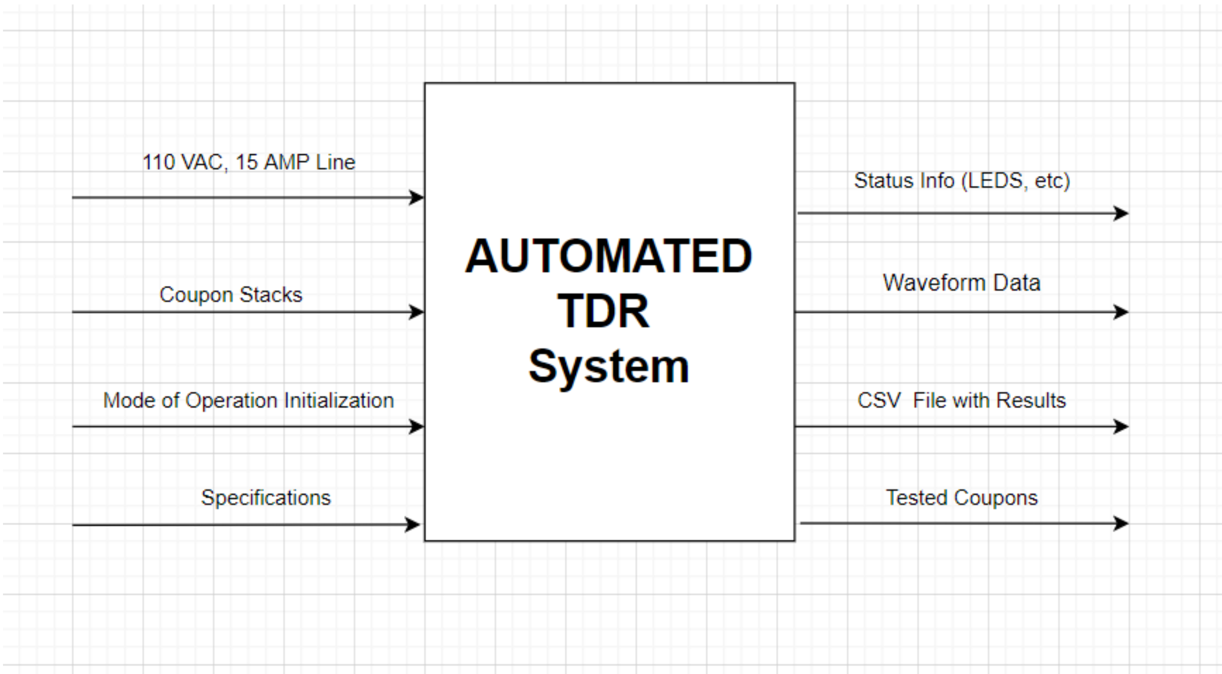


Figure 1 : Overall Automated TDR

Module	Automated TDR System
Inputs	• Power input 110 V from a 15 AMP line using wall socket • Stacks of coupons • Mode of operation selection • Specifications for specific coupons loaded into machine
Outputs	• Status Signals from LEDs (Stopped vs Working, Emergency Stop lights, etc) • CSV file with results from TDR tests • Tested Coupons
Functionality	The Automated TDR System accepts a stack of up to 100 coupons of the same size and specifications to be tested, and runs through the coupons one by one, making a TDR test. Options for manual or automated mode, and other specifications will be set by the operator prior to the tests. Results from TDR measurements are stored in CSV files and stored on the operator's PC.

Level 1: Functional Decomposition

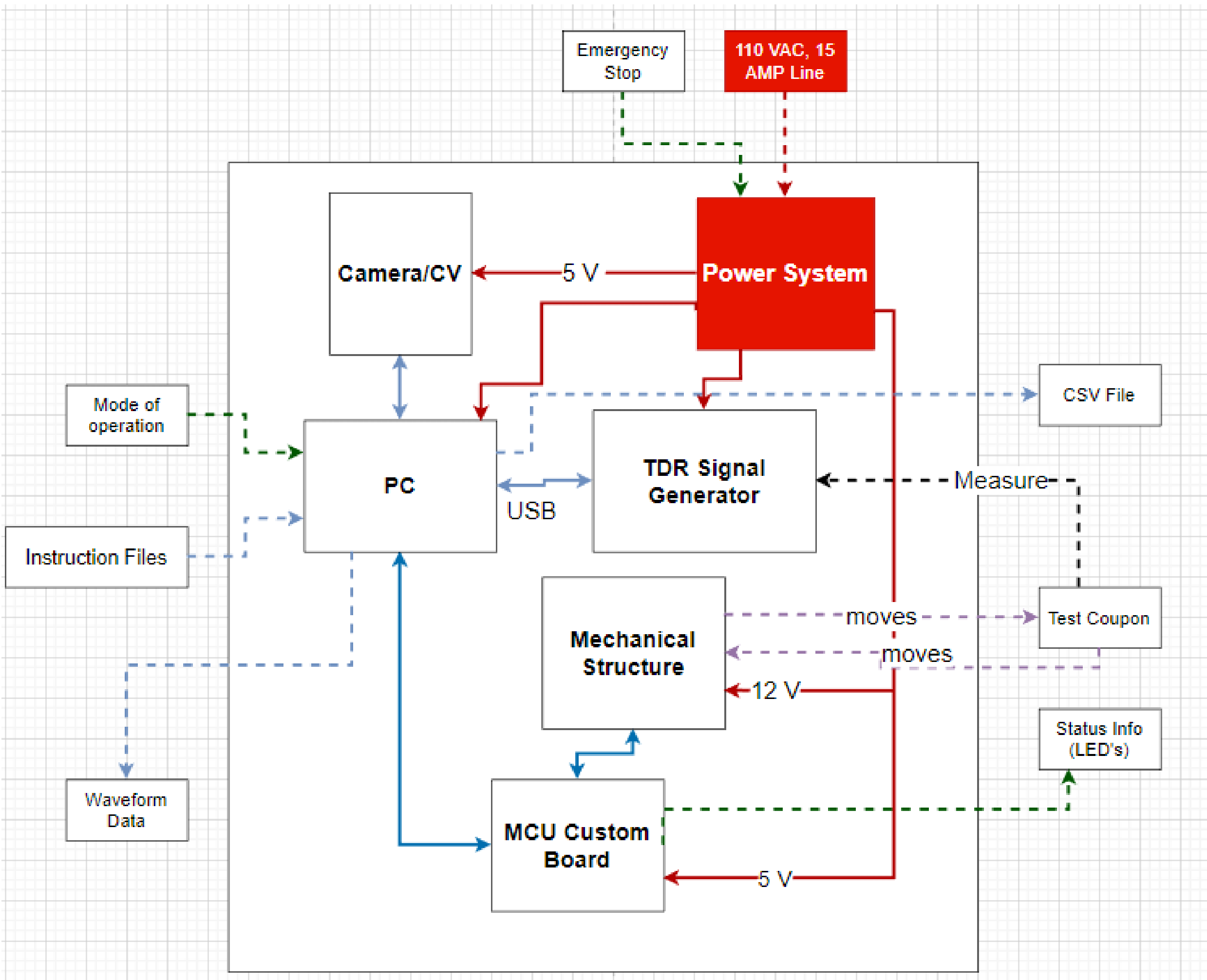


Figure 2

Blue: Data
Green: Physical input/output
Red: Power
Purple: Physical movement

Module	Custom Microcontroller Unit (MCU) with added motor drivers
Inputs	● UART(from USB PC) ● 5 V Power ● GPIO(Estop, Mechanical Structure) ● GPIO(Limit Switches, Mechanical Structure) ● GPIO(BL Touch, Mechanical Structure)
Outputs	● GPIO(Status LEDs, Mechanical Structure) ● 4 GPIO(Motor Power, Mechanical Structure), Through motor driver

	● 2 GPIO(Servos, Mechanical Structure) ● GPIO(Servos, Mechanical Structure)
Functionality	An ATMega328p in the same configuration as an arduino with extra headers for the motor drivers* and other controllable peripherals. It takes in commands from an external PC (Gcode) and then interprets these commands to operate the mechanical portions of the machine. This means it's responsible for interpreting the Estop, controlling the coupon clamp servos, using the CRTouch probe to self calibrate, indexing the coupons, moving the test probe and Driving the stepper motors using added motor drivers. *Note: the current MCU PCB uses headers to allow the slotting of the motor driver hats into the board and they will likely be incorporated into the design of a later revision.

Module	PC
Inputs	● USB(from USB MCU) ● USB(from USB TDR) ● USB(to camera)
Outputs	● USB(to MCU) ● USB(to TDR)
Functionality	Runs all of the software responsible for controlling the machine and its outputs. It has access to the test parameters of the DUT to allow proper interpretation of the data and pass/fail criteria.

Module	Mechanical Structure
Inputs	● GPIO(Motor Power, MCU motor drivers) ● GPIO(Status LEDs, MCU) ● GPIO(Servos, Mechanical Structure) ● 12 V Power ● Untested Coupons
Outputs	● Tested Coupons ● GPIO(limit switches, MCU) ● GPIO(CR Touch, Mechanical Structure)
Functionality	The mechanical structure (MS) of the machine covers all the passive and mechanical portions of the project. Together they form the basis of the machine and comprise the test equipment, moving components, structural pieces and sensors. The majority of the MS is from an Ender 3 3d printer and has the same layout and operational space of one.

Module	Camera
Inputs	● UART(from USB PC) ● 5 V Power
Outputs	● UART(from USB PC)(Images)
Functionality	The camera is an endoscopic rotating camera that has a high enough resolution to provide adequate data on scanned images. Capable of real time and single image capture. Camera will be run off of the users desktop computer

Module	Power System
Inputs	● 110v Wall power
Outputs	● 5 V power line ● 12 V power line
Functionality	Power system functionality is to provide the necessary voltage and current requirements to all the components in the system. The only exception is the PC that will be run off of it’s own PSU

Module	TDR (Hyperlabs HL1101)
Inputs	- USB - Coupon trace under test - BNC connector/Cable
Outputs	USB(data plot points, specifically impedance measurements over time)
Functionality	Performs a time domain reflectometry Test with the given parameters from the PC. It then returns the results to the PC.

Level 2: Software Flowchart (PC module)

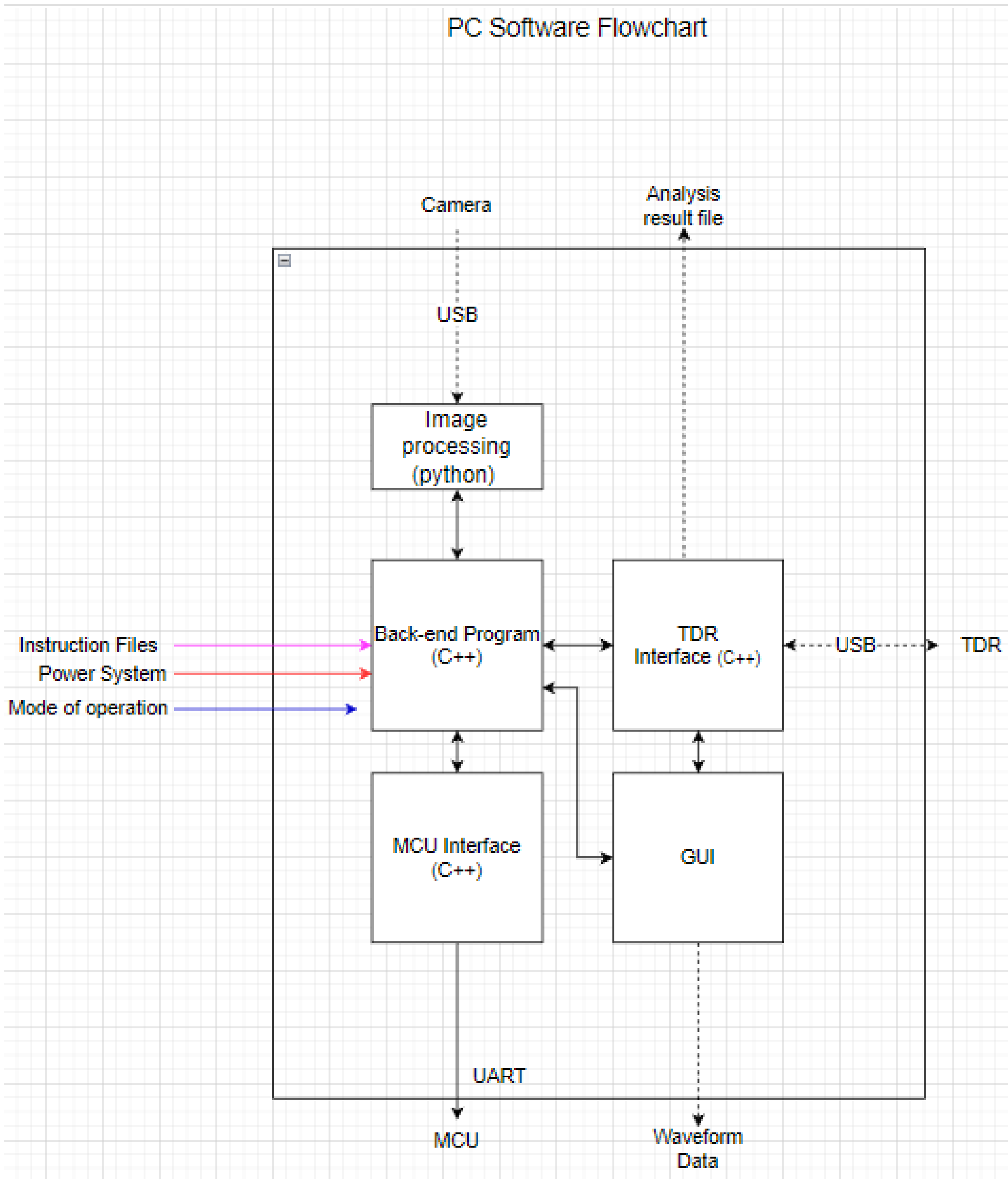


Figure 3

Component/ SubModule	Back-end Program
Inputs	• Mode of Operation (manual vs automated) • Instruction Files
Outputs	• Instructions

Functionality	Program is a general component that will include software code for running the neural network on image character recognition, code for reading and analyzing TDR data to save to a file with measurement analysis, code for control of the GUI. It will also have a state machine to control the flow of the process.

Component/ SubModule	MCU Interface
Inputs	● Custom gantry 3d movement commands
Outputs	● Custom gantry 3d movement commands
Functionality	The MCU interface functionality within the PC back-end program is to send and receive custom gantry 3d movement commands from the MCU using UART by utilizing Windows api . This includes updating the current location of the gantry, moving the gantry to the desired location, or homing the gantry if the current location is unknown.

Component/ SubModule	GUI
Inputs	● Measurements (Ohms vs Nanoseconds) from the TDR machine ● To stop measurements in case of some emergency!? ● User Input for Commands
Outputs	● A visual waveform display ● Communication to the controller script for requested operations
Functionality	Measured TDR waveforms will be displayed so as to include incident and reflected rising edges. Main purpose of this is to observe any discontinuities indicating a failed test. It will also be able to halt the complete testing process, in case of some emergency

Component/ SubModule	TDR Interface
Inputs	● USB connection to the physical TDR
Outputs	● Waveform measurements saved for test analysis and display
Functionality	The TDR interface functionality within the PC is to read the measured data from the physical TDR, and save the data so that it can be used by other parts of our system (GUI, pass fail criteria, etc). This will most likely be an already developed component that will be provided by the manufacturers of the TDR.

Component/ SubModule	Image Processing
Inputs	● Various Images taken from the camera ● USB (from Camera)
Outputs	● One complete Stitched image ● Testing locations csv file
Functionality	The camera can take multiple images of the test coupon and then it will use an algorithm to stitch the multiple images into one one combined image and run image processing on it to determine the location of vias and other measurement parameters. Also, it will run deep analysis for edge detection and text recognition/OCR through pre-processing the data and then comparing it to the trained data set.

Level 2: Power System

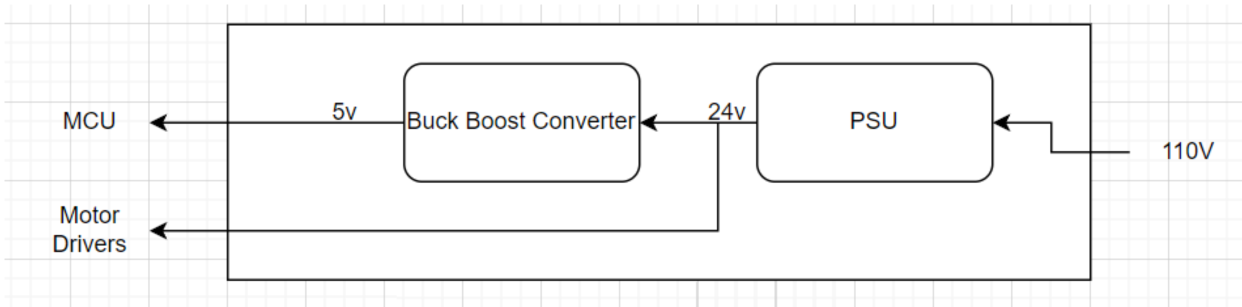


Figure 4

Component/ SubModule	Power Supply Unit (PSU)
Inputs	• 110 V line from wall outlet
Outputs	• 24V output
Functionality	The power supply will try to output a constant 24 volts. However after testing we found the voltage drops a lot under load. This is fine because even with the reduced voltage under a load it is still within the specs of our other components.

Component/ SubModule	DC-DC converter
Inputs	• 24 V line
Outputs	• 12 V
Functionality	This is an off the shelf dc-dc converter to step the voltage down from the native 24v of the PSU to 12v for the motor drivers to keep out heat manageable as both do work.

Level 2: Mechanical System

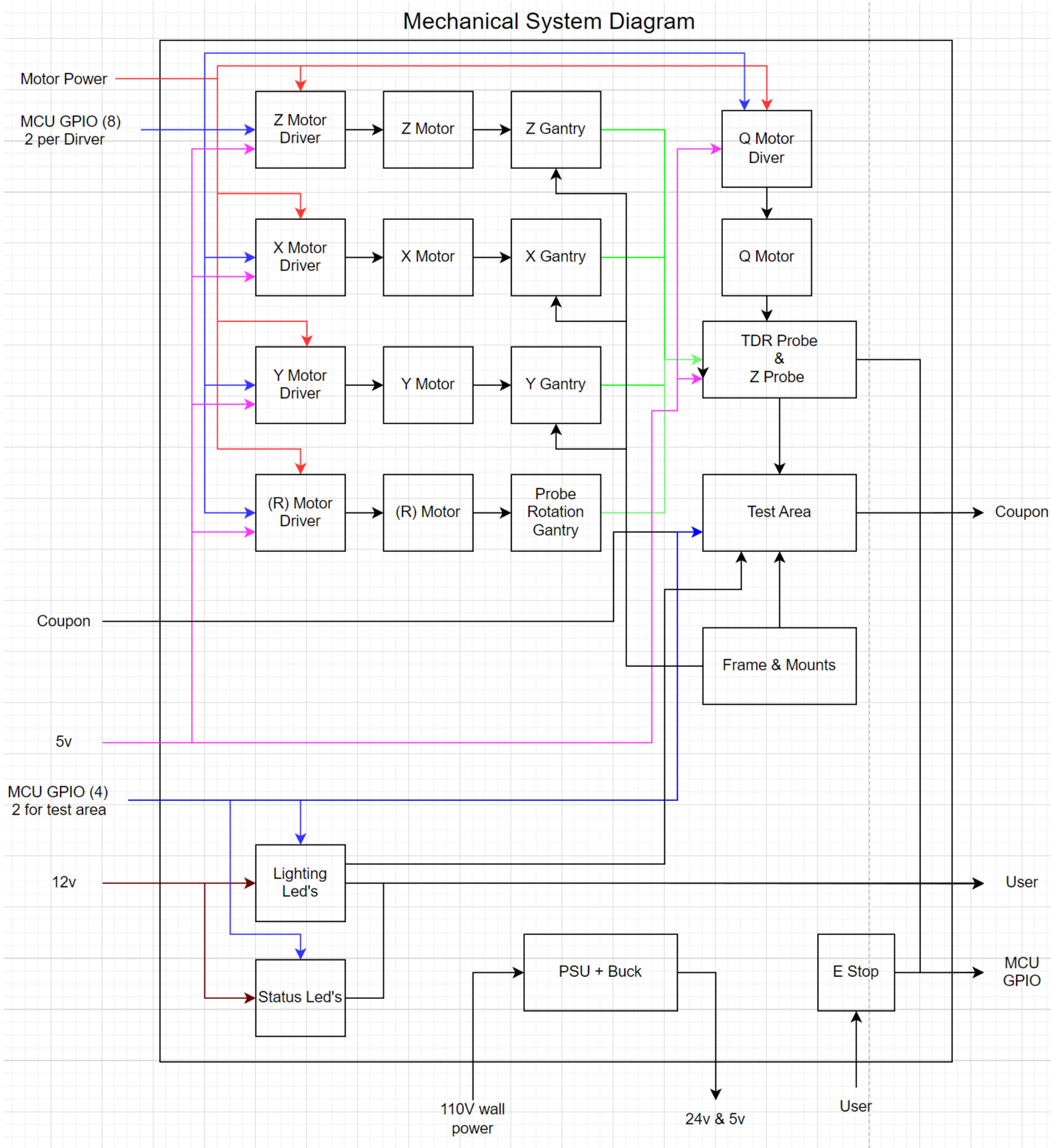


Figure 5

Component/ SubModule	Motor Driver *(These exist on the MCU board and will likely be incorporated into it in a later iteration hence the inclusion here and in MCU section)
Inputs	● 12-50V line (for motors) ● 5v line (for logic) ● 2 GPIO from mcu (Step, Direction) ● 3 manual switches to calibrate step resolution (ms1,ms2,ms3)
Outputs	● 12V stepper output over 2 coils
Functionality	The Motor driver Uses a motor voltage to supply a switching current to the motor while changing the polarity over the windings to cause the motor to rotate in fixed angled “steps”. The 5v logic rotation direction and step signals come from the MCU to control the driver. These drivers allow for the controlled “stepping” of the motors which is a fixed amount of rotation using the design of the motors stator and coils. This allows us to step a specific number of times with no feedback to move a set and known amount. Also because the system characteristics dont change once the drivers have been set to the proper power level the motor should never “slip” or “skip” keeping known position.

Component/ SubModule	Status and Lighting Led’s
Inputs	● 12V line from Power Distribution ● GPIO form MCU for control
Outputs	● Visual light for the operator and cameras vision
Functionality	The Status Lights function to help the user understand what the machine is doing and thinking. This helps improve safety and usability. The Lighting Led’s light the test area for better visuals.

Component/ SubModule	E-Stop (emergency stop)
Inputs	● User interaction
Outputs	● Interrupt to MCU ● Power cut off
Functionality	The functionality of the emergency stop is to be a safety mechanism in case the operator wants the machine to quickly stop all operations.

Component/ SubModule	Test Area
Inputs	• Untested coupon
Outputs	• Tested Coupon
Functionality	The test area will be a flat surface that can clamp the sides of any sized coupon using servos. It will have a single coupon loaded onto it and clamp it so the TDR test can be performed with the probe on the gantry. The clamp is to improve repeatability and reliability as the machine has no sense if the DUT moved during a set of tests. One finished, the tested coupon will be unclamped and removed from the surface. Additionally the Test area is made of an ESD filament that works to protect the probe during testing.

Component/ SubModule	TDR Probe *(this is including the spinning mechanism)
Inputs	• Coupon to test • Motor Driver for rotation
Outputs	• TDR Data
Functionality	Probe will be lowered by the gantry and used to test the actual coupons by connecting its two pins with the coupon pads or vias. This will also be capable of spring around 180 degrees for tests that face the other direction. As a Part of the spinning mechanism there is a clamshell of ESD safe filament that protects the exposed parts of the probe making it more ESD safe but couldn't cover the whole probe still allowing for discharge at the screw terminal because access was needed there.

Component/ SubModule	Z Probe specifically the CR Touch
Inputs	• Coupon to test • GPIO (MCU)
Outputs	• GPIO (MCU)
Functionality	The Z probe can be lowered by the gantry and triggered to drop a pin that when pushed up will cause the CR touch to send a signal to the MCU. This allows for the machine to know the height of the gantry relative to the item being probed.

Component/ SubModule	Gantry
Inputs	● Motors
Outputs	● Position
Functionality	The gantry is the physical structure of the machine and uses belts and threaded rods to convert the rotation of the motors into xyz movements.

Component/ SubModule	Motor
Inputs	● Coil Power (motor drivers)
Outputs	● Rotation in fixed steps of 1.8 degrees
Functionality	The motors are nema 17 stepper motors that will rotate a fixed amount based on which of its two sets of coils are energized and in what order/polarity. The motor drivers can increase this step resolution by fractionaly energizing the coils if needed.

Component/ SubModule	Power enclosure
Inputs	● 110v
Outputs	● System power rails
Functionality	This is the location that the high voltage is converted into lower and safer values for being used in the machine. This is simply a box that keeps people from touching live wall power lines or any other of the power connections.

5. System Diagram

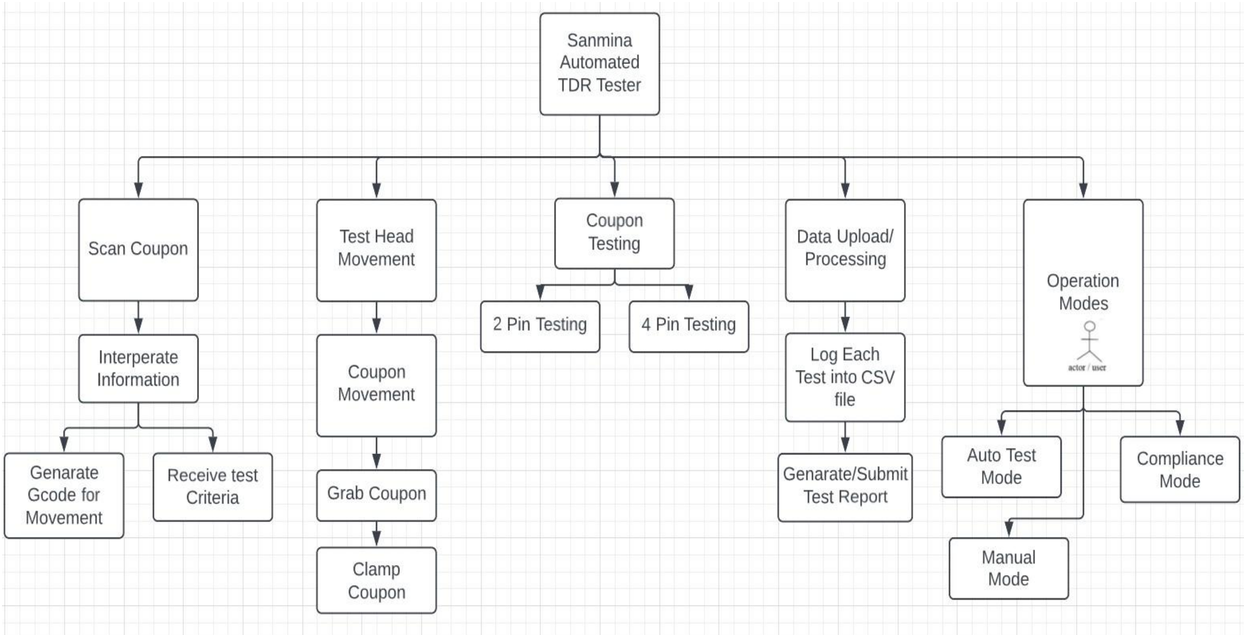


Figure 6 : System Diagram for the Project

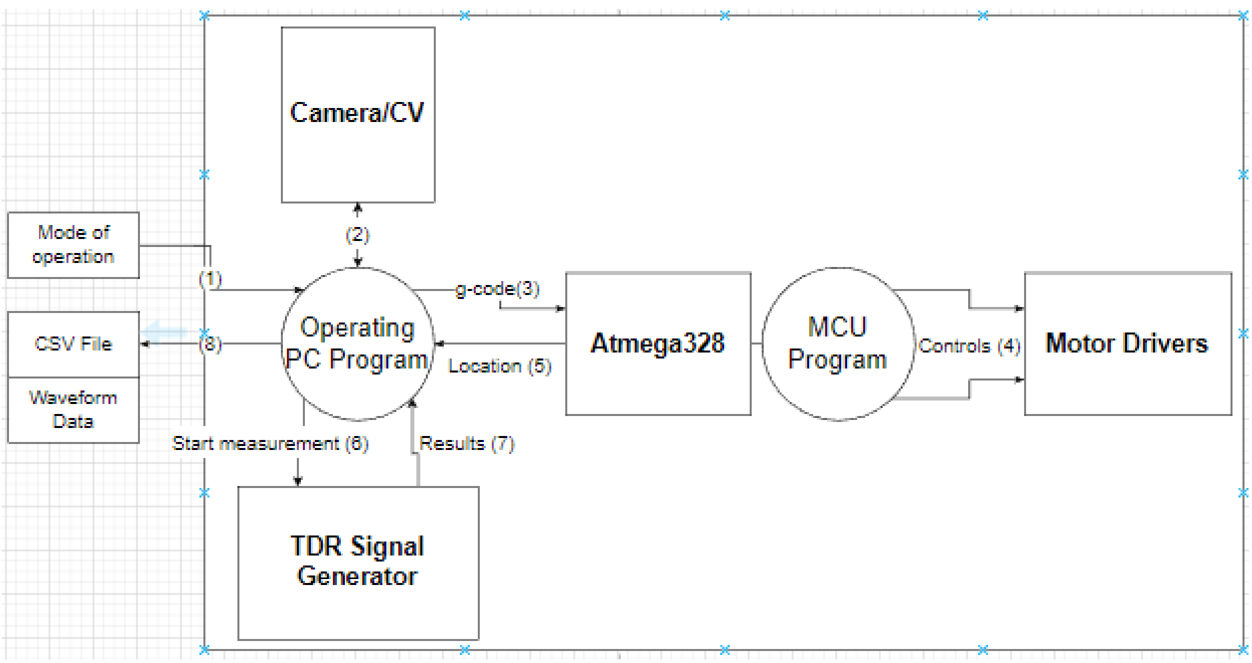
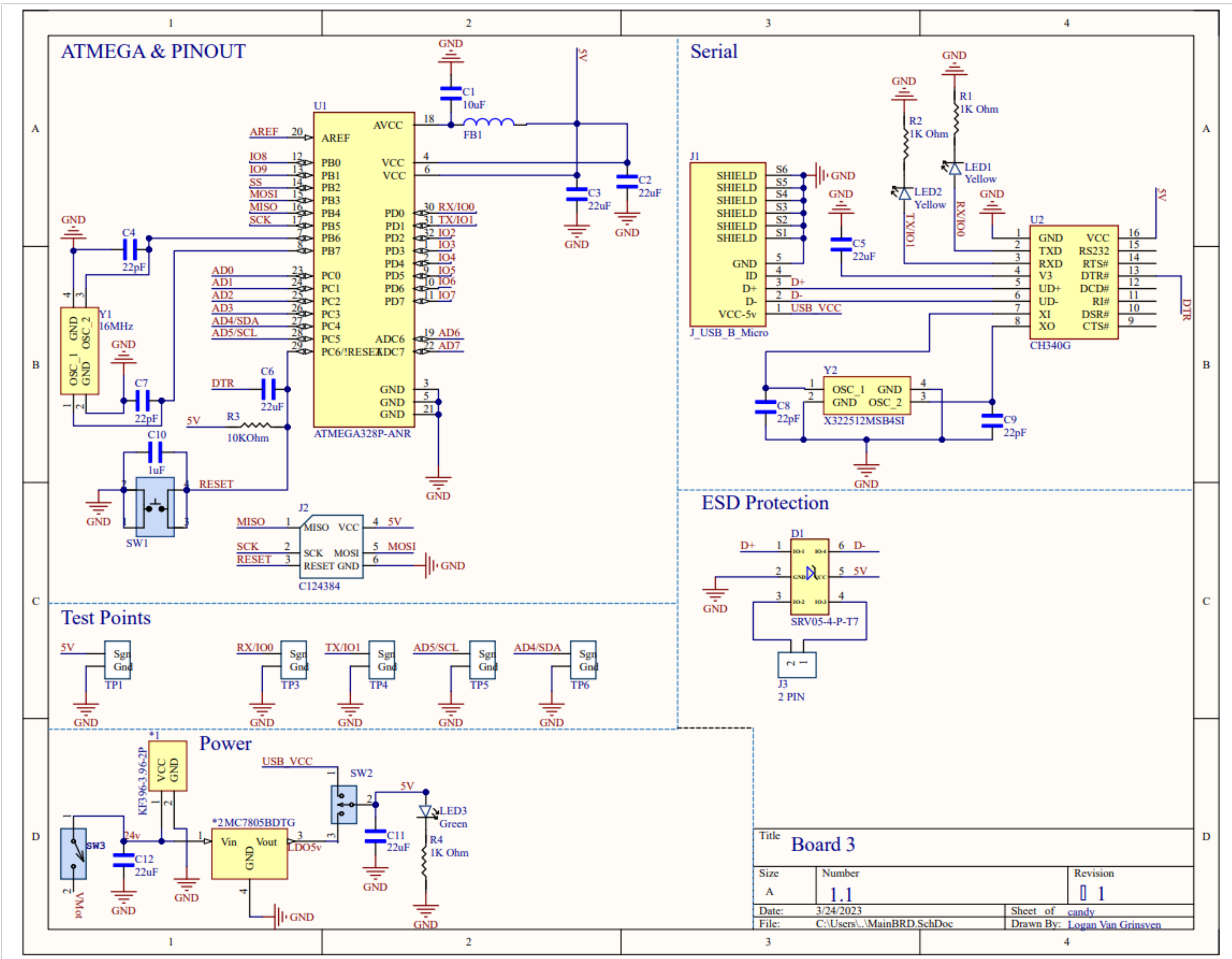
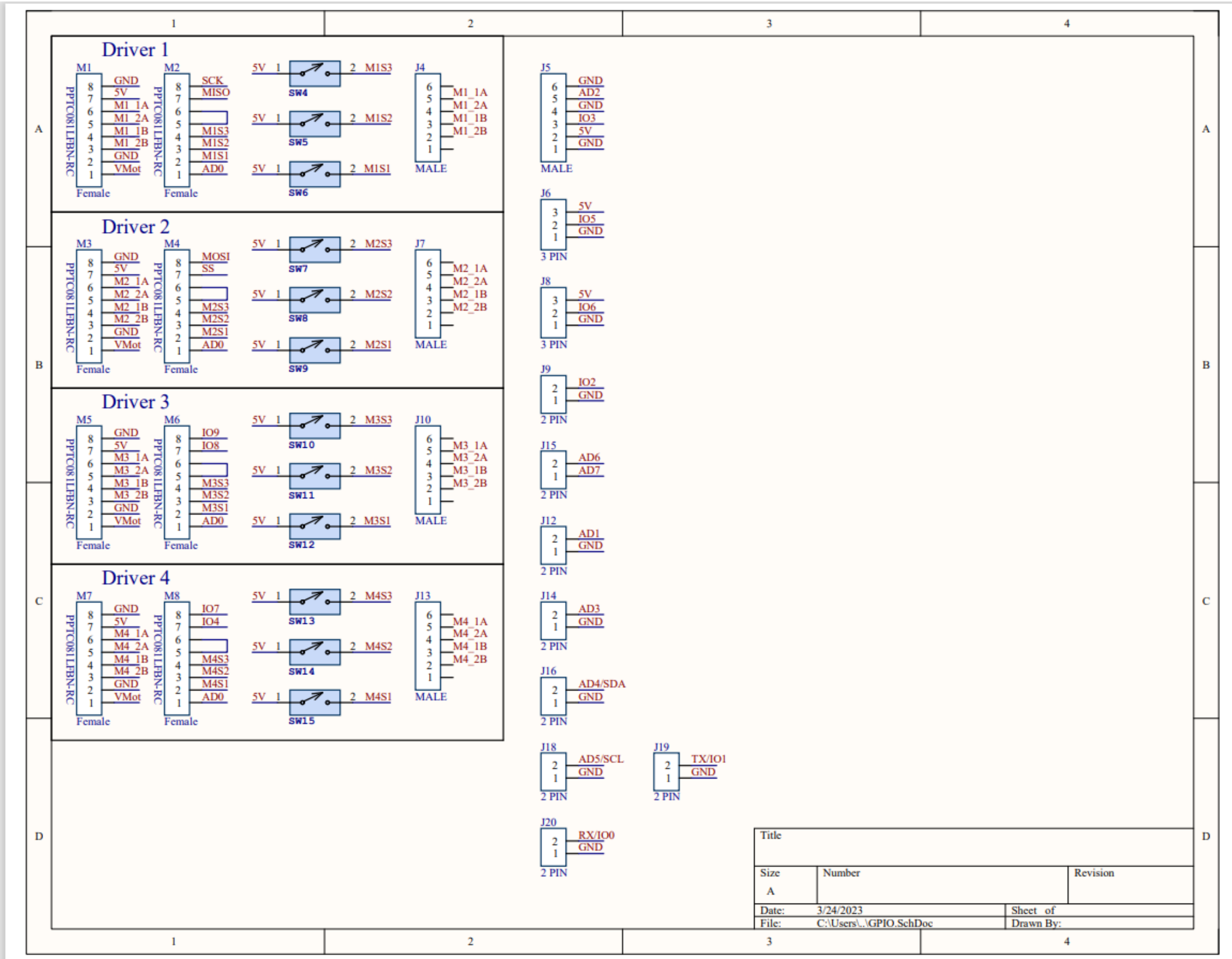


Figure 7 : Another Perspective of the System Diagram

6. Electrical Schematic



This first electrical schematic forms the basis of our AtMega 328p microcontroller custom PCB board. It features the main chip,the serial communication chips, and power conditioning / selector. Additionally there is a small ESD protection chip tied to the serial lines for stability and longevity.



This second schematic is the GPIO pinouts on the board and what junctions are tied to the pins on the ATMega. We have 4 junction pairs set up to accommodate the stepper motor drivers that are being used alongside our main board. These junctions also contain 3 jumpers for the option of microstepping the drivers. Additionally There is enough pinout for the use of two servos, a CR touch, 4 limit switches, and extra headers to be used as seen fit given any changes made to the design.

7. Technology Options

Power Budget Calculations :

Our Power Supply (from a 3d printer frame) is more than 185W and it has plenty of power for our application. We followed through the steps below to come to that conclusion. Additionally we had to address heat issues that arose during testing.

- Tested the PSU with a variable load tester to the testers maximum of 185W.
  - This verified that for sure we could deliver at least 185 watts from the PSU and under this load the voltage never falls below 8.5 volts
- Then we determined the main draw of power was 4 Stepper motors at ~15W which is at most 60W leaving us much under 185W
- We know the our stepper motor drivers can operate at 8.5-50V input and
  - Because they are stepper motors so long as they do not start slipping from being too weak (~10v) running at a lower or higher voltage doesn't affect the operation of the machine because the motors rotate fixed amounts at any speed.
- WE also planned on Using an LDO to power the MCU which drew under 10 Watts to power the PCB
  - There was worry that the LDO would be hot coming from 24 volts down to five but it never broke past 90 degrees.
- TDR < 5W
- We considered running some LED Strips that are under 20W
- With all the things we had to consider we found that the sum of listed considerations are under 100 Watts.

The power budget of our system was affected by heating issues with the motor drivers. Improper calibration resulted in significant heat generation due to the high power running through the drivers. Initially, we added a large aluminum heat sink to the chips using thermal adhesive tape. Although this reduced the heat inside the chip, it wasn't sufficient since the heat sink lacked surface area to radiate the heat away from the metal, and could cause damage if the system reached thermal saturation. To solve this, we used the heat sinks from the original PCB that powered the motors on the 3D printer frame. We applied the same thermal paste/adhesive solution, reducing the temperatures to an average of around 150 degrees at our intended voltage of 24 volts. To be 100% certain that the drivers could run for an extended period in an enclosed space, we used a DC to DC converter to drop the voltage down to 12 and used it as our motor supply voltage. After dialing in the motor drivers, we optimized the torque ratios for each motor with the new voltage, resulting in an average temperature of about 90° Fahrenheit for each stepper motor driver. We also hooked up the original blower-style fan from the 3D printer to blow fresh air across the heat sinks of our stepper motor drivers, solving all of our thermal issues. Below is an image of our intermediate test setup for measuring the temperature directly on the PCB with thermistors.

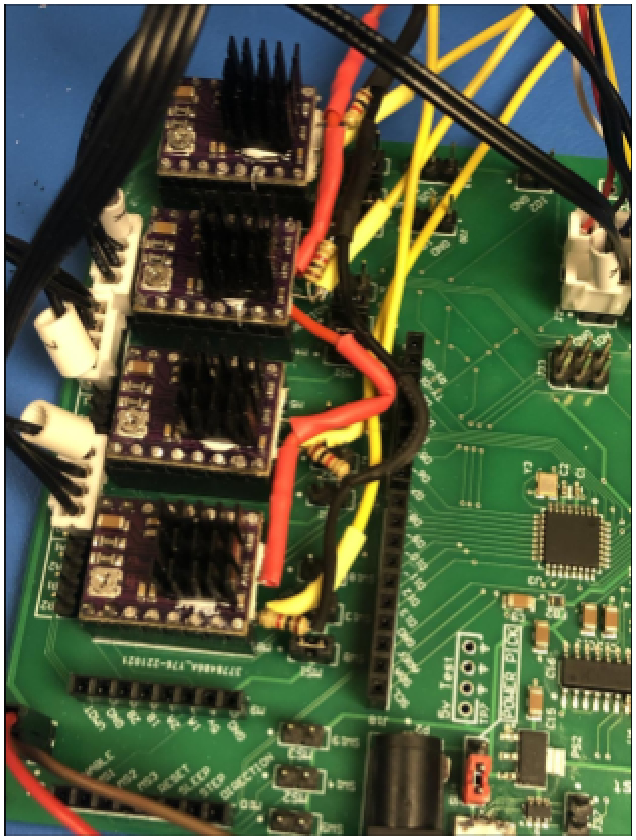


Figure : Thermistor Testing for the heat management

Computer Vision System :

Figure : Detection of the via holes on the coupon

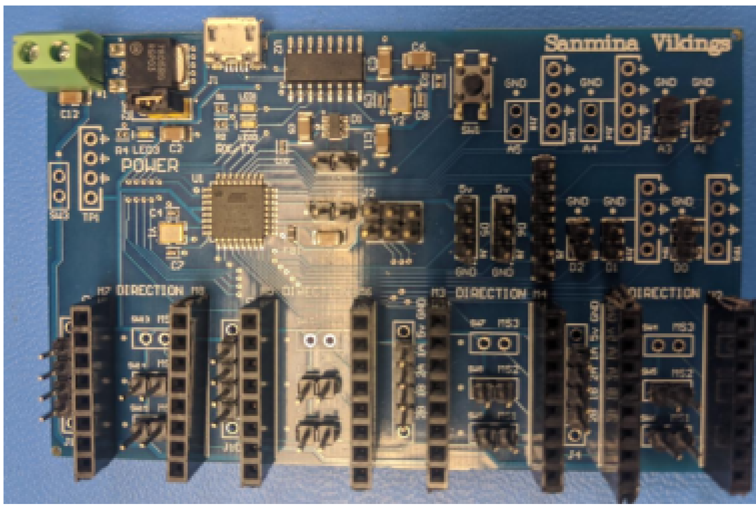
For the computer vision system we first decided to use static images and then run our via hole detection algorithm which is basically a modified version of the Hough circle detection algorithm of the OpenCV library. However we later realized such modification cannot work as static images cannot extract the correct location data consistently and reliably and thereby we need a real-time analysis solution to run the detection for a fixed amount of time and extract the accurate location data of the via holes from the coupons. We then used the standard deviation method to filter out the unnecessary points and get the accurate detection and location result. The resulting output is also very cool and the operator can also view the real time via-hole detection on the coupons.

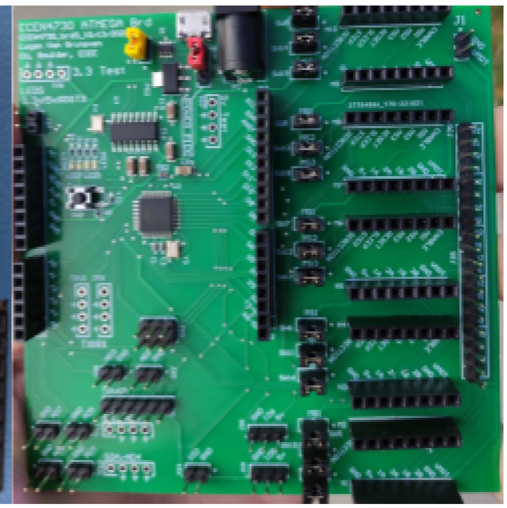
For more information on Hough Circle Detection, Please visit :
https://docs.opencv.org/3.4/d4/d70/tutorial_hough_circle.html

Figure : Character extraction and recognition through OCR and their confidence in a perfect setting

For the OCR portion we designed our algorithms which can adjust various parameters like the thinness, thickness, noise on the characters being extracted. We also made available an array of filters which might work in all lightning conditions. However this did not pan out as reliable as we had hoped for and unfortunately we had to eliminate this portion from our final demo.

PCB design :



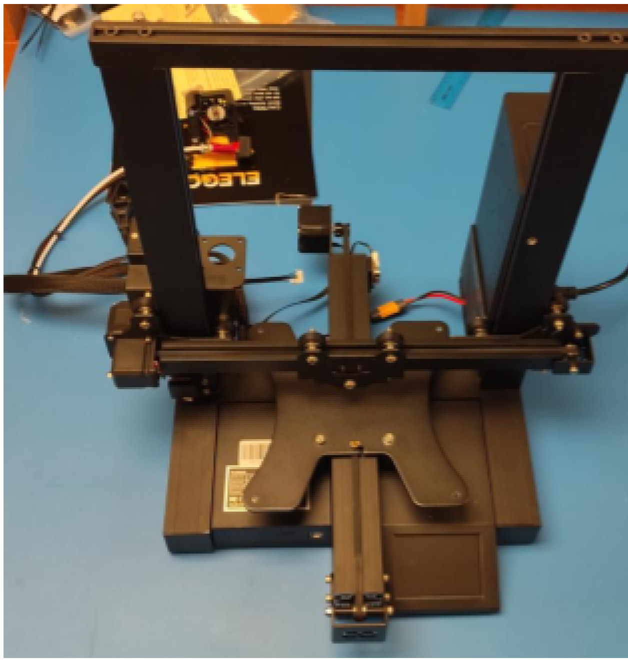


Version 2 (half the size)   Version 1 (not to scale)

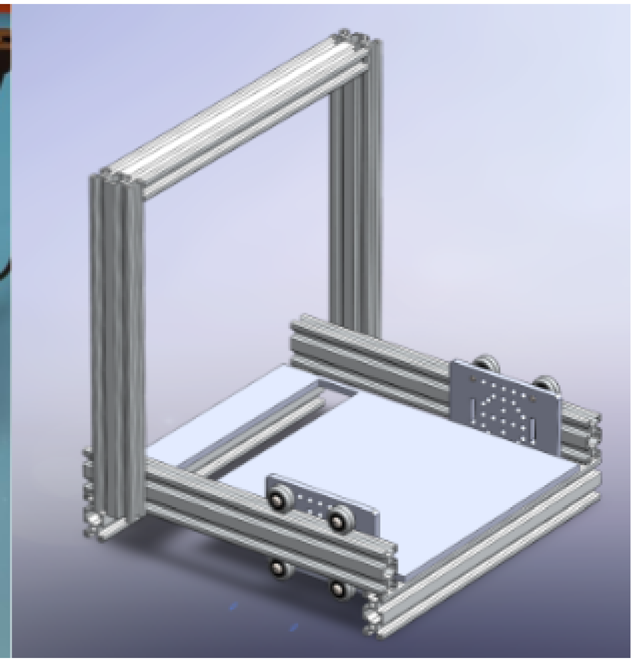
The PCB was originally designed in the PCB manufacturing class based off of a normal Arduino using an atmega328p. We made two revisions of this board though the second one never was properly used due to some sort of error that made it occasionally explode. The PCB had several features that were really cool and made it unique outside of a normal Arduino clone.

First, while not unique but still nice, is that the use of an Atmega328p microcontroller makes it compatible with the Arduino development environment, which is a powerful yet simple tool for programming and debugging. Additionally, the ability to replace motor drivers allowed for flexibility in the types of motors that can be controlled, which could be useful for different applications. These replaceable drivers also meant that when the broke we could replace them quickly without impeding testing. Moreover the Ldo (low-dropout) regulator is another cool feature, as it allows the board to be powered off of the motor power line if needed. This could be useful in situations where a separate power source for the board is not available. The choice of any ldo might not have been perfect considering we were dropping from 24 volts to 5 but it didn't end up generating enough heat to keep it from sustained operation without a heat sink.

Mechanical Gantry :



3D Printer Frame (before adding custom parts)



Early Form of a Potential Custom Frame

The mechanical gantry is the framework for the machine. From the beginning, we knew it had to be made from aluminum extrusions because it was versatile and robust. Additionally, it ensured that when the design changed whatever we bought would still be usable. Knowing this we had considered the option of making a custom solution using open builds kits. However, we found that their pricing was high making it much more affordable to just buy a premade consumer product that came with a frame and then modify it. This was an initial consideration of a CNC machine or router because that matched the footprint of our specifications and would have been more applicable. During our search, we found a 3D printer gantry that was on sale and made the budget much more reasonable even though it didn't perfectly match our requirements. Luckily we were able to adjust the requirements with our sponsor so that the 3D printer gantry worked. Once we had the gantry in hand it was as simple as removing the electronics and assembling the parts of the kit that we needed. Leaving us with some leftover parts like the extruder and the hot plate that we didn't end up using but made a quick, simple, and easy solution that worked out well. Now we had the full XYZ movement although we did still have to add the custom solution for the rotational axis of the probe.

CR Touch:

Figure: CR Touch

Traditionally the CR touch is a 3D printer bed leveling sensor. However for our purposes it has been repurposed for coupon height detection. This probe is Really neat because it lets us physically touch the system to know exactly where the height of the coupon is, meaning that we'll have perfect touchdowns every single time. It also means that we could theoretically touch the coupon in several places and make an offset for a sloping coupon or an unleveled coupon. The accuracy is amazing and well within the 10th of a millimeter of Tolerance that we have which you can see in the data sheet.

Product datasheet:
https://img.staticdj.com/08582340baaa0bb280d3d5e6863163f2.pdf?spm=..product_ca58ac35-a13e-45c9-9863-ffb9220605c5.download_support_1.1

Graphical User Interface :

TDR:

Figure: HL1101 TDR

The HL1101 is an electrostatic-robust, USB-driven TDR suitable for deployment in a wide variety of lab, field, and industrial applications.

Specifications:

- Rise Time: 200 ps
- Time Resolution : 10.2 ps
- Signal Amplitude: 250 mV
- Output: BNC
- Interface: USB
- Internal Resistor: ± 1 Ω at 50 Ω

Product datasheet: https://www.hyperlabs.com/wp-content/uploads/HL1101.pdf

8. Schedule

WBS NUMBER	TASK TITLE	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	**Start**				
1.1	Team Finalized	Summer	8/25/22	N/A	100.00%
1.1.1	Project Selected	8/25/22	8/26/22	1	100.00%
1.2	Initial Drawings	8/30/22	8/30/22	0	100.00%
1.3	1st Communication from Sanmina	9/6/22	9/6/22	0	100.00%
1.4	Product Manual	9/6/2022	Continuous	N/A	100.00%
1.5	2nd Communication from Sanmina	9/15/22	9/15/22	0	100.00%
1.6	Confirmed specs and plans from Sanmina	9/21/22	9/21/22	0	100.00%
2	Product Design,Planning,tech exploration				
2.1	Finalize gantry specifications	9/27/22	10/7/22	10	100.00%
2.2	Selection of MCU	9/27/22	9/27/22	0	100.00%
2.3	TDR Lab	9/27/22	10/6/22	9	100.00%
2.4	Computer Vision+Camera Research	9/23/22	9/27/22	4	100.00%
2.5	GUI Research and Planning	9/27	10/6	9	100.00%
2.6	Functional Decomposition + Systems Diagrams	9/20	9/27	7	100.00%
2.7	System Drawings	9/23/22	9/30/22	7	100.00%
2.8	Budget Formulation	9/29/22	10/7/22	8	100.00%
3	Prototype Building				
3.1	Initial Risk Assessment + PoC design	10/7/22	10/11/22	4	100.00%
3.2	PDR : presentation	10/11/22	10/11/22	1	100.00%
3.2.1	Custom MCU prototyping	10/17/22	10/28/22	11	100.00%
3.2.2	Further Risk Assessment	10/13	10/28/22	15	75.00%
3.3	Computer Vision Prototype Solution	10/3/22	10/28/22	25	100.00%
3.4	PoC design	10/18/22	10/28/22	10	100.00%
3.4.1	Testing again	10/25/22	10/28/22	3	100.00%
3.5	Phase 1 Prototype	10/11/22	11/4/22	23	100.00%
4	Risk Management				
4.1	Compile potential failure points	11/10/22	11/14/22	4	100.00%

4.2	Review TDR damage risks	11/14/22	11/18/22	4	100.00%
4.3	Circuit boards/Mechanical	11/18/22	11/21/22	3	100.00%
4.4	Sanmina demonstration	11/10/22	TBD	Unknown	100.00%
5	CDR				
5.1	New PCB testing	01/17/23	01/22/23	5	50.00%
5.2	Switch to 24V	01/23/23	01/30/23	7	0.00%
5.3	Design Documents Update	01/24	01/28/23	4	100.00%
5.4	CDR Presentation	01/27/23	TBD	Unknown	100.00%
6	Final Design Implementation				
6.1	Final Custom Software Integration	02/01/23	02/12/23	11	75.00%
6.2	Final Custom Hardware Integration	02/01/23	02/19/23	18	75.00%
6.3	Updating Manual and Design Docs	02/20/23	02/25/23	5	100.00%
6.4	Testing	02/20/23	02/28/23	8	50.00%
7	Modifications and Testing Again				
7.1	Modifications + Internal Tests	03/01/23	03/10/23	9	50.00%
7.1	Freezing Final Design (HW/SW)	03/11/23	03/19/23	8	50.00%
7.1	Integration Tests + Demo	03/19/23	03/24	5	100.00%
7.1	AcceptanceTests + Demo	03/25/23	03/31/23	6	0.00%
8	Expo Plans and Final Testing				
8.1	Polishing	04/01/23	04/09/23	8	0.00%
8.2	Testing	04/09/23	04/18/23	9	15.00%
8.3	Prep for Demo+Final Showdown	04/18/23	04/24/23	6	0.00%
8.4	Expo+Delivery	04/25/23	04/28/2023	3	0.00%

9. Budget

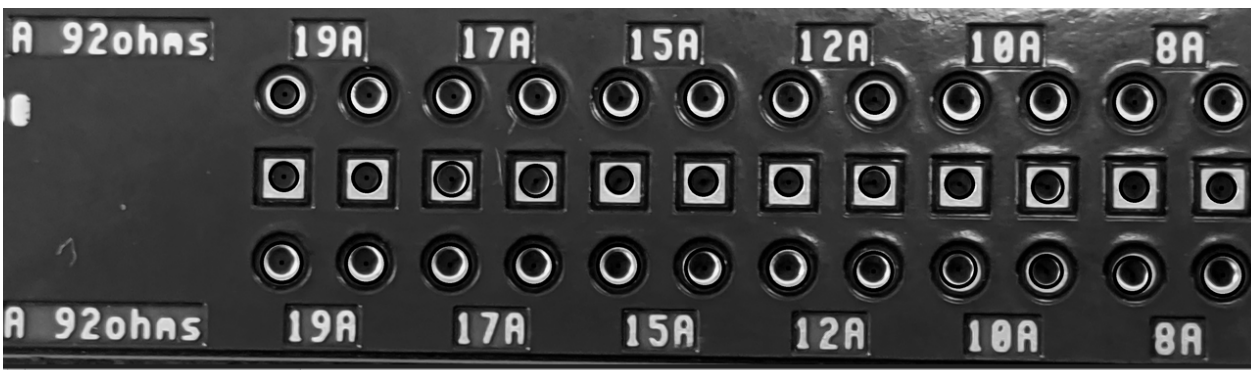
Item Description	Manufacturer	Mfr Part Number	Unit Cost	Quantity	Total Cost
Neptune 2 FDM 3D Printer	ELEGOO	-	169.99	1	169.99
RF Coaxial SMA to BNC converter	DHT Electronics	-	5.5	1	5.5
Stepper Mottor Driver	Aideepen	DRV8825	14.99	1	14.99+G4:G17
CR Touch Level	Creality	SV-CRTOUCH	39	1	39
ESD_Filament	Polymaker		32.99	1	32.99
Deep Groove Ball Bearing	uxcell	B07TV2HVZ3	8.99	1	8.99
Lathe Round Rod	Eowpoer	B072JPQX4Q	9.98	1	9.98
Threaded Inserts	initeq	B07457F9ST	9.99	1	9.99
Auto Focus Endoscope	Teslong	B07HVT2XZL	49.99	1	49.99
LED Lights			17.99	1	17.99
Timing Belt Rubber	POWGE	NA	13.29	1	13.29
CR-Touch	Creality	NA	39	1	39
Thermistor	NTE Electronics	NA	1.68	1	1.68
Buck Converter	Eboot	MP1584EN	11.59	1	11.59
Stepper Motor Drivers	HiLetgo	DRV8825	14.99	2	29.98
Thermal Tape	AVNTKER	NA	10.99	1	10.99
PCB_Cost				1	68.61
Emergency Stop	MXUTEUX	NA	11.99	1	11.99
Thermal Paste	Thermal Grizzly	NA	8.99	1	8.99
Timing Belts	BEMONOC	NA	13.99	1	13.99
Stepper Motor Drivers	HiLetgo	DRV8825	14.99	$1.00	14.99
CR-Touch	Creality	NA	39	$1.00	$39.00
Buck Convert 24-12V	NA	NA	12.98	$1.00	12.98
Thermal Glue	GENNEL	G109	11.99	$1.00	11.99
Thermal Conductive Adhesive	MG Chemicals	8329TCS	16.6	$1.00	16.6
Assorted Breadboard Jumpers	EDGELEC	NA	6.99	$1.00	6.99
Team Activity	NA	NA		$1.00	68.41
					725.49

Link to budget spreadsheet:
https://docs.google.com/spreadsheets/d/1dKsdRoarI9UxyWmKjm9TnyFcVoGY2APgbsrVd2NL7ls/edit?usp=sharing

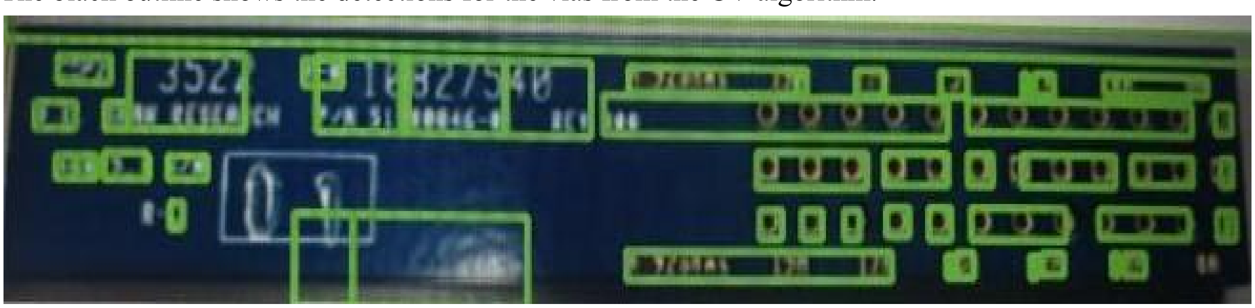
10. Proof of Concept Testing - Phase 1

We conducted a number of experiments to convince ourselves that the product would be a success, before pouring our time and resources into it.

- We initially had concerns about the computer vision system, so we took photos of the coupons with our phones and began writing software in Python to analyze them using a public library of code. Within about a week, we were able to read the text off the images. About another week later, we had figured out a way to detect the vias and outline their locations and size with circles in the image using these libraries. While improvements are being made to the reliability. This quick prototyping step made us feel much, much more confident about the potential success of the project. Below are some images from the early prototype software:



The black outline shows the detections for the vias from the CV algorithm.



The green bubbles are the rudimentary feature detection, which is then fed into an OCR script to pick out the text.

- We also tested out the ability for a mechanical gantry system to align precisely enough to make contact with the via pads on the coupons. We did this by using a needle attached to an existing 3D printer extruder head, and manually controlling it with a coupon taped down to the bed. Overall the test was a success, but we realized a few key aspects of the alignment which could make or break the system. Namely, the coupon must be aligned parallel to the two axes (x, y) of the printer, so that an angular offset wouldn't accumulate over the length of the coupon. Also, we found the z-axis location would be different for each coupon, so we had to determine a way to know how far above the surface of the coupon we are (not the bed). This led us to order the CR Touch, an optical pin based z-axis distance sensor.

- Lastly, we tested the ability to interface with the TDR device with custom C++ software. The DLL interface made it easy to connect to and command the device, but we also had to figure out a way to parse the impedance measurement buffers so that we had a representative picture of what was going on. Through some experiments in Professor Bogatin's lab, we were able to determine different criteria which would allow us to understand the measurements. For example, when the impedance goes up to infinity at the end of the buffer, it means that there is an open circuit. We also determined that using a fixed length cable would allow us to know exactly where to slice the buffer to only analyze the coupon measurement, and nothing to do with the connection interface.

11. Preliminary Design Review (PDR)

Feedback:

- The power dissipation in the LDO and the motor drivers will be too high with the 24 volt supply. We are switching to a buck converter.
- Overall the scope of the project is manageable and the failure points are minimized. We will have something to show for Expo.
- It will be important to get things working early, so that the timing requirements can be honed in.
- The TDR calibration might not need to happen between every pin, but the proof of concept is good to see.
- We can improve the signal to noise ratio of the detections by aggregating and filtering over time.

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12. Customization Plans- Phase 2

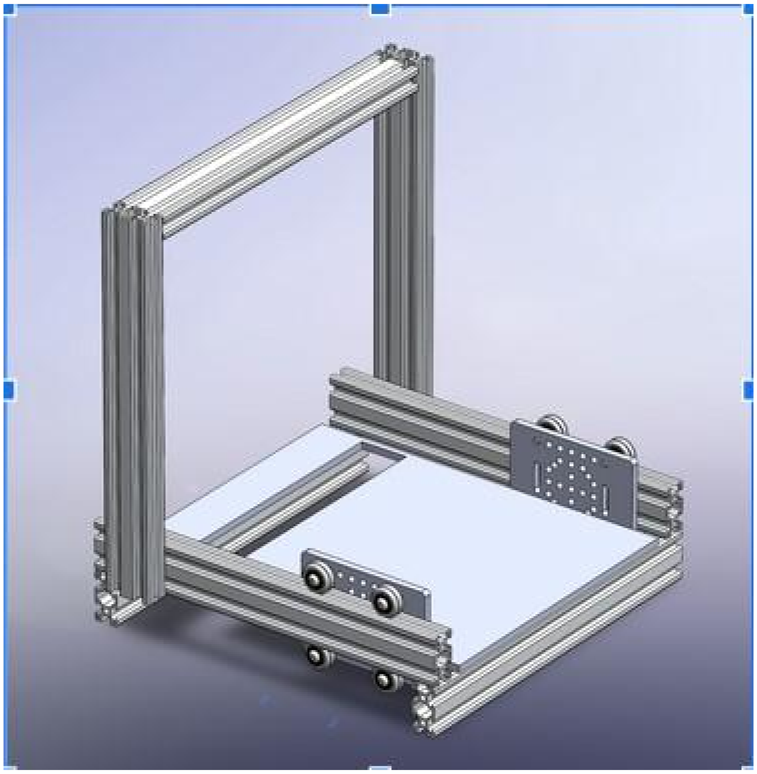
Mechanical

- Assembly of frame
- Mechanical tuning
- Dissipative mechanical base for safe TDR measurements..
- Mechanical Gantry and structure

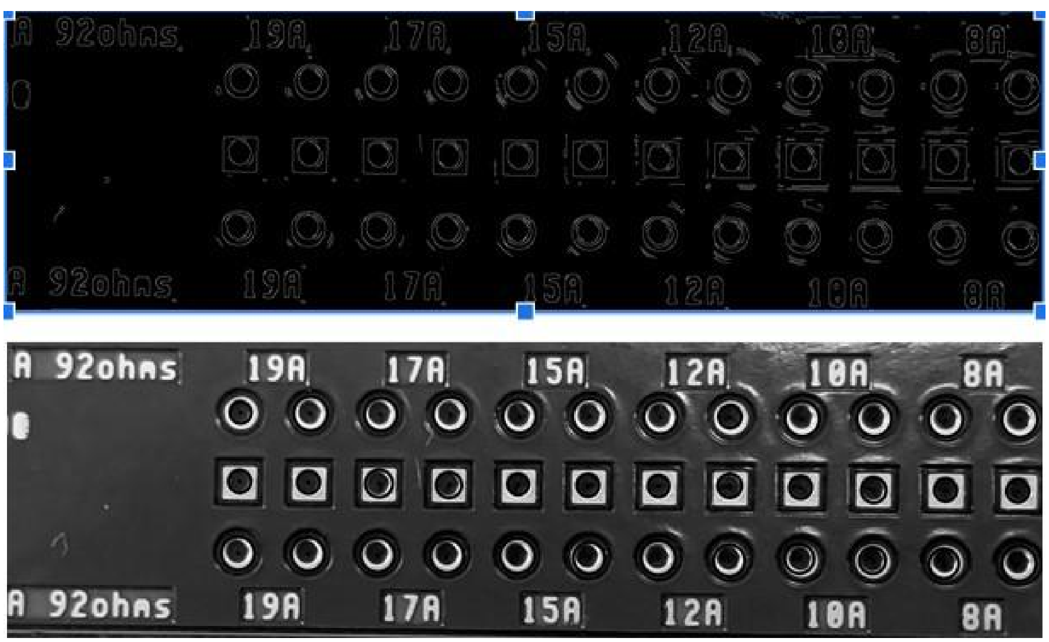
Software

- Real Time Computer Vision Application
- User can adjust & confirm detections
- View data in real time
- Measurement can be made from CV detections for a single coupon
- Sample version of the GUI which could be developed later

Early concept of the GUI



Early CAD of the gantry frame



Early Computer Vision Test for Via-Holes Detection

13. Risk Analysis and Alternative Strategies

Risk 1: ESD damage to TDR

The time domain reflectometer (TDR) is a sensitive piece of equipment whose measurements could easily be affected by any electrostatic discharge by those operating the equipment. A buildup of static electricity can easily come from clothing the operator wears, anything the operator touched in a prior time, and even dry air, especially during the winter. This could lead to faulty measurements in the most mild scenario, or catastrophic damage of the inner electronics of the TDR in the worst. With the consideration that the TDR is very expensive and arguably the most important part of the project, measures need to be taken to minimize the chance of ESD damage.

Risk 2 : Loading Mechanism might not work properly

The loading mechanism to load the coupon onto the test bed for the computer vision system and the mechanical head with the probes attached to take tests automatically might not work properly as intended. The issue arises from the fact that the coupons are of various sizes and thickness and this is complicating the process to automate the process. If the coupons aren't lined up properly the vision system will not be able to pick up the veils for testing and the entire process will fail catastrophically.

Risk 3: Proper coordinate mapping between software and hardware

Computer vision software solutions for detecting locations of vias that are to be tested will be calculated based on local coordinate values. These values will not align with the hardware gantry's fixed coordinates, meaning coordinate transformation needs to be made. As with any transformation method, for proper results, the inputs have to be assured to be correct. If the via holes are off by more than 10 mils, then conversion will not be possible. Errors can occur with the amount of variation there is in the coupon sizes, potential improper lighting on the coupons being tested, and other attributes.

Alternative Section:

Risk 1:

1) To prevent ESD discharge damage, we will require the operator to ground themselves before operation of the machine by touching the metal gantry. All electronics will also be grounded to the metal gantry, which will be powered by a 3 prong wire for grounding as well.
2) Another alternative is designing a probe specifically for the gantry. This means that we can ground the probe casing, and anything attached to the probe is only in contact with the grounded casing. This would be an alternative to grounding the entire gantry.

Risk 2:

1) For the Loading mechanism, in order to bypass the complicated automated loading , we have decided to work on the automated testing process first(gantry head with probes and computer vision system) and have the operator personnel load the coupons onto the test bed manually. This will save us a lot of time if things do go according to the plan and we can instead focus on perfecting other parts of the project.
2) Another alternative, accepted by our client, is designing a loading mechanism with a fixed sized board. This means that the various sizes and thickness complications that come with the loading mechanism are null.

Risk 3:

1) As mentioned in the section above, we can design our computer vision based on a fixed sized board, so issues arising from various sized boards can be ultimately resolved that way.
2) Errors that originated from improper lighting and camera focus can be resolved by purchasing a higher end camera.
3) Proper testing regimen needs to be implemented so that errors can be caught quickly and rectified so as to increase the reliability of the automated testing process, this includes proper calibration methodologies.

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14. Risk Site Test Demo Sheet

Test1: Single axis mechanical gantry accuracy using custom control board

Type: Feasibility and Performance

Purpose of risk site being tested and How it Relates to Project:

The purpose of this test is to verify that while using the custom designed control board, that we can move any axis to a specified location repetitively at a reasonable speed without losing track of the probe's actual location. Additionally this test will also make clear the maximum speed that the system can move each axis tested. This test is important because it will prove if this risk will be a point of failure and if dead reckoning will be a viable solution for tracking the machine's gantry location. Plus it's important because it allows us to test if any changes to the system have adversely affected the accuracy or maximum speed of the system.

Delineated Test Setup and Pre-conditions):

<u>Delineated Test Setup</u>

The test setup consists of a custom arduino based atmega328P control board connected to a DRV8825 stepper motor driver. The motor driver is set up to run the motors at the chosen motors rated voltage and amperage compatible with the driver. The motor driver should also be set to the coarsest level of microstepping possible unless it is required to meet the system requirements, if a previous test determined there was no valid setup. Additionally the axis being tested will need to be loaded with the expected weight of the final design or more to verify that later adding inertia will not cause issues. Then the axis will be moved to any location within 20 millimeters of a measurable reference. Finally the control board will need to be capable of being programmed to move the axis back and forth at least 10 times. The program will be made to move the axis from the starting location a specific distance no more than 100 millimeters away from the reference and back at a defined and fixed speed starting at 50mm/s. Calculating the number of steps per millimeter will be required for each axis design. Each step of these movements will be started upon receiving an input signal via the GPIO of the board.

<u>Pre Conditions</u>

1. Axis being tested is not obstructed.
2. Axis being tested has the range of motion required for the test.
3. Reference being used will not be affected by moving the axis under test.
4. Reference being used can be repeatedly measured from using a pair of calipers.
5. A power delivery to every component that is capable of supplying them during the whole test and does not lose power at any point in the test.

Test Procedure:

A List of the required steps, in logical order, to perform the test demo. These steps should be reproducible by a test engineer, without providing overwhelming technical details.

1. Verify that all of the setup and preconditions are met and satisfied.
2. Measure the distance from the reference point to a point on the axis under test
3. Send a signal to the GPIO pin designated to activate the movement of the axis (This can be done by a button)
4. Wait for the axis to move to its defined location and come to a full stop
5. Measure the distance from the reference point to the same point on the axis under test as before
6. Send a signal to the GPIO pin designated to activate the movement of the axis (This can be done by a button)
7. Repeat steps 2-4 at least ten times recording all of the measurements taken
8. Keep repeating the whole procedure after increasing the defined speed 10mm/s until the system can either no longer move or the accuracy of the movements is less than +- 5%. (optional) if starting speed is suspected to be too high lower it by 10mm/s each test instead of increasing it
9. Average all of the measurements for each speed and determine what speeds will both satisfy the accuracy and speed requirements of the system for the axis under test.
10. (optional) If the test does not find a valid accuracy and speed combination for a given axis. repeat the test with finer microstepping enabled. If this is the second repeat after adjusting the micro stepping and the results were worse than before do not repeat again for the current axis.
11. Repeat the whole process again for each moving axis of the machine

1) Success Criteria (feasibility) / Performance Info (gathering):

1. Every axis under test will be capable of moving at any speed with less than 99% deviation and is within 2 full steps of accuracy. 2 steps of accuracy will be different distances per the axis being tested. For example a single full step on the X axis is 0.1mm
2. There is at least one speed/microstepping setup for each axis that meets the requirements for that axis to properly meet specifications. (defined in the product manuel)
3. Gather the highest viable speeds each axis can reliably move at for use in project

2) Test outcome and what was learned:

The outcome of this test was that the motors that we had intended to use have a compatibility issue with the drivers. So the motors do not spin rather they shake violently in place while still applying the holding current. This problem comes from several different factors. One is a timing issue and the other is a power consumption issue. The drivers that we had planned on using are rated to run around a 6 ohm coil inside of the stepper motor, this isn't exact but it's much more than the motors we have. This makes it so that the driver overheats and draws too much current. The other issue is the timing. The current idea is that the motors we have are 0.9 degree steppers which means that they require a higher operating frequency to run smoothly.

Overall the most likely cause of the issue is the inability to supply the motor with enough power. We will investigate in January.

3) Instructional Team Notes:

This test can also be repeated to test motion smoothing, changes to system characteristics, and to find speeds between the 10mm/s steps or any other applicable speed/accuracy related tests.

|Test done December 1st|

Test 2: Validity of Computer Vision Analysis

Test Type: Gathering

1) Purpose of risk site being tested and How it Relates to Project:

The purpose of gathering information in this part of the project is to verify that the camera computer vision system records proper coordinate locations. It's also to ascertain whether lighting, and the color of the coupons themselves have any effect on reading coupon values and determining via hole locations. This test will also show whether image stitching will be required if camera resolution isn't strong enough to gain all details necessary from a single overhead image. This will help mitigate the risk of our software systems outputting false data to our mechanical control components.

2) Delineated Test Setup and Pre-conditions:

Delineated Test Setup

Pick 10 coupons that vary in widths, lengths, thicknesses, color, and the number of test pads on their surface from the collection given to us by the client.

Pre Conditions

1. Camera is calibrated and ready for test
    a. Resolution, focal length, and any other camera settings set
2. Mechanical test head at proper height for camera to take full image of coupon
3. Gantry test head movement is initialized
4. Program is prepared to show image bounding boxes
5. For image stitching the initial number of images that will be stitched together is entered into program

3) Test Procedure:

List the required steps, in logical order, to perform the test demo. These steps should be reproducible by a test engineer, without providing overwhelming technical details.

Single Image Test Procedures From Gantry

1. Operator places a single coupon on the surface plate of the machine
2. Single picture taken of the test coupon
3. Repeat Steps 1 and 2 for all 10 coupons
4. Images moved to /Images folder within the directory where analysis programs are stored
5. Run analysis.exe program to start image analysis of all images within the /Images folder, the program will export CSV files for markings on test coupons, test pad locations, and altered png files.
6. Open /output folder for analyzed image files

Stitching Image Test Procedures From Gantry

1. Operator places a single coupon on the surface plate of the machine
2. Multiple images are taken iteratively such that the entire coupon has been imaged
3. Repeat steps 1 and 2 for all coupons
4. Images moved to /Images folder within the directory where analysis programs are stored
5. Prior to running analysis.exe, run stitch.exe
6. Run analysis.exe program to start image analysis of all images within the /Images folder, the program will export CSV files for markings on test coupons, test pad locations, and altered png files.
7. Open /output folder for analyzed image files and CSV data files

4) Success Criteria (feasibility) / Performance Info (gathering):

1. Based on variation of test pads on the surfaces of the different coupons, we would compare the highlighted holes by the program. Success of test pad detection would depend on whether every single hole has been highlighted by the program, and a CSV output file is created that stored all their locations. Being able to detect surface pads is the most important risk that needs to be resolves for performance
2. Analyzed image bounding boxes appear to be in proper locations in respect to the pad locations on the coupon, and textual artifacts
3. Associated marking CSV files for each coupon are able to decipher at least the larger labels on the test coupons
    a. Impedance marks near test pads have varying readability levels based on background color against the test coupon. Success will be determined by how difficult the reading would be to decipher by a human being to determine if the amount of error is acceptable by the software, and to detect if there are any differences in detection based on coupon color.

5) Test outcome and what was learned:

From the conducted test we learned that the via detection program worked best when the endoscopic camera was as close to the board under test as possible. This highlighted that image stitching would be required because getting a resolution to take only a single picture, and at the same time have it at a high enough resolution, is too difficult. One of the suggestions that the instructional team recommended is to do analysis on live footage instead of a singular image, or singular stitched images. This would give the program more data to work through to get an accurate analysis of the chips. Another suggestion was to use a specific color background against which the board would be placed on, be it some kind of blue tape, or other colors. This would allow the software to be able to filter out that color and leave just the coupon itself. This will make outliers less frequent among data collected.

6) Instructional Team Notes:

- Do analysis on live footage instead of singular images.

Test 3: Software Flow Test

Test Type: feasibility

1) Purpose of risk site being tested and How it Relates to Project:

The TDR needs 3-5 seconds to recalibrate between each pad measurement, and uninterrupted tests take as much time to measure the impedance value. Also, the gantry needs to move with a precision of 10 mils to accurately line up with pads. The system must flow between each of these states without losing precision while completing the measurement of each board in under 120 seconds. This test will consider all these factors by testing our software state machine.

2) Delineated Test Setup and Pre-conditions:

<u>Delineated Test Setup</u>

The initial test setup would include a COTS gantry control system, which receives G-code and includes an MCU and stepper motor drivers, and the motors we intended to use for our final product. The probe will be attached to the gantry head with zip ties which is enough to ensure that the probe will not move for the purpose of our test. This setup will run our custom code which consists of a state machine replicating the system flow.

<u>Pre Conditions</u>

1. Probe, attached to the gantry head with zip ties, does not move by the force of the gantry pressing it on a coupon
2. A single test coupon is measured by hand and saved to a file to replace the information that will be retrieved from camera vision
3. The same test coupon is placed in the center of the testing area
4. Connecting the TDR and gantry control system to a computer via USB

3) Test Procedure:

1. The state machine program is launched.
2. Communication between the computer and both the gantry control system and the TDR is initialized. The gantry returns to point (x:0, y:0, z:0) and the TDR is calibrated
3. The file which has the coupon measurements is read.
4. The software directs the gantry to the first pad.
5. The impedance is measured.
6. The software directs the gantry to the next pad and the TDR is recalibrated while the gantry is moving.
7. Steps 5 and 6 are repeated until all pads are measured.
8. The gantry returns to point (x:0, y:0, z:0)
9. A CSV file with impedance measurements of each pad is exported.

4) Success Criteria (feasibility) / Performance Info (gathering):

1. All board measurements are done in under 120 seconds.
2. The motor step accuracy loss due to acceleration does not affect the 10 mils precision needed to correctly line up the probe to the pads considering the system has to adhere to the 120 second deadline.
3. There is enough time in the opening where the gantry moves from pad to pad to recalibrate the TDR in open circuit (probe pins don't touch any surface).
4. TDR measurements match measurements done by hand with same the TDR.

5) Test outcome and what was learned:

The servo motors do have enough accuracy to achieve the 10 mils precision needed to go from test point to test point. However, there is a bit of a wobble to the base plate which can be fixed by making sure it is screwed in tighter. ESD remains an issue and the TDR itself couldn't be measuring data at the time of test due to grounding issues.

6) Instructional Team Notes:

- The device needs to be UL certified, and have a dissipative mat for the coupons to rest on. This means that all of the metal chassis parts must be connected to earth ground through a grounding wire. The earth ground connection will prevent the user from being electrocuted, and it will stop charges from building up on the metal surfaces. In addition, to keep the TDR safe from ESD, a dissipative mat will be used as the coupon testing surface. This will allow enough leakage current so that the potential of the base is brought down to earth ground. Then the coupon vias will be in contact with this surface, ensuring no charge is built up on the coupon test pads. In addition, the high impedance surface will be virtually invisible to the TDR measurements since the expected coupon impedance values are ~5 orders of magnitude lower than the impedance introduced by the dissipative surface.

15. Critical Design Review (CDR)

15.1. Modifications based on what has been learned

The product design has been tweaked and molded based on the outcomes of our early prototyping, as well as our risk assessment tests.

- The software stack now places the C++ backend as the primary driver of the state machine, with a GUI wrapper connected by a web server CRUD API. We originally had thought that the GUI could be the main driver of things, but it became clear that it would be most effective to use C++, as it is easier to connect all of the submodules into it. This only became clear once we started writing the code, and the TDR DLL, camera stream interface, and python child processes were under inspection.
- The COTS camera went through a number of changes. We began by using our cell phones to prototype. When this had some issues, we looked into specialty cameras, but found out they were out of budget when we got a quote from a representative. We also talked with another capstone team facing a similar issue and tested out their COTS prototyping camera. Although we ended up ordering the same camera, we still were unsure if it was right for us because we wanted to avoid image stitching. Once we had ruled out a full frame solution without image stitching, we settled on a boresight microscope camera for macro imaging. This led us to run an additional software test using an image stitching library. While the test worked partially, there are some quirks which will need to be ironed out in the future.
- We learned that the 3D printer base we are using is not UL certified, and it could electrocute someone, or break the ESD sensitive TDR. We learned from Professor Bogatin about strategies to mitigate these issues, and we plan to address them as a top priority for the final design.
- We learned about the importance of having a power budget when designing a product when our MCU board hadd a brown out due to the motors drawing too much current.

15.2. Any remaining unknowns or Risks

- The image stitching algorithm was challenging and unreliable with the test photos. The algorithm seems to be much more reliable on distortion corrected and properly spaced image sets.
- The stepper motor controllers had an issue with the stepper resolution during our risk site assessment. We are still needing to investigate this issue.
- The GUI still needs to be linked to the back end with an API or IPC interface.
- The mount for the gantry head still needs to be defined and designed.

15.3. Current Final hardware configuration

- The existing 3D printer hardware will be used for XYZ stepper control and limit switch mounting.
- We are replacing the bed with an ESD mat connected to earth ground. On top of this mat we will have a clamp to hold the coupon in place. The specifics of this clamp is TBD. It must align a variably sized coupon to two datums and allow it to sit flat on the mat / bed.
- The control electronics for the 3d printer will be replaced by our custom MCU / motor driver board.
- The extruder connected to the flying gantry will be replaced by a custom mount including the 50 ohm impedance matched TDR probe (provided by Sanmina), the CR touch z-axis contact sensor, and the boresight camera. The alignment of this feature is critical to the functioning of the

product. We must consider the FOV of the camera, relative height of the CR touch and the probe pogo pins.

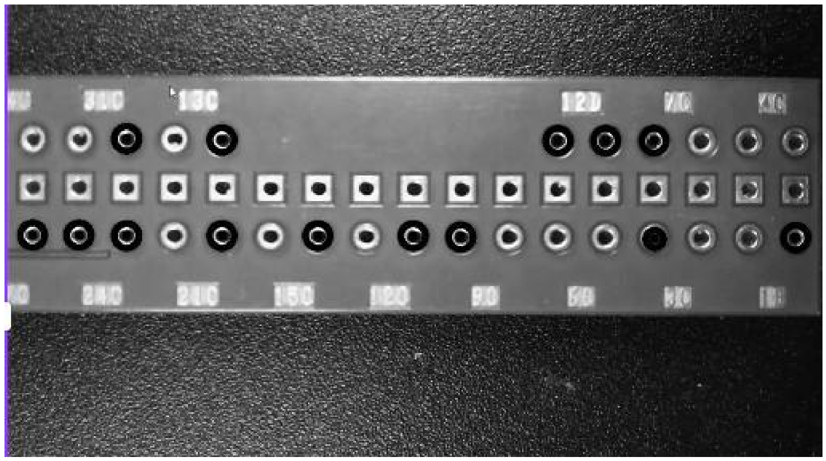
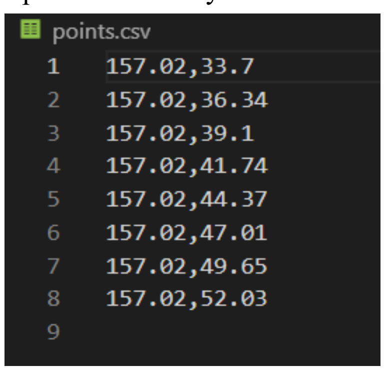
- We will be reusing the power supply provided by the 3D printer to have enough supply current for the stepper motors.
- The TDR enclosure must be mounted to the base of the 3D printer module.
- The metal parts which are “floating” and moving with the gantry must be grounded with earth ground wires.
- There will be two USB cables and one AC power cable coming off of the machine. One USB is for the TDR and the other is for the MCU serial connection.
- There is an E-STOP button accessible on the top or side of the device which will cut the main power to the dangerous parts (motors).

15.4. Current Final software architecture

- The C++ back end program will be responsible for the main command and control of the system. This component is effectively a state machine with a few different interface abstractions:
  - Interface to user interface to allow users to modify the operation, edit data, pause, play, and configure settings. This part is being worked on over break. The stack for this is Electron, React.js, TypeScript, and Bootstrap CSS. This is a stack that we are familiar with so it should be somewhat quick to spin up. This component will be connected to the backend though either inter-process-communication such as pipes or sockets, or with shared memory. The latter option gets complicated due to synchronization issues, and I’m more familiar with an API like a socket.
  - Interface to the TDR instrument. The DLL provided by the manufacturer of the TDR allows users to operate the device with simple method calls (e.g. calibrate, measure, adjust offset and other settings).
  - Interface to the python backend through a child process. The computer vision software is written in Python and will act as a CLI to operate on image data. This python sw will likely be responsible for the connection to the USB camera. It will do this by using the (Windows) operating system abstraction for stream data (as camera frames).

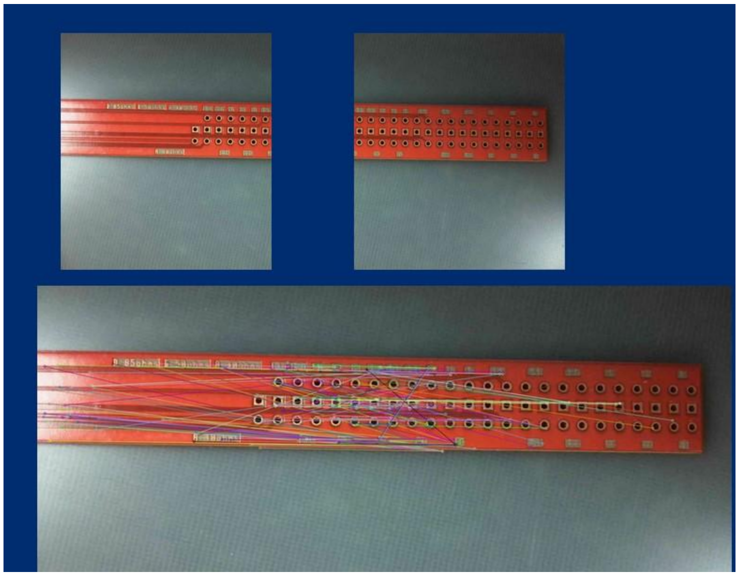
16. Construction and Test of each Subsystem

Computer Vision System

- Detection of test pins separate from ground pins
    - 
    - Test pins are detected in real time (the circles in the image above), separate from the ground pins (the squares with circles inside of them). Real time detection has allowed us to have a large sample size allowing for filtering of specific points using standard deviations.
- Points outputted for use by C++ firmware
    - 

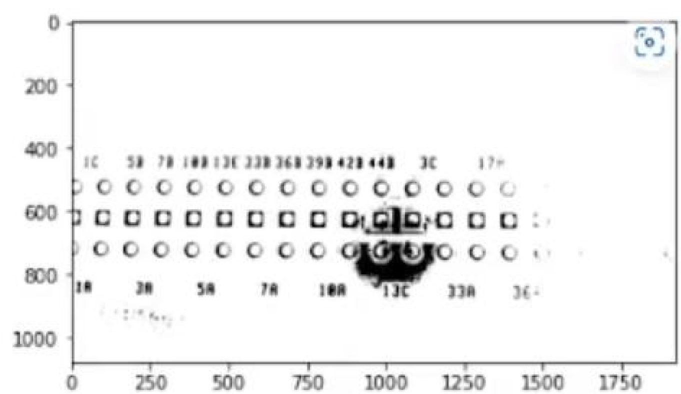
      points.csv

      ```
      157.02,33.7
      157.02,36.34
      157.02,39.1
      157.02,41.74
      157.02,44.37
      157.02,47.01
      157.02,49.65
      157.02,52.03
      ```
    - Test point locations are currently being successfully sent out as a CSV (comma separated list), with the first index being the x axis location, and the second index being the z axis location. The Y axis is determined automatically by the firmware.
- Image Stitching

- 
- As described before, the camera captures only a small section of each coupon, so a working method was developed to stitch multiple captures of a coupon together into one whole as shown above. Necessary for text detection via OCR.

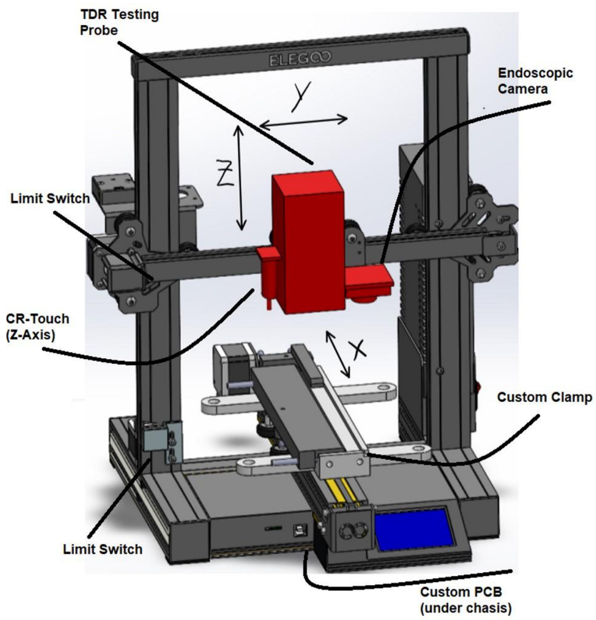
* OCR Detection

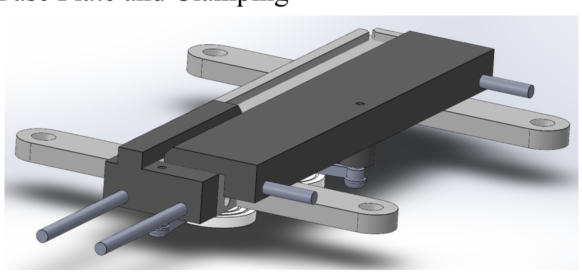
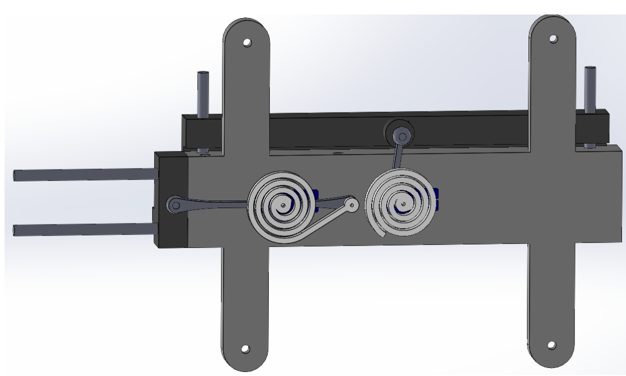
```
1C SB 7B 10B13E 33B36B39B42B44B 3C 17e
20COCOCOCCVCOO GOO

IDO00OOCOOO Goro o0c :
```

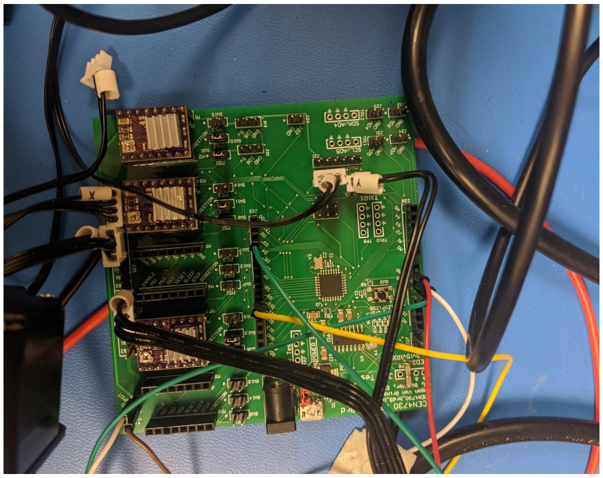
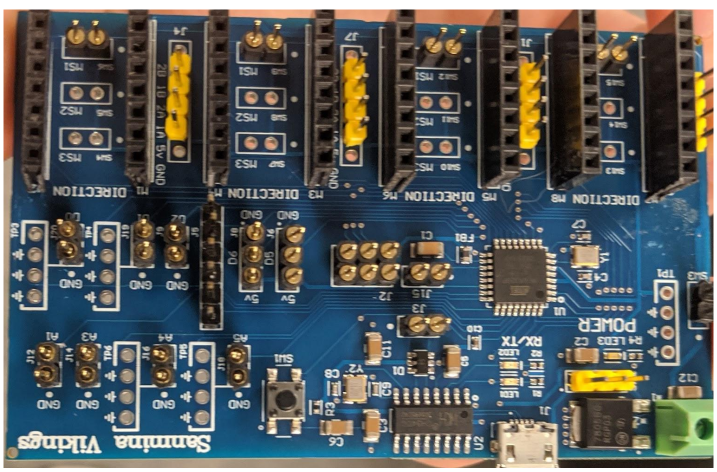
- 

- OCR (optical character recognition) currently partly recognizes text on the coupons. It doesn't work 100% of the time, and varies with different coupon characteristics such as color.
- Current plan is to develop the code for OCR further, or as a plan B, not include it in the final product.

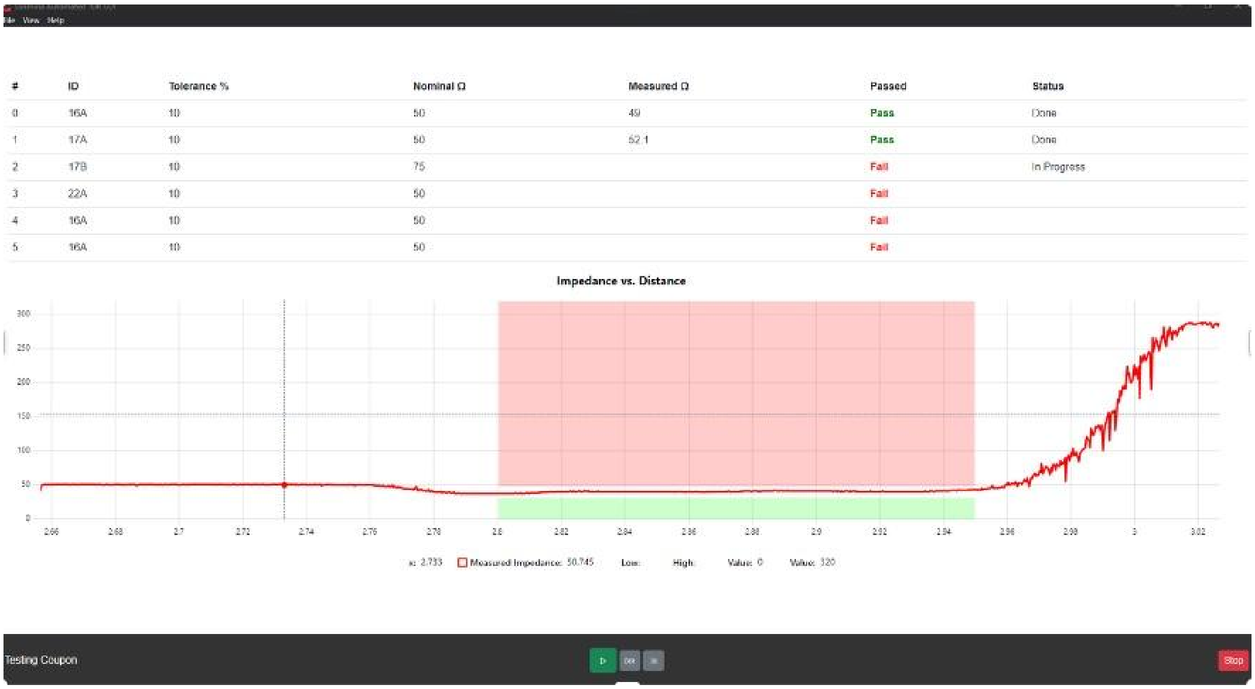
Mechanical/Hardware System

- Gantry Head
  - 

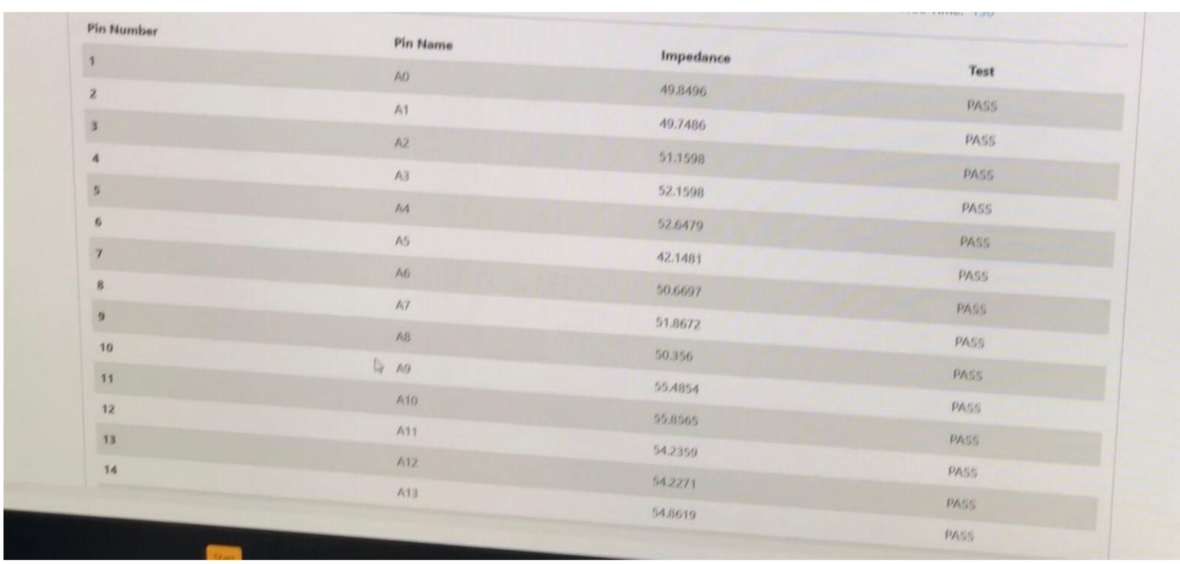
    - The gantry head is printed out of ESD filament and attached. There are some concerns about the camera not being clamped tightly enough, allowing it to rotate. We are also concerned that the probe measurements are being affected by the ESD filament
- Gantry Base Plate and Clamping
  - 
  - 

        - Current clamping mechanism for holding coupons in place. This has also been printed and attached to the machine.
- Custom PCB Progress
    - 
        - First iteration of our custom board. This board has been tested and shown to work with all of our firmware code and motor drivers.
        - Overheating of the motor drivers is a worry. Plan B is to lower operating voltage to 12 V and install better heat sinks with thermal paste
    - 
        - Second iteration of our custom board. There have been some problems with the board due to user error. We had open power wires that may have shorted the board.
        - Plan is to solder a new board, as a plan B we will use our first iteration since it does still work.

GUI - Graphical User Interface

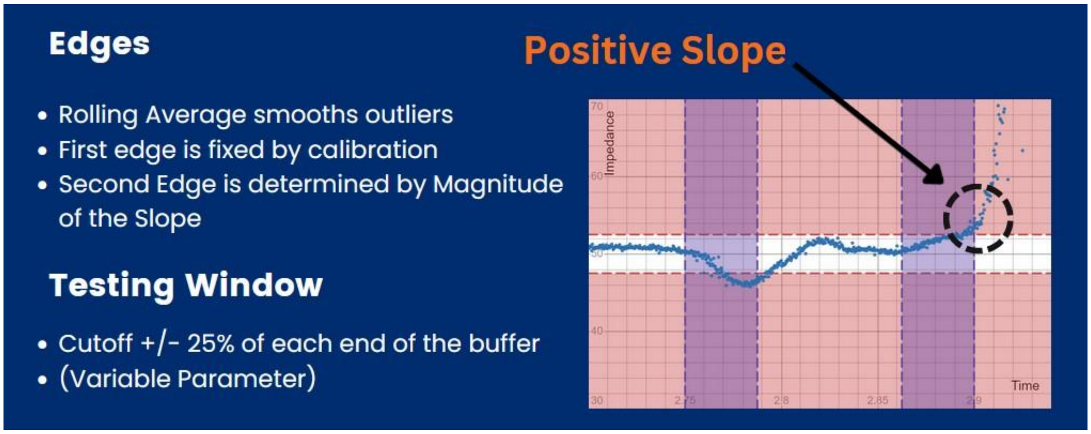


- The GUI is currently a work in progress, the above sample of the GUI currently all the testing performed with the Pass/Fail criteria and the progress status of each of the tests being performed. It also displays the graph for the TDR tester which is the plot of Impedance vs Distance.



- The GUI with the Pass/Fail criteria for the various testing points of the via , measured by the TDR and then displayed via the GUI

TDR



- The image shows the testing using the TDR and the resultant graph we are able to receive.

17. Integration Tests

Computer Vision + PCB Integration

Test Writer: Iskandar Shoyusupov			
Test Case Name:	**Computer Vision Integration with PCB motor driving and CRTouch**	**Test ID #:**	1
Description:	The integration test will be acted upon several hardware components, those primarily being the PCB, the CR-Touch, and the camera. Two software components: computer vision and arduino code will also be integrated. The test flow will have the arduino move the gantry head down on the z axis until the CR-Touch signals positive contact. This value will be communicated to the computer vision program to adjust detection parameters. Afterwards, the gantry plate on which the DUT will sit on will be moved a number of steps, and then pause to let the computer vision program get it's data. This will be iterated until the gantry plate reaches the end of the DUT	**Type:**	Partial Test

		The results from this test will be a completed spreadsheet of physical position data outputted in a csv by the computer vision code, along with an image for all detected via hole and ground positions. Success criteria will be dependent on how accurate the detection algorithm is and how well the motor drivers and arduino code is able to communicate with computer vision code. Main goal is to fulfill engineering requirements pertaining to the vision system being integrated with motor drivers to capture the entire DUT and to output some kind of physical data that can be used for later TDR measurements						
Tester Information								
Name of Tester:		**Iskandar Shoyusupov, Shambaditya Tarafder, Logan Van Grinsven**					**Date:**	February 16th
Hardware Ver:		**PCB : 1.1, CV : 1.6**					**Time:**	TBD
Setup:		Camera and CR-Touch module will be mounted onto the gantry head. Camera will be connected to laptop through USB, and PCB motor drivers set up to control gantry plate movement. Gantry plate will be at "0" (starting) position						
Test	**Inputs/Action**	**Expected Output**	**Pass**	**Fail**	**N/A**	**Actual Output**		
1	Steps to move per section set on arduino	Gantry plate moves correct number of steps per section, and proper amount of sections total		x		This was not implemented in time, so vision test was only done for a small section of the coupon		
2	Coupons of various thickness placed on gantry plate prior to test start. Individual test will be run for each coupon	Appropriate Z axis adjustment from CR-Touch data		x		CR-Touch was only just implemented by test date, so the data received from the CR-Touch was not useful and not adjusted for a proper offset from the CR-Touch pin hitting the board		

3	Time recorded for amount of time gantry plate motor pauses movement between each movement	Time should be consistent between all sections, and around 2 seconds		x		The amount of time per measurement wasnt measured fully as we didn't fully implement the integration of all components
4	Computer vision code is run for each pause after gantry plate movement	All holes on DUT detected and ground/test pins are properly differentiated		x		While the holes were detected, there was no output file to actually measure where the test points were and there was no differentiation between the ground and test pins
5	Time of test start and test end recorded	Time for analysis under 20 seconds	x			The simulated test time did indeed meet the amount of time we expected from the test
Overall Test Result:						For the first integration, the overall test did not go as planned and to some extent can be classified as somewhat of a partial success. We were able to attach the endoscopic camera on the gantry and run the computer vision system to detect the via holes and their corresponding location on the coupons. However the translation of the location coordinates (from the vision) to the gantry movement could not be resolved or performed and thus needs to be accomplished on a priority basis in the next integration test

TDR, PCB, and C++ Backend Software Integration

Test Writer: Abdulrahman Alduaij			
Test Case Name:	**TDR, PCB Firmware, and C++ backend integration**	**Test ID #:**	2

<table>
<tr><td>Description:</td><td colspan="3">This integration test will feature several hardware components: the three stepper motors, a TDR and a custom PCB motor controller, and two software components which are the C++ backend state machine (SM), and the PCB custom firmware.
The test will also include a 3D printed attachment that fixes the TDR probe in place at the head of the gantry. The test will have the C++ SM complete a full impedance test on a predetermined PCB coupon with handmade pin location measurements.
This is done through the C++ program controlling the gantry motors by using custom commands, and using the TDR’s DLL to communicate to the TDR when the probe is in place.
After all test points are tested the time it took for the single coupon measurements will be recorded to confirm that the test finished by the accepted deadline.
The main goal of this test is to integrate the PCB firmware, the C++ backend SM, and the TDR while ensuring that the gantry moves to each test point correctly and the test finishes before the deadline.</td><td>Type:</td><td>Partial</td></tr>
<tr><td colspan="6">Tester Information</td></tr>
<tr><td>Name of Tester:</td><td colspan="3">Matthew Teta, Abdulrahman Alduaij</td><td>Date:</td><td>March 2nd</td></tr>
<tr><td>Hardware Ver:</td><td colspan="3">PCB : 1.1, TDR : !</td><td>Time:</td><td>TBD</td></tr>
<tr><td>Setup:</td><td colspan="5">TDR probe will be mounted onto the gantry head using a TDR probe attachment. The TDR and the custom PCB board
will be connected to a windows desktop computer through USB. The PCB motor drivers are set up to control three motors that adjust the gantry head's 3D movements. A custom C++ program will be launched on the computer.</td></tr>
</table>

Test	Input parameter/Action	Expected Output	Pass	Fail	Actual Output
1	Run the program, and wait for the program to end	The program ends in under 100 seconds	X		When considering the movement alone without the vision system we were able to finish testing a board in under 85 seconds
2	Place Predetermined PCB coupon on gantry plate, and run the program	Machine begins to probe the desired points and test them (TDR)	X		At this point safety wasn't ensured when considering the TDR might be damaged by ESD. This means that this test was partially successful since although disconnected we were able to move the gantry to the desired points.

3	Machine begins to probe the desired points and test them (TDR)	The impedance results values are recorded in a CSV file		X	At this point safety wasn't ensured when considering the TDR might be damaged by ESD
4	Probe head moves to next testing point	The motor step accuracy loss due to acceleration does not affect the 10 mils precision needed to correctly line up the probe to the pads considering the system has to adhere to the 100 second deadline.	X		We were able to accurately probe all need contact points
5	Program state machine ends	All testing points where tested	X		All test points were probed by the probe, but no actual measurements were made
Overall Test Result:					Overall, this test ensured that our current software and firmware set-up can correctly progress through a complete board test. Accuracy of the gantry was visually confirmed by looking at the probe head as it hit each testing pad; however, measurement accuracy confirmation is still not yet possible.

Final Integration Test

Test Writer: Logan Van Grinsven			
Test Case Name:	**Final Integration tests (Final Software+Final Hardware Integration)**	**Test ID**	77889900

		#:	
Description:	The final integration will combine all major elements of the automated impedance testing machine to work in conjunction to simulate measurements of devices under test (our coupons). Hardware integration will involve modules such as the CR-Touch to assist in y-axis adjustments based on coupon surface height, a TDR probe and the TDR itself for taking measurements of test points on coupons, a fully working gantry with motors and a 3D printed gantry head and surface, and finally a fully working custom PCB that is able to control multiple motors in three dimensional space with pins for interrupts, digital logic, and more. On the software side we will integrate python computer vision code that will scan a coupon for test points, release the data to a C++ TDR application which will use the data to instruct the PCB to control the motors in such a way that the test probe hits every via hole. Afterwards, the c++ code integrates a DLL program that controls how waveform data is captured which is developed by the TDR company themselves For the test, we will go through several coupons, validate that the test point data from the python code allows the probe to comfortably land on the via holes, and then make impedance measurements and verify their integrity	**Type:**	Final
Tester Information			
Name of Tester:	**Iskandar Shoyusupov, Shambaditya Tarafder, Logan Van Grinsven, Matthew Teta, Abdulrahman Alduaij**	**Date:**	March 16th
Hardware Ver:	**1.1**	**Time:**	10:00 AM
Setup:	Two coupons are prepared of differing thickness. PCB is connected to a desktop computer which has both the TDR code and Python vision code prepared. The TDR is hooked up to the desktop via USB, and then attached to a probe that will take measurements. Gantry is sufficiently grounded to avoid ESD shock		

Test	Input parameter/Action	Expected Output	Pass	Fail	Actual Output
1	Device turns on / "home"	Home limits are found Gantry moved to camera scan position	x		Device homed the x axis, z axis, and proceeded to use CR-Touch data to set a constant height above the coupon no matter it's size
2	Test started by user	Move to scan position Begin Vision software	x		Test was started on a desktop computer, leading to the gantry head to start the scanning of the coupon for vision test points.

3	Press 'q' to end vision detections (after ~10s)	Detections filtered, sorted, coordinates transformed	x		A video of the vision finding the test points was shown and user pressing q did end the vision scanning, after which coordinates were outputted to the C++ program
4	Vision program exits (0)	C++ code calibrates TDR Moves gantry to each test pad Records impedance data for each pad	x		Gantry head was moved to each test pad and impedance data was measured and collected in an output file. There was indeed a calibration between each measurement that was made
5	All measurements are finished	Data is analyzed for pass/fail criteria CSV is saved with measured impedance and pass/fail data	x		While the impedance data was measured as expected at the test points needed, the data wasn't necessarily useful and all test points were labeled as failing. This was a consequence of most of the test points not being made out for single ended probes.
Overall Test Result:					The test overall had gone very well and shown that there was good integration among all of the software and hardware components. Test point positions were found effectively and the translation of the virtual coordinates to physical was very accurate.

18. Acceptance Test Plans

<table>
<tr><th colspan="7">Automated TDR Acceptance Testing</th></tr>
<tr><td colspan="2">Use case description:</td><td colspan="3">An operator will load coupons, and watch the automation procedure test each coupon.</td><td>Test ID #:</td><td>4</td></tr>
<tr><td colspan="2">Description of the test:</td><td colspan="3">The final acceptance testing will be based upon several hardware components, namely the TDR machine, TDR probe, endoscopic camera, the custom PCB, the CR-touch, and finally the 3D printer based gantry and primary assembly. The software components, namely the state machine in C++, the firmware code, native python CV system, and the GUI for the operator. Initially the coupon will be selected and clamped in place on the 3d printer testing surface. The GUI will be opened , where the operator will initiate the testing of the coupon. The test flow will begin by homing the gantry head, setting the x and z axis based on limit switches, and the y axis using our CR-Touch. Distance to coupon will be communicated to the computer vision program to adjust detection parameters. Afterwards, the gantry plate on which the DUT will sit will be moved a number of steps, and then paused to let the computer vision program collect data. This will be iterated until the gantry plate reaches the end of the DUT. The TDR will be moved by the motors to the proper orientation and lowered towards the necessary via holes on the coupons to take the impedance measurements.The data will be then be outputted as a .csv file for the GUI to interpret and show the graph from the TDR measurement and also state whether the certain test points passed or failed based on the defined criteria.</td><td>Type:</td><td>Final Acceptance Testing</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="2">Name of Tester:</td><td colspan="3">Iskandar,Matthew,Shambaditya,Logan,Abdulrahman</td><td>Date:</td><td>April 13</td></tr>
<tr><td colspan="2">Hardware Ver:</td><td colspan="3">PCB : 2.0 CV : 2.1</td><td>Time:</td><td>TBD</td></tr>
<tr><td colspan="2">Setup:</td><td colspan="5">Camera, CR-Touch and the TDR probe module will be mounted onto the gantry head. Camera will be connected to the desktop through USB, and PCB motor drivers set up to control gantry plate movement. The TDR Probe will be connected to the TDR device and the desktop via USB cable .The coupon will be placed at the bottom of the Gantry and clamped in place by the custom hardware.Gantry plate will be at "0" (starting) position. The GUI will be opened and will be made ready for the start of the testing</td></tr>
<tr><th>Step</th><th>Action (Marketing Requirement)</th><th>Expected Output</th><th>Pass</th><th>Fail</th><th>N/A</th><th>Comments</th></tr>
<tr><td>1</td><td>Device is connected to the computer, GUI connects to the device.</td><td>The device shows up as a COM port and the user can select it from the GUI.</td><td>X</td><td></td><td></td><td>It is simple to connect the device with one cable</td></tr>
</table>

2	Test started by user	Device locates the home position. Moves to scan position (camera view aligns with the corner of the clamp). Begin Vision software.	X			The machine is swift and controlled in beginning it's test operation
3	Vision software automatically exits after it is done scanning for Vias.	Detections filtered (Outliers are not detected, successful detections are clearly shown with precision), sorted. The translated coordinates are sent to the C++ backend and GUI indicates the completion.	X			Proper vias are shown on the monitor
4	Probe moves to each of the test locations with the proper probe rotation.	Moves gantry to each test pad Records impedance data for each. Measurement graphs show up in GUI	X			Impedance data is recorded in a separate file accurately. Graphs show current measured data
5	All measurements are finished	Data is analyzed for pass/fail criteria CSV is saved with measured impedance and pass/fail data. Success criteria is reported in the GUI.	X			GUI reads impedance data and assigns pass/fail markers based on criteria
6	User switches to the next coupon for testing	The machine disables the motors, the coupon can be	X			

		swapped by the user, the user can start the next test with a button in the GUI.				
So-What?			*The acceptance test allows us to simulate our device to see if it holds up to our marketing requirements. In our case, we make sure we have a proper GUI for an operator to use, that data collected is usable with high precision and high accuracy, that we can present our data in a digestible manner so that pass and fail criteria for DUT's can easily be ascertained, and most importantly that it is safe to operate the device without concern for overheating, or operator error*			

Overall Acceptance Test Result : Overall we would say that we were able to make most of our system to perform as defined by the engineering requirements. We were able to detect the via holes and extract location via the computer vision system. We were also able to test another motor for the rotation of the TDR probe to test on double sided coupons and it is robust enough to detect both single sided and double sided coupons and test accordingly.The computer vision then talked to the custom PCB to count steps and move the TDR probe to the specified via location on the coupon. After each measurement from the TDR , the result which is the resultant graph and the pass/fail criteria is displayed on the custom GUI. We were also able to demonstrate that we are starting and stopping the automated system from the GUI as well. The next step before the expo would be to take testing measurements from the entire length of the coupon, as we are currently taking the testing measurements for half of the coupon and hopefully integrate OCR for the corresponding pin values and display them on the GUI as well.

19. Expo + Poster

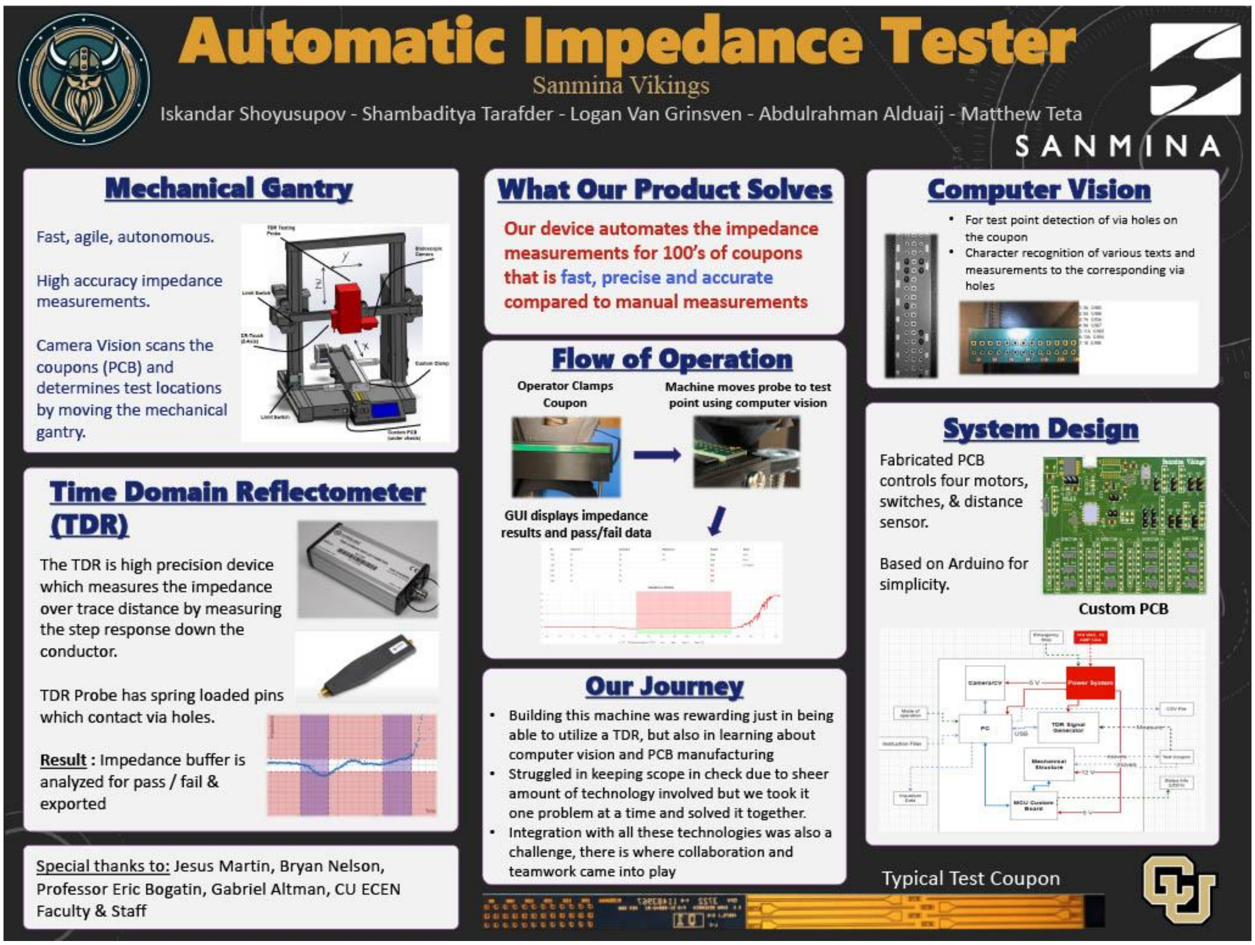


Figure : Poster for the Expo

During the expo we were able to meet all our required objectives from the engineering requirements. We were able to integrate the measurements from the TDR to the GUI and display the pass/fail criteria for each of the testing points on the coupons. We were also able to display the graph for these individual testing points.

There were some stretch goals like extracting the values of each of these coupons via the OCR and then matching with the corresponding pins and measurements and then displaying that on the GUI as well. However, we were not able to integrate that mostly due to variable lighting conditions and unreliability of the OCR in extracting these values. We also didn’t want to take any of these risks right before the expo and thereby hampering our working system.

During the expo we were able to display our fully functioning project to the judges, industry personnels and the audience alike. We definitely had a lot of fun demoing our project to the various groups of inquisitive people which includes a lot of juniors and sophomores who will soon be in our shoes taking the same class. At the end of the day, we were just glad that our hard work over two semesters had finally paid off and we were able to demonstrate our project.

Figure : Sanmina Vikings at the Engineering Expo 2023

Figure : Complete Project with the functioning GUI showing the test results

Figure : Demo of our project to one of the judges during the Expo

20. Website Description

Team Name : Sanmina Vikings

Team Members : Matthew Teta , Iskandar Shoyusupov , Abdulrahman Alduaij , Shambaditya Tarafder , Logan Van Grinsven

Sponsors : Sanmina Corporation

Project Title : Automated Impedance Tester

ELEVATOR PITCH :

Hook : Our device automates the impedance measurements for 100's of coupons that is fast , precise and accurate compared to manual measurements

The Samina automated PCB coupon tester is an autonomous system that when given a test coupon will automatically position a TDR testing probe on each of the single ended test pad locations to measure the impedance of the PCB fabrication process and compare the value to the expected value. This will allow Sanmina to save labor hours and money by speeding up the procedure for the validation of the board manufacturing processes. Through the use of image processing and computer vision, automation can be ensured for up to 100 PCB test coupons in a row with minimal human interaction. The results of which are displayed via graphs and the pass/fail criteria of each of the testing points on the coupons via the GUI. The operator can then take the necessary action and move onto the next coupon.

DETAILED DESCRIPTION OF THE PRODUCT :

The product is broken up into two user-facing components. The first of which is the physical test platform. The test platform is based on a 3D printer. The test platform has a flying gantry holding an endoscopic camera(with lights) , single ended TDR probe, and a CR-touch to measure the height of the coupons. It also has custom clamps to hold the coupons in place and it also houses our custom PCB which is the brains behind the entire testing procedure. The custom PCB has four motor controllers and will adjust and move the flying gantry based on the location data gathered from the computer vision system. The other piece of the product is the user interface (GUI) which is responsible for command and control of the test platform, data processing, and procedure sequencing. The GUI will allow the operator to prepare the system for measurements, view and verify the data from the TDR.

The operator first places the coupons at the base of the test platform and positions it in place by using the custom clamps. The operator then connects it to the necessary COM ports and starts the automated testing procedure. The various motors responsible for the movement of the gantry will home, then the CR touch will measure the height of the coupon. Following these steps, the computer vision system will run to detect the location of the via holes on the coupon. After the detection phase is over, the gantry will lower itself down to take the measurements from the TDR probe to the corresponding via holes on the coupon. The result of which will be available to the operator via the custom GUI . The GUI shows the Pass/Fail criteria for each of the testing points on the coupons and also shows a graph for these individual testing points.

ACKNOWLEDGEMENTS:

We would like to Thank our sponsors from the Sanmina Corporation, Brian Nelson and Jesus Martin with their support and meetings for the fulfillment of this project. We would also like to take this moment and thank Prof. Eric Bogatin for his constant support and technical assistance with the project. And finally we would like to thank our Project Supervisor Gabriel Altman and all the instructional ECEE capstone staff members for helping us get to where we are today.

21. Lessons Learned

We had learned several lessons about the engineering process and working as a team through our experience with building, coding, and manufacturing the automatic impedance tester. Those lessons include being flexible enough to realize and respond to the scope of a project being too large to meet a certain deadline, responding to sudden and unexpected failure of components that can throw a wrench in an entire plan, being able to restructure and improve working elements, and finally being patient with one another as team members and doing our best to create the best product we possibly can.

Initially the scope of our project was fairly vast, with our sponsor requiring the ability to use image recognition algorithms to read text on a coupon, to be able to test a large number of coupons at the same time, having an auto loading feature, and a lot more that we would just not have been able to implement in time for the April 28th exposition. However, just being up front and honest with our sponsor about what we believed we could fully deliver helped us resize the scope into something that was manageable for the team to process but also something that the sponsor would have been happy with, even if it was not as complex as initially planned. For industry or any professional projects in the future, this taught us that honesty and communication with all parties involved on a project is a great way to ensure success.

We've also had to respond to things breaking down suddenly on multiple occasions. As part of our development, a new version of the PCB used to control our motor drivers was developed and five of them had been ordered which, compared to our old board, would have saved space and looked generally more professional. Unfortunately, one board had fried due to an exposed 24V ground wire touching it, which made us a lot more conscious about safety by wrapping all our wires in electrical tape. Another board had a communications chip fail and then another board after that had the same issue. This led to multiple weeks of debugging that didn’t pan out to any conclusive results. In the end we had to compromise and go back to the old board. This taught us that we have to be willing to go back to prior iterations that work and sometimes things need to be dropped to meet requirements.

This project wasn’t all engineering work however, we also had to learn important lessons in teamwork and delegation of different parts of the project. Since we all were seniors with very busy schedules, we learned to be understanding of each other's capabilities in doing certain work, which may have led to potentially unequal delegation, but still ensured that we got our respective sections done or at least had some kind of results. Having clearly defined roles really helped us not step on each other's toes too much and in the end we just had to integrate each other's respective sections.

As our team went along the design process, many changes had to be made to the scope of our project and the final structure that we planned to have completed. Along with that, we had to respond to several unpredictable results when everything was put together. These experiences taught us valuable new ways in how to solve engineering problems and how to work effectively as a team.

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