WeldRight Technical and Product Plan

New Venture Design

Group 5

Engineering: Hooman Pirouz, George Hollo, Samuel Stelzl

Commerce: Matthew Austin, Sophia Millar, Rewa Roy

April 10th, 2025

Table of Contents

Executive Summary

In the welding industry, quality assurance is typically performed only after the welding process is completed. Current nondestructive testing (NDT) methods such as visual inspections, ultrasonic testing, and X-ray imaging are effective but time-consuming, expensive, and require downtime if a defect is found. Rework caused by failed inspections leads to lost productivity, increased downtime, and increased labor costs.

This report outlines the technical work which has already been done on the project as of April 10th, 2025, along with the next steps and future planned iterations. Along with this documentation an online repository can be found here containing the following documentation:

- 490 sub-folder contains dossiers 1-7 which were produced for the MECH capstone course
- NVD sub-folder contains: Product Gantt Chart, Interview repository (document and excel tracker), the MVP procedure documentation, and the V0 unit breakdown (verification & validation) excel spreadsheet

Our Solution: WeldRight

WeldRight is an AI-powered welding assistant designed to detect weld defects in real-time using non-intrusive acoustic sensors paired with machine learning. The system enables welders to receive immediate feedback during the welding process, allowing them to address issues like shallow penetration or porosity before inspections occur. This product functions as a modular add-on, compatible with standard TIG welding equipment, and provides a path to eliminate costly re-inspection while increasing weld quality and efficiency.

Key Features and Capabilities

- **Real-Time Acoustic Monitoring**: Captures high-fidelity acoustic data during welding without interfering with the process.
- **Machine Learning Analysis**: Extracts frequency features using STFT and FFT to distinguish between good and defective welds.
- **User-Friendly Modular Hardware**: Includes a spark-shielded, EMI-protected microphone mount, robust enclosure, and clean signal circuitry.
- **Actionable Feedback**: Provides welders with interpretable, data-driven insights that are visible during or immediately after welding.

- **Training Tool**: Assists novice welders by accelerating their learning curve through real-time guidance.

Technical Achievements

The **Version 0 prototype (V0)** demonstrated several key milestones:

- Acoustic sensors and signal processing circuitry passed verification tests, accurately capturing weld-related frequencies between 0.6–15 kHz.
- Data acquisition and storage modules reliably recorded and formatted data for machine learning input.
- STFT analysis revealed frequency patterns that distinguish good vs. bad welds, which were used to train SVM and CNN models.
- Verification testing confirmed key functionality including EMI protection, voltage regulation, and clean signal acquisition.

Future Development and IP

To scale WeldRight toward commercialization:

- New iterations will include live feedback mechanisms (e.g., LED or haptic alerts) and further ML training with larger datasets to reduce overfitting.
- IP strategy involves filing utility and design patents, with a projected filing cost of $30,000. The team plans to use Canada's **AccelerateIP** program to support patent development and protect data and hardware innovations.

Product Brief

Product Description: WeldRight is an AI powered weld defect detection system which works as a non-intrusive modular add-on. It is compatible with all TIG welding equipment. It provides real-time feedback on weld quality, focusing on penetration depth and porosity, helping welders catch their mistakes before inspection.

What will it do?

- Analyze weld quality in real-time using acoustic sensors.
- Identify common welding defects (e.g., porosity, shallow penetration) and provide actionable feedback
- Reduce downtime and costly weld re-inspections.
- Accelerate skill development for novice and intermediate welders.

Customer Segments:

- Professional Welders: Seeking efficiency and consistent weld quality.
- Welding fabrication Shops: Aiming to lower downtime and inspection costs.
- Training Programs: Needing innovative solutions to improve student learning.

Final Product Sketch:

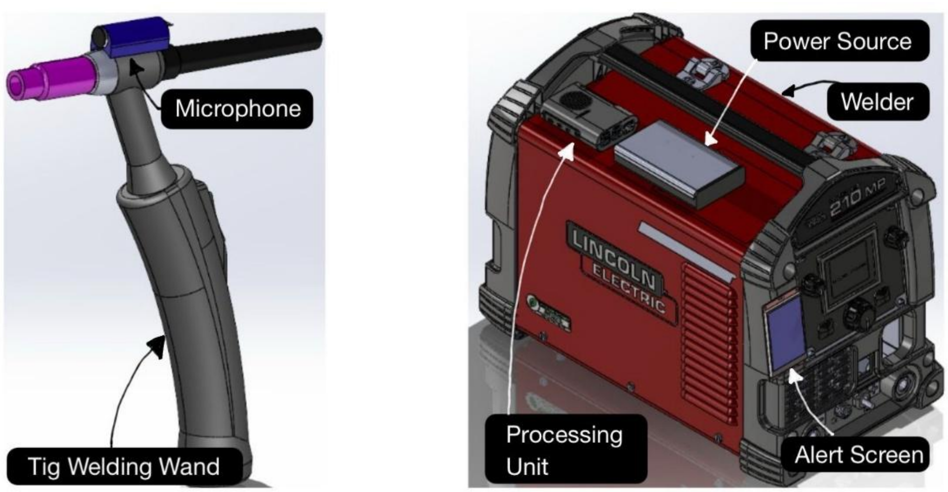

Figure 1: Product Sketch

Requirement Specifications

Context

Before considering requirements for the product, the preliminary step is to identify key stakeholders targeted by our venture. After conducting customer interviews to validate the problem hypothesis, we can confirm that that our key stakeholders are the following:

- Inspection and certification bodies (e.g. CWB, ASME, CSA, etc.) – includes individual inspectors.
- Large fabrication lines & production companies (e.g. Seaspan ULC, Irving Shipbuilding, Fort Fabrication, etc.)
- Professional welders with less than 10 years of professional experience – although it is noteworthy that all other welders would also be stakeholders but perhaps not as prominent as those with less professional experience.

These stakeholders were identified courtesy of the customer discovery process and are people who continuously engage with us during R&D and initial product deployment.

Problem statement

Armed with the knowledge provided by these stakeholders, we can form our problem statement. In addition to this we consulted with UBC professors and mechanical machine shop staff to derive our key design issues:

1. The device can record data during the welding process in a nonintrusive manner.
2. Device can use gathered data to determine penetration depth, porosity, & overall weld quality.
3. Overall package is durable to function in harsh working environments
4. Results of analysis are displayed to welder without disturbing the welder’s field of vision
5. The product can be outfitted on every welder

Requirements

Here we shall break down our process of requirement definition as well as provide a complete list of requirements for the complete product. From this list, we shall identify critical function requirements which will be achieved by the MVP. Later in this report, we shall explore the verification and validation processes with which critical function requirements are guaranteed. A common workflow and the one which we shall execute is demonstrated in Figure 2 by the V-model.

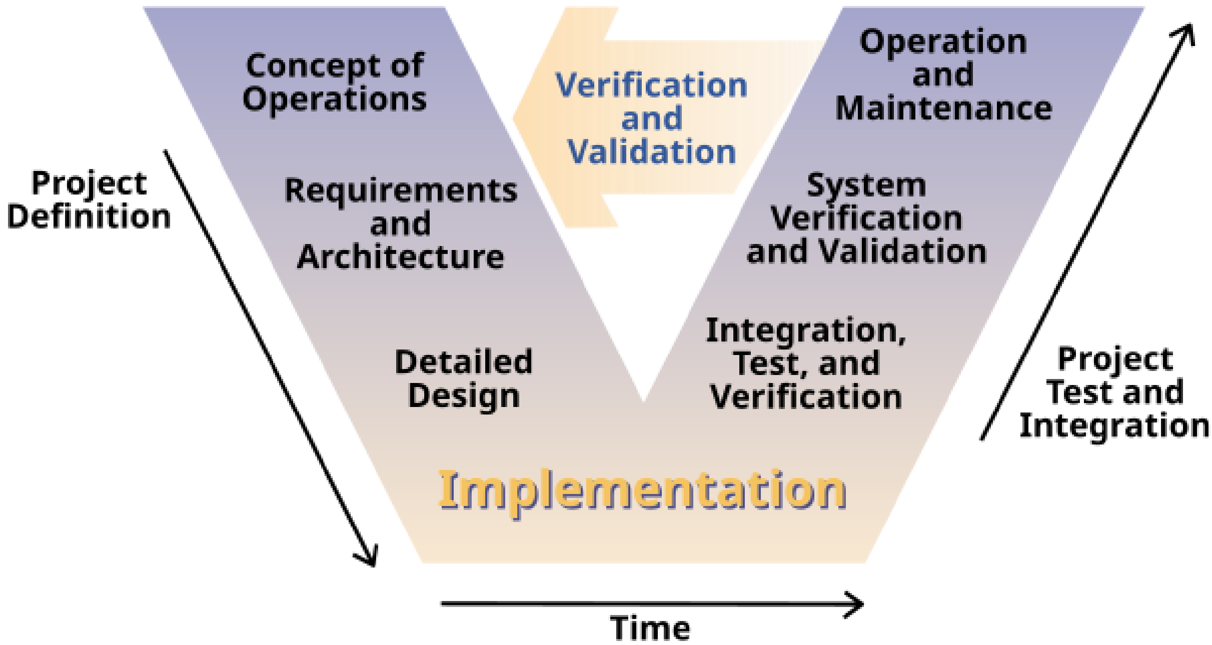

Figure 2: V – Model for Engineering Product Design

The main strategy to validate technical requirements that will follow in the next bodies of text is to superimpose said requirements within "use narratives" which can be presented colloquially in subsequent stakeholder interviews. Use narratives consist of a fabricated scenario where one or a group of specific design requirements are tested through a given function. Quantitative details should be emphasized in presentation of narratives; they should be articulated in a fashion that encourages the listening party to examine and scrutinize. This feedback will allow us to refine requirements through iteration.

Final Product: Functional & Non-functional Requirements

With that being said, the following is an exhaustive list of requirements for the final product. We will then outline which are critical function prototype, defining the MVP, and then validate that we achieved these critical requirements.

Needs				Requirements					
Type of Need	Needs Category	Explanatory Notes and needs as expressed	Need Statement	Metric		Acceptable Threshold			Justification
		Expand on Need for clarification/ definition and where they were derived from		Entity to be measured	Units	Minimum	Maximum	Go /no-go	
Threshold	Functional Need	This is the main source of data in our project. We will use this data to construct our initial concepts	Obtains sensory data from the welding process	Sensory data	-	-	-	Go /no-go	
Expressed	Functional Need	"Must last for at minimum a entire day of work"	Device can record for entire day of work	duration of work	hours	8	-	-	The typical work day in the blue-collar industry is 8 hours
Threshold	Functional Need	Processes data that the sensor collects	Processes data	If it processs sensory	-	-	-	Go /no-go	Required to process the data, without it, it will not work
Expressed	Functional Need	This is to account for the fact that professional welders desired this to be a separate unit from computers	Stores all processed data	Storage Capacity	Gb	5	-	-	As audio files can be quite large and one of the requirements is it lasts an entire day as well as the programs that must be stored on It.
Expressed	Functional Need	In many interviews, without prompting the interview brought up the lack of technology that gauges the performance of welds before inspection.	Differentiates between good and bad welds	differentiates between good or bad welds	-	-	-	Go/no-go	This is one of the rudimentary systems that the device must do to make it viable for the market.
Expressed	Functional Need	In some interviews with novice welders, they expressed that a lot of the time they do not know what exactly they are doing wrong.	Differentiates between different welding issues	Between issues outlined in dossier 1	-	-	-	Go/no-go	This is an aspect of the device that is targeted towards novice welders to help them improve.
Expressed	Functional Need	Professional welders identified that the only way they know that there is porosity and the weld penetration depth is through spectroscopy inspection.	Outputs weld porosity in real-time	Accuracy of purrosity output	%	90%	-	-	"According to the AWS D1.1 welding code, the acceptable size of weld porosity is generally considered to be no larger than 3/8 inch in any linear inch of weld". It will need to accurately capture porosity for inspectors and welders to understand how much porosity has occurred in the weld. As this is a secondary screening we felt 90% accuracy to be satisfactory. https://law.resource.org/pub/us/cfr/ibr/003/aws.d1.1.2000.pdf
Expressed	Functional Need	Professional welders identified that the only way they know that there is porosity and weld penetration depth is through spectroscopy inspection	Accurately outputs weld penetration depth in real time	Weld penetration depth accuracy	%	90%	-	-	This device is to help welders pass inspections, help inspectors identify possibly bad welds, and improve project progression. The device is to be 90% accurate with the penetration depth to ensure product usability. Thresholds determined by standards: ISO 23277, ISO 17640, and DIN EN ISO 17638
Expressed	Functional Need	The inspector said it would be greatly helpful to get a record of the overall quality of the welds being done on large-scale projects.	Can determine the quality of the weld	Confidence of weld passing inspection	%	90%	-	-	As this is a supplementary screening device for weld quality we want the device to indicate weld quality as inspection parameters. It should be at least 90% accurate with the pre-inspections. Weld penetration standards that it must pass: ISO 23277, ISO 17640, and DIN EN ISO 17638
Expressed	Functional Need	This is to elaborate on the inspectors' comments	Can determine the integrity of the weld	Weld integrety accuracy	%	90%	-	-	As this is a supplementary screening device for weld quality we want the device to indicate weld integrity. It should be at least 90% accurate with the calculations. This will be the combination of the previous 3 requirements.
Expressed	Functional Need	This was a comment from novice welders and teachers. If the device can help welders close the steep learning gap it would be greatly helpful.	Can determine steps the welder can take to improve weld	Correctness of steps taken.	% correctness	90%	-	-	When advising novice welders. The advice given should be correct 95% of the time to allow for the welders to improve. This will be used as an educational aid alongside traditional teaching methods which is why we gave it a 5% buffer.
Threshold	Functional Need	If the unit needs to be separate from a computer and welders express disinterest in bringing computers onto the manufacturing floor. For that reason, we inferred that data would need wireless transfer	Be able to transmit data wirelessly	If it transmits data	-	-	-	Go/no-go	

Expressed	Functional Need	Welders expressed that the unit needs to be separate from a computer and are disinterested in bringing computers onto the manufacturing floor. For that reason, we inferred that data would need wireless transfer	Does not require computer (laptop or desktop) to perform tasks	Can work without extrenal computing	-	-	-	Go/no-go	
Latent	Functional Need	All welders said they would want it to be displayed but did not mention where. If it is in view they do not need to stop welding if it detects a problem.	Displays outputs within welder's view	Displays outputs within welder's view	-	-	-	Go/no-go	
Expressed	Functional Need	Everyone expressed a interest in "real-time" monitoring of the device instead of post-processing	Outputs must be displayed live	Time delay	Seconds		5	-	We considered an acceptable time delay from weld puddle and weld to be 5 seconds as it can give the necessary data. 5 seconds of welding results in a maximum distance of 1 inch. Our stakeholders considered this real-time equivalent.
Latent	Functional Need	This was not an expressed need and would be intended for the management of welding shops and people who are learning how to weld.	Records welders progress	Records welders progress		-	-	Go/no-go	
Threshold	Durability	This is because welding produces a lot of heat from the act itself and the metal around it. How equipment should be able to handle this harsh environment	Withstands hot temperatures	Hot temperatures	celcius	320		-	We judged this off the ANSI 105 standard for glove rating, which results in a temperature rating of 320 degrees celcius. The reason behind this is the closest the device will get to the weld is as close as the glove would get.
Threshold	Durability	Welding is not only done indoors but in every out doors as well. The device should be able to withstand temperatures the welding is being done in.	Withstands cold environments	Temperature	celcius	-15	-	-	As we want the device in all working temperatures, we discussed with stakeholders that weld outdoors. They said the coldest they will work in is -15 degrees celsius however not for very long.
Latent	Functional Need	This would be beneficial for managers, inspectors, and welders who are trying to improve. It shows them what they are doing well and if they are working according to regulations.	Quantifies and records welders' key performance indicators (KPI)	Quatifies progress in number of key areas	# of key areas	2	-	-	These key areas are average weld quality, average weld integrity, average penetration depth, and time spent welding.
Threshold	Durability	The device may be exposed to all sorts of environments and for that reason should be water resistant.	IP65 water resistant rating	Water resistant	Graded of water resistance	IP65	-	-	
Expressed	Functional Need	This was derived from the comments made that this should work on every welder and should be easy to integrate in any environment	Needs to power itself wirelessly for a day of work.	Duration of charge	hrs	8	-	-	This is because the average work day in Canada is 8 hours. We want our device to work for at least that long.
Expressed	Functional Need	We derived this need from interviews that tell us that this device would have to be easy to use, charge, and install. This includes charging, data transfer, and utilization.	Needs to be able to be charged quickly	Charge time	hours	-	8	-	If it works for the entire work day they can charge it over night without losing time on projects.
Latent	Functional Need	This comes from our own experiences with products and how if having to start it and turn it off every time detures us from using them.	Begins recording data when welder starts to weld	Time it starts to record automatically	Seconds	-	5	-	Typically when starting a tig weld the initial pool takes about 5 seconds to form. Once it forms the weld commences.
Latent	Functional Need	To know when the device is recording, on or off without having to remove gloves or other PPE. If the results in lost time it is undesirable to use.	Indicates when recording data	Indicates when recording data		-	-	Go/no-go	
Threshold	Functional Need	This was not expressed as a need but expected to not interfere in the welding process, or change their ability to weld.	Wearable weight is light	Total wearable weight	grams	-	500	-	This number was derived from customer interviews. They made it clear that it could not interfere with their welding process. They also stated that "if too heavy it would get annoying, cannot be more than half a kilo or so"

Threshold	Functional Need	Welders often weld different materials using the same welder. For that reason, the device should work on those materials	Works on all weldable alloys and metals	Works on all weldable alloys and metals		-	-	Go/no-go	
Threshold	Functional Need	If it obstructs the view of the welder it will not be used.	Display does not impede welders view of welding process	Display does not impede welders view of welding process		-	-	Go/no-go	
Expressed	Functional Need	This is expressed in terms of professional engineers wanting the device to be used in a shop environment without the need for and computer.	Device displays output	Device diplays output		-	-	Go/no-go	
Latent	Functional Need	As we have a wide customer base the customization of what is being displayed is important to encompass all possible users	Operator is able to control what is being displayed	Can control what is being displayed		-	-	Go/no-go	
Expressed	Functional Need	This is derived from conversation of integration with any welder and should be easy to use." If it is difficult to set up or change it between devices no one will use it."	Easy to install or incorporate into existing welding station	Time it takes to install	minutes	-	10	-	This number still needs to be verified with customers, however, if we are saving a lot of time in other places we deem it justifiable to have a 10-minute installation time.
Threshold	Functional Need	If it interferes with the welding process it will not be accepted into the industry.	Does not impede in welding process	Does not impede in welding process		-	-	Go /no-go	
Latent	Functional Need	We think this is a required feature as this is an additional device to the welder. People who have been welding for a long time will not be used to turning an additional device off. For that reason shutting itself off is a need to conserve power and make the device more useable.	Automatically stores data and shuts down after 20 minutes without use	Automatically stores data and shuts down after 20 minutes without use		-	-	Go /no-go	
Latent	Functional Need	As we have a wide customer base the customization of what is being displayed is important to encompass all possible users	Operator is able to control what is being displayed	Can control what is being displayed		-	-	Go/no-go	
Expressed	Functional Need	This is derived from conversation of integration with any welder and should be easy to use." If it is difficult to set up or change it between devices no one will use it."	Easy to install or incorporate into existing welding station	Time it takes to install	minutes	-	10	-	This number still needs to be verified with customers, however, if we are saving a lot of time in other places we deem it justifiable to have a 10-minute installation time.
Threshold	Functional Need	If it interferes with the welding process it will not be accepted into the industry.	Does not impede in welding process	Does not impede in welding process		-	-	Go /no-go	
Latent	Functional Need	We think this is a required feature as this is an additional device to the welder. People who have been welding for a long time will not be used to turning an additional device off. For that reason shutting itself off is a need to conserve power and make the device more useable.	Automatically stores data and shuts down after 20 minutes without use	Automatically stores data and shuts down after 20 minutes without use		-	-	Go /no-go	
Latent	Functional Need	This is derived from the need for it to be used without a computer in the workspace. As this need was not explicitly stated we thought it would add to the useability of the device.	Automatically uploads to external storage and deletes data locally when connected to external software	Automatically uploads to external storage and deletes data locally when connected to external software		-	-	Go /no-go	
Threshold	Functional Need	All welding is done with gloves on. If the device cannot be used while wearing gloves it will deter the welder from using the device.	Power button can be used while wearing welding gloves	Can be used with standard TIG MIG and STICK gloves		-	-	Go /no-go	

Latent	Functional Need	Group members have had frustrations in the past with data being overwritten or not saved due to being unaware of the storage limit. As a computer for this device might not be checked regularly the device should indicate when the storage should be saved externally.	Indicates when close to local storage limit	Indicates when close to local storage limit		-	-	Go /no-go	
Threshold	Functional Need	This is another useability function for the device. Cannot be used if out of power and if there is no indicator then how would anyone know.	Indicates when low on power	Indicates when low on power		-	-	Go /no-go	
Latent	Regulatory	This is a common frustration in the blue-collar industry. So much so there is the right to repair act. This states that everyone has the right to repair their tools.	All wearable components can be replaced	All wearable components can be replaced		-	-	Go /no-go	
Threshold	Regulatory	If data is being transferred wirelessly then we must follow this encryption standard	Data encryption with ISO/IEC 27001 standards	Data encryption with ISO/IEC 27001 standards		-	-	Go /no-go	
Expressed	Functional Need	"The device cannot cost more than what it would save us from redoing inspections." In other words it must save them money	Cost of device results in net cost benefit to the users	% of margin saved	% margin saved	3%	-	-	This comes straight from interviews with manufacturing shop owners. To use this device it must save them at least 3% of lost income due to failed inspections.

Figure 3: Complete Product Requirements

This list, along with a detailed description of the evaluation criteria defined for a given requirement, is exhibited in Dossier 2. The spreadsheet containing these requirements is also submitted. All in all, 7 Dossiers & other technical documentation will accompany this report as a technical archive.

MVP: Functional & Non-functional Requirements

Within the requirements outlined, we have identified the following as critical function requirements; some requirements were modified to be captured within the scope of the course:

	Needs				Requirements					
	Type of Need	Needs Category	Explanatory Notes and needs as expressed	Need Statement	Metric		Acceptable Threshold			Justification
			Expand on Need for clarification/ definition and where they were derived from		Entity to be measured	Units	Minimum	Maximum	Go /no-go	
1	Threshold	Functional Need	This is the main source of data in our project. We will use this data to construct our initial concepts	Obtains sensory data from the welding process	Sensory data	-	-	-	Go /no-go	-
2	Threshold	Functional Need	Processes data that the sensor collects	Processes data	If it processs sensory	-	-	-	Go /no-go	Required to process the data, without it, it will not work
3	Expressed	Functional Need	This is to account for the fact that professional welders desired this to be a separate unit from computers	Stores all processed data	Storage Capacity	Gb	5	-	-	As audio files can be quite large and one of the requirements is it lasts an entire day as well as the programs that must be stored on It.
4	Expressed	Functional Need	In many interviews, without prompting the interview brought up the lack of technology that gauges the performance of welds before inspection.	Differentiates between good and bad welds	differentiates between good or bad welds	-	-	-	Go/no-go	This is one of the rudimentary systems that the device must do to make it viable for the market.
5	Threshold	Durability	This is because welding produces a lot of heat from the act itself and the metal around it. How equipment should be able to handle this harsh environment	Withstands hot temperatures	Hot temperatures	celcius	100	-	-	We judged this off the ANSI 105 standard for glove rating, which results in a temperature rating of 320 degrees celcius. The reason behind this is the closest the device will get to the weld is as close as the glove would get.
6	Threshold	Functional Need	If it interferes with the welding process it will not be accepted into the industry.	Does not impede in welding process	Does not impede in welding process		-	-	Go /no-go	-
7	Threshold	Functional Need	Majority of the welding you'll find these days is on steel	Analyzes welds on mild steel	Analyzes welds on mild steel		-	-	Go /no-go	-
8	Threshold	Functional Need	Since we will be using this to show potential customers and stimulate interest in our product. For this we will need to be able to easily bring into shop environment	Is easliy portable	Portability	One person is able to transport all needed items	-	-	Go /no-go	-
9	Expressed	Functional Need	Only have been given $2000 dollars for all research and development, $1500 of that we have alotted for research and design	Cost less than 1500 dollars	Cost	Canadian Dollars		750		Only have been given $2000 dollars for all research and development, $1500 of that we have alotted for research and design. As there are many other costs than just a single unit of the MVP we have determined a maximum cost of $750.

Figure 4: MVP Requirements

For each of the needs described, where necessary, a verification or validation test will be defined later in the text.

Design Constraints

Due to our limited budget, it was decided that expensive components of the MVP were to be loaned from the department of Mechanical engineering at UBC. Namely, we signed out a piezoelectric-crystal microphone which retails at well over 3000$ including the pre-amp that it requires. The use of this microphone imposed some constraints that are not captured by the requirements for the instrumentation design. Namely, the output of the pre-amp needed to be amplified again, filtered via anti-aliasing, and level shifted to interface appropriately with the analogue-digital converter.

Product Design

This section will outline the detailed design of the current product version (prototype V0).

Product architecture

The product system architecture for the MVP is shown in the figure below

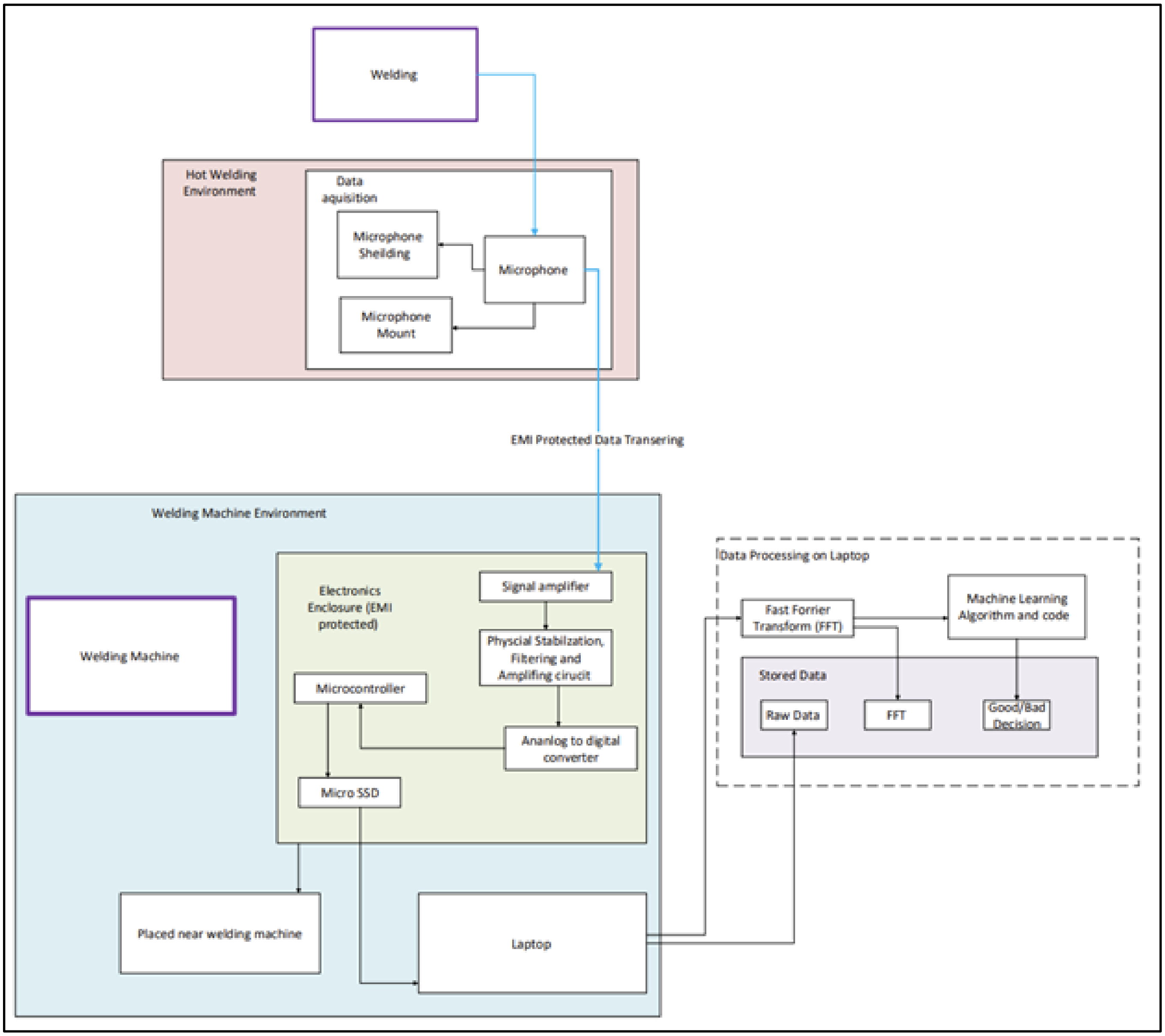

Figure 5: MVP System Architecture Diagram

Component Descriptions

The current V0 prototype serves as a proof of concept, this version doesn't incorporate live feedback yet but focuses on data collection and the development of Machine Learning algorithms. It consists of a microphone mount holding a microphone near the weld, circuitry, an enclosure protecting circuitry, and the Machine Learning code. Please refer to the requirements section to see the exact requirements this version will fulfill. Figure 6 shows the V0 prototype as built with all components labeled.

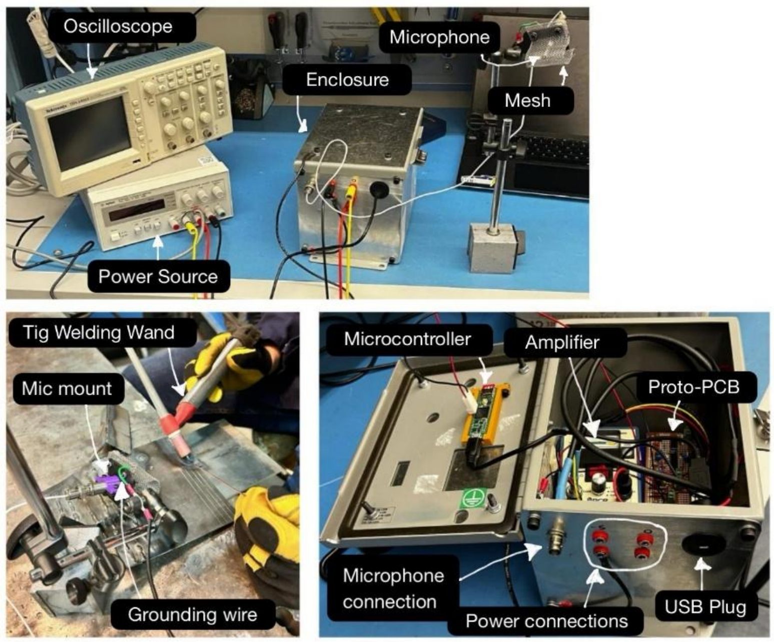

Figure 6: Prototype setup with labeling

Circuitry

The circuitry serves to process the acoustic data collected through the microphone to make it readable for the microcontroller by ensuring the signal meets the desired controller input criteria.

Design

The circuit filters, shifts, and amplifies the signal to meet the desired output levels. It consists of several key sub-circuits, outlined below:

1. INA Initial Filter
    - This filter removes high-frequency noise before any adjustments are made and applies a gain of 100 to the signal. The input is 36mV peak-to-peak, and the output needs to be 3.6V peak-to-peak.
2. Bessel Low-Pass Filter at 30kHz

- Since we are sampling at 15kHz (Nyquist frequency) for anti-aliasing, we filtered out any noise above 30kHz. We selected the Bessel Filter for its sharp roll-off at the desired frequency.

3. Level Shift
   - This stage shifts the signal to ensure it is always above 0V peak-to-peak, as the microcontroller can only read voltages in the 0-3.6V range.
4. Voltage Regulator
   - The microcontroller's ADC channels can handle a maximum of 5V, but optimal operation occurs within the 0 to 3.6V range. To ensure this, we incorporated a voltage regulator and diode protection circuit to prevent voltage from exceeding 3.6V. This is crucial because EMI can cause large voltage spikes, and this circuit provides robustness and reliable operation in the presence of such interference.

The figure below shows the circuit diagram connected to the microcontroller.

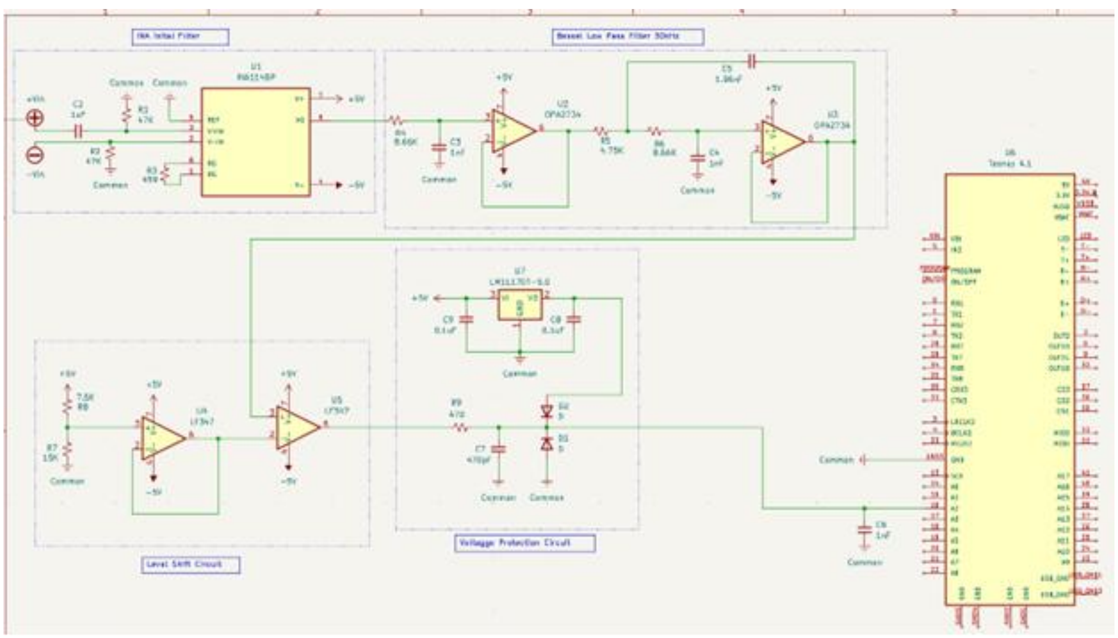

Figure 7: Circuit diagram

Construction

The construction of the circuit was completed in two steps. First, we built and tested the circuit on a breadboard, constructing and testing each sub-circuit individually using a signal generator and oscilloscope.

Once we were satisfied with the breadboard setup, we transferred the circuit to a proto-PCB to be placed inside the enclosure. The proto-PCB provides several benefits:

1. Reduced noise in the circuit.
2. Prevented short circuits caused by components being pulled out.
3. Made the circuit easier to handle and integrate into the prototype.
4. Used screw terminals and clips to secure removable wires, reducing the likelihood of wires becoming dislodged during assembly.

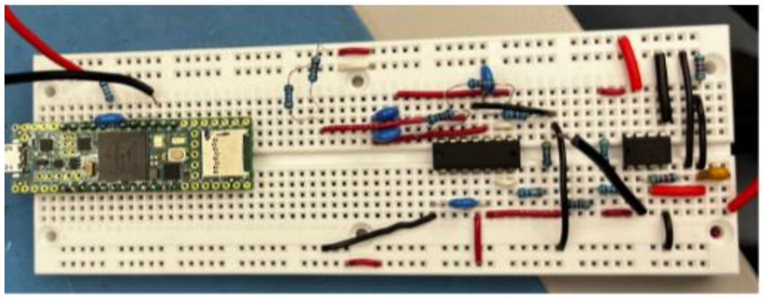

Figure 8: Breadboard circuit

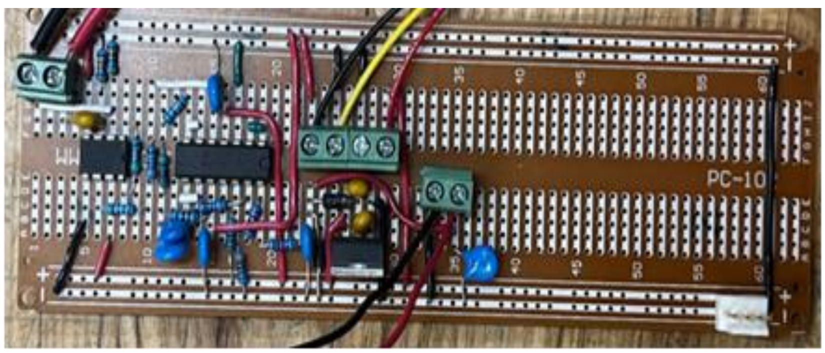

Figure 9: Proto-PCB circuit

Iterations and Improvements

With the new electronic equipment, the circuits are undergoing a complete overhaul. We will follow the same process as before, starting with breadboard testing, moving to proto-PCB, and finalizing component placement. Once the components are optimized, and the proto-PCB is complete, we will design and fabricate custom PCBs for testing. This will help us optimize the manufacturing process, address spatial constraints, and ensure we meet all the necessary requirements and objectives.

In addition to optimizing the existing circuits, we have designed a wall plug power supply for the device. So far, we have been using a DC power supply borrowed from the MECH department. While effective, it's cumbersome and prone to accidental power channel switching during setup, which could damage the circuit. To solve this, we developed a wall plug power supply providing ±5V to be integrated into the enclosure.

The system consists of an AC/DC converter that steps down to 5V, followed by a DC/DC converter to produce both +5V and -5V channels, along with a common ground. To reduce switching noise from the converters, common mode chokes are placed on either side of the DC converter, and low pass filters further reduce any residual noise. The circuit design is shown below.

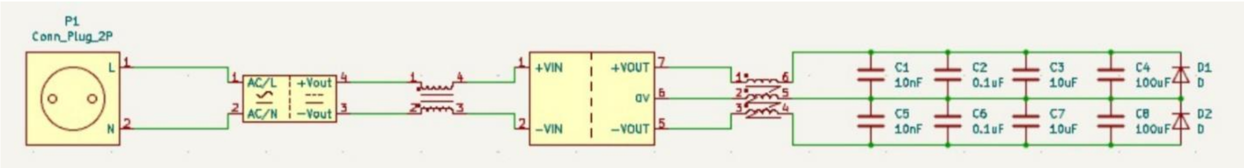

Figure 10: 5V Power Supply circuit diagram

Microphone Mount

The microphone mount serves to hold the microphone in a stable position near the arc of the weld to collect high quality acoustic data.

Design

Microphone: PCB Piezotronics 130D20 SN 29230

Specific Design Requirements:

1. Spark shield
2. Non-conductive
3. Grounded
4. Can articulate and place easily within a 3D space
5. Does not obstruct welding process

What we decided on was a 3D printed microphone mount that connects to a electromagnetic shield with a mesh covering the microphone. We did this by 3D modeling the microphone then using a friction fit clamp design to secure the microphone. This design allowed for easy assembly and protected the microphone from electrical arcing, and sparks.

Modeling the microphone mount:

The design is two parts the main body, and the lower clip. The 4 holes surrounding the microphone hole are to mount the mesh on. The ear that comes off the main body is to mount to the articulating electromagnetic stand. The clips hold the microphone in place by the means of friction using M3 hardware. Please refer to appendix A for detailed engineering drawings for the mount.

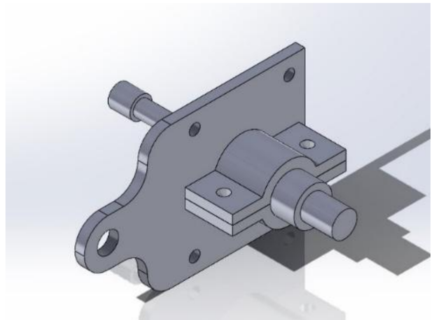

Figure 11: 3D model of microphone mount

Construction

The main body and lower clamp were 3D printed out of PLA for its easy quick prototyping and electrical insulative properties. We bent the mesh to the desired dimensions and grounded it to the base using a wire with an eyelet on it.

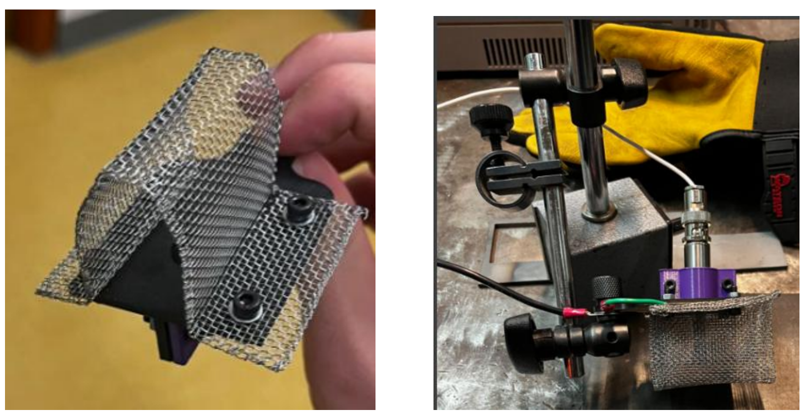

Figure 12: Constructed Microphone Mount

Iterations and Improvements

The first iteration we made to the design was double the mesh and offsetting the two. This effectively halved the openings that sparks could enter and doubled the thermal mass in front of the microphone. From calculations in Dossier 4 we knew that the microphone will not heat up past critical temperatures. However, by adding this extra mesh we added redundancy. In the future we look to put the microphone on the end of the welding torch and have modeled this later on in this report. For this to be done we need to optimize the audio profile, source and test a smaller microphone and build a circuit to use that microphone with. After the smaller microphone has been tested and confirmed reliable, we will design and optimize the microphone torch mount to fulfill all requirements.

Enclosure

The enclosure serves to protect the circuit and microcontroller from EMI, water, and dust in the shop environment.

Design

Specific requirements for the enclosure:

1. Made from steel or aluminum to shield components from EMI
2. Holds all necessary electrical components
    a. Amplifier
    b. Proto PCB
    c. Microcontroller: Teensy 4.1
3. Has all necessary electrical bulkhead connections
4. All mounting plates are electrically isolated from box
    a. This is to prevent grounding issues

We designed and optimized the enclosure for easy disassembly and reassembly to minimize procedural and setup errors that could lead to failed data collection. The enclosure was built to maximize EMI protection and circuit isolation while remaining practical to work with.

Initially, we collected data without a conductive enclosure, but the recordings were too noisy and inaudible. We identified EMI from the welder as the primary issue, as it introduced significant interference into our signal. To address this, we built an EMI-shielded enclosure to isolate the circuit.

Due to budget constraints, we repurposed a high-voltage circuit breaker box we obtained for free. This choice balanced cost and functionality. We mounted all necessary bulkhead connectors and grounded the enclosure to the circuit, including:

- 1 BNC connector
- 1 Micro-USB connector
- 4 Banana plug connectors (5V, -5V, common, and enclosure ground)
- 1 AUX connector

We designed a mounting plate to secure and isolate the amplifier and circuit, along with a microcontroller mount on the lid for easy access. Since the enclosure was retrofitted, we did not model it, but we designed the plug layout for optimal placement.

To further improve usability, we replaced all internal electrical connections with clip connectors, allowing for quick and easy removal and reassembly.

Microcontroller mount

The microcontroller mount had to secure the microcontroller to the lid while keeping access to the SSD card, pins, button and Micro-USB. In addition, we would need the capability to remove the controller easily. Please refer to appendix B for the engineering drawings.

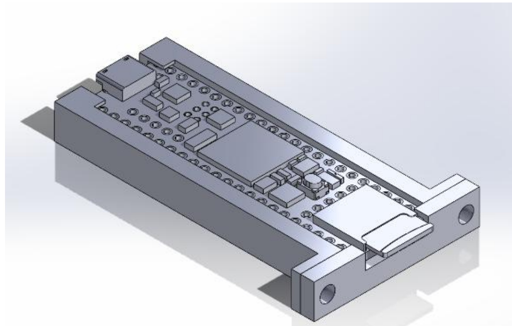

Figure 13: Microcontroller 3D model

Circuit Base Plate

The circuit base plate mounted to the bottom mounting holes of the enclosure. It was required to hold the circuit and amplifier in place as well as isolate them from the system. Please refer to appendix C for the engineering drawings.

Construction

The enclosure was a repurposed high-voltage box that we retrofitted to meet our requirements. We cut and bolted 1/16-inch stainless steel mounting plates onto the top and front to cover existing holes from its previous use. Holes were drilled to the required sizes, and bulkhead connectors were mounted on the front panel. This design ensured easy assembly and minimized wire lengths for improved signal integrity. The final setup is shown in the figure below.

Figure 14: Enclosure front plug panel

Once that was complete, we added quick connectors to the circuit board, bulkhead head connectors and microcontroller. This allowed us to dissemble and remove parts easily and separately while ensuring proper connections are made.

Figure 15: Inside view of enclosure connectors

We 3D printed both the circuit base plate and microcontroller mount using PLA due to its low cost, good insulative properties, and suitability for rapid prototyping. This method was the cheapest, fastest, and most precise option available.

The microcontroller mount was epoxied to the enclosure lid to allow easy access to the SSD and microcontroller button. Our initial circuit design highlighted the importance of easy microcontroller access for component safety and streamlined data acquisition. The circuit board mount is bolted to the bottom of the enclosure, utilizing existing blind-threaded bolt holes originally designed for a grounding plate.

The figures below illustrate various aspects of the enclosure and mounting system.

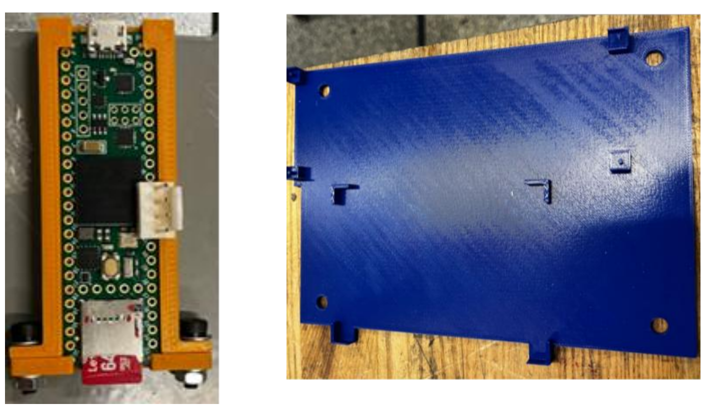

Figure 16: Base plate and microcontroller mounts

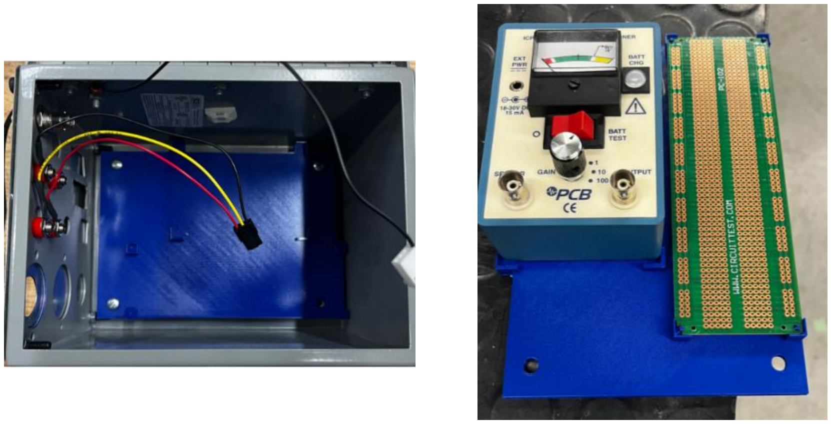

Figure 17: Base plate within enclosure and with circuitry on it

Iterations and Improvements

The enclosure is one of two designs that will be undergoing redesign with the new microphone and electronic equipment we aspire to use. With the new electronics we will be having 2 smaller proto-PCBs and eliminating the need for the larger amplifier. The improvements will include but are not limited to:

1. New bulkhead connectors
    a. With circuit redesign we are looking to remove existing components and integrate more widely universal plugs (ex. USB-C) to minimize the number of plugs we must use.
2. Bulkhead connectors being placed on the bottom of the panel
    a. This is with the idea of having the base plate on top of the wiring. As seen below the wiring is messy and this makes it difficult to assemble and dissemble.
3. Elevating the base plate and base plate redesign
    a. As mentioned previously, elevate the base plate above the wiring while designing the base plate to incorporate the new PCBs, wire strain relief and improve PCB isolation and mounting methods.
4. Optimize wire routing and wire length
    a. Optimizing wire length and routing will limit the amount of wire strain/fatigue and minimize the potential for snags and possible damage to components.

After we do these iterations to the design, we will be looking at shrinking the enclosure with every iteration. This is to optimize the ease of installation and use throughout the project. We will be continuously consulting with customers to better understand the form factors and aspects of the project to improve.

Figure 18: Inside enclosure with wiring attached

Machine Learning

The machine Learning algorithm serves to determine when a weld is good or bad. In future iterations this will need to identify specific defects but for prototype V0 it simply needs to classify good welds and bad welds.

Design

The machine learning (ML) algorithm has been designed to focus on the prevalent frequencies in the sound with respect to time. Instead of running the raw audio data through an algorithm a frequency analysis similar to a Fast Fourier transform was done on the data. This analysis is a Short Time Fourier transform (STFT) which creates a spectrogram showing the frequencies on the y-axis and time on the x-axis. This provides more data to the machine learning algorithm compared to a simple FFT analysis by adding time-based and spacial information. This allows the algorithm to pick up on more nuanced differences between samples. Figure 22 below shows an example of real welding data collected displays the STFT generated from the sound collected for a good weld and a bad weld.

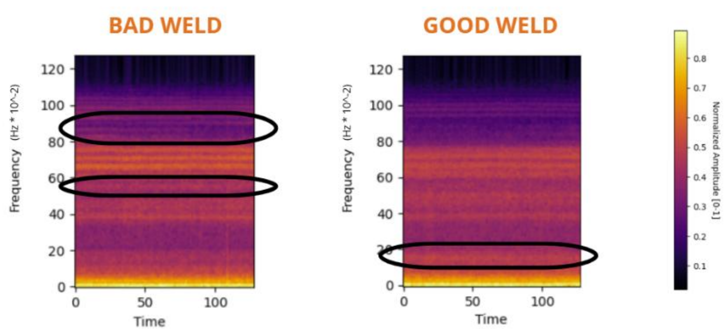

Figure 19: STFT comparison of sample good and bad welds

Circled in the figure above are a few of the key frequency bands which differentiate a good weld and a bad weld within the collected data set. However, it is important to note that the

ML algorithm would pick up on more nuanced differences than which are discernable by humans. This is one of the key advantages of ML models allowing high precision applications.

Construction

The ML algorithm has been developed using the Python programming language in a Jupyter Notebook. This allows for fast iterations while testing different algorithms and fine-tuning them. The main algorithms which were tested on the current data set is a Convolutional Neural Network (CNN), a Support Vector Machine (SVM) algorithm, and once again an SVM algorithm after using Principal Component Analysis (PCA) to reduce the number of features in the data set. CNN is a deep learning algorithm used for high accuracy image classification while SVM is a simpler classification algorithm.

Iterations and Improvements

Once the Jupyter Notebook was built the next step was to train each model and evaluate them. When comparing the results obtained from each the CNN algorithm achieved a precision of 85%, the SVM model achieved a precision of 92%, and the SVM after PCA got a precision of 100%. The really high precision scores, especially the post PCA SVM algorithm is most likely due to overfitting to the data. This means that the model understands the presented data very well and will struggle at classifying anything given to it which slightly differs from the database it was trained on. The PCA was able to reduce the number of features from the original 16,384 to merely 105 while keeping 99% of the original information (as calculated by the explained variance). A graph showing the cumulative explained variance as a function of principle components kept is shown in figure 23 below:

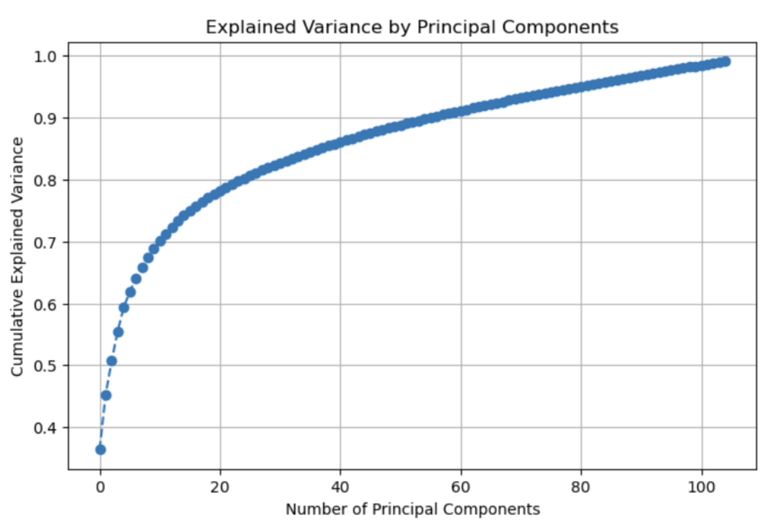

Figure 20: Cumulative Explained Variance compared to Number of Principle Components

The next steps to further refine the ML models will be to build a larger database to reduce overfitting and re-test the newly trained models. As PCA shows a lot of promise by drastically reducing the number of features each model needs to analyze, more models will be tested after conducting the PCA, such as XGBoost algorithm which utilizes GPU processors to its advantage when classifying images.

Verification and Validation

To ensure that the WeldRight MVP performs as intended and meets both technical and user-driven requirements, we conducted a comprehensive suite of verification and validation tests. These tests were designed to assess both the functionality of individual components and the usability of the full system in real-world welding environments. Please refer to Appendix D for further explanations on the tests which were conducted, their results, and the rationale behind them.

Verification Testing

The verification tests mainly focused on the subsystems involved in audio data collection, data processing, and the welding setup. Each test was designed to confirm that the specific technical requirements (such as signal clarity, data integrity, and real-time audio feature extraction) were met. For example:

- The acoustic sensor and amplifier circuit were tested to confirm accurate capture of known frequencies without interference.
- The FFT and STFT algorithms were tested to verify correct identification of signal features.
- Protection and EMI components were tested to confirm they operate within electrical safety thresholds.

Test outcomes were recorded in a detailed table, linking each unit to its design requirement (as numbered under the MVP Requirements section), verification criteria, method, and pass/fail status as shown in figure 21 below. Most of the tests passed, with a few pending further development (e.g., data labeling and ML model validation).

Sub systems	Unit	Unit Design	Requirements	Verification criteria	Verification Test description	Verification Passed?
		V0				
Audio Data Collection (circuitry)	Amplifier Clean power source	Amplifier and Phantom power source Secure and safe mount far from weld	1,5,6	1. Clean power output from Amplifier, 2. Splatter cannot be sprayed onto amplifier	1. Connect amplifier to an oscilloscope to ensure that the output is clean 2. Ensure that there is no direct route for splatter to reach amplifier (it is blocked)	☑
	Acoustic Sensor	PCB Piezotroncis 1030D20 Microphone mount and protection screen	1	Can precisely and accurately collect acoutic measurements of frequencies between 0.6 kHz and 15 kHz	Set up the microphone to collect data, play sounds of known frequencies with no background noise, view data collected and confirm that accurate frequencies are shown	☑
	DAQ ADC	Teensy 4.1 On-board 12bit analog to digital converter programmed via Arduino IDE	2,3,7	1. Quantization error is not observable post FFT 2. High quality audio captured by ADC and can be replayed and accessed easily	1. Apply FFT to a know frequency played and observe for any additional or noise frequency present in the response. 2. Use an audio monitor speaker to replay or "access" acoustic data captured.	☑
	Protection Circuit(s)	Utilizing two diodes and a voltage regulator in combination to ensure full protection of the circuit	1	Maximum possible output of the protection circuit is 30mV peak to peak.	Connect the input of the circuit to a wave generator an oscilloscope to the other side of the protection circuit. Slowly increase the peak-peak amplitude of the input and monitor the oscilloscope. Ensure that the maximum peak to peak voltage after the protection circuit is 30mV.	☑
	EMI Protection	Enclosure for all unprotected circuitry components provides EMI protection	1	1. Collects clean data in high EMI environemnts. 2. Uses ferrous materials	1. Collect data while in a high EMI environment and play it back, ensure data is clean from noise. 2. Check material specifications for materials used, ensure they are ferrous	☑
	Other Circuitry Components	Resistors, Capacitors	1	Resistors and Capacitors are within the specified error of their stated values	Simply measure their value using a multimeter, ensure it is within the specified acceptable error	☑
Data processing (anything on computer)	Feature Extraction	Will be done using python code sourced from MANU 465 (ML & AI) course to complete an FFT and STFT	4,7	Accurately extracts main features of acoustic data	Generate sound file with specific frequency, perform FFT and STFT using code to see if it identified correct frequencies (features). If there are some extra features we will know this comes from an error in the code as this was isolated	☑
	Data storage	Stores acoustic data as RAW audio file which is then converted once saved onto the laptop into a WAV file	2,3,7	Stores data in the desired manner	When collecting sound for above verification tests, ensure that the saved data on the laptop is in the desired file format and can be opened	☑
	Data labeling	This will be a manual process where welds will go understand acid etching and dye penetration tests	4,7	Weld should pass acid etching and dye penetration testing	Dye penetrant testing will be done first (as this is non destructive), afterwards the weld will be cut and acid etching will be performed to verify that the penetration was acceptable (or not for bad welds). Test results will be documented with pictures and saved in the associated folder in one-drive	☐
	Machine Learning algorithm	Once all data is collected train the machine learning to decide between good and bad welds	4	Can accurately categorize unlabeled data as good/bad	Once model is trained run it on some known data which is unlabeled, see if the model can accurately identify it as good/bad. Test it on multiple samples to find accuracy of the model	☑
Welding	Welder	DC TIG welder		Ensure welder used can do DC TIG	Check type of welder and welder manual for specifications and uses	☑
	Material and material set up	Low carbon steel 1/8" thick	7	Ensure it is low carbon 1/8" Steel	Request data sheet when sourcing material and check	☐
	Weld	Perform good and bad welds of same length on same material. # inches long weld	4	See Data labeling Unit for Verification info	See Data labeling Unit for Verification info	☐

Figure 21: Verification Tests and Description

Validation Testing

The validation tests mainly focused on ease of implementation, durability, cost, and the quality of actionable data, as experienced by potential users in welding environments. The methods used to validate involve potential customers such as interviews, product demos, etc. Figure 22 below shows a more in-depth list of areas which need validation, the rationale behind why it is needed, and the method to be employed. Each validation test is linked to a requirement as previously numbered under the MVP Requirements section.

Evaluation criteria	Validation Areas	Requirements	Rational	Methods
Ease of implementation	Does not get in the way of welding process	6	For this system to be effective it must not effect the welders ability to weld.	Method of validation is going to be through customer consultation. We have a list of interested potential customers that want to trial our product. We will leverage these connections to validate our MVP and its validation areas to better understand how to better fit our customers needs. Through this validation process it will create new requirements, validate the Target design specifications that we used for our MVP and get a path on how to iterate our design to further improve it.
	Can be transported easily	8	When demoing and setting the product up we want it to be professional and not hap hazzard. In addition, one of the main requirements and evaluation criteria for the final version is it does not interupt the work day. We want to encorperate this idiology early on to allow us to fulfill this requirement more easily later when it is introduced.	
	Set up time	6		
Durability	Reliably works in welding environment	5,6	Since all the data collection and demoing with customers will be happening in the welding shop environment we must validate that the MVP is fulling these requirements and if there are any more we over looked.	
	Does improper use result in breaking (ie over 36mv input, wrong terminal input)	6		
	Resistant to damage in transport	6		
	Microphone does not get damaged	8		
Cost	Cost customers are willing to pay	9	For understanding market viability and devolge whether there actually is a potential for profit.	
	Did MVP exceed cost parameters	9	We want to validate our budgeting methods we used for the MVP and better understand how we can optimize them for future portotypes.	
	Is it fanacially valid, are there areas to optimize cost	9		
Quality of actionable data	Does it act how we designed it	1,2,3,4,5,6,7,8,9	Scientifically validate whether our MVP fulfilled what we desired of it. Then take it to the customer and get an idea if this is what they had in mind when they heard about our product. Any ways to improve it any sectors. Are we on the right path	
Customer validation	Do they care about penetration and porrosity specifically (and in what industry)	N/A	Ensuring that we are solving an existing problem and the correct one, along with specifying which industries care about what. Some industries may not have a need to verify penetration but porrosity is crucial to them (or vice-versa). It is also important to find out if there are other quality measurements they have for welding which would be important to incorporate into later prototypes	
	Are customers excited to test the MVP	N/A	For a valid business we need customers to be excited about the product. This shows that it would solve a major pain in their lives	

Figure 22: Validation Tests and Description

IP Assessment

We shall first look at an overview of related IP in the industry. Afterwards, we will discuss our assets and strategy for IP protection.

Related Patents

There are no patents that directly cover what we are producing. Namely, there are no patents from our research that claim the same functional features as those which were presented earlier in the product brief and design requirements. Thus, any related patents we shall present merely provide an aid for us. Here are 3 which stand out:

US20150209887A1 : Voice activated controls to present visual information to the welder when vocally prompted to. This product uses a lot of components that we also use but for a completely different purpose. Moreover, the patent has also been abandoned. This patent will be used as a direct reference to formulate our claims.

US11961417B2 : A process patent that covers a method to provide welding training. This is primarily described through the interface of the user with the actual weld machine and covers “weld simulations” as defined. This patent mainly focuses on protecting the process of teaching welding by way of simulating the resulting weld based on a series of user input parameters, thus it does not pose any restrictions to us as we shall discuss shortly. We can also use this patent as a reference to formulate claims for a process patent.

CN107567369B : Like the first related patent provided, this product is a “vision enhancement” system that is voice controlled. Once again, it uses similar components but for a different function. It does not constrain us in any way since the novelty of our product relies heavily on its purpose and function.

Operation Freedom & Patentability

Based on the descriptions of the patents related to the project, we can comfortably say that we are able to deploy the product without hinderance. It is noteworthy to mention that the function of this product is somewhat similar to that of a control system used in robotic welding machines. However, given that this product is aimed at a human user who shall operate it, we are once again in a completely different context of applications and so can reasonably assume that we are not hindered by any patents covering robotic welding inventions.

We plan to protect our IP assets. Within the classes of patents, our first asset consists of a utility patent concerning the process of executing functions of the final product. Namely, one of the main functions is to identify the quality of weld based on sensory input data. The manner in which this function is executed dictates a process which will be protected by the utility patent asset. The second IP asset would be a design patent that protects physical design features of the product; this includes and is not limited to the design form factor, instrumentation design, deployment mechanism, etc. Collected data of welding samples shall be protected under Common Law. Meaning, private storage of data using a cloud service protects against theft. The use of the specific type of data, say for example a .jpg file, to interface with a component outlined by one of the independent claims in the design patent to achieve a given process in the utility patent will be listed as a dependent claim thereby also protecting the data gathered to produce the product.

Economic Implications

Of course, to actually receive these patents, we have to spend a considerable amount. Let's say we are going to file these patents here in Canada to simplify things. There are 4 main programs available for start-ups in Canada to acquire IP protection:

1. AccelerateIP
2. ElevateIP
3. NRC IRAP IP Assist
4. CanExport SMEs

We have opted for AccelerateIP since the process seems the most straight forward. Using ChatGPT's deep search feature, in Canada the average costs of filing and receiving a patent are as follows:

	Utility Patent	Design Patent
Filing	$1000- $3000	$500
Examination Request (Extra)	$500- $1000	$500- $1000
Drafting & Legal Fees	$7000- $15000+	$1000- $3000

As a conservative estimate, we are looking at a total cost of at least $30,000. Looking at the process offered by Accelerate IP, there are 3 streams. We would first go into stream 1 where they provide foundational IP training through online modules and certification programs. Towards the end of the Summer of 2025, we will have a more developed product and can enter stream 2 which covers up to $25,000 for activities like IP audits, strategy development, and legal analyses. Stream 3 looks at implementation which provides up to $60,000 for IP registration, including patent and trademark applications, and associated legal fees. We aim to have gone through stream 2 by the end of 2025 as outlined in our product roadmap in previous submissions for the class. Moreover, the financial model will be adjusted to reflect details as we discover them in the patenting process.

Appendix

Appendix A: Microphone Mount Engineering Drawings

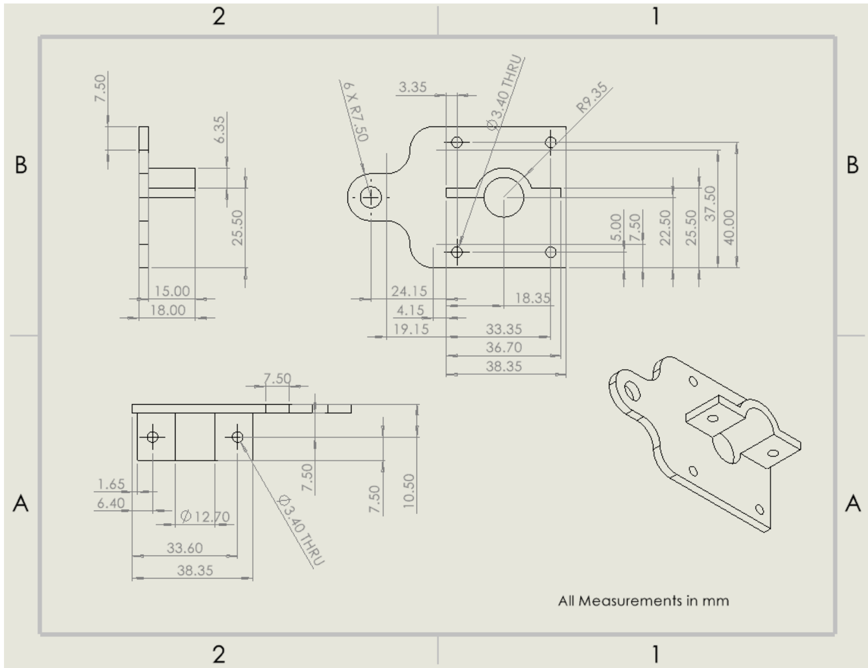

Figure 23: Engineering Drawing for Microphone main body mount

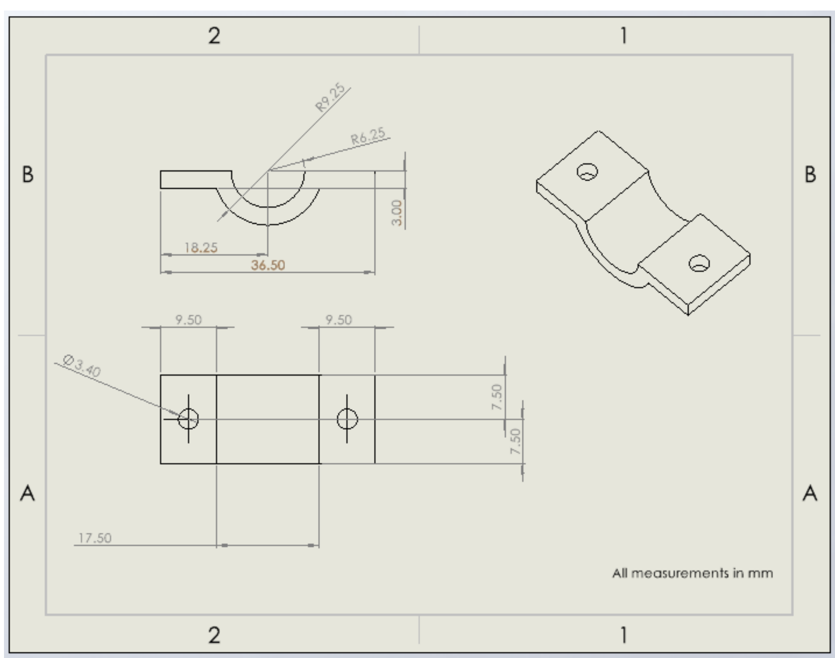

Figure 24: Engineering Drawing for Lower Microphone Mount

Appendix B: Microcontroller Mount Engineering Drawings

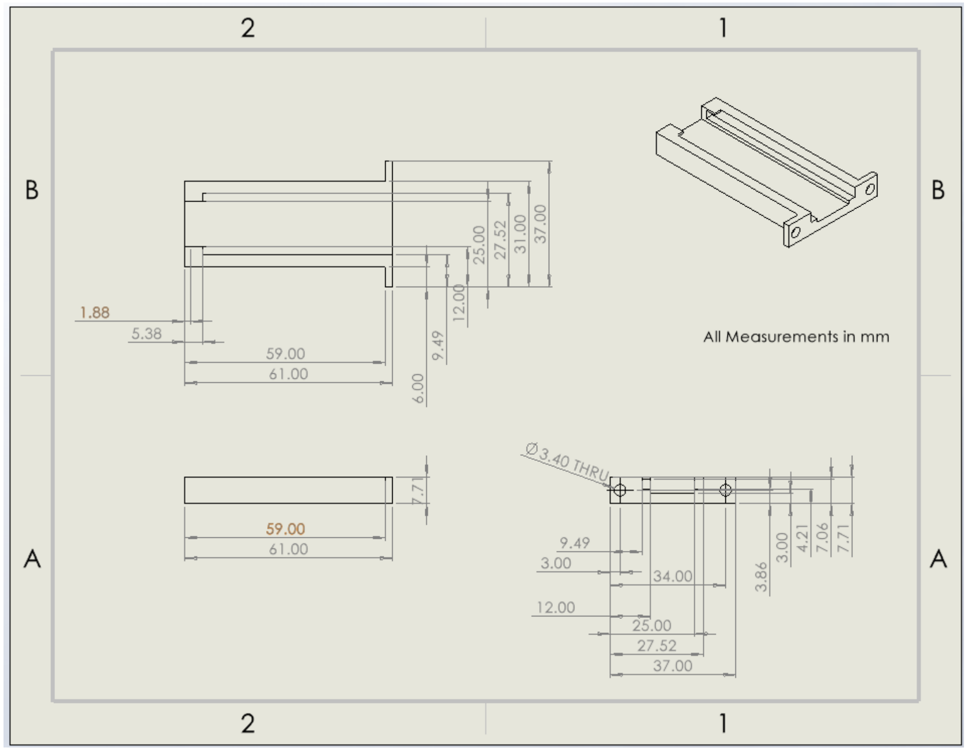

Figure 25: Microcontroller mount body engineering drawing

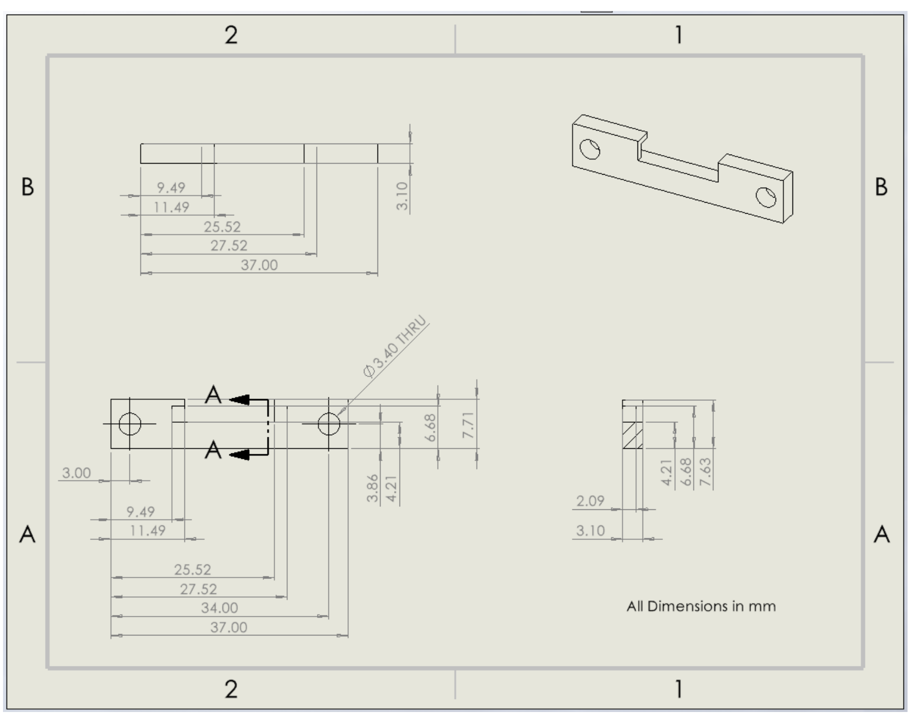

Figure 26: Microcontroller mount lid engineering drawing

Appendix C: Circuitry base Plate Engineering Drawing

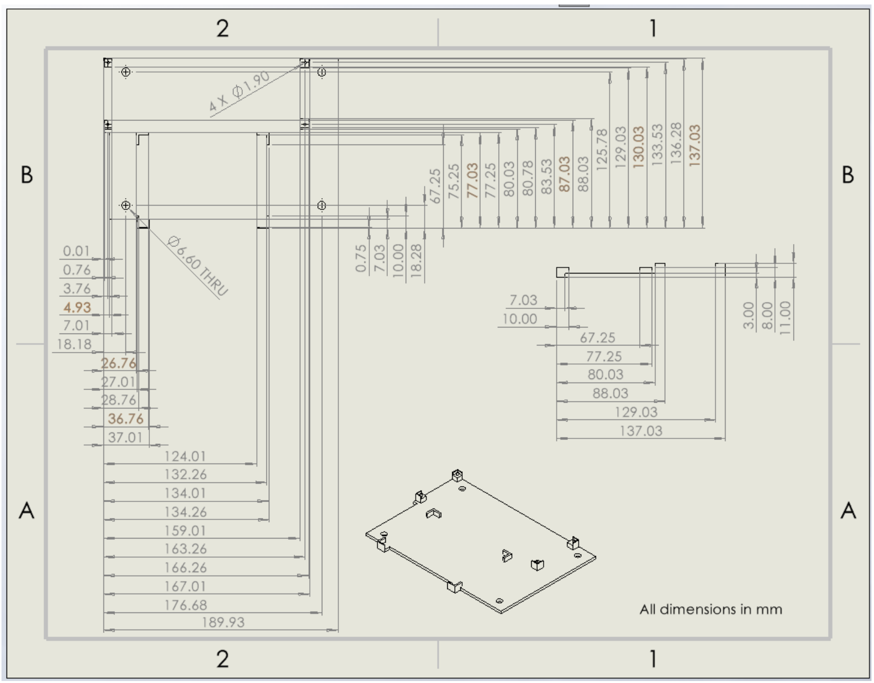

Figure 27: Circuit Base Plate Engineering drawing

Appendix D: Further Verification Information

Verification by unit breakdown

Microphone Amplifier Circuit

Rationale: Ensuring clear, interference-free acoustic signals is essential for precise defect detection. Accurate signal acquisition directly influences ML model performance.

Methods: The amplifier circuit was tested using a function generator and oscilloscope to assess frequency response over the required range (50Hz-10kHz). Additionally, EMI shielding effectiveness was assessed by exposing the system to simulated electromagnetic interference conditions typical in welding environments.

Results: The amplifier circuit exhibited a stable and flat frequency response across the required range. EMI shielding effectively blocked external interference, resulting in a clean output signal.

Acoustic Sensor Accuracy

Rationale: Accurate acoustic measurements are crucial for detecting weld defects, which present unique acoustic signatures within the specified frequency range.

Methods: The PCB Piezotronics 1030D20 microphone was rigorously tested using audio signals of known frequencies within 0.6 kHz - 15 kHz.

Results: The microphone consistently captured accurate and precise acoustic signals within the desired frequency range. Signal precision and reliability were confirmed across multiple trials.

ADC and FFT Analysis

Rationale: High-quality analog-to-digital conversion (ADC) and reliable frequency analysis (FFT) underpin effective signal processing, directly impacting the reliability of defect detection.

Methods: FFT analyses were conducted on audio data of controlled welding trials (both defective and non-defective) to assess ADC clarity and FFT reliability.

Results: The ADC captured audio clearly with some additional noise, notably a 60Hz base frequency that we had to filter out using the software. FFT analyses reliably distinguished between normal and defective weld signals, clearly identifying relevant frequency peaks associated with defects.

Voltage Protection

Rationale: Protecting electronics from voltage spikes is critical for maintaining the longevity and operational reliability of the system.

Methods: Tested using waveform generators and oscilloscope monitoring, incrementally increasing input voltages to evaluate circuit resilience.

Results: The protection circuitry consistently maintained the input voltage below the threshold (30 mV peak-to-peak), successfully safeguarding the components.

EMI Protection and Component Verification

Rationale: Electronic components must function accurately in environments with electromagnetic interference typical of welding environments.

Methods: EMI shielding tested through controlled environmental exposure; electronic components (resistors, capacitors) tested using multimeters to confirm adherence to specified values.

Results: Shielding was highly effective against EMI. All measured resistors and capacitors were within specified tolerances.

Data Handling and Storage

Rationale: Correctly formatted and reliably stored data are fundamental for subsequent analysis and ML training.

Methods: Captured acoustic data verified to ensure correct RAW file recording, followed by conversion to accessible WAV formats on laptops.

Results: Audio data was consistently recorded in RAW format and reliably converted into WAV files accessible for further analysis.