MAVinator

Design Document

Group SDMay25-15

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Executive Summary

The Center for Nondestructive Evaluation (CNDE) lab plays a critical role in examining and evaluating metals and other materials to determine their safety and suitability for research, development, and various applications. By using advanced non-destructive testing techniques, the lab identifies cracks, flaws, or other potential defects in materials before they are used in industrial or governmental applications. This evaluation process is essential in ensuring that materials meet safety and reliability standards.

The lab has few scanning products and has tasked us with building a new one that can be used by the professors and members of the lab. The goal of this project is to build a 3D (XYZ) scanning platform for millimeter wave imaging.

The key design requirements are that the scanner must have an imaging volume of 300 mm x 300 mm x 300 mm or larger and a positional accuracy of 0.5 mm. In order to accomplish this we will be modifying an open source Voron 3D printer with an in-house designed millimeter wavelength PCB sensor set. As such, the 3D scanner will utilize a stepper motor and belt-driven gantry design. This greatly reduces the cost of the design and allows us to focus on the design of the physical interface and the user interface.

The graphical user interface will have the following features:

1. Home and align the scanner.
2. Perform automated scans on a uniform cartesian or user-defined gird.
3. Perform data collection from a millimeter-wave device (Pythion scripts for interfacing to the device will be provided).
4. Process the data using SAR algorithm and display the results (scripts for SAR will be provided).

Our overall approach consists of

1. Construct structural build of Voron motion system (scanner) - at the same time as manufacturing the sensor PCB pair.
2. Continue build of scanner with control boards and all wiring for them.
3. Test sensor and Motion system (scanner) independently

4. Implement Sensor into motion system and perform rudimentary complete system testing.
5. Implement Web-based GUI from Python scripts (Next Semester)

In constructing the physical build, we will specifically modify a Voron2 2.4R2 Build Guide, with Dr. Tayeb providing the materials. So far we have the entire build done. We have completed the physical build with a proper gantry system with an as of yet untested movement. Dr. Tayeb will also graciously provide a basic script for testing the motion system.

After testing the PCBs for the sensor, we will attach the sensor to the 3D-printed housing and fix that in place of the Voron's toolhead. From there we will do full system testing to ensure that the PCB setup and the Voron printer will work together. Our next steps are to finish the wiring electronics, and testing. Afterward, we will work on the firmware and web-based GUI, which will be the major components for next semester's work.

From our initial research we have committed to recreating a similar experience to accessing a Fluidd UI on a Klipper based 3D printer. That is to say, when you enter the scanner's IP address and correct port your browser will be given a copy of the UI from our web server, that UI will then utilize websockets to communicate with the scanner. This eliminates the burden of any software client, and allows for a more modern experience.

Learning Summary

The development of the MAVinator scanner provided valuable learning opportunities, allowing the team to apply engineering skills and principles while gaining hands-on experience in hardware assembly, circuit design, software development, and system integration.

Development Standards & Practices Used

- Hardware development Practices
  - Followed structured assembly guidelines using the build guide
  - Ensuring precision alignment during the gantry assembly to meet accuracy requirements.
- Circuit Design Practices
  - Designing custom PCBs with proper routing, grounding, and power management.
  - Applying best practices in wiring such as labeling, bundling, and securing cables to prevent damage or interference.
  - Practice safe soldering techniques
- Software Development Practices (Next Semester)
  - Writing clean, modular, and well-documented Python scripts for the user interface and data collection.
  - Testing the motion control firmware using iterative debugging and verification procedures.
  - With multiple threads running concurrently ensure safe memory usage at all times.
- Engineering Standards:
  - IEEE standards for embedded systems and software development.
  - ISO standards for accuracy and repeatability in measurement equipment.
  - IPC standards for PCB design and manufacturing.
  - ANSI standards for safe mechanical assembly practices.

Summary of Requirements

- **Build Requirements:**
  - Develop a 3D (XYZ) scanning platform for millimeter-wave imaging.
  - Base the design on an open-source platform and adapt it for millimeter-wave imaging.
  - Achieve an imaging volume of at least 300 mm x 300 mm x 300 mm.
  - Ensure positional accuracy of 0.5 mm.
- **Mechanical and Electronic Assembly**:
  - Utilize a stepper motor and belt-driven gantry design.
  - Assemble the mechanical and electronic components of the scanner.
  - Upload and configure the motion controller firmware.
- **Graphical User Interface (GUI) Features**:
  - Enable homing and alignment of the scanner.
  - Allow automated scans on a uniform Cartesian grid or user-defined grid.
  - Perform data collection from a millimeter-wave device (with Python scripts provided).
  - Process data using SAR algorithms and display results (scripts provided).
- **Additional Features**:
  - Integrate functionality to map the surface profile of an object using a probe attached to the gantry.
  - Enable the scanner to follow the surface profile during scanning.

Applicable Courses from Iowa State University Curriculum

- *EE 4140*
  - *This course introduces students to microwave circuit design and testing which was valuable in the assembly of the PCBs*
- *EE/CPRE 3300 (maybe)*
  - *Circuit design*

New Skills/Knowledge acquired that was not taught in courses

This project has provided the team with the opportunity to learn and develop a variety of skills that go beyond normal coursework, offering valuable hands-on experience in real-world engineering challenges

- **Mechanical Assembly**:
  - Assembling a complex gantry system and aligning axes for precise movement.
  - Understanding and implementing 3D printer-based motion platforms.
  - 3D modeling parts built off of other models to be put to use in real life.
- **Circuit Design**:
  - Designing, fabricating, and testing custom PCBs tailored for scanner electronics.
- **Firmware Integration**:
  - Configuring and debugging firmware for stepper motors and motion control systems.
- **Python Development**:
  - Creating web-based GUIs for scanner operation using Python frameworks.
  - Interfacing Python scripts with external sensors and hardware.
- **Millimeter-Wave Imaging**:
  - Understanding the principles of millimeter-wave technology and its application in imaging.
- **Project Management**:
  - Coordinating multi-disciplinary tasks such as mechanical assembly, electronics integration, and software development.
  - Documenting processes and results for academic and professional purposes.

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1. Introduction

1.1. Problem Statement

Scanning can be a time consuming process and there are often not enough scanners to go around. Simply buying a scanner would be an option if they were not exorbitantly expensive. Fortunately with a single **M**illimeter sensor **A**rmed **V**oron(**MAV**inator) we can build a cheap scanner with a large scan volume. With the addition of a simple user interface that can be remotely accessed; Scanning at Center for Non-Destructive Evaluation (CNDE) will become better than it ever has been for the technicians, leadership, and clients.

1.1.1. Project Narrative

Everyone here at the CNDE is well aware of the shortage of millimeter wavelength scanners within our facilities. Lab technicians have to work harder than ever to ensure their scans in a timely manner so that they do not interfere with others using the facilities. This is a problem as millimeter wavelength scanning can safely reveal obstructed and less than visible details of a medium sized object. In addition to being cool, a lack of access to these scanners can result in further project delays due to increased difficulty in troubleshooting and evaluation. More scanners would have been purchased long ago if it were not for the exorbitant cost of a packaged system.

So the CNDE is indeed in need of a cheap and effective millimeter wavelength scanner solution. That is where the **M**illimeter wavelength **A**rmed **V**oron(**MAV**inator) scanner comes in as a viable solution going forward. This system makes use of the open-source Voron 3D printer motion system and an in-house millimeter wavelength scanner PCB, its sister control board, and our design of the physical and digital user interface, to allow for a cheap and effective machine with a large scan volume and simple user controls. If the first build proves the concept then this system could be implemented on a larger scale as well due to the low cost.

Our project is bringing the MAVinator to fruition and doing it well. A lot of the quality of the scan will hinge upon the quality of the printer build, PCB testing, and programming of the system, so we will do our best to document the process and any areas of improvement to further refine our process and the MAVintaor. If we are successful we will have a novel fully functioning non-destructive scanner operating within the millimeter wavelength range (119-134GHz) for the lab to make use of.

1.2. Intended Users

1.2.1. Background of Users

Our users have a variety of requirements, but many of them share some common needs. One of these common requirements is that the scanner must operate with millimeter waves. Another common requirement is a reasonably short scan time to promote efficiency. It also must be able to scan a 300mm x 300mm x 300mm region. Additionally the product should look professional and have a user interface that is easy to understand, and overall easy to operate. We have created some different personas that represent the different users and their needs that this project aims to address.

1.2.2. Four Types of Users

1. Lab Technician

Eli needs to be able to scan materials at a quicker rate because he is experiencing too much downtime in his project which is leading to unmotivated work and adding another scanner could do that.

He also wants to be able to extend upon the research he does in the lab to higher frequencies which is why a millimeter wave scanner is important.

Requirements:

- ➢ Functional
  - ○ Needs a scanner that works in the millimeter wave frequency range
  - ○ Needs the scanner to be able to move in 3 dimensions
- ➢ Resource
  - ○ This system needs to be able to connect to a web app or computer to control
- ➢ Physical
  - ○ Should be large enough to scan the things his boss gives him (which will be a max size of 300 mm x 300 mm x 300 mm)
- ➢ Aesthetic

    - The app should look good enough that it is easy to use and understand
- ➢ User experiential
    - Needs the software to be easy to use either from a web app or a computer connected to the device
    - Needs it to export a file of the data to be analyzed

2. Governmental Clients

As an investigator at NASA Magnum needs to reveal the internal structural makeup of his custom manufactured item because he needs to be able to make a more informed decision based on that.

Requirements:

- ➢ Functional
    - Reliable and repeatable results
    - Analysis even through opaque materials
    - Non destructive investigations
    - Reasonable scan times
- ➢ Resource
    - Time it takes to perform the scan is valuable to this type of user
- ➢ Physical
    - Maintain the safety and integrity of the item to be evaluated
    - Could need anywhere from 1cm x 1cm x 1cm to 30cm x 30cm x 30cm or possibly larger
- ➢ Aesthetic
    - High fidelity scan results
- ➢ User experiential
    - Simple ordering experience

3. Private Clients

Ted needs a way to seamlessly integrate reliable 3D millimeter wave scanning hardware and software components into advanced security systems because this ensures precise sensing capabilities and simplifies product development for WaveSense Innovations, keeping their solutions at the forefront of the industry's technological advancements.

Requirements:

- ➢ Functional
    - It needs to be able to do millimeter wave scanning
    - Scanner must be able to identify various materials within scanning area
    - System should provide API for integration with other applications

- ➢ Resource
  - It should be cheap to build
  - Scanner should not require more than 4 GB of RAM
- ➢ Physical
  - Could need anywhere from 30cm x 30cm x 30cm to 1m x 1m x 1m or possibly more
  - Total weight should not exceed 5 kg for ease of portability and installation
- ➢ Aesthetic
  - Scanner exterior should have modern design
  - App should have a sophisticated design and be user friendly
- ➢ User experiential
  - Company associates should be able to operate easily
  - Software interface should be intuitive with clear visual indicators and real-time feedback
- ➢ Environmental
  - System should be able to operate indoors and outdoor environments

4. Senior lab Technicians

As a lead researcher at CNDE, Tabey needs to look deeper inside small volumes of material for her own research and vicariously through her team for larger projects. Tabey needs a more affordable scanner in the CNDE lab because the number of scanners in the lab is too few to effectively complete work.

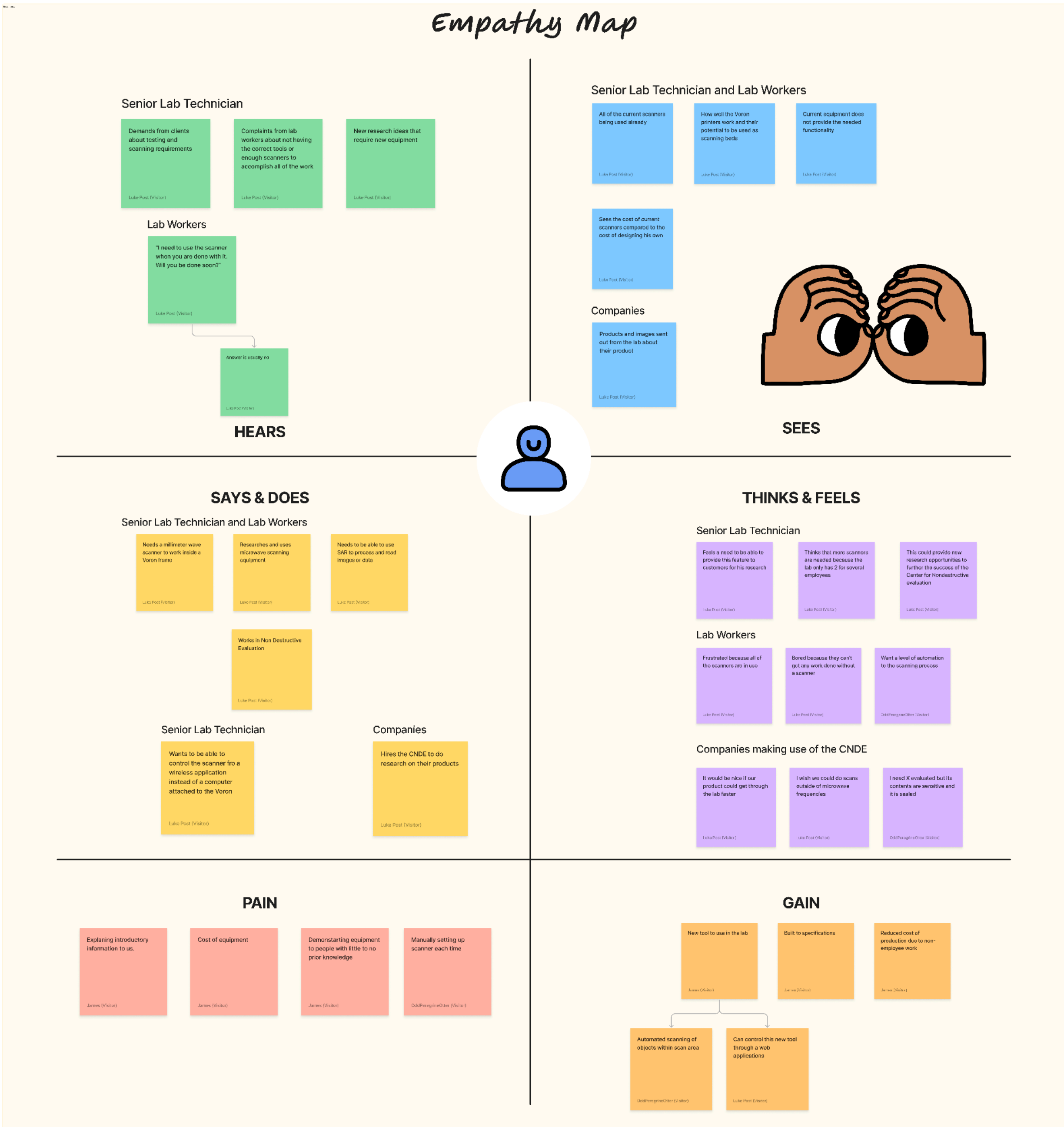
Requirements:

- ➢ Functional
  - It needs to be able to do millimeter wave scanning
  - It needs to fit within the existing lab environment
- ➢ Resource
  - It should be cheap to build
  - Build time should not be longer than one month
  - The time it takes to operate should be the same if not less than other scanners
- ➢ Physical
  - It needs to be able to be implemented on a Voron printer
  - It needs to cover an area of 300 x 300 x 300 mm
  - It needs to make use of the in house millimeter scanner
- ➢ Aesthetic
  - The app should look sleek while still providing good user experience
  - The scanner should look sturdy and professional
- ➢ User experiential

- Lab technicians should be able to operate easily
- The scanner should be able to be remotely started and stopped

1.2.3. Empathy Map

Empathy Mapping helps identify the thoughts and feelings of a user. As our primary user is a senior Technician, we used him to create our primary empathy map. In this empathy map, we were able to understand how this user will interact with the final product .


Empathy Map
Senior Lab Technician
Demands from clients about testing and scanning requirements
Luke Post (Visitor)
Complaints from lab workers about not having the correct tools or enough scanners to accomplish all of the work
Luke Post (Visitor)
New research ideas that require new equipment
Luke Post (Visitor)
Lab Workers
"I need to use the scanner when you are done with it. Will you be done soon?"
Luke Post (Visitor)
Answer is usually no
HEARS
Senior Lab Technician and Lab Workers
All of the current scanners being used already
Luke Post (Visitor)
How well the Voron printers work and their potential to be used as scanning beds
Luke Post (Visitor)
Current equipment does not provide the needed functionality
Luke Post (Visitor)
Sees the cost of current scanners compared to the cost of designing his own
Luke Post (Visitor)
Companies
Products and images sent out from the lab about their product
Luke Post (Visitor)
SEES
SAYS & DOES
Senior Lab Technician and Lab Workers
Needs a millimeter wave scanner to work inside a Voron frame
Luke Post (Visitor)
Researches and uses microwave scanning equipment
Luke Post (Visitor)
Needs to be able to use SAR to process and read images or data
Luke Post (Visitor)
Works in Non Destructive Evaluation
Luke Post (Visitor)
Senior Lab Technician
Wants to be able to control the scanner fro a wireless application instead of a computer attached to the Voron
Luke Post (Visitor)
Companies
Hires the CNDE to do research on their products
Luke Post (Visitor)
THINKS & FEELS
Senior Lab Technician
Feels a need to be able to provide this feature to customers for his research
Thinks that more scanners are needed because the lab only has 2 for several employees
This could provide new research opportunities to further the success of the Center for Nondestructive evaluation
Luke Post (Visitor)
Lab Workers
Frustrated because all of the scanners are in use
Bored because they can't get any work done without a scanner
Want a level of automation to the scanning process
Companies making use of the CNDE
It would be nice if our product could get through the lab faster
Luke Post (Visitor)
I wish we could do scans outside of microwave frequencies
I need X evaluated but its contents are sensitive and it is sealed
PAIN
Explaning introductory information to us.
James (Visitor)
Cost of equipment
James (Visitor)
Demonstarting equipment to people with little to no prior knowledge
James (Visitor)
Manually setting up scanner each time
OddPeregrineOtter (Visitor)
GAIN
New tool to use in the lab
Built to specifications
Reduced cost of production due to non-employee work
Automated scanning of objects within scan area
Can control this new tool through a web applications
Luke Post (Visitor)

2. Requirements and Standards

2.1. Design Requirements

2.1.1. Physical Requirements

- ➢ The finished product should easily fit into the CNDE lab environment.
- ➢ The overall frame dimensions will be 350mm x 350mm x 350mm.
- ➢ The design should be compact, stable, and easy to position within the lab setting.

2.1.2. Functional Requirements (specification)

- ➢ Scanner should operate within a volume of 300mm x 300mm x 300mm.
- ➢ Scanner should be able to detect dense materials at least 2.4mm in width.
- ➢ Sensor head should work with the existing toolhead mount and raspberry pi board.

2.1.3. Resource Requirements

- ➢ The scanner should be cost effective, utilizing affordable components without sacrificing performance or reliability.

2.1.4. Aesthetic Requirements

- ➢ The final product should look professional, clean, like a commercially available scanner.
- ➢ The wiring and electronics should be hidden where possible.
- ➢ The print head should fit with the aesthetic of the overall build. This is aided by the already professional Voron motion system.

2.1.5. User Experiential Requirements

- ➢ The scanner should be designed for ease of use, enabling users to start scans quickly without needing to make physical adjustments.
- ➢ Preparation for scans should be intuitive, and the scanning process should be as fast and efficient as possible while maintaining accuracy.

2.1.6. Environmental Requirements

- ➢ The design should comply with environmental standards for electronic devices, using materials that are durable yet environmentally friendly where possible.

2.1.7. UI requirements

- ➢ The user interface should be intuitive, easy to navigate, and designed to guide the user through the scanning process with ease.
- ➢ The UI should present only essential features, keeping the workflow streamlined.
- ➢ The design should be visually appealing and cohesive with the professional aesthetic of the hardware

2.2. Engineering Standards

Engineering standards are an essential part of modern design and engineering. Without them the likelihood of two devices using a similar communication protocol would drop drastically. Our team has placed a great deal of emphasis on recognizing and incorporating IEEE standards where possible. Below is an outline of the key standards relevant to our project.

2.2.1. Built-in Standards

Built in standards are standards that are implemented by subcomponents that our team has no hand in designing but will still be pertinent to know.

- ➢ 802.11ac (Wi-Fi standard)
  - This standard governs wireless networking and communication protocols, ensuring our scanner integrates effectively with the CNDE lab's existing wireless infrastructure. Compliance with this standard allows for reliable and fast data transmission over Wi-Fi.

2.2.2. Design Standards

Design standards are standards that are not given to us by subcomponents but are selected by design. These are chosen to ensure the scanner complies with standards for devices in a similar class.

- ➢ IEEE 149: Standard Test Procedure for Antennas

    - This standard provides test procedures for evaluating antenna performance. This standard is applicable to our project because we will be using an antenna to transmit and receive millimeter waves. Adhering to IEEE 149 ensures that the antenna used in our scanner is accurately tested and optimized for effective signal transmission
- ➢ IEEE C95.3: Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0Hz to 300 GHz
    - This standard addresses the measurement of electric, magnetic, and electromagnetic fields, specifically with regard to human exposure to such fields. This is applicable to our project because we will be using millimeter waves between 119 and 134 GHz
- ➢ IEEE 26514: Standard for Adoption of ISO/IEC 26514:2008 Systems and Software Engineering--Requirements for Designers and Developers of User Documentation
    - This standard guides the creation of user documentation for systems and software products. It is applicable to our project for the documentation we create on how to interface with our finished product and maintain it.
- ➢ P3397: Standard for Synthetic Aperture Radar (SAR) Image Quality Metrics
    - This standard defines quality metrics for SAR imaging systems. It applies to our project because we will use SAR to process the data and display the results of the scanner

3. Project Plan

3.1. Project Management/Tracking Progress

Project Management Methodology:

We will employ a hybrid approach combining elements of both Waterfall and Agile methodologies to efficiently manage the MAVinator project.

Waterfall Methodology:

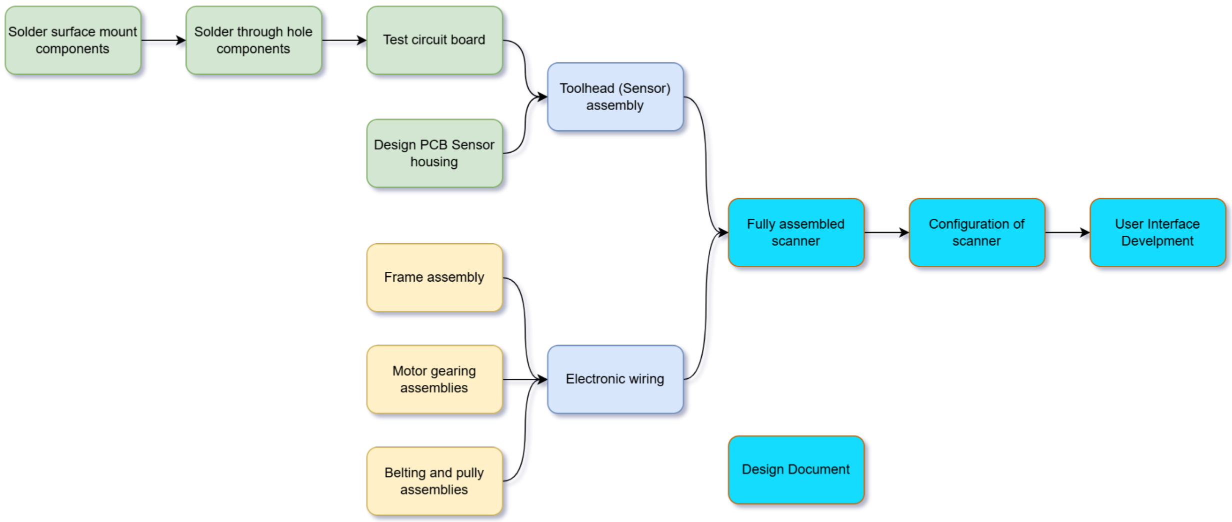
- Phase-based: The project will be divided into two distinct phases: Hardware, and Software with the hardware phase scheduled to be completed this semester. The software development phase will consist of developing the user interface and is anticipated to to approach completion towards the end of next semester.
- Sequential: Certain sprints will rely on others being completed before they can begin. The assembly of the sensor tool-head relies on the completion of the housing and PCB. The electronic wiring requires the frame and motors to be mounted to have anything to wire. Lastly the user interface will require all other components be assembled before it can begin.
- Documentation-heavy: Documentation will be maintained throughout the project, including requirements/specifications, this design document, test plans, and user manuals.

Agile Methodology:

- Task decomposition: We have broken down the phases of this project into simpler segments or sprints. The housing for the scanner, the printer frame, and the PCB as smaller components of the Hardware phase can be worked on in parallel.
- Frequent feedback: Regular feedback loops have been established with the project stakeholders to ensure that the project is aligned with their needs and expectations.
- Continuous improvement: We will continuously evaluate and improve our processes and methodologies throughout the project. This will be accomplished through team meetings, and independent research.

We primarily utilize discord for communication and tracking progress.

3.2. Task Decomposition



Task decomposition starts with the foundational PCB, soldering all components, followed by testing the circuit board. The PCB is then ready for the design and print of a housing/mount, after which the sensor toolhead is ready for assembly. Concurrent to those, the frame and drives are assembled, once they're ready, the wiring will be integrated. With those two major milestones reached the MAVinator is ready for full assembly and our goal for this semester is complete. The design and implementation of a software user interface can then begin. All throughout the design documentation is being updated, referenced, and polished.

3.3. Project Proposed Milestones, Metrics, and Evaluation Criteria (Hardware)

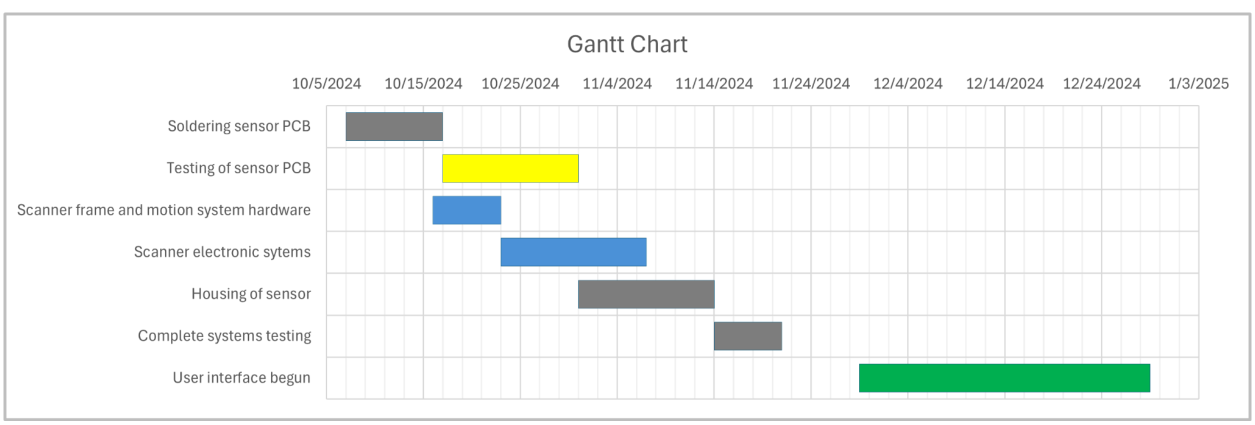
3.3.1. Milestones:

1. PCB Soldered and ready for testing
2. Scanner body assembled
3. Scanner wiring ready for sensor component mounting
4. Testing of PCB completed
5. Wiring of motion system complete
6. Sensor mounted and wired
7. Systems testing completed

3.4. Project Timeline/Schedule (Hardware)

This is the schedule the project will follow for the hardware development portion. The scanner electric wiring end date has had to be pushed out by one week, resulting in an overlap with the housing design.

Milestone	Start Date	End Date	%	Lead	Notes
Soldering sensor PCB	10/7/2024	10/17/2024	100	Luke	Two connectors needed reversing
Testing of sensor PCB	10/17/2024	12/4/2024	100	Luke, James	The scan using the sensor was great quality
Scanner frame and motion system hardware	10/16/2024	10/23/2024	100	Nate, Daniel	Two of the rails, one z one y are short bearings Was actually completed 11/7/2024
Scanner electronic systems	10/23/2024	11/7/2024	100	Nate, Daniel	Was actually completed 12/4/2024
Housing of sensor	10/31/2024	11/14/2024	100	James, Daniel	Was actually completed 12/1/2024 Installed 12/4/2024
Complete systems testing	11/14/2024	11/21/2024	5		Thanksgiving break begins- did not begin until return from break
User interface begun	11/29/2024	Semester 2 end	0		Back from break

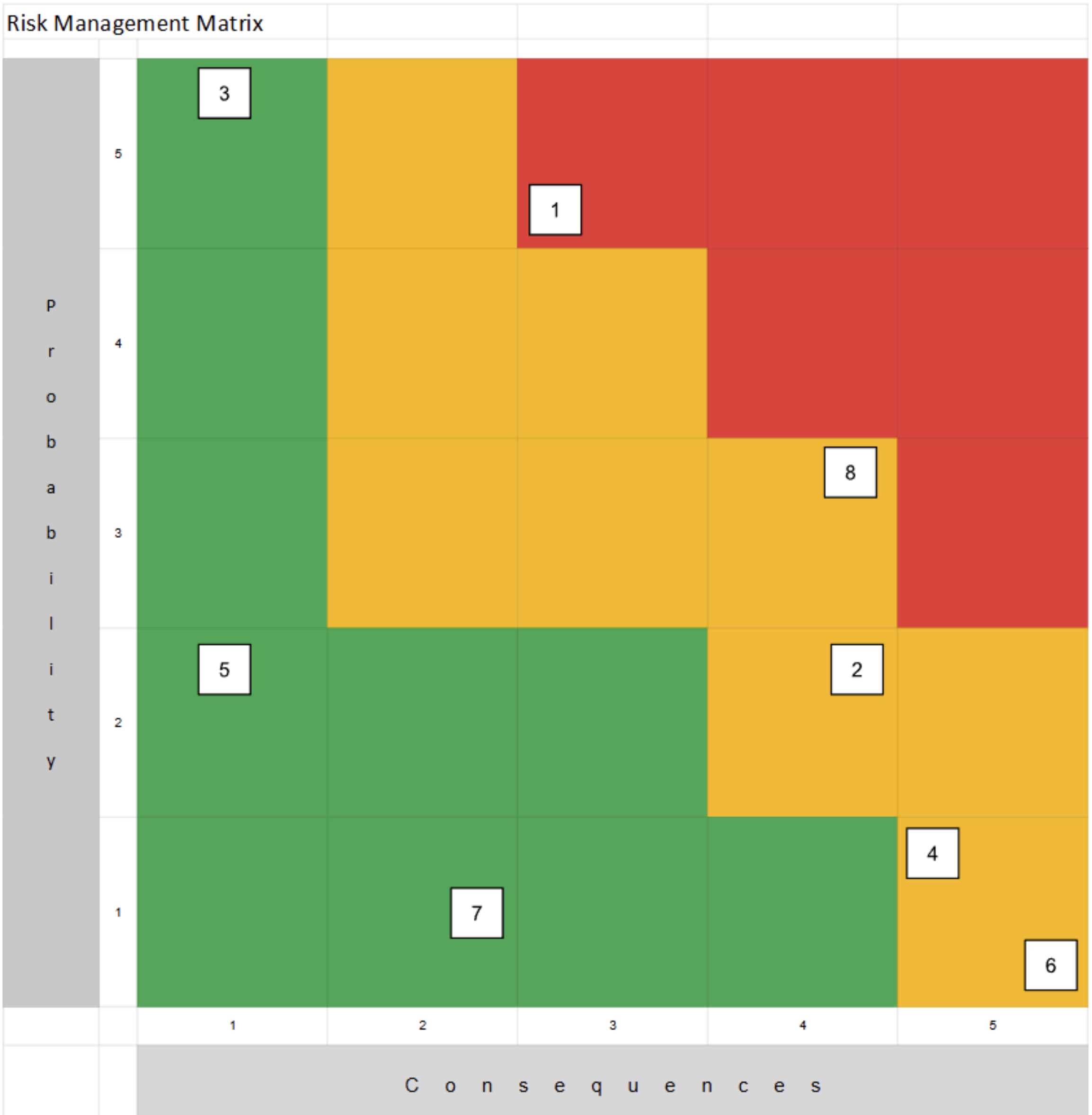


3.5. Risks and Risk Management/Mitigation

3.5.1. Key Risks:

Risk	Description
PCB does not work as intended initially	A fixable issue occurs with PCB sensor, could not scan
Physical build runs catastrophically over schedule	Build runs into next semester, could not scan
Linear rail missing bearings	One linear z and y rail are missing <4 bearings, we have accepted this and plan to replace, can scan
PCB has catastrophic short	A short bad enough it burns the board irreparable, could not scan
Frame out of square during testing	Frame being out of square and gantry not being properly de-racked results in inaccuracies, could scan
Sensor toolhead can not determine its location	Sensor looses or has no way to determine its position, would probably break the sensor pcb
Over-voltage motors	Motors are ran over-voltage due to improper Stepper Driver configuration, burnt out, could still scan

3.5.2. Risk Management Matrix



Risk Assesment					
Rank & Trend	Risk Title	Approach	Likelihood	Consequences	Description
1	PCB does not work as intended initially	M	5	3	A fixable issue occurs with PCB sensor, could not scan
2	Physical build runs catastrophically over schedule	W	2	4	Build runs into next semester, could not scan
3	Linear rail missing bearings	A	5	1	One linear z and y rail are missing <4 bearings, we have accepted this and plan to replace, can scan
4	PCB has catastrophic short	R	1	5	A short bad enough it burns the board irreprably, could not scan
5	Frame out of square durring testing	W	2	1	Frame being out of square and gantry not being properly de-racked results in inacurracies, could scan
6	Sensor toolhead can not determine its location	R	1	5	Sensor looses or has no way to determine its position, would probably break the sensor pcb
7	Over-voltage motors	R	1	2	Motors are ran over-voltage due to improper Stepper Driver configuration, burnt out, could still scan
8	Electrical interferance	M	3	4	Elecitrical interferance can impede an accurate measurement, we need to elminate as much internal interferance as possible
9					
10					
11					
12					

Approaches:
M - Mitigate
W - Watch
A - Accept
R - Research

3.6. Personnel Effort Requirements (Hardware)

Milestone	Person-hours
Soldering sensor PCB	15
Testing of sensor PCB	10
Scanner frame and motion system hardware	24
Scanner electronic systems	16
Housing of sensor	12
Complete systems testing	8

3.7. Other Resource Requirements (Hardware)

Part	Quantity
Millimeter wavelength transceiver board	1
Transceiver control circuit board	1
Voron printer kit	1
Raspberry Pi	1
Computer	1
FTDI cable	1
Coaxial cable	4
Loctite	1
3D printer (to manufacture mount)	1

Part	Quantity
Cable Management Kit	1
USB A (male) -> USB C (male) cable	1
Faraday insulation	10ft

4. Design

4.1. Design Exploration

4.1.1. Design Decisions

In our project, we needed to design a housing for the sensor PCB. This is important for a couple of reasons. To protect the PCB from the elements to ensure the product works reliably, provide a more professional looking design, and ensure optimal sensor positioning. For this mount, we have significantly deviated from the prototype first designed by Arron McCarville. This was the optimal solution for us as we could extract all the measurements directly from the existing STL (file format used to represent 3D models) and start over with them.

The next thing we had to design was a UI to control the scanner. This is needed in order to complete scans and view the results in a human understandable format. For this, we have chosen to utilize Python as the base language with libraries to supplement our needs. We chose Python due to its widespread support and ease of use, allowing the users to update the UI down the road as well. Tkinter has been researched as the primary library for the GUI design due to its ease of use and broad support as well.

Lastly, we designed a calibration/testing method for the scanner and sensor. This is vital in completing scans as it will position the scanner in a known position to accurately image an object. We will use three limit switches for homing the X, Y & Z axes. A home button will be pressed in the GUI, which moves the sensor all the way in one direction on the x-axis and does the same for the y-axis to get its location in those planes. Then, it will move up until it hits a limit switch at the top of the Voron frame, allowing the sensor to know its relative location at all times.

4.1.2. Ideation

For the UI, we went through multiple iterations of design concepts. One idea was to build off the previous UI using Labview, but this UI was not user-friendly and needed improvements. Our next option was to build the UI from scratch, given our ideas; however, this left some unknown variables for the client and unfamiliarity with the current UI. We then thought that we could improve upon the old UI in Labview, but since none of us had experience with it and thought there were better options out there, we decided against that. Now we decided to build a new UI, but with the same look as the current UI for familiarity and better usability. Finally, we added that this UI should be web-based for ease of use and more portable.

With the scanner body (Voron motion system), we had fewer ideas to work off of as a bulk of the design was set by the kit designer. The bulk of the decisions were between modifications to the kit and the firmware to use on both the Raspberry Pi and Octopus MCU. The modifications considered were switching out limit switches, adding mesh bed leveling, and adding cable insulation to motor wiring.

At first, we were only looking at the build as laid out by the kit. In the later stages of the scanner's construction, modifications to the kit began to be considered as options. We found the options available to us through discussion with print enthusiasts and research online with the exception of the cable insulation. Ultimately, we decided to get the scanner up and running as simply as possible with a first prototype motion system, then look at hall effect sensors and mesh bed leveling if time permits. The decision to insulate the motor cabling came from an examination of the pre-existing scanners and a discussion with our advisor. These talks ultimately led us to believe the shielding for the A/B motors would be necessary to mitigate the electric interface in the scan.

The process of deciding a firmware has been a bit of a winding road. Initially, we selected Klipper for the firmware to be installed on the Raspberry Pi, which would then flash firmware to the Octopus MCU. We moved away from this idea primarily because of the existence of Marlin firmware that was used in the previous version of this scanner that could be modified for our purposes. This also shifted our goal of software design as now we would be interfacing with the Octopus running the firmware with the Raspberry Pi acting as a server/controller.

4.1.3. Decision-Making and Trade-off

Using Previous UI	
Pros	**Cons**
Easy to implement	Not user friendly
Familiar to client	Clunky
Know it works	Not portable
Made in-house	Uses LabView
Building from Scratch	
Pros	**Cons**
Made to our needs	Hard to implement
Customizable	Not familiar
Can work with tools we know	Time-consuming
Can be made with Python	
Can be made easier to maintain	

Utilizing Marlin Firmware	
Pros	**Cons**
Basic version provided to us	Every change requires compilation and flashing
Has better support community	Does not include web interface
Runs only on the Octopus MCU, reducing demand on Raspberry Pi	
Simpler in concept as we can make direct modifications to the firmware	
Utilizing Klipper Firmware	
Pros	**Cons**
Easy and quick updates and/or modifications	Documentation may be out of date
More actively supported	Harder to modify for large changes
Has a web interface	Changes are made via changes to a configuration file
	The nature of Klipper means that its proprietary firmware installed on the motion board (Octopus) must support needed commands, or require a custom plugin library for support of unusual commands like triggering the sensor.

4.2. Proposed Design

4.2.1. Overview

Our project is to build a 3D scanning platform designed specifically for millimeter-wave imaging, allowing us to capture detailed internal aspects of an object. Just like a 3D printer, this machine will be a scanner that will move in three dimensions: X, Y, and Z directions. Instead of printing, our scanner will use a specialized millimeter-wave trancer device to capture internal aspects of objects in its imaging area.

The frame of the scanner allows for 300 mm^3 of space across all directions. The movement of the scanner head will be powered by stepper motors and belts, to allow for a smooth and accurate scanning movement. The motors are small motors that rotate with the belts connected to them to allow for the movement of the gantry system.

The central portion of the machine is the millimeter-wave imaging device, which will collect data by sending out and receiving millimeter-wave signals. The data from this device lets us create a 3D map of the object.

Lastly, we will develop a user-friendly graphical interface in Python, making it easy for anyone to control the scanner. This will be able to move the scanner to a starting position, set up, and perform scans automatically.

4.2.2. Detailed Design and Visual(s)

Our design plan requires us to start with the assembly of the frame for the scanner. Extra Care is taken to ensure that the corners are Square from the start of the build. We define our X, Y & Z. This is shown in **Figure 1.**

The z-motors are placed under each of the bottom corners, working as legs for it. These motors are connected to a drive train gear reduction, the output of which is connected to the corners of the gauntry. This allows the gauntry to move along the Z axis as the belts move through the idlers.

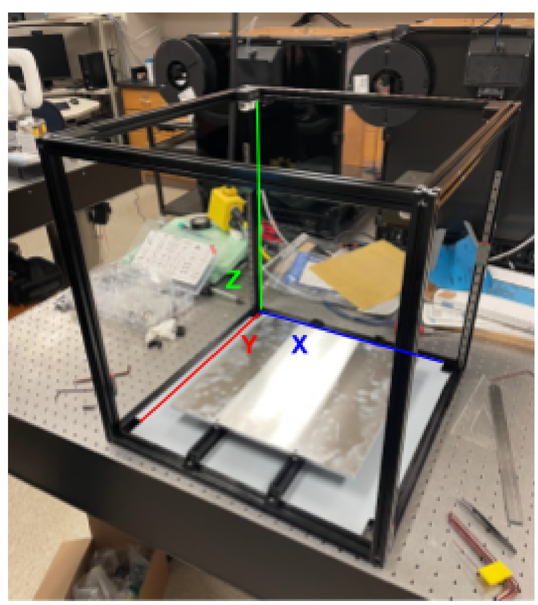


Figure 1: Scanner Framing

The X and Y rails are implemented on the inner workings of the printer, creating the gantry system. A/B belts run along each rail, which allows the sensor head to move in the X and Y-axis while the entire gantry system moves vertically. Both A/B are connected directly to a gear on the motors motors, then attached to the idlers and toolhead mount to be able to pull it one direction or the other. This happens with a differential between the motors.

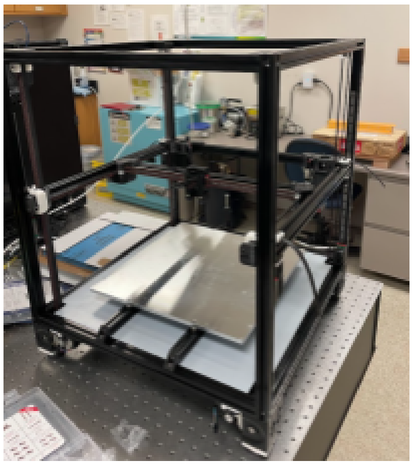


Figure 2: Angled View

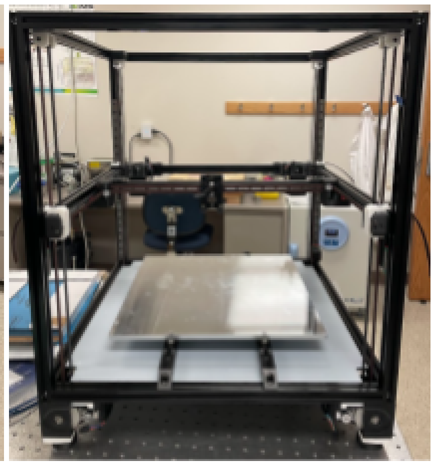
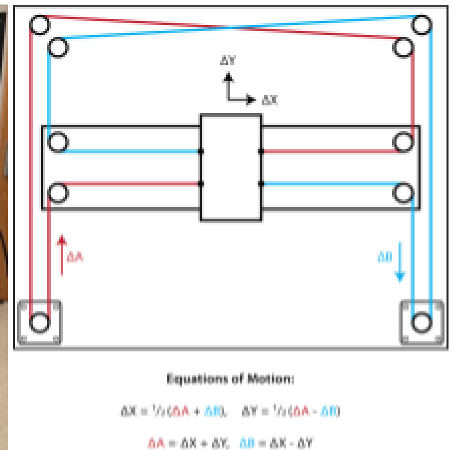


Figure 3: Front Face View



Moyer, Ilan E. "Reference Mechanism." *CoreXY*, 2012, corexy.com/theory.html.

When there is a differential between them the toolhead moves in the Y-axis and if they are moving simultaneously then the toolhead moves in the X-axis (see Reference Mechanism).

On the bottom of the scanner is where all the electrical parts are located. These parts include a Raspberry Pi, controller board, 24V Power Supply Unit, and Power inlet. These will collectively control the Scanner.

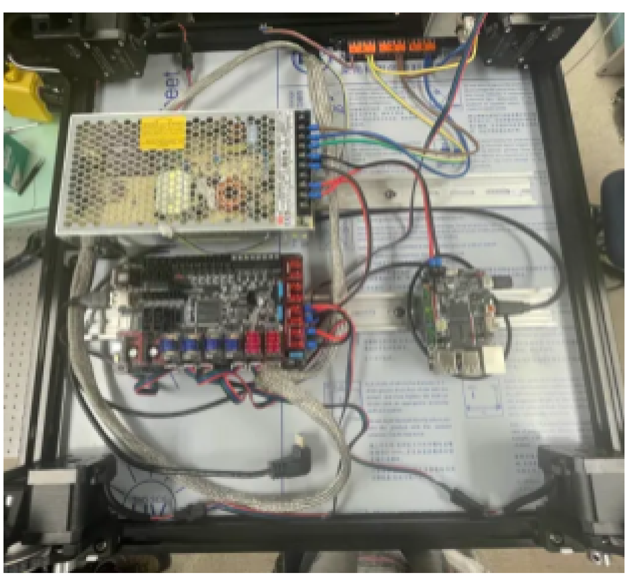


Figure 4: Electrical Bottom View

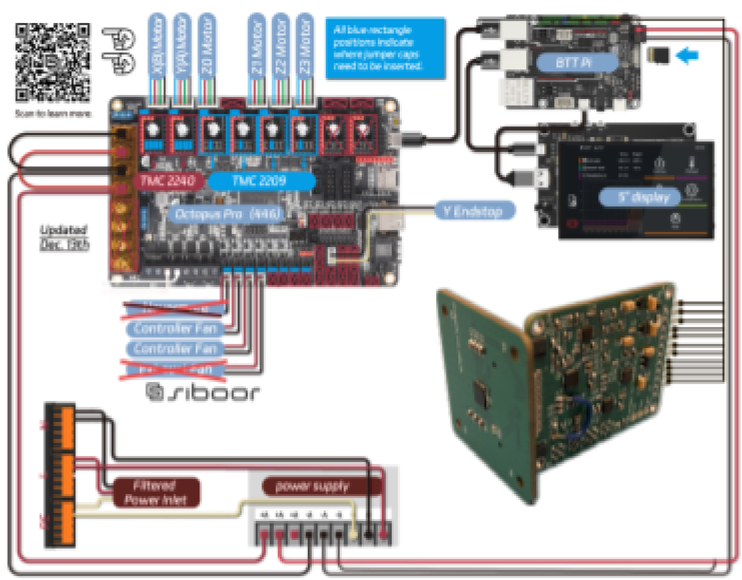


Figure 5: Wiring Diagram
Lzhikai. "Lzhikai/Siboor-Voron-2.4-AUG: Octopus Pro+btt Pi + CAN RP2040." *SIBOOR-Voron-2.4-AUG*, 2023, github.com/Lzhikai/SIBOOR-Voron-2.4-AUG.

The most important part is the scanner head. It is a combination of two PCB's (printed circuit board). One, **Figure 6**, is known as the control board, which is connected to the electrical components on the bottom via wire to control the other PCB for sensing. The second PCB is known as the sensor head. This component is the actual sensing piece that will send and receive millimeter wave scans. **Figure 7** is the combination of those 2 PCBs that will be a part of the scanner head that will connect to the middle of the gantry system. The

Figure 6: Control Board

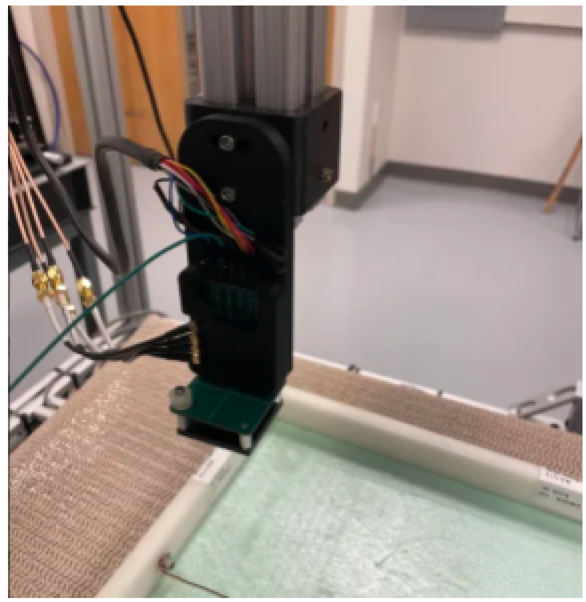


Figure 7: PCB Combination

two of them combine to allow the control board to interpret the raw data returned from the sensing board then output it via SPI cabling. This is then stitched together using SAR algorithms to create a composite image.

To ensure easy and convenient control of the scanner, we will implement a web application that connects directly to the Raspberry Pi, which will serve as the central control hub for the scanner.

4.2.3. Functionality

Our 3D scanning platform is designed to be intuitive and easy to operate, even for users without technical expertise. The system integrates a web application that controls the scanner remotely. Below, we outline how a typical user might interact with the system and how it would respond.

1. Setup and Initialization
    a. User Action: the user powers on the scanner and opens the web application on a browser.
    b. System response: The web application connects to the Raspberry Pi, which serves as the control hub and initializes communication with the scanner's hardware. The user is greeted with a welcome dashboard.
2. Homing and Alignment
    a. User Action: the user selects the ‘home and align’ button to ensure that the scanner is in the correct starting position
    b. System Response: The Scanner head moves to its home position in the XYZ space, preparing for a scan
3. Running the Scan:
    a. User Action: The user clicks the “Start Scan” button on the web application
    b. System Response: The scanner's stepper motors, connected by belts, begin moving the scanner head along the XYZ coordinates while the mm-wave imaging device collects data by emitting and receiving millimeter waves. This data is relayed back to the Raspberry Pi for processing. The web application provides real-time feedback, displaying a progress bar and any relevant status updates.
4. SAR processing:
    a. User Action: none - the scanning is done
    b. System Response: Once the scanning is complete, the system runs a Synthetic Aperture Radar (SAR) algorithm on the collected data to process and create a 3D image of the object's surface
5. Viewing and Saving Results
    a. User Action: the user reviews the processed 3D map or image on the web application

b. System Response: the system displays the final 3D data. The user has the options to zoom, rotate, or save the data for more analysis.

Figure 7 below shows the typical User Interface that the user will view on the web application.

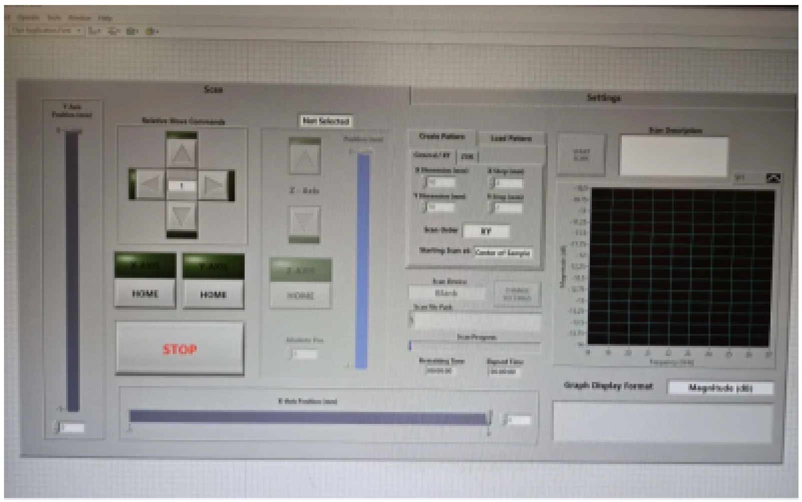


Figure 7: Web Application UI

4.2.4. Areas of Concern and Development

Our current design provides the basic functionality of a 3D scanning platform with millimeter-wave imaging capabilities. It meets the key requirements of a scanning volume of 300 x 300 x 300 mm and a user-friendly web-based interface. These features align well with the goal of delivering high-quality scans with ease of use for non-technical users.

While we are confident in the functionality and general design, we have some concerns. One concern regards the timing of the actual scan. Achieving a scan in a short period of time compared to the already existing scanners is a potential challenge. One other concern is about the complexity of the user interface. Although the web-based interface is intended to be user-friendly, ensuring that all users can operate it smoothly will require testing and may cause more of a challenge than expected.

Regarding the time requirement, one possible plan could be to experiment with the SAR processing algorithm or implement an adaptive scan that could reduce scan time as well. Regarding the user interface, to ensure that we create a user-friendly one, we can conduct usability tests with a sample group of users and collect feedback.

4.3. Technology Considerations

We have implemented a number of different technologies to bring the MAVinator to life.

- Voron Motion System

  The Voron motion system comes from a cannibalized Voron printer kit ordered specifically for this project. Voron's open-source licensing, modability, and large community make it an ideal technology to implement into our design. The alternative option would be to buy a three-axis motion stage/platform. While this would require a lot less assembly it would be exorbitantly expensive [1], hard to modify, and still require some setup physically or digitally.

  Other alternative options within the Voron family include any other version of Voron printer as the motion system. We selected Voron 2.4 with the core XYZ (floating gantry) due to the client's request and we agreed due to its higher theoretical top speed, availability of an example, and popularity.

  Within the Voron 2.4 motion system that we are using we could have selected other end-stops than the limit switches currently implemented. The alternatives there are using Hall effect sensors, or going for a sensorless homing process. We have shied away from doing so in the first phase of the design due to the complexity hall effect sensors would add, because of the risks involved in sensorless homing, and because we have access to all of the limit switches that we need.

- 3D Printed Housing

  The Housing being 3D printed offers up a number of options for iterations and prototyping. The alternative in this case would be to have housing manufactured by a company such as PCBway through a more traditional method like CNC. While sending the designs off to have them manufactured could result in parts with higher durability the time trade-off is too severe. With 3D printing we can have a part made of PETG in a matter of hours or a day at most resulting in a much faster and more satisfying prototyping process. Additionally using a material like PETG or ABS can result in a part with more than enough strength.

- In-House Sensor Board

  The sensor and radar boards created in-house offer many advantages over other alternatives. They were designed specifically for the purpose of making millimeter wave scans. These boards have still required the soldering of all the surface mount and through hole components. The radar board is the more complicated of the two and is the one that creates the millimeter wave signal. Much testing has to be done in order to ensure that the board functions correctly as the main driver in the sensor. The second board contains the antenna and a biasing network to send out the signal generated by the radar board and then capture the return signal to be processed.

  Having the boards designed in-house gives us great access for any questions or concerns we have about the operation of the boards. Several of the workers at the lab have experience with testing and issues associated with them so we will be able to use their expertise to help us diagnose issues along the way.

4.4. Design Analysis

So far, we have built almost the entire scanner: the initial frame, gantry system, steppers, motors, and electrical parts. This is shown in section **4.2 Proposed Design**, the implementation of all these parts works properly. We have just tested the electrical portion of the system with initial power tests, confirming that each component responds correctly and functions as expected. For the future of the design, we plan on implementing the rest of the electrical components and the wiring, completing the scanner build. After that, we will implement the sensor head and finally design a user interface to interact with the scanner.

5. Testing

5.1. Unit Testing

The MAVinator is composed of two main physical parts that need to undergo testing: the Voron itself and the two circuit boards. The following sections will discuss the testing of each component.

5.1.1. Voron Build

The Voron based portion of the scanner requires testing, and will occur in three primary phases: Electronics smoke test, Basic motion testing, and Advanced Motion testing. This phased testing will help to mitigate some risks, risks of electronic component failure, risk of mechanical damage to motion system components due to “dumb” motion, and risk of damage to the millimeter wavelength sensor.

The first test upon completed construction consists of powering on the printer with protection, our smoke test if you will. While the scanner is plugged into a surge protector that has protection for shorts we will turn on the power switch and inspect the printer with power on for 1 minute or until we see something of concern. If there is a short due to component failure, the surge strip should trigger and prevent catastrophic failure.

With a successful smoke test we begin the testing of the functionality of the motion system with simple movements. After powering on, using a provided test script we will ensure that the gauntry shuttle can move in the X, Y, and Z directions both positive and negative. This test will not test the outer or inner bounds, just short movements in all directions. If the distances, and directions are correct and as expected then we will move onto the final.

Lastly there is the advance motion test. This test consists of implementing automated paths and making sure they operate as intended. The automation that will be tested is “homing” the gauntry shuttle. In this motion the shuttle is moved to X = 0, Y = 0, and Z = 350 with each motion ending when the shuttle triggers an end stop. The first position moved to should be the X, then the Y, and then the Z in order to properly trigger the third end stop. With that test successful and positional accuracy established, we are ready to attatch the sensor.

5.1.2. Circuit Boards

The circuit boards required extensive testing as there are several opportunities for errors to occur in the soldering process. Resistors or capacitors could stand up in the reflow oven, integrated circuits could be placed with the wrong orientation, or components could be shorted to ground. Testing began with the more populated board which will henceforth be referred to as the control board. The second board will be called the radar board.

Testing of the control board began by visual inspection after soldering. Immediately a couple of components were discovered that were not soldered down correctly. The second step of the testing phase was ensuring that nothing was connected to ground that wasn't supposed to be. This is done by using a multimeter and tapping soldering connections along the board to check if they are grounded. Again, several connection points were discovered to be incorrectly soldered. Those points were fixed, and testing continued with path tracing. Path tracing involves following connected paths from the power source back to where the power is needed to make sure there are no breaks in the path. This test showed no issues and we moved on to the next major test: connecting the control board to power.

The main purpose of this test is to check if the correct voltages are showing up at every node. The board was tested using an FTDI cable to supply the voltage. This test raised a flag which meant that something was awry. After doing several tests with the integrated circuits and shift registers, then taking them off completely and the error remained. This showed that the issue was not related to those components. After some more investigation, we discovered that the oscillator on the power board was shorted, but it was covered up by a jumper wire not included in the original design which is why it was originally overlooked. Once we took the oscillator off, cleaned up the solder, and placed it back on the board, the power was much closer to accurate, and we moved on to the radar board.

The radar board was much more simple to test as there are much less components. The same tests were done on this board as on the control board. The test for shorts came up with a few issues, but those were solved and no other problems were detected.

We followed up with testing the two boards when placed together. When checking the voltage levels at critical nodes, we noticed a lower voltage level than expected, but continued to try and program the PLL on the board using the FTDI cable. We discovered the board was not beginning programmed so we traced each critical signal from the FTDI cable to the PLL using a picoscope and discovered through this that a resistor was not fully soldered and the PLL got rotated the second time we were putting it on the board so the pins were misaligned. After fixing these two issues, the board passed all of the tests needed before we attach it to a DAQ and observe the output.

The final test was to ensure proper functionality. We attached the IF_Q+, IF_Q-. IF_I+, and IF_I- cables to the control board and set up the PCB system on a scanner which allows us to read the data. The scanner in this test will be replaced by the Voron in the final product. A piece of foam was scanned with nine rubber plugs located at different depths throughout the foam. The data was then filtered and had synthetic aperture radar(SAR) applied to it which created two and three-dimensional images and those images came back great, which means the PCB system is ready to be attached to the Voron.

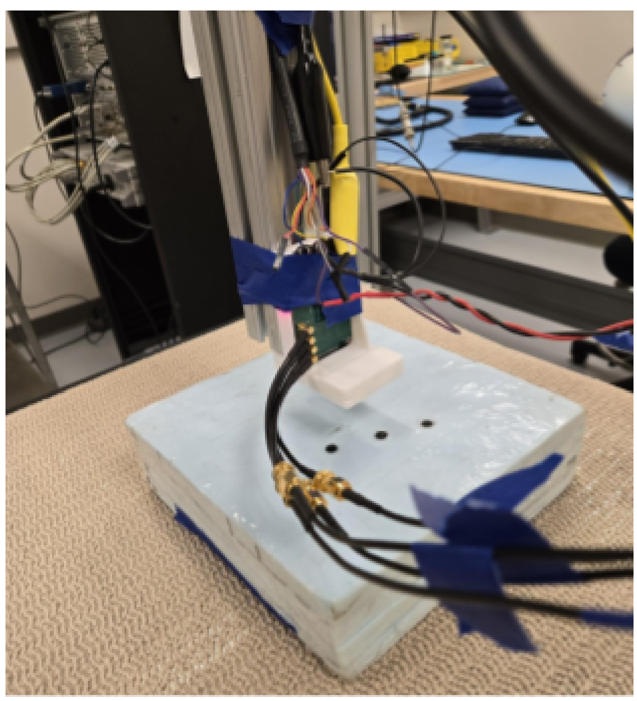


Figure 8: Test Scan Setup

5.2. Interface Testing

We have not been able to do any interface testing as this will be a major part of next semester's work

5.3. Integration Testing

Integration testing will occur at the conclusion of the build of the Voron frame and the PCB system. At that point we will integrate the PCBs into the Voron frame and test to ensure we get a flawless interaction between the two. The PCBs have been integrated into the 3D printed housing. A few iterations were needed to ensure proper functionality, but the final design has worked well. The wiring is easily accessible and the radar part of the system can be screwed into the housing.

5.4. System Testing

System testing will start once the GUI has been developed because that is our method of controlling the Voron printer and PCB system. This will take place at the middle to end of the next semester.

5.5. Regression Testing

We have just received the firmware as the last stage of the first semester. Regression testing will start once we start work on the firmware which will occur at the start of next semester.

5.6. Acceptance Testing

Acceptance testing has been completed for the sensor (PCB system). After testing, the results were presented to our client and he gave positive feedback on the output images.

5.7. Results

The following results came from the PCB testing. These results come from a scan of a piece of foam with nine rubber plugs dispersed at three different levels within. The plugs can be clearly seen in the images which was the desired outcome.

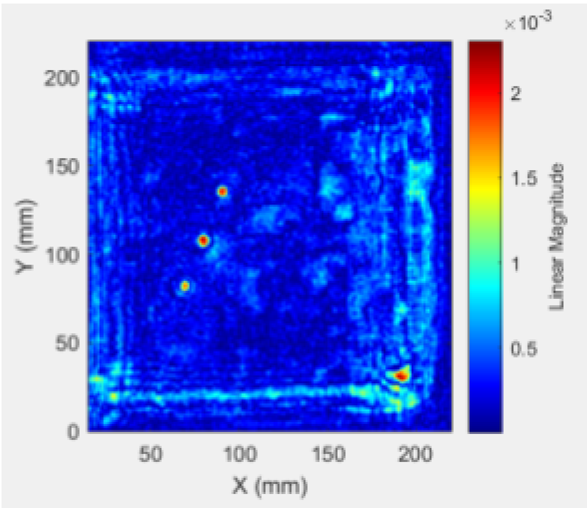


Figure 9: Top Three Rubber Plugs

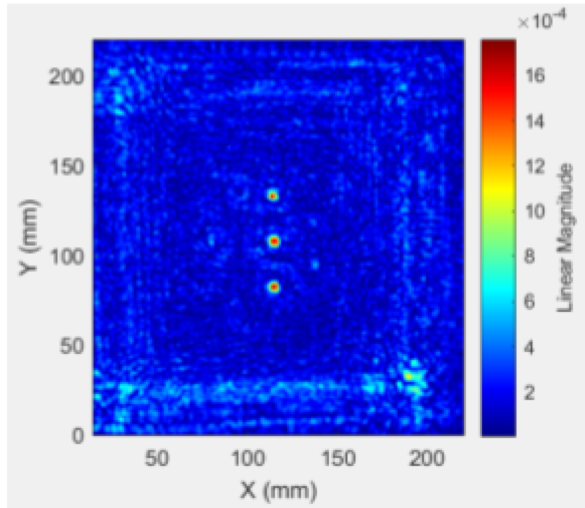


Figure 10: Middle Three Rubber Plugs

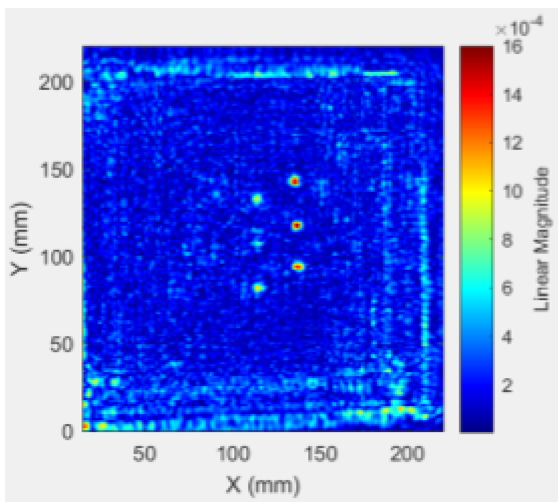


Figure 11: Bottom Three Rubber Plugs

6. Implementation

The implementation of the build has been completed in different stages: mechanical assembly, electronics integration, sensor and housing, and end stops. While Section 4. Design provides an in-depth look at the technical details, this section offers an overview of the work completed this semester.

6.1. Mechanical Assembly

Thus far, the majority of the mechanical assembly for the MAVinator scanner has been completed. We began by constructing the frame using a Voron 2.4R2 printer kit as our foundation. This open-source motion platform provided a base. Following the Voron build guide, we first assembled the frame, ensuring that it was square. The gantry system, composed of linear rails, belts, idlers, and stepper motors, was then integrated to enable precise three-axis (X, Y, and Z) movement. The mechanical assembly now closely resembles a high-precision 3D printer, but repurposed for millimeter-wave scanning.

During this assembly phase, we focused heavily on proper alignment and tensioning. The drive belts were carefully tensioned to ensure smooth, backlash-free travel, and linear rails were checked for parallelism to meet our 0.5 mm positional accuracy requirement. Although this process involved significant iteration—tightening, loosening, realigning—we have achieved a stable, rigid motion platform capable of consistent, repeatable movement.

6.2. Electronics Integration

Following the mechanical build, we began integrating the electronic components. We mounted the main controller board (Octopus MCU), power supply, stepper drivers, and Raspberry Pi onto a lower deck beneath the scanning platform. Each stepper motor has been wired into the motor drivers, and initial continuity checks have confirmed that all wiring connections are correct and secure.

Before adding sensors and end stops, we ran a basic power-up test to verify the correct voltage outputs from the power supply and confirm that the controller board powered up without issue. Preliminary tests show that the motors can be energized and that no electrical shorts or grounding issues were present.

6.3. Sensor and Housing

After completing the soldering and testing of the PCBs, we began to implement it into the Voron. This required us to design a housing for the sensor (PCBs put together) that would fix it to the Voron extruder. We used an existing design for the housing as a base template for our design. Modifications were necessary to attach it to the pre-existing mount on the Voron and to hold the radar part of the scanner more firmly in place as it will experience some vibrations as it moves around the scanning platform.

6.4. End Stops

The Voron kit we were supplied with did not come with the necessary end stop parts to ensure that the extruder would not travel too far in any direction. The Voron step file model contained many different mount versions, so we simply selected the right one, then printed our own pieces. The kit did come with the Y and Y end stops but the wires were too short for our implementation so we redid those to make them the needed length and routed them to the mount we printed.

The Z-axis end stop did not come with the kit. The CNDE lab had two more already assembled Voron printers that were no longer using their Z-axis end stops so we were able to salvage one of those end stops for our purposes. Typically this end stop is located at the bottom of the printer, but for our application, we needed it at the top. It is not designed for that, though, so we created another 3D printed part that would hit the end stop when the extruder travelled all the way to the top of the Voron frame in the home position.

7. Ethics and Professional Responsibility

In designing and developing the MAVinator scanner, our team recognizes that engineering ethics and professional responsibility extend beyond technical correctness. Ethical conduct involves considering how our work affects users, the environment, society, and compliance with professional standards. We aim to uphold the highest ethical principles, ensuring safe, beneficial, and equitable outcomes.

7.1. Areas of Professional Responsibility/Codes of Ethics

Area of responsibility	Definition	IEEE	Team interaction
Willingness to learn and improve	Having an open mind and active desire to gain new knowledge and skills, constantly seeking ways to enhance your performance or abilities in any given situation	To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others;	The team has constantly sought out feedback internally, from our advisor, and at certain points from external sources as well. Always giving great care to the feedback received and finding ways to take it into account.

7.1.1. Area in Which the Team is Performing Well:

One area in which we are doing well is communication honesty. This is defined as Perform work of high quality, integrity, timeliness, and professional competence. The team has had honest and transparent communication with each other and has assisted in high quality work. By maintaining open lines of communication with our mentor, we can acknowledge when we are behind schedule and also actively seek feedback on any issues we have. This approach enables us to meet professional standards in timeliness, competence, and overall project integrity

7.1.2.Area in Which the Team Needs to Improve:

While our technical progress and open-source platform help with cost benefits, we recognize that we need to improve our financial responsibility to ensure that the final product remains valuable and cost-effective. Some high-priced electronic components can cause a challenge to budget constraints. An approach to improve this area is to consider more thorough cost-benefit analyses, engage in market research, and explore more resource-efficient designs.

7.2. Four Principles

Below is a table connecting four ethical principles—beneficence, nonmaleficence, respect for autonomy, and justice—to broader context areas. We assume these broader context areas include: **Public health, safety, and welfare; Global, cultural, and social; Environmental** and **Economic** considerations

7.2.1. Four Principles Table

	Beneficence	NonMaleficence	Respect for Autonomy	Justice
Public health, safety, and welfare	The Scanner supports safe imaging for non-invasive applications	Design avoids harmful practices by sourcing reliable components and uses proper documentation	UI allows users to control scans safely	Implementation allows user-friendly accessibility and reliable performance
Global, cultural, and social	Scanner gives access to advanced imaging technology that can benefit 3D scanning industries	Scans will not harm people due to safety standards during building	The MAVinator will use a simple user interface making it usable by people of all different backgrounds	Since it is open-source, it will be made available to several groups of people
Environmental	design promotes sustainability by using durable components to minimize waste	The design will be aesthetically pleasing, kept indoors, quiet, and resources will be used properly to reduce power consumption	The MAVinator will not use up excessively more space than it needs for the scam	Our scanner will be kept indoors and not affect the environment directly, and it also uses common resources to build
Economic	The scanner will speed up workers preforming scans, cutting down on time costs	Cost effective design would not hinder other projects	We are creating this scanner as an open-source attachment for the Voron printer so the user can adapt it to their needs	The scanner will not affect any users or peoples in an unfair manner

7.2.2. Broader Context-Principle Pair

Our design strongly meets the pairing of Economic Respect of Autonomy. Going so far as to make the project Open Source with python as the predominant language in use for our software interface. Conversely we are lacking in Global social and cultural respect for autonomy because we have not yet researched any ways of making our software more accessible to non-english speakers.

7.3 Virtues

7.3.1. Team Virtues

Integrity: Being honest and transparent in communication, test reporting, and documentation. We have consistently provided truthful updates to our advisor and documented both successes and challenges.

Responsibility: Owning our tasks and deadlines, ensuring that everyone completes their work on time and at a high standard. We create shared timelines and check in regularly to ensure accountability.

Collaboration: Supporting one another by sharing knowledge, assisting with complex tasks, and respecting each other's expertise. We hold weekly meetings to discuss progress, solve problems collectively, and ensure no member is left struggling in isolation.

7.3.2. Individual Virtues

Nathan Reff

- Demonstrated Virtue:
    - This semester, I believe I have demonstrated strong collaboration skills, particularly through the work in the lab sessions with Daniel. Whenever we met to work on the scanner, we would delegate tasks properly. For example, if one of us was focusing on aligning and tensioning the gantry belts, the other would handle preparing the necessary tools and components, ensuring that our workflow remained smooth and efficient. By rotating responsibilities and working cohesively, we were able to make substantial progress this semester.
- Not Yet Demonstrated Virtue:
    - One virtue I feel I didn't have the opportunity to demonstrate effectively this semester was innovation, particularly in terms of creativity. Most of our project this semester was following a guide in building the scanner, which left limited room for open-ended problem-solving.
    - With the design of the user interface, and the more open ended requirements I hope to use innovation more next semester. I'll have more freedom to introduce innovative ideas into the GUI's layout, workflows and data presentation techniques

Luke Post

- Demonstrated Virtue:
    - This semester I have done a good job demonstrating the virtue of commitment to quality. A commitment to quality is important to

me and this project because without it, our product will not work well and it won't be something that I would be proud to have created. I do not want to put out a product that I am embarrassed to put my name on.
  - I have demonstrated this virtue throughout the assembly of the PCBs. They need to be carefully and accurately created to ensure a clean output. If we do not have a clean output then our product will not function properly. After testing the PCBs, we do see a clean output due to the quality of work that was done when assembling them.
- Not Yet Demonstrated Virtue:
  - I have not done an amazing job demonstrating the virtue of having respect for nature. Several times I have used more product or materials than I needed because I made a mistake on the first attempt. These products come from natural materials that get wasted. Our final product will also not give back to the environment in any way.
  - What I need to do to demonstrate this virtue is be more considerate of the materials I am using and do things correctly the first time so those materials are not wasted.

Daniel Ripley-Betts

- Demonstrated Virtue:
  - A high degree of social awareness has been demonstrated consistently in this project. There has been a great deal of value put on collaboration and efforts for equitable teamwork within myself. This has paid off in spades and I could not have asked for a better group as the effort has been reciprocated.
- Not Yet Demonstrated Virtue:
  - Consistency has been consistently an area of struggle. While what is lacking in consistency is attempted to be made up for with tenacity and perseverance this is a stopgap. Improved consistency or rigidity in my schedule would help to increase the sustainability of the pace at which I work. This would also help contribute to a more healthy work/life balance.

James Peterson

- Demonstrated Virtue:
    - This semester I have demonstrated the virtue of listening to feedback. This is true of feedback from teammates, clients, advisors, etc. I feel I have effectively taken feedback from others to use it to improve upon our project or my understanding of requirements. This has been quite useful in creating the right product for our client.
- Not Yet Demonstrated Virtue:
    - One virtue I believe I can continue to improve on is stepping out of my comfort zone. I have avoided doing things I am not already knowledgeable about and leave that to others you are more experienced while taking on tasks I am already experienced with myself. Improving this virtue could help not only myself to expand my knowledge base but also help the team once I've learned the task.

8. Closing Material

8.1. Conclusion

Over the course of this semester, we have made substantial progress toward building the MAVinator scanner. Our initial goals included creating a 3D (XYZ) scanning platform for millimeter-wave imaging, ensuring an imaging volume of at least 300 mm x 300 mm x 300 mm, achieving positional accuracy of 0.5 mm, and developing a user-friendly Python-based interface. Thus far, we have successfully completed the core mechanical assembly, assembling a gantry system adapted from the Voron platform. We also completed initial electronics integration, set up sensor mounting solutions, and laid the groundwork for firmware implementation. Although we have not fully integrated the firmware or finalized the user interface due to end-of-semester timelines, the essential infrastructure for these tasks is now in place.

Looking ahead, the best plan of action is to continue the progress we have already made. Early next semester, we will apply the newly received firmware and begin intensive testing and calibration to ensure accurate motion control. Following that, we will integrate the Python-based GUI to provide an accessible and intuitive user experience. This approach ensures that each part of the project will advance concurrently, bringing us to a fully functional and reliable scanning solution by the end of the semester.

8.2. References

Zaber Technologies, www.zaber.com/products/xy-xyz-motorized-stages/XYZ.
Accessed 7 Nov. 2024.

Ramanathan, Parmesh et all. *MilliCam: Hand-Held Millimeter-Wave Imaging*, cse.sc.edu/~sur/papers/Sabbir_ICCCN20_MilliCam.pdf
Accessed 7 Dec. 2024.

Voron Design, https://vorondesign.com/voron2.4
Accessed 7 Dec. 2024.

8.3. Appendices

8.3.1. PCB Layout

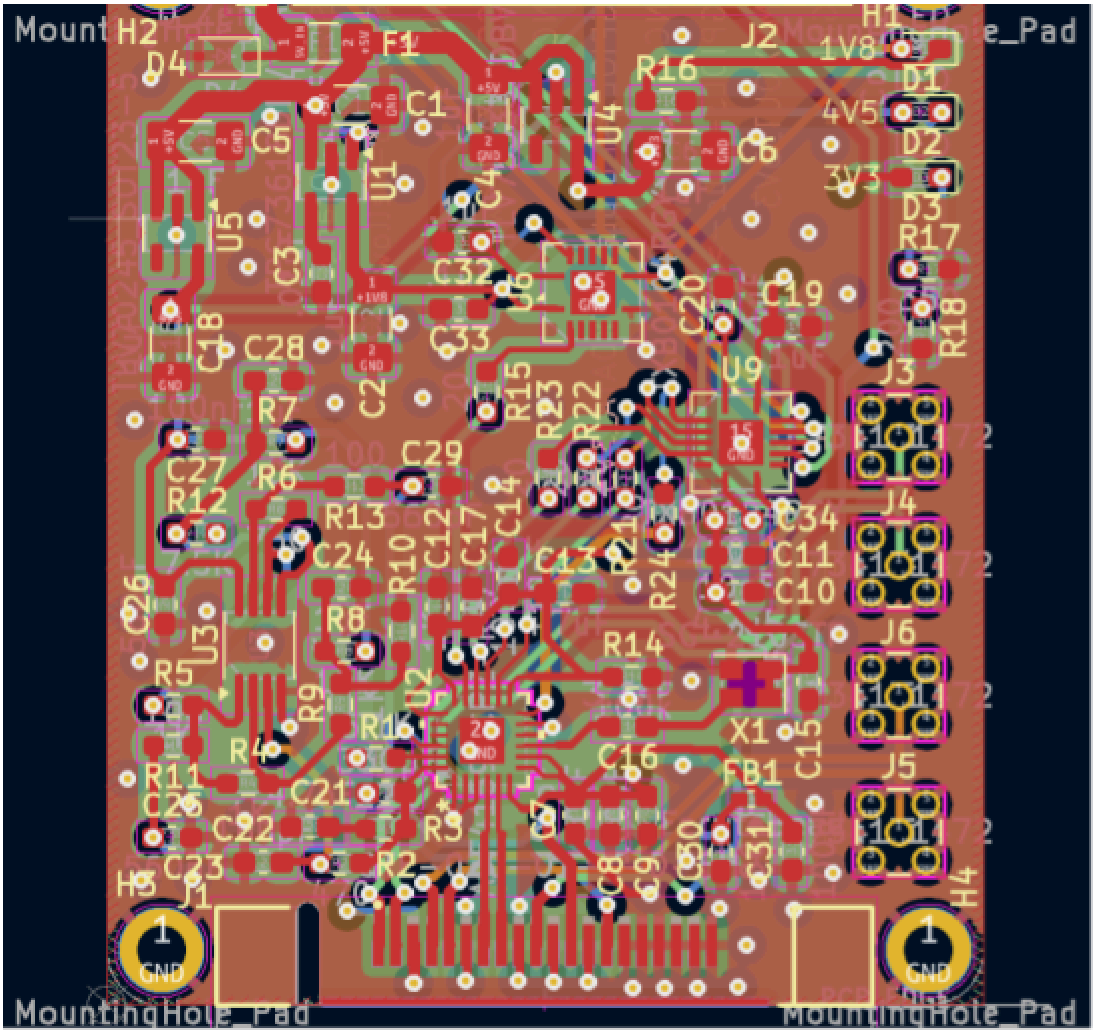


Figure 12: Control Board Layout

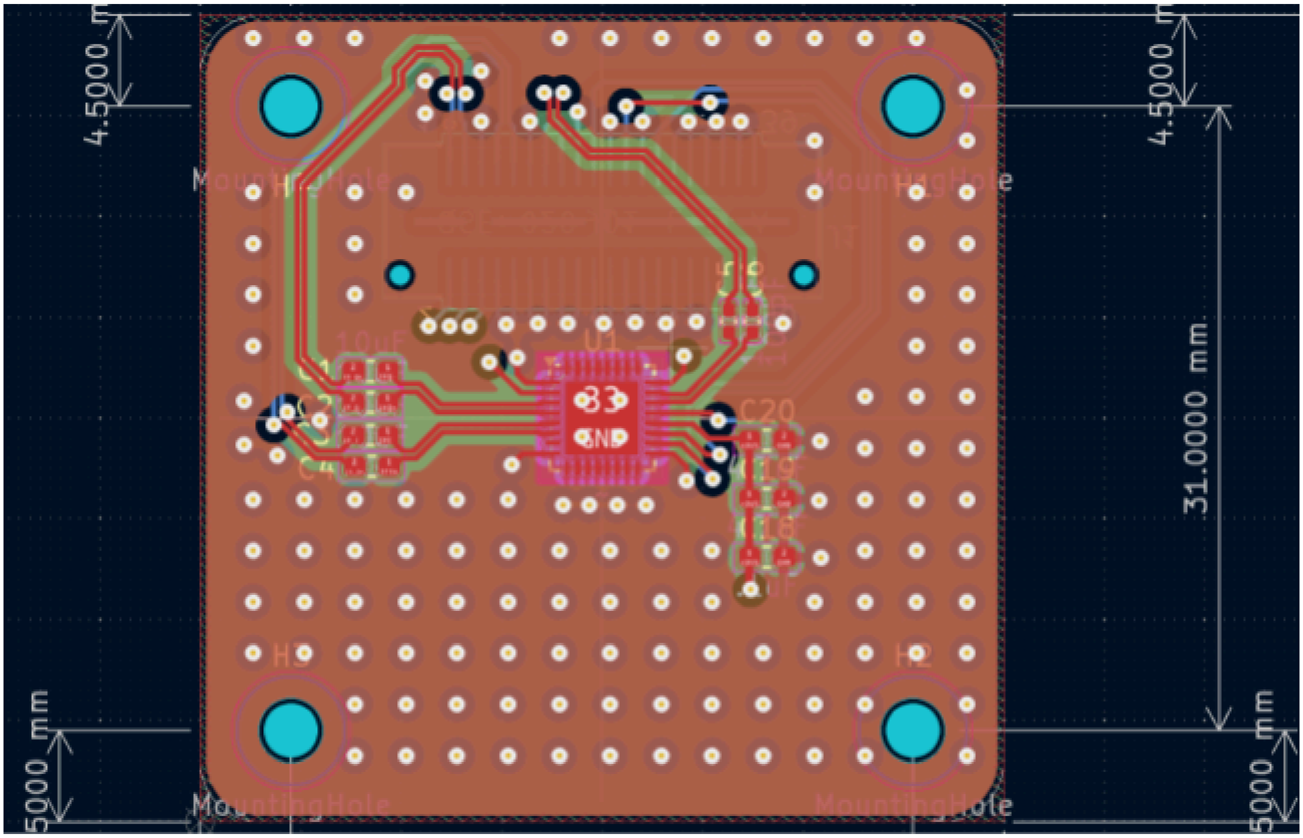
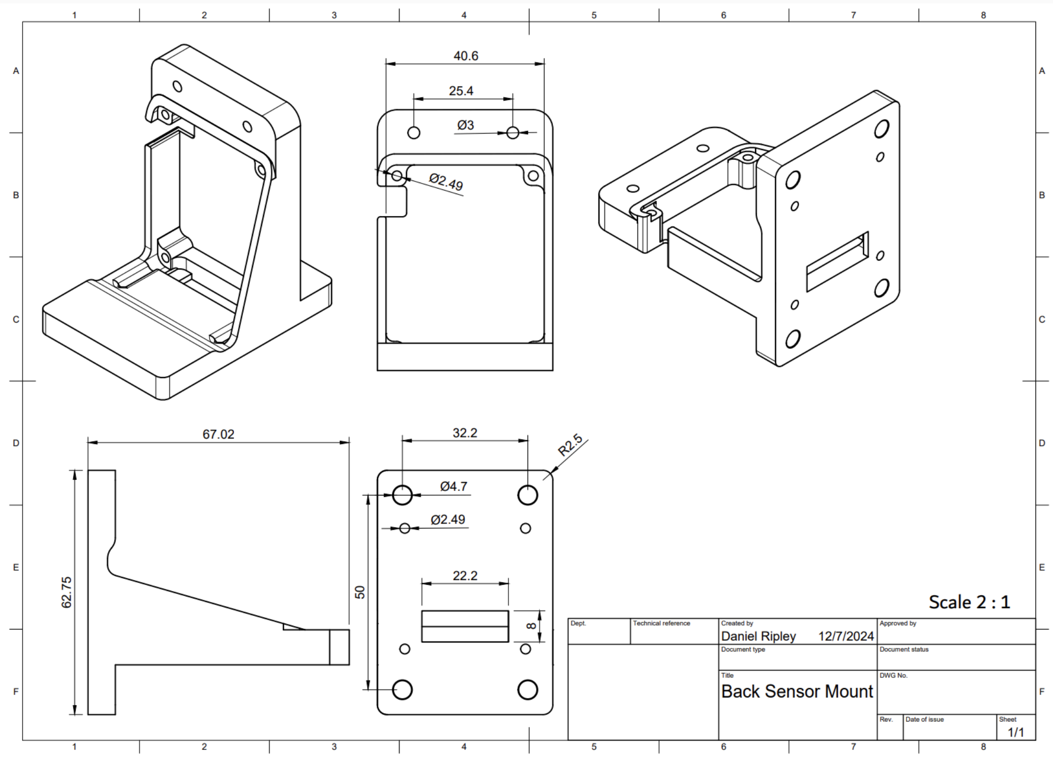
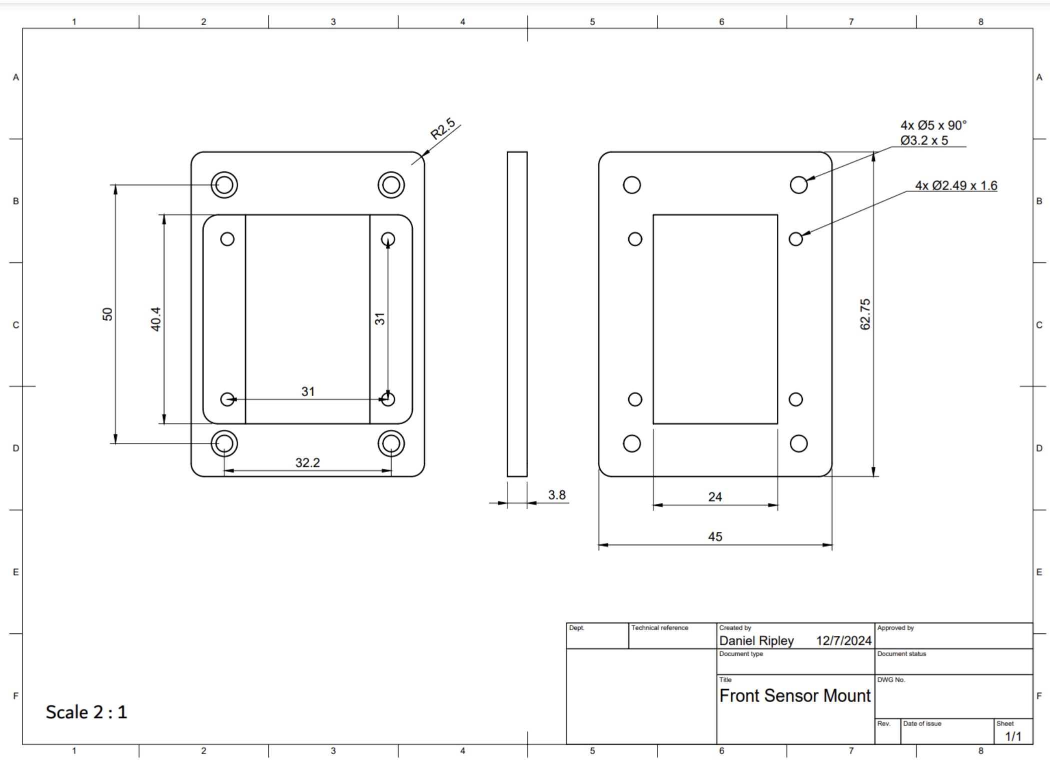


Figure 13: Radar Board Layout

8.3.2. Sensor Mount Drawing





9. Acknowledgements

The MAVinator project would not be where it is today if it were not for a collective effort from many people. This section is where our team would like to acknowledge some of the direct and indirect contributions of people who helped us along the way, and from work others performed in the past.

Arron McCarville - Arron's invaluable work on millimeter wavelength sensor and its original mounting solution was done before we began.

Trent Moritz - Trent has helped us at almost every step of the way, whether that was access to the build space, 3D printing assistance, testing the sensor, or discussing how the scans will actually happen.

Burk Weber - Burk and Trent both work in and around the lab we were building in at the CNDE. Burk was instrumental in high quality 3D prints and bouncing ideas off of. Good company to be around.

Dr. Tayeb - While Dr. Tayeb is both our advisor and our client and was somewhat pressured to help, our team would still like to acknowledge the lessons that Dr. Tayeb shared with us in the process of building the motion system.

Thank you to the above and many more unmentioned heroes who listened to our speeches and supported us through late nights of work on our project.

10. Team

10.1. Team Members

- Nathan Reff
    - Motion System Lead
    - Computer Engineering
- Daniel Ripley-Betts
    - Sensor Mount Lead
    - Computer Engineering
- Luke Post
    - Sensor PCBs Lead
    - Electrical Engineering
- James Peterson
    - Software Design Lead
    - Computer Engineering

10.2. Required Skill Sets for your Project

Creating the MAVinator scanner has several necessary skill sets. Without these, the product could face design delays and an inefficient product.

- Electrical Circuit Soldering
    - This is essential to this product because the PCBs needed to be assembled. We received schematics and unpopulated boards for both of the PCBs, but they still needed to be accurately soldered to ensure proper operation. The end stops needed wire extensions as well which required recreating the wire leads from the end stop to the control board.
- Electrical Circuit Testing
    - The PCBs have several sources of potential error which need to be identified. Proper knowledge on how to test and find errors in circuits is essential to the timeliness of the creation of the MAVinator.
- Mechanical Systems Knowledge
    - The assembly of the Voron scanner required a lot of knowledge about mechanical systems. Although the documentation on the assembly process is detailed, the assembly kit still has several

advanced features that need to be properly installed including the belt and gantry system and the electronics and wiring.

- Web Application Development
    - The MAVinator will be controlled through a web application that we will make. Therefore it is crucial that this skill set is covered otherwise the MAVinator will not function properly. The GUI for this web app also has to be aesthetically pleasing according to our client beyond just providing functionality.
- Software Development
    - The code controlling the MAVinator that will be sent through the use of the web application must be developed by our team as well. This will be what sends the gcode commands to the Voron printer which is how the printer moves and is therefore vitally important.
- 3D design/modeling
    - A housing is needed to integrate our PCB system into the Voron scanner. To create this we will use 3D modeling software, then print it out on a 3D printer.

10.3. Skill Sets covered by the Team

- Electrical Circuit Soldering
    - Luke + Daniel
- Electrical Circuit Testing
    - Luke
- Mechanical Systems Knowledge
    - All
- Web Application Development
    - Daniel + Nate + James
- Software Development
    - Daniel + Nate + James
- 3D design/modeling
    - Daniel

10.4. Project Management Style Adopted by the Team

We employ a hybrid approach combining elements of both Waterfall and Agile methodologies to efficiently manage the MAVinator project.

10.5. Initial Project Management Roles

In this project we adopted a democratic or participative leadership style amongst ourselves. In this management style everyone is considered equal, and issues or major changes must be adopted by all group members with equal say in the matter. No one group member controlled the project, instead we all followed a logical flow according to our individual understandings of the project.

10.6. Team Contract

Team Members:

1) _James Perterson________________ 2) _Nate Reff______________________
3) _Luke Post______________________ 4) _Daniel Ripley-Betts_____________

Team Procedures

1. Day, time, and location for regular team meetings:
    - ❖ We will meet Friday at the university library from 2:30pm-3:00pm
2. Preferred method of communication updates, reminders, issues, and scheduling:
    - ❖ Communication will occur via Discord: https://discord.gg/jzKjzVqc
3. Decision-making policy:
    - ❖ Final decisions will be made with majority rule + Rock Paper Scissors & Tayeb for ties
4. Procedures for record keeping:
    - ❖ We will make use of Google Drive, Git, and Discord

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
    - ❖ If you can't make it to a meeting let us know, otherwise, please participate wherever possible.

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
    - ❖ We will all share responsibility for all aspects of this project, but if a task is assigned or taken specifically, that individual is responsible for a minimum 51% of that task.
3. Expected level of communication with other team members:
    - ❖ Read and react/respond to messages in the general channel on the Discord server
    - ❖ Use the appropriate channels for your messages on Discord. For example, avoid using general group chat channel for non-general or individual communication.
4. Expected level of commitment to team decisions and tasks:
    - ❖ Please make your opinion known & voice heard wherever possible.

Leadership

1. Leadership roles for each team member (flexible and subject to change):

    Luke: Circuit board testing, Tayeb outreach

    James: Voron & Scanner calibration

    Nate: Team Organization

    Daniel: Team internal communication & Voron build
2. Strategies for supporting and guiding the work of all team members:
    1. Being gently, honestly, and openly critical
    2. Holding each other accountable
    3. If not meeting standards, a direct example will be given
3. Strategies for recognizing the contributions of all team members:

1. Active: Reflection & Reports, Verbal expression of gratitude
2. Passive: Author of documents/code, sending a message, notes

Collaboration and Inclusion

Skills, expertise, and unique perspectives each team member brings to the team:

Luke: Experience Soldering, electrical circuit knowledge, experience with microwave scanners

James: Experience with Python development, GUI development, and sonar & IR scanning/calibration

Nate: Experience in python, and with Arduino platform

Daniel: Experience with 3D printing, coding, soldering, older perspective

Strategies for encouraging and supporting contributions and ideas from all team members:

1. No idea is bad idea (brainstorming channel)
2. Do not hesitate to provide honest Feedback, but try to do so in productive ways

Procedures for identifying and resolving collaboration or inclusion issues:

- post in general or bring it up during a meeting, preferably with as much specifics as possible
- Alternatively message any of us

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
   - Get all hardware assembled, & a plan for software
   - Have fun working together on a large scale engineering project

- ❖ Learn a bit about professional design & engineering practices

2. Strategies for planning and assigning individual and team work:
    1. Based off interest & skill sets
    2. Based on current workloads
3. Strategies for keeping on task:
    - ❖ Weekly meetings
    - ❖ Trying to ask productive questions

Consequences for Not Adhering to Team Contract

1. How will the team handle infractions of any of the obligations of this team contract?

   First perform a sanity check with other group mates. If they agree, everyone arranges a group meeting to try to resolve the infractions.

2. What will the team do if the infractions continue?

   The group will seek out our Professors (Fila/Shannon), or in some odd circumstances Dr. Tayeb.

****

a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*

b) *I understand that I am obligated to abide by these terms and conditions.*

c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

1) ______________________________ DATE ____9/17/2024______

2) ______________________________ DATE ____9/17/2024______

3) ______________________________ DATE ____9/17/2024______

4) ______________________________ DATE ____9/17/2024______