Ahead Wind Final Design Review

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Agenda

- Project Overview
- Key Requirements
- System Overview
  - Printer & Sensors
  - Electronics
  - Code
  - Cloud
- Fabrication
- Verification
- Risk Analysis
- Schedule
- Milestones
- Budget

Project Overview

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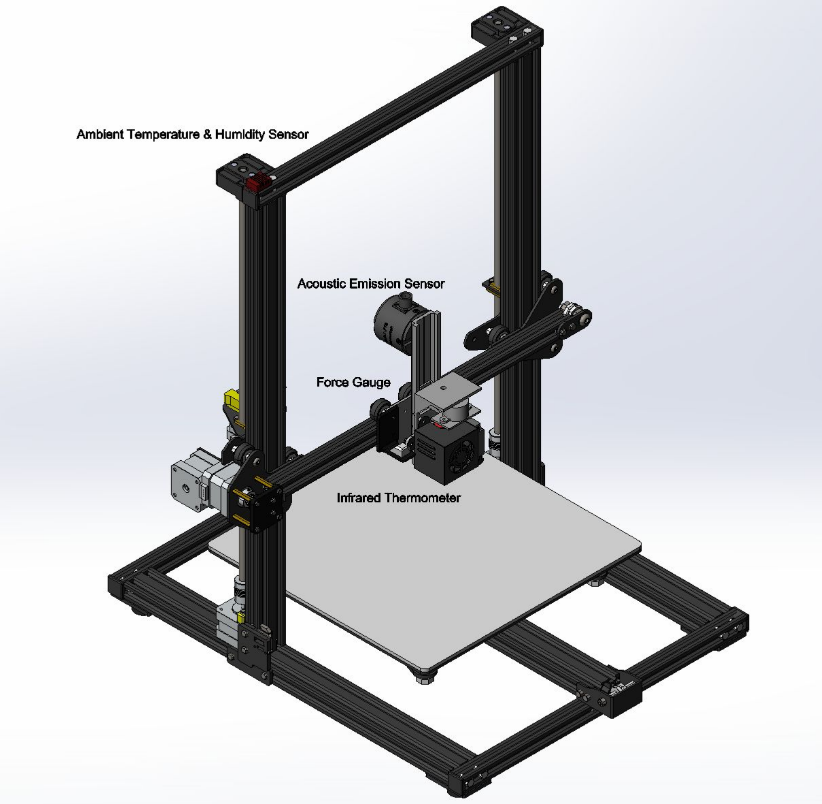
https://www.filabot.com/blogs/news/where-failed-3d-prints-go-to-die-and-what-you-can-do-about-it

- The Fused Deposition Modeling (FDM) industry is highly prone to unreliable, inconsistent printing outputs.
- Failure examples include:
  - Layer separation.
  - Inconsistent heating of filament.
  - Inconsistent extrusion.
- FDM's is currently used for prototyping, NOT industrial production
- Objective of our project:
  - Detect, mitigate, and counteract these failure modes.
  - Minimize downtime, produce more reliable and consistent parts, increase efficiency in FDM industry.

Our Project



1. "Smarter" handling of existing sensor data
2. Adding extra sensors
3. Data analysis

Key Requirements

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1. The system shall be able to print objects of at least 300mm x 300mm x 300mm.
2. The printer shall be a filament-fed extrusion system.
3. The system should be capable of printing materials with melt temperatures less than 300° C such as PC, PETG, ABS, and NYLON.
4. The system shall take in sensor data and process the data to be sent to a database(s).
5. The system shall produce a report post-print that details print metrics and failures and contains time-series graphs.
6. The system shall have a function to allow the user to report/archive errors when they occur.

→

1. Print objects of average size for a small 3D printer.
2. Use filament (tube) based plastic.
3. Print with plastics that have melting temperatures less than 300° C.
4. Receive sensor readings and save values in a database.
5. Sensor readings will be easy to analyze using graphs.
6. The user will be able to archive print failures for later analysis.

Traceability Matrix

Subsystem	Applicable Requirements
Printer	Requirements Section 3.1.0-3.1.4
Spool	3.1.1 (Filament fed extrusion)
Extrusion Hot-End	3.1.1 (Filament fed extrusion), 3.1.2 (Capable of printing multiple plastic types)
Bed	3.1.0 (Print 500mm x 500mm x 500mm objects), 3.1.1 (Filament fed extrusion)
Motors	3.1.0 (Print 500mm x 500mm x 500mm objects), 3.1.1 (Filament fed extrusion)
Structural Support	3.1.0 (Print 500mm x 500mm x 500mm objects)
Sensors	Requirements Section 3.1.5-3.1.10
Temperature Sensor	3.3.4 (Temperature thresholds), 3.1.5 (Environment Temperature Sensing)
Wind Speed Sensor	3.1.6 (Environment Wind Speed Sensor), 3.3.7 (Windspeed thresholds)
Humidity Sensor	3.1.7 (Envirnment Humidity Sensor), 3.3.4 (Humidity thresholds), 3.1.13 (Humidity of filament location)
Thermistor	3.1.8 (Nozzle Temperature), 3.3.6 (Hot End thresholds)
Force Sensor	3.1.10 (Real Volumetric Output), 3.3.1 (Volumetric output threshold), 3.2.0 (Nozzle Pressure), 3.1.13 (Torque of extruder)
Encoder	3.1.10 (Real Volumetric Output), 3.3.1 (Volumetric output threshold), 3.1.9 (Computation of volumetric extrusion output).
Control	Requirements Section 3.2.0-3.2.4
Database	3.1.11 (Indexing falure drift between prints), 3.2.1 (Sensor system will interact with databse), 3.2.4 (Identification of failures during print), 3.3.0 (Post print graphs), 3.3.13 (Indexing print layer diognostics), 3.3.12 (Indexing data based on layer).
User Interface	3.3.11 (User artifact data), 3.3.10 (User reporting), 3.3.9 (Entering of print parameters), 3.3.0 (Time Series Graphs)
Processing/Software	3.2.3 (Updating print parameters), 3.2.5 (Stop print before error), 3.3.0 (Post processing for graphs), 3.3.1-3.3.8 (Failure threshold identification), 3.3.11 (Control of system in the future), 3.1.3 (90% Uptime), 3.1.4 (Success rate of 90%), 3.3.12 (Indexing data based on layer).
Control Board	3.2.3 (Updating print parameters), 3.1.0 (Print objects)
Data Analysis	Requirements Section 3.3.0-3.3.8
Graphs	3.3.0 (Failure and diognostic graphs)
Failure Reporting	3.3.0 (Failure and diognostic graphs), 3.1.11 (Failure Metric Drift), 3.2.5 (Failure Detection), 3.3.10 (User reporting)
Data Artifacts	3.1.11 (Failure Metric Drift), 3.2.5 (Failure Detection), 3.3.10 (User reporting), 3.3.11 (User artifact data)
Post-Processing	3.3.0 (Post processing for graphs), 3.3.1-3.3.8 (Failure threshold identification), 3.3.11 (Control of system in the future).
Power System	3.1.0 (Print 500mm x 500mm x 500mm objects), 3.1.1 (Filament fed extrusion), 3.1.5-3.1.10 (Sensor Suite), 3.2.2 (Control Board)
User Interface	Requrements Section 3.3.9-3.3.10

Traceability Matrix

System Overview

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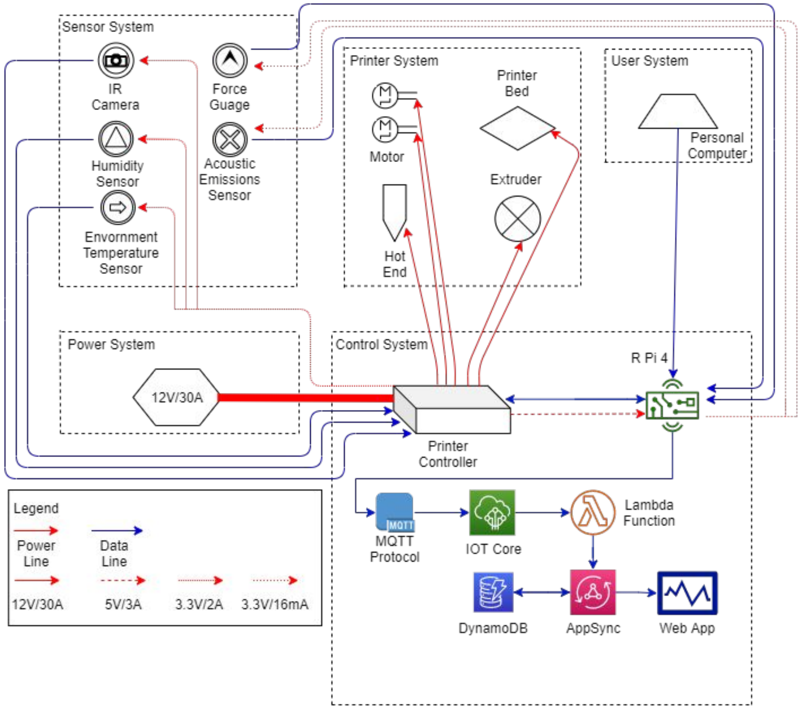
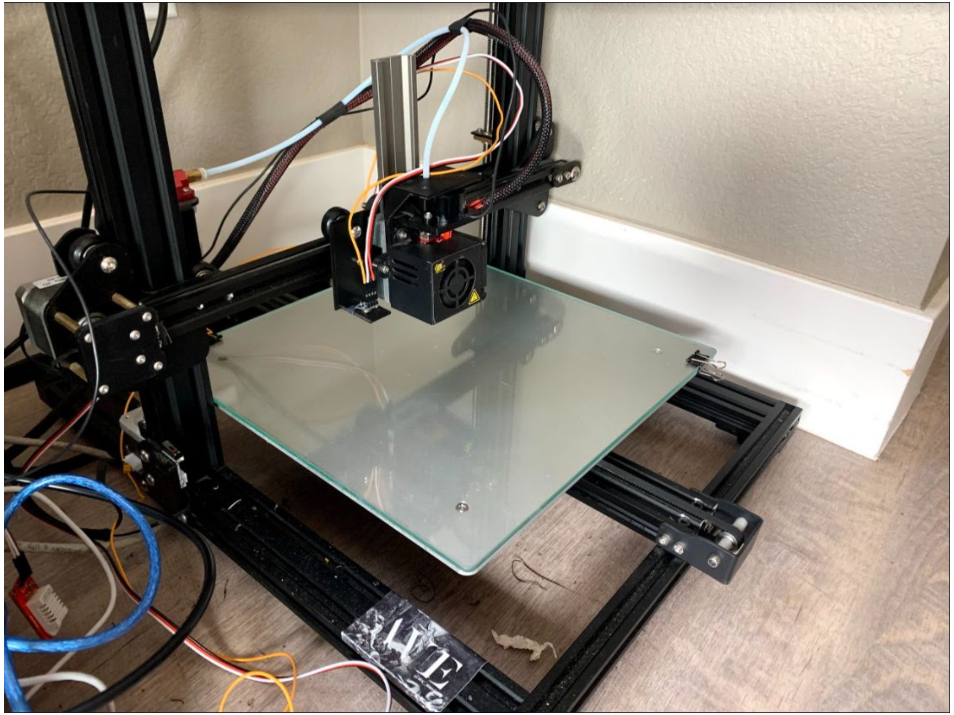
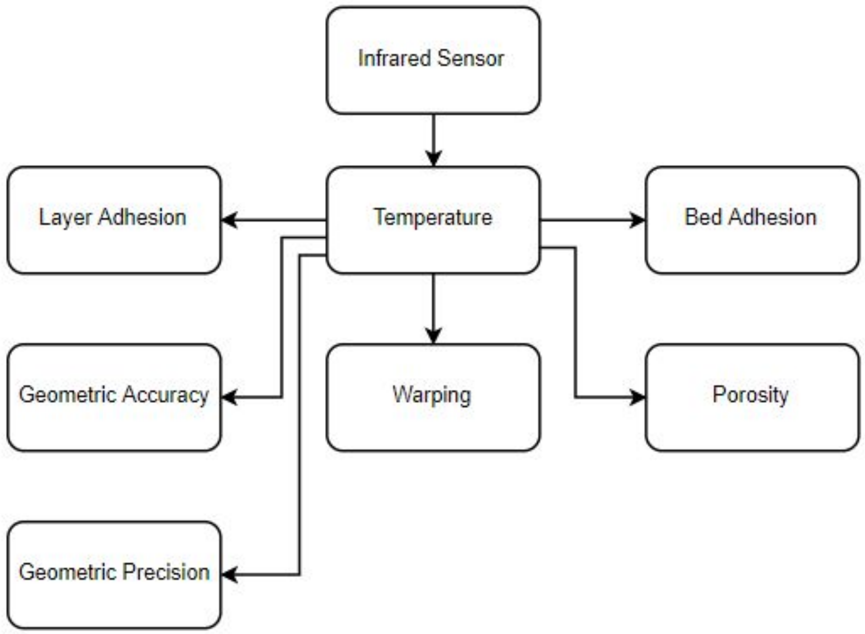
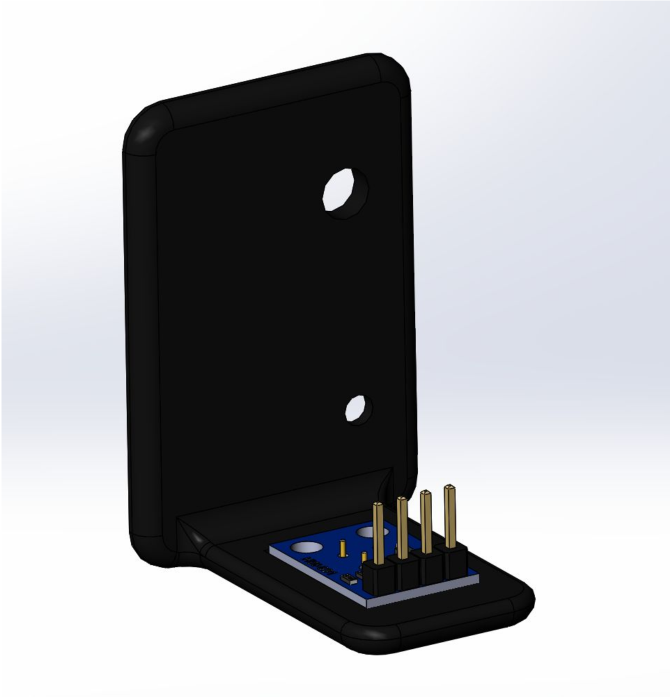


System Diagram

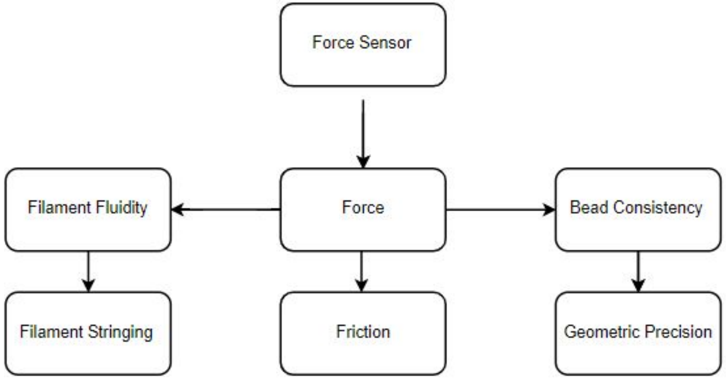


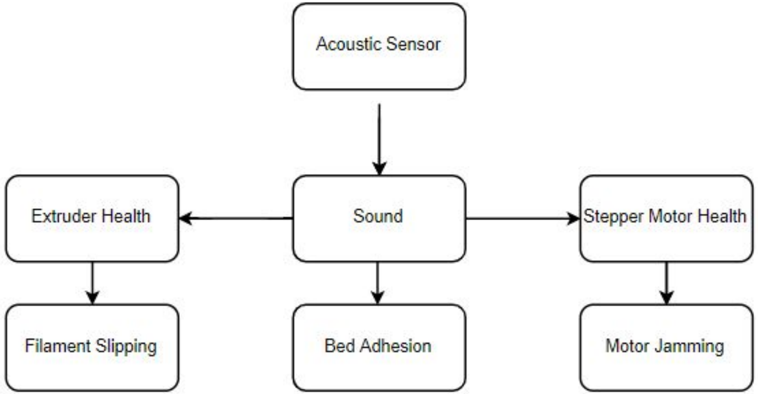
Sensor Insights Matrix





Sensor Insights Matrix





Correlation vs Causation

Infrared Sensor:

Temperature Causation

- Layer Adhesion
- Bed Adhesion
- Porosity
- Warping

Temperature Correlation

- Geometric Precision
- Geometric Accuracy

Force Gauge Sensor:

Force Gauge Causation

- Filament Fluidity

Force Gauge Correlation

- Geometric Precision
- Geometric Accuracy
- Bead Consistency
- Filament Stringing
- Friction

Acoustic Sensor:

Acoustic Sensor Causation

- NA

Acoustic Sensor Correlation

- Extruder Health
- Filament Slipping
- Bed Adhesion
- Motor Jam
- Stepper Motor Health

Implementing a Force Gauge

Purpose:

Understand nozzle back-pressure as it relates to volumetric output, nozzle size, nozzle temperature, and material.

Requirements:

1. Isolate hot end motion to Z-axis.
2. Decouple the Bowden tubing from the hot end
3. Utilize existing mount patterns on printer

Electronics

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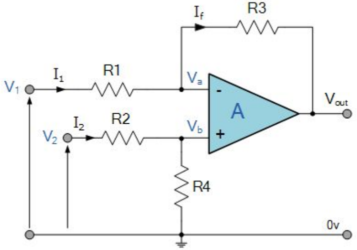
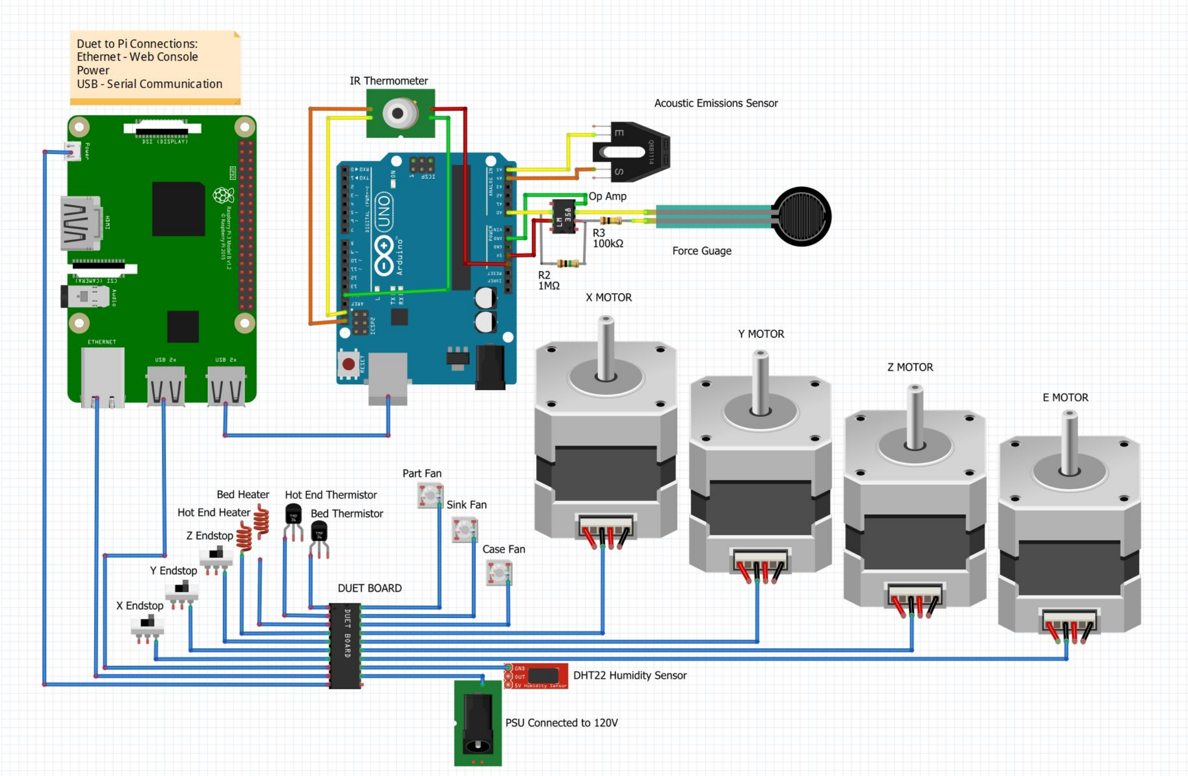
Differential Amplifier



$$V_{OUT} = \frac{R_3}{R_1}(V_2 - V_1)$$

Arduino Added!

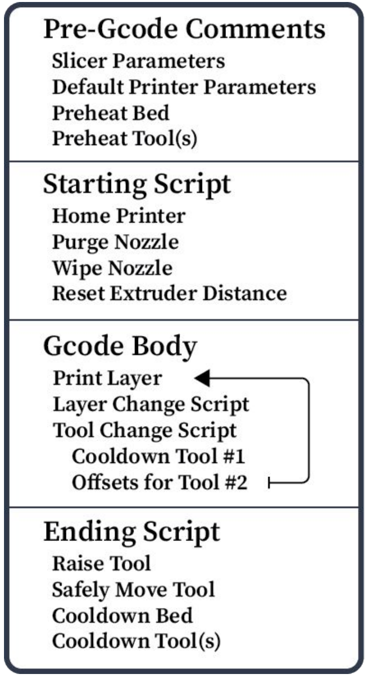
1. RTOS better for reading sensors at regular intervals
   a. Thinking ahead to the AE sensor



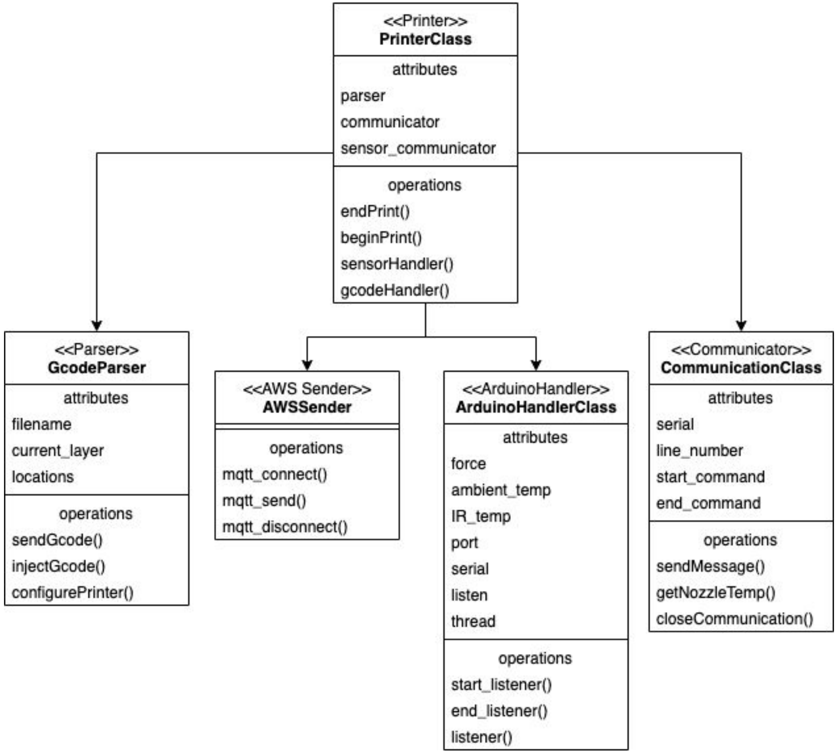
G-code Parser Class

- Reads print parameters
- Generates G-code for any desired commands
  - Ask Duet for temperature
  - Move printer to appropriate location for IR readings
- Determines when G-code should be injected, based on active print process
  - In between layers
  - In between line segments

Gcode Anatomy



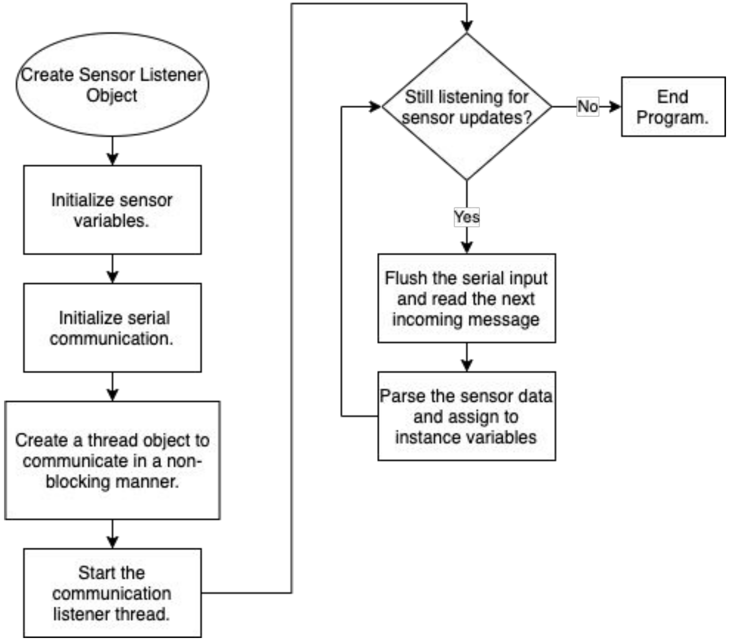
Raspberry Pi



Program UML Diagram

- Printer Class
  - Orchestrates all operations on the Raspberry Pi
- GcodeParser
  - Initialized with a filename.
  - Helps the printer class parse a GCODE file to send commands to the DUET and configure the print.
- AWSSender
  - Sends data to the cloud database.
- ArduinoHandlerClass
  - Handles communication between the Raspberry Pi and the Arduino
- CommunicationClass
  - Handles communication between the Raspberry Pi and the DUET.

Raspberry Pi



Data Collection Thread Flowchart

```
Message from arduino:
Force 0.41
IR_Ambient 18.11
IR_Object 16.91
Message from arduino:
n 65
Force 0.41
IR_Ambient 18.07
IR_Object 17.01
Pi iteration: 7
```

Key Requirements:

- The system <u>shall</u> take in sensor data and process the data to be sent to a database(s).

Raspberry Pi

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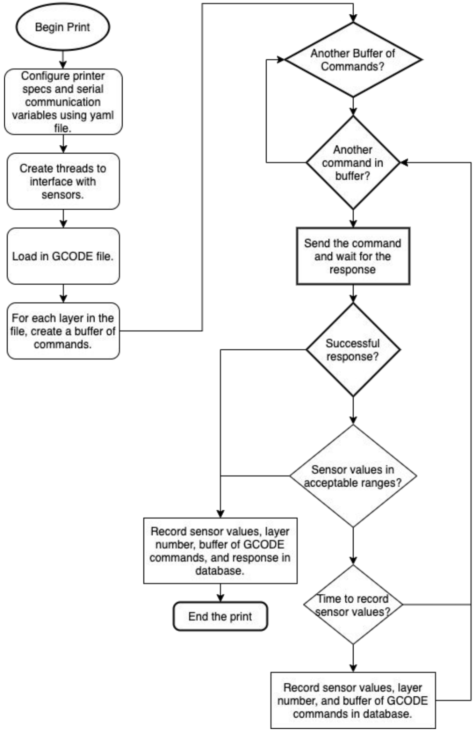

Program Flowchart

Key Requirements:

- The system shall be able to print objects of at least 300mm x 300mm x 300mm.
- The system should update the print parameters for the next layer to correct for errors of the current layer before the current layer is finished.
- The system should identify failures that cannot be corrected by updated print parameters and pause the print before those failures occur.

Arduino

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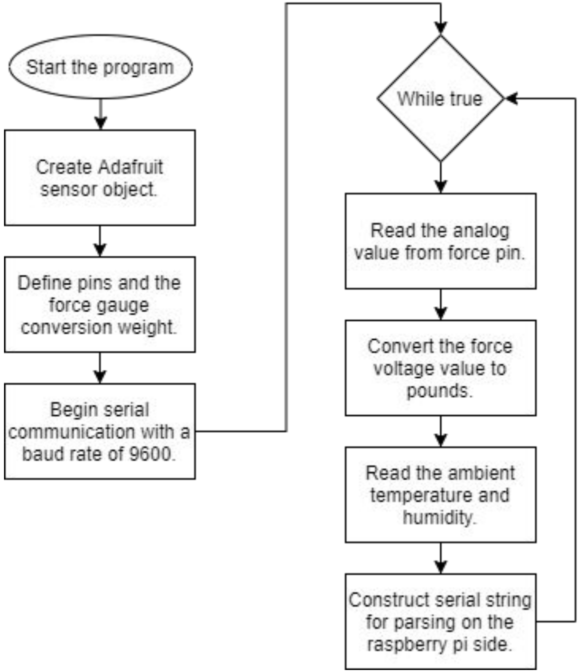
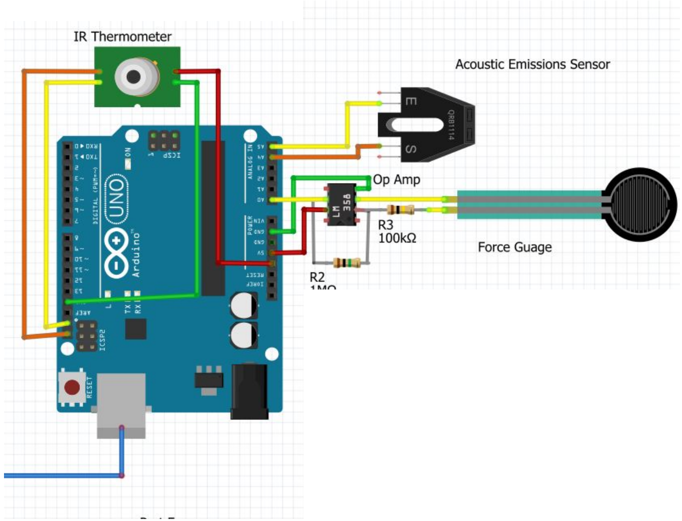


Data Collection Flowchart

Key Requirements:

- The system shall take in sensor data and process the data to be sent to a database(s)



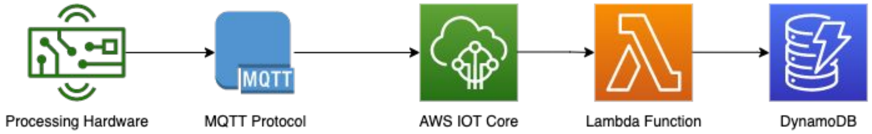
Cloud

Design Criteria		Alernatives			
Description	Criteria	DynamoDB	Redshift	Timestream	Local
Reliability	99%, Duplication enabled.	High availability zones and duplication offered.	High availability zones and duplication offered.	High availability zones and duplication offered.	Can be designed to have duplication and high reliability.
Cost	Free Tier.	Could fit into free tier, otherwise would cost on the scale of tens of dollars per month.	Dedicated redshift options are not financially viable	Does not fit into Free Tier for application. Would cost on the scale of tens of dollars per month.	Hardware Costs
Portability	Ability to port the data and infrastructure to another provider.	Can produce a CSV of the data to transfer to another service.	Able to port to other service providers infrastructure	Can produce a CSV of the data to transfer to another service.	Roll out on various hardware types, operating systems
Type	Meets the payload specifications.	NoSQL. Not the ideal solution to this problem, but could work.	SQL	SQL	Anything
Matenience	Low server management and engineering cost.	Services automatically expand based on current need.	Services automatically expand based on current need.	Services automatically expand based on current need.	Need to worry about operating system updates, security maintenience, storage size
Useability	The data is accessable by the whole team.	Can query data from anywhere with network access.	Can query data from anywhere with network access.	Can query data from anywhere with network access.	CSV data can be stored on the cloud
Risk	Low level of risk involved financially while using the service.	Can easily run up costs with a rogue program or miscalculation of time scaling for writes as the system will upgrade itself to meet our needs.	Can easily run up costs with a rogue program or miscalculation of time scaling for writes as the system will upgrade itself to meet our needs.	Can easily run up costs with a rogue program or miscalculation of time scaling for writes as the system will upgrade itself to meet our needs.	Managing whole stack, HW, security, data storage redundancy

Database Decision Matrix

- Amazon Web Services was deemed to be the best cloud service provider due to available funding.
- Of the four options, we have the option to fit into the free tier for DynamoDB.
- The other options would cost anywhere between $10 and $100 per month or have high upfront hardware costs.
- DynamoDB is also NoSQL which is an ideal database for a project with unknown structure.

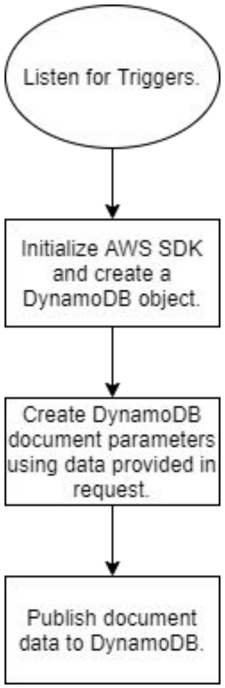
Cloud



Current Design

- AWS IOT core subscribes to messages sent from the Raspberry Pi using MQTT protocol.
- AWS IOT core then triggers a Lambda function that can be used for cloud processing.
- The Lambda function then uses the DynamoDB SDK to publish the processed data to the NoSQL database.
- In the future, we will have a web-platform subscribe to the data published to the DynamoDB database for real time analysis.

Cloud



Lambda Function Flowchart

- AWS Lambda Functions are a cloud computing tool that can be used to offload processing functions.
- Utilizes HTTP requests to trigger and transfer data to functions.
- The function can be written in python, Ruby, and Node.js (Javascript).
- Javascript was utilized for this project due to previous experience writing Lambda functions that utilize the AWS SDK in the language.

Key Requirements:

1. The system shall take in sensor data and process the data to be sent to a database(s).
2. The system shall produce a report post-print that details print metrics and failures and contains time-series graphs.
3. The system shall have a function to allow the user to report/archive errors when they occur.

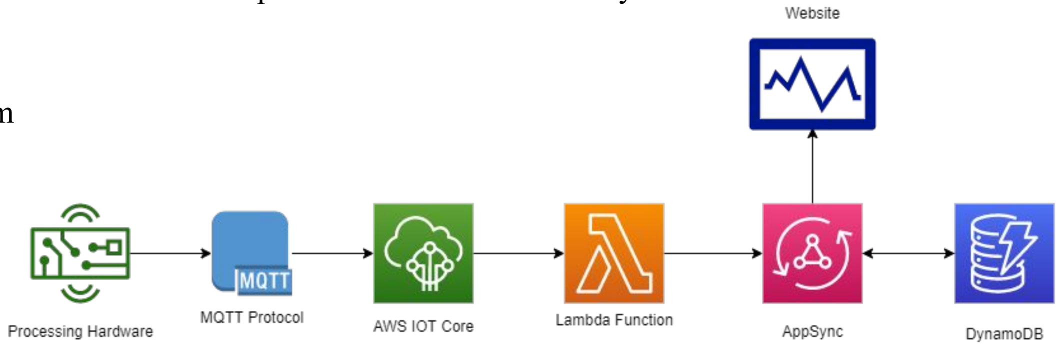
Cloud

Web Application:

- The web application will be built using the React Node Framework.
- It will utilize AWS AppSync in order to receive real time updates when data is modified or added to our DynamoDB database.
- The Lambda function will need to be refactored to use AWS AppSync mutations to publish data to DynamoDB.
- This subsystem will be completed over spring break so that we can begin analyzing and testing the system in the spring.

Key Requirements:

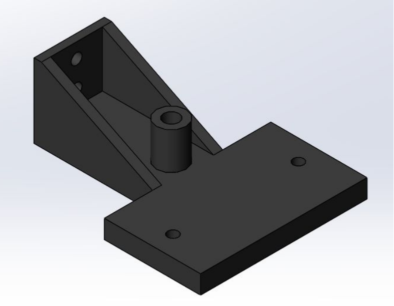
1. The system <u>shall</u> produce a report post-print that details print metrics and failures and contains time-series graphs.
2. The system <u>shall</u> have a function to allow the user to report/archive errors when they occur.

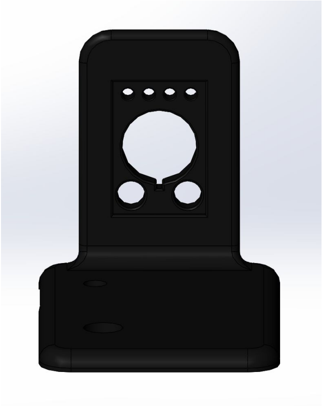


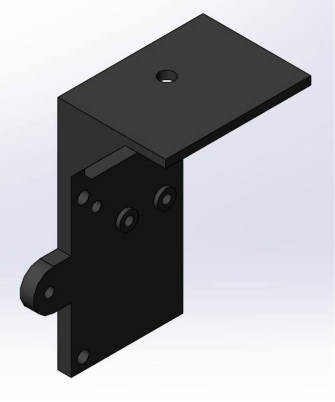
Proposed Web Application Design

Fabrication Update

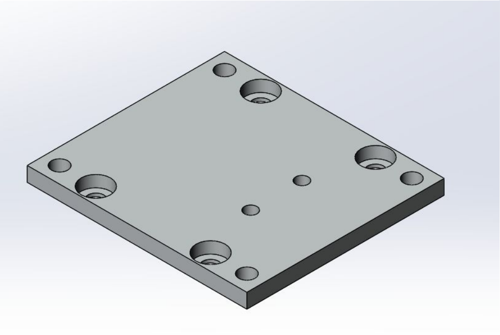
Printing

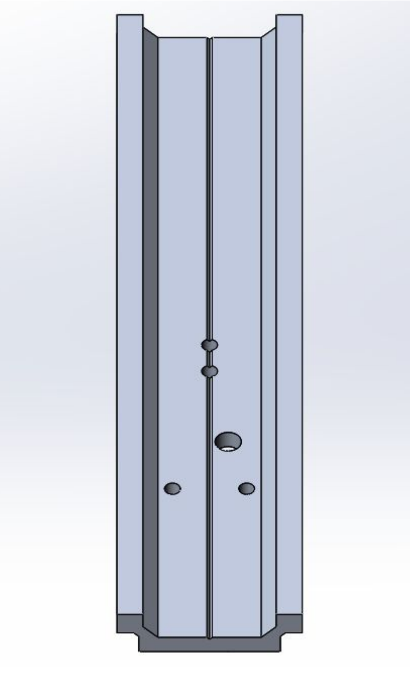




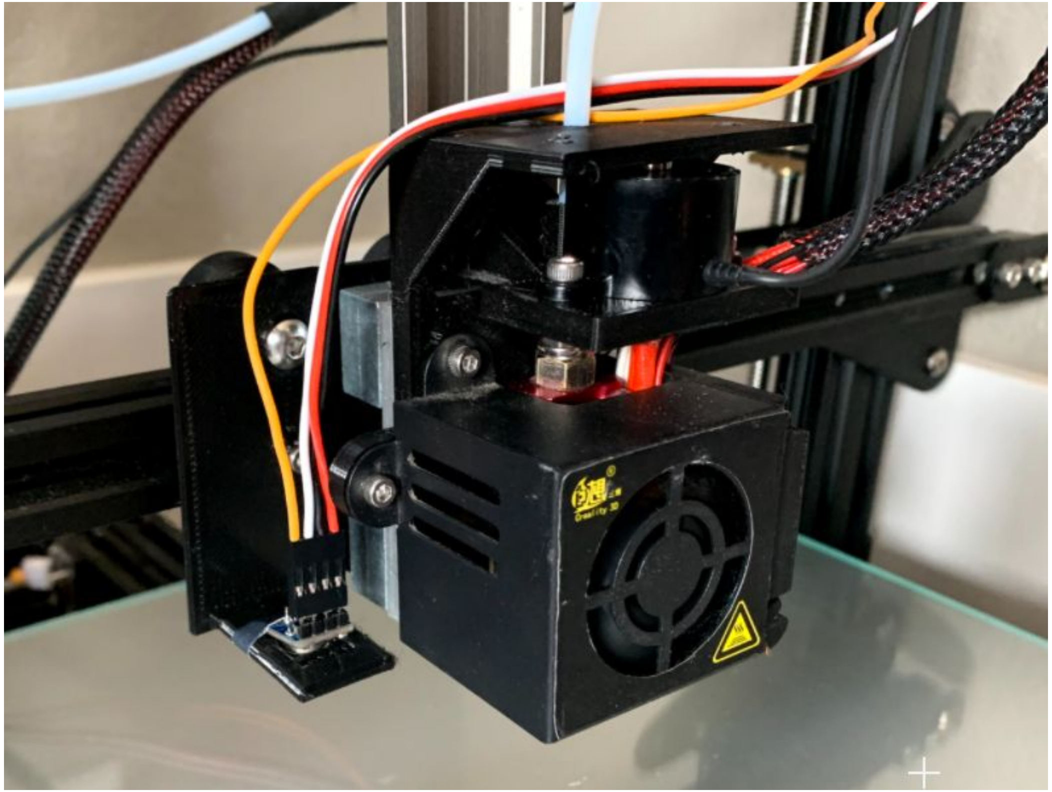


Machining



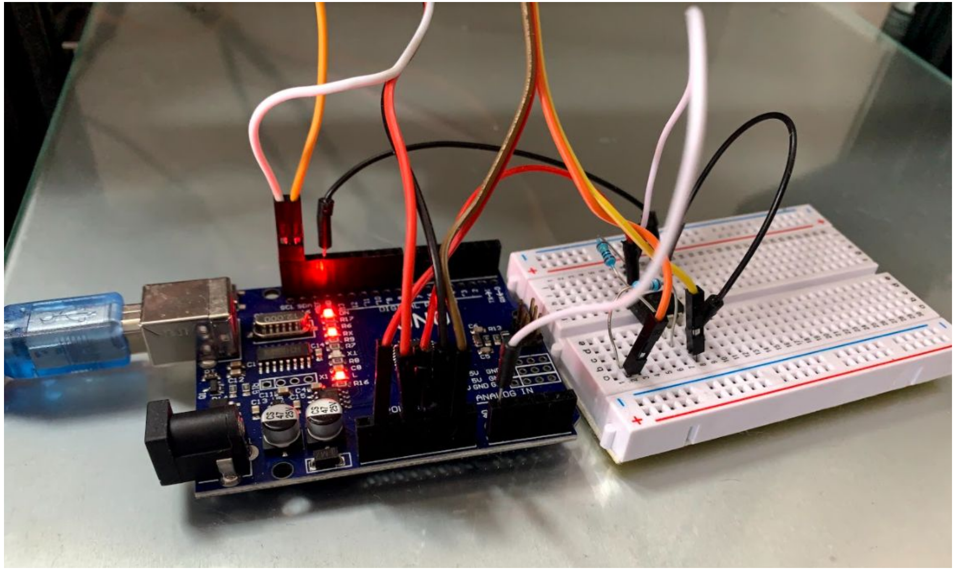


Finished Fabrication



Planned Fabrication Changes

1. Update electronics
    a. Use a protoboard to create a “shield” for the arduino
2. Update CAD and reprint parts
    a. Access holes in “hanger” for easier assembly
    b. Fix clearance issue in “force gauge mount”
3. Design and print bowden tubing guide to go above hanger.
4. Mount Rpi & Arduino to a board that sits on the printer’s case



Verification

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Requirement		Inspection	Demonstration	Test	Analysis
3.1 Structural	3.1.0 Size	x			
	3.1.1 Filament Driven	x			
	3.1.2 Plastic Melt Temperature			x	
	3.1.3 Success Rate		x		
	3.1.4 Filament Protection	x			
	3.1.5 Environment Temperature			x	
	3.1.6 Environment Humidity			x	
	3.1.7 Layer Temperature			x	
	3.1.8 Theoretical Extrusion Volume			x	
	3.1.9 Actual Extrusion Volume			x	
	3.1.10 Metric Drift	x			
	3.1.11 Filament Humidity			x	
	3.1.12 Nozzle Backpressure			x	

Verification Table Preview

- Each requirement has been mapped to a testing framework.
- Inspection: Nondestructive examination of the product using visual, tactile, or other senses.
- Demonstration: Observation and recording of the system’s functional operation without the use if testing equipment or data.
- Test: Operation of a subsystem under controlled conditions to determine that quantitative requirements have been met.
- Analysis: Verification of the system using models, calculations, or simulations

Verification

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2.1 Force Gauge Validation

2.1.1 Introduction

The force gauge on the printer nozzle will be tested and calibrated in order to confirm that it is working effectively.

2.1.2 Procedure

A one pound weight will be applied to the force gauge and the voltage value will be recorded. Then a five point weight will be applied to the force gauge and the voltage value will be recorded. Using the slope between the two measurements, a scale will be determined. The scale will be programmatically implemented and a ten pound weight will be applied to test the linearity of the measurements.

Verification Snapshot

- Tests will be conducted for each component or subsystem to validate the project meets all relevant requirements.
- Each test will include an introduction, procedure, analysis and conclusion section.
- The tests will be well documented with test setup diagrams and expected results so that tests can be easily reproduced for calibration.

Risk Analysis

	Consequence				
Likelihood	Negligible	Minor	Moderate	Major	Severe
Certain					
Likely		Acoustic Emissions Sensor			
Possible			Inducing Repeated, Controlled Failures	Effective Data Analysis & Visualization	
Unlikely					
Rare					

Acoustic Emissions Sensor & Signal Processing Difficulties

- ➔ Reduce Consequence: Focus on successfully implementing all other sensors and data analysis first.
- ➔ Reduce Likelihood: Isaiah’s experience

Inducing Repeated, Controlled Failures

- ➔ Reduce Consequence: Create documentation about all failure modes - work out to the edge cases

Effective Data Analysis & Visualization

- ➔ Reduce Likelihood: Work closely and iteratively with Jacob
- ➔ Reduce Likelihood: Utilize frameworks and tools familiar to Meier & Thomas

Schedule

WBS NUMBER	TASK TITLE	TASK OWNER	PCT OF TASK COMPLETE
5	Stage 5: Build and Test MVP		
5.1	Printer Class Code	Thomas	70%
5.2	Communicator Class Code	Meier	95%
5.3	Parser Class code	Tim	50%
5.4	physical implementation of sensors	Peter, Tim	100%
5.5	data management system to support sensors	Meier, Thomas	95%
5.6	Sensor Software & calibration	Meier, Tim	90%
5.7	End of Quarter Design Review	All	80%
6	Stage 6: Integration of subsystems		
6.1	Develope a Standardized Test Print	Tim	20%
6.2	Verify Sensor Readings	Tim	10%
6.5	Verify Database	Meier, Thomas	10%
6.6	Verify Communication Class	Meier, Thomas	20%
6.7	run initial tests	Tim	0%
7	Stage 7: Iterative Design and Data Analysis		
7.1	Construct Web Interface	Meier, Tim	0%
7.2	Developing Data Analysis via Prior Research	Peter, Thomas	0%
		Tim	0%
8	Stage 8: Finalize project		
8.1	Prep for Symposium	All	0%

Upcoming Milestones

Planned Activities

- Design unit tests and verify all components. (**Meier, Thomas 4/12/2021**)
- Develop standardized test prints. (**Tim 3/20/2021**)
- Begin creating a web platform that assists in the visualization of data and the inputs for process parameters. (**Meier 4/22/2021**)
- Connect AWS communication program to the printer class. (**Thomas 4/2/2021**)
- Integrate sensor insights logic into quantitative format. (**Peter 3/20/2021)**

Budget Update

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Item	Descirption	Quantity	Price	Link	Purchaser	Total
Insights Discovery	Team Building	2	$ 75.00	https://www.ins	Team	$ 150.00
MLX9016	Infrared thermometer	1	$ 75.00	https://www.am	Team	$ 75.00
SRI 150	Acoustic emission sensor	1	$ 200.00	https://www.alil	Team	$ 200.00
MEAS FC22	Force gauge	1	$ 60.00	https://www.te.	Team	$ 60.00
Filament (PLA)	Material to run test prints with	10	$ 22.00	https://filament	Team	$ 220.00
Raspberry Pi 4 B	Data control board	1	$ 30.00	https://www.ras	Ahead Wind	$ 30.00
Arduino Uno	Sensor control board	1	$ 23.00	https://store.ar	Ahead Wind	$ 23.00
Linear Rail	Mounting the force gauge	1	$ 12.50	https://www.igu	Ahead Wind	$ 12.50
Linear Carriage	Mounting the force gauge	1	$ 36.42	https://www.igu	Ahead Wind	$ 36.42
CR-10S Printer	Printer to test prints with	1	$ 380.00	https://creality3	Ahead Wind	$ 380.00
741CN Op Amp	Provides gain for acoustic emissions sensor	1	$ 0.68	https://www.ti.c	Ahead Wind	$ 0.68
22 Gauge Wire	Wiring sensors	10	$ 0.76	https://www.am	Ahead Wind	$ 7.57
Dupont Wire Connector	Connect sensors to boards	20	$ 0.02	https://www.am	Ahead Wind	$ 0.40
M3 Bolt & Locknuts	Mounting the force gauge	20	$ 0.20	https://www.bo	Ahead Wind	$ 4.00
M4 Bolt & Locknuts	Mounting the force gauge	8	$ 0.25	https://www.bo	Ahead Wind	$ 2.00
M5 Bolt & Locknuts	Mounting the force gauge	4	$ 0.30	https://www.bo	Ahead Wind	$ 1.20
Duet 2 Ethernet Board	Printer control board	1	$ 165.00	https://www.du	Ahead Wind	$ 165.00
Resistors (1M, 100	Op Amp gain configuration	2	$ 0.20	https://www.dig	Ahead Wind	$ 0.40
DHT22 Sensor	Ambient temperature and humidity sensing	1	$ 9.95	https://www.ad	Ahead Wind	$ 9.95

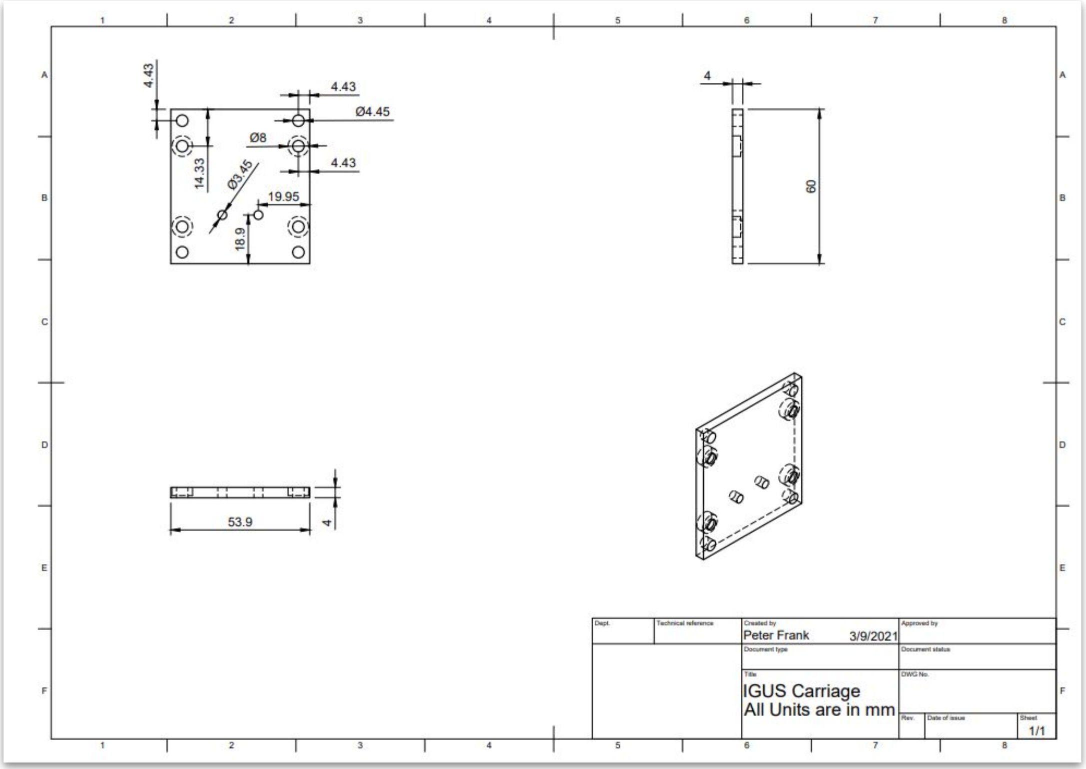
Expenses to date: ~ $485

Planned Purchases: Filament (~ $220)

Estimated Total Cost: ~ $705

Questions?

IGUS Carriage Drawing



IGUS Linear Rail Drawing