Final Design Report

27 March 2024

Revision 1.0

A device for rapidly measuring maize stalk stiffness and strength

Project Sponsors:

BYU Crop Biomechanics Laboratory

Capstone Team 9: R.E.A.P.E.R

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Executive Summary

Introduction

This project will allow scientists and farmers to measure the stiffness of their maize stalk quickly and reliably. Stalk stiffness allows scientists to engineer resilient maize stalks and record data measurements on their stalks to validate their experimentation. It also allows farmers to make data informed decisions about when to harvest crops, an industry that currently faces $4 billion in losses yearly due to stalk lodging (stalks tipping over).

We currently are using the Amiga robot from Farm-ng to test our sensor. However, the goal is to build a sensor package that is independent of the robot used so that companies could mount it to whatever robot or tractor they are currently using in their fields. This document will discuss our solution to this problem and will explain the several different ideas and prototypes we went through to find this solution.

Project Objective Statement

Our team of 6 engineers will design and build an easily transferable measurement device costing less than $2,000 to assess maize stalk stiffness of individual stalks rapidly and accurately, by April 17th, 2024.

Brief description of design:

The Rodney sensor was an improvment from a previous capstone sensor called the ARM (Assessment of Rigidity in Maize). This device used two force load cells to measure the force in plane, and friction as the maize stalk passed the sensor. This sensor was able to collect some data, but had less accuracy and reliability than desired. This lead to the development of Rodney, a novel sensor which used strain gauges and moments to calculate stalk stiffness.

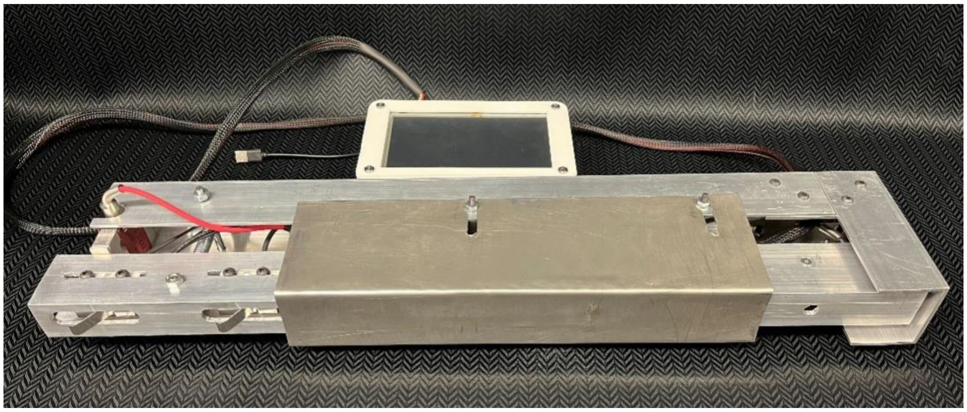


Figure 1: ARM sensor developed by previous capstone team.

The Rodney is a sensor that can be pushed along maize talks to measure the stalks stiffness in a continuous motion. This is accomplished by measuring the strain in the cylindrical rod in two places and two planes, allowing the calculation of both the force with which the stalk presses on the rod and the amount the rod has deflected the stalk. The full derivation for this process will be shown later in this package in the Prototype Testing and Results.

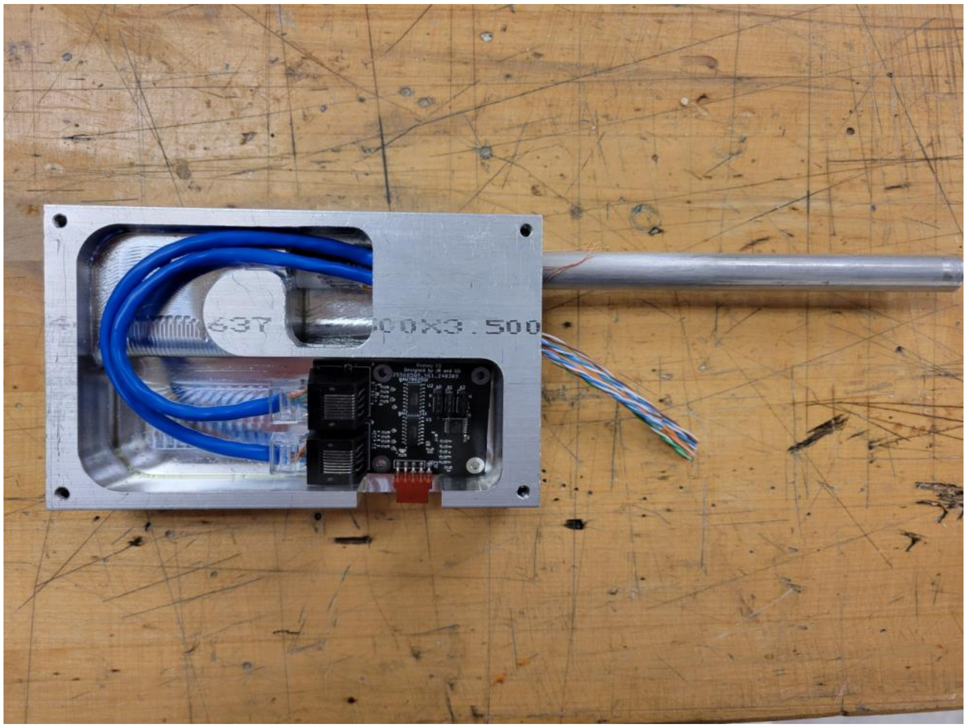


Figure 2: The Rodney prototype with PCB

Figure 1 shows how Rodney could be attached to a robotic system. In our setup we wire half-bride Wheatstone bridges to amplifiers and feed those signals to our microcontroller. These signals are then exported to a csv file where the data is processed and analyzed. There will be some improvements added to this electrical system that will be discussed later in this paper including a touch screen graphical interface.

There are three base subsystems for the project. 1) A mechanical system which includes the mechanical arm and guarding. 2) The electrical system includes the strain gauges, wiring and PCB design. 3) The software system, which is focused on processing the electrical signals, building a graphical user interface, and exporting the data in user friendly formats.

Summary of Final Performance:

Rodney was able to perform well on all of our most imprtant performance measurments.

Table 1. Summary of Performance Measures

Measure	Stretch	Excellent	Good	Lower	Requirement Met?
Accuracy of Flexural Stiffness	3% error	5% error	7% error	15% error	Lower-Good
Repeatabliity Error	3% error	5% error	7% error	15% error	Excellent-Good
Rate of Measurement	120 stalks/ min	90 salks/min	60 stalks/min	30 stalks/min	Stretch

Our device is capable of measuring the strain coming off of the Rodeny device. With this data and some post processing, we can measure the stiffness of the maize stalks. The use of multiple strain gauges has provided us with an accurate system. Additionally, our system is able to get reiliable readings at a rate of 2 stalk/second. This is a significant improvment from the previous design.

Additionally we are able to get both force in both directions and distance data from the measurement device. This gives us more rich data, which we can use to get more accurate results.

Conclusion and recommendations:

The Rodney device accomplishes what the sponsor has asked. It can reliably measure data and save it for future processing. It is somewhat lacking in professionalism and a finalized package. Quality of life features such as waterproofing are not as robust as one would desire. However, it achieves its purposes.

There are some features on the Rodney device that with some more time could create significant improvments. First, Rodney currently uses the simplified beam bending equations to solve for flexural stiffness. With our sensor we have the ability to use more advanced equations taught in the field of compliant mechanisms. This would give us more control over assumptions that are made in the simplified beam bending equations. Another recomendation would be to get better power regulation. Currently the system powers the raspberry pi which in turn powers the rest of the system. The raspberry pi is not known for consitancy in the power regulation. When using precision sensors, these fluxuations could be some of the source of error in the system. We would reccomend reworking the power system so that both pi and sensor system are powered by a more regulated voltage source.

Overall there were many improvments on the system and it does its job accuratly. However, more accuracy is always appreciated, and the more accurate our system can be, the more we are able to deal with the inconsistancies which are inherent in the agricultureal field.

Artifact ID: WVD-1	Artifact Title: Written and Visual Description
Revision: 01	Revision Date: 03 MAR 2024
Prepared by: Gustavo Oliveira	Checked by: Ryan Hall
Purpose: Uses both words and images to clearly describe the design. Defines the principal components and subsystems.	

Revision History			
Revision	Revised by	Checked by	Date
01	Caleb Price	Landon Beutler	25 MAR 2024

Rodney Subsystem:

Rodney is a corn stalk stiffness measurement device that is made up of four subsystems. We have defined them as Rodney, Whiskers, PCB, Software. The Rodney subsystem is the casing and rod that will be deflected to produce our strain gauge values. We can see in Figure 1 the casing with the rod connected that will also contain the PCB responsible for converting the strain gauge values from analog to digital.

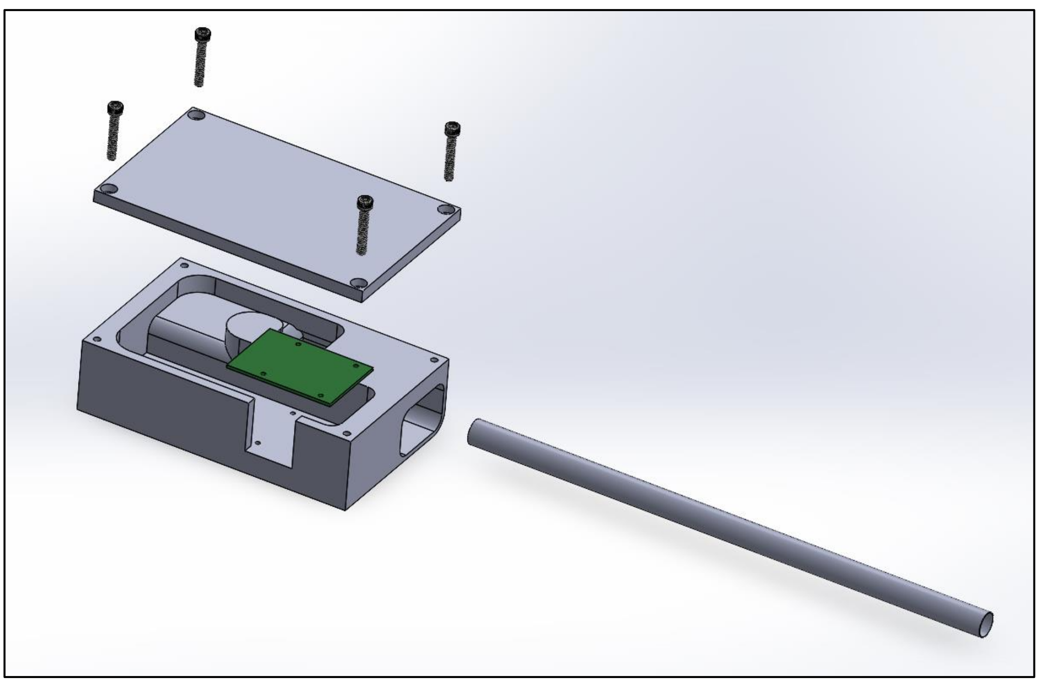


Figure 1: Exploded view of the Rodney Assembly

The strain gauges are attached as shown in Figure 2. d1 and d2 are the distances between each strain gauge and the fixed segment, with the difference between them as the distance between the strain gauges. As force is applied to the bar some distance x away, we can calculate the force and distance at which the force is applied from the base using the two measured strain values. By comparing the force and distance values from several locations along the beam, we can find the actual strain of the corn stalk.

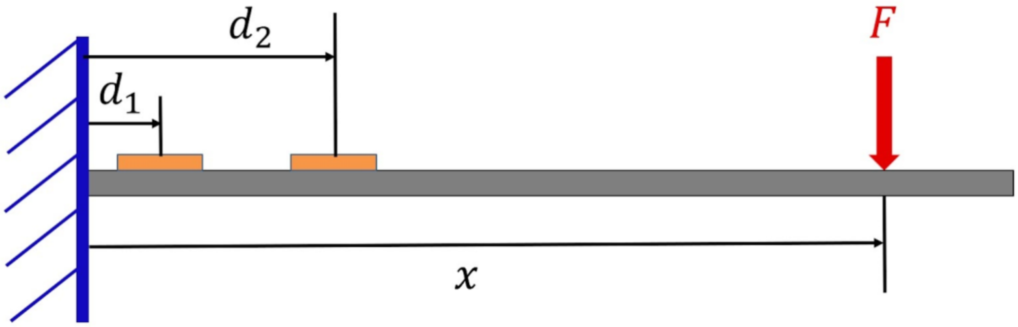


Figure 2: Diagram of how stalk deflection

Whisker Subsystem:

The purpose of this system is to find the distance from the base of the cornstalk to the robot base without deflection both immediately before and after measurement. This is essential because we cannot assume that Rodney is perpendicular to the stalk or that the angle of Rodney relative to the cornstalk doesn't change. It is accomplished by measuring the maximum angle to which each stalk moves the Whisker and using known lengths with this angle to find the distance. Figure 3 is an exploded view of the Whisker device.

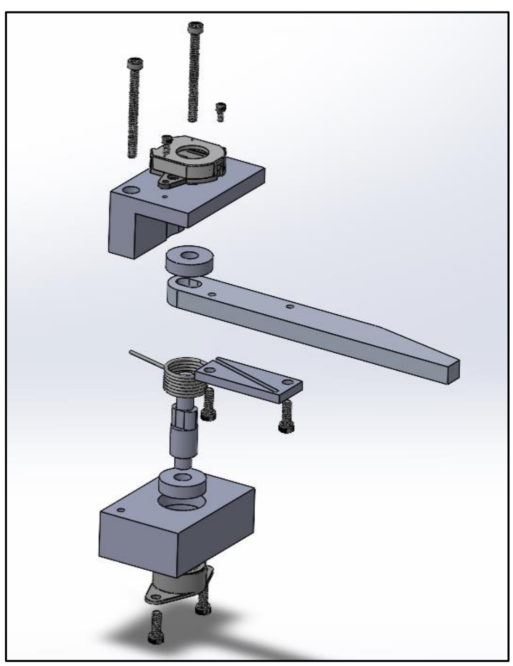


Figure 3: Exploded view of the Whisker device

PCB Subsystem:

The purpose of this subsystem is to take in analog voltages from the strain gauges, filter as needed, and to convert to digital values. The PCB will accomplish this by filtering high frequencies and using a Sigma-Delta ADC to convert the signal using 24-bit resolution. Below is the design we have made for the PCB.

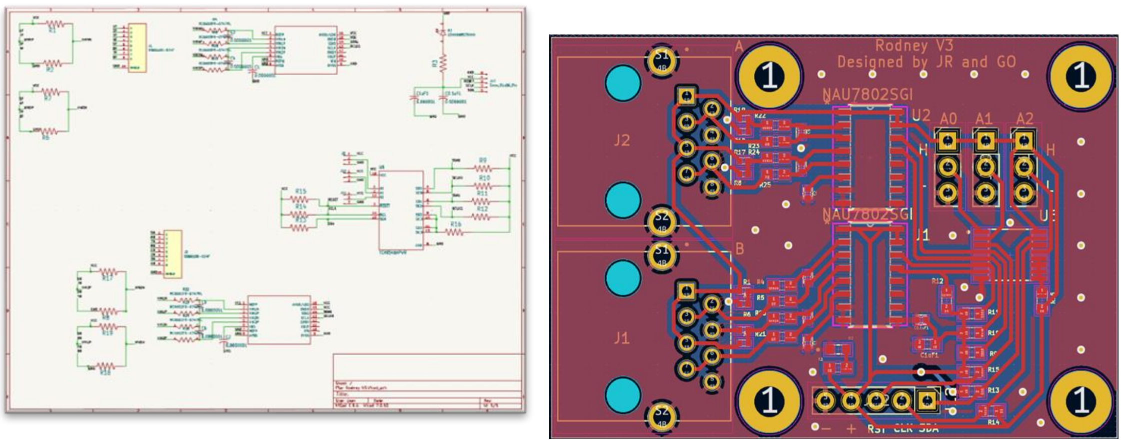


Figure 4: Schematic of PCB

Software Subsystem:

The final subsystem is the software subsystem which is responsible for the processing of the digital signals, the display of the live plotting, and the exporting of the data to csv files. This subsystem will be represented below by the UML flowchart. It is a very complicated subsystem with many different screens, leading to a lot of source files. The following UML diagram gives a rough idea of the size of the project for one device. It is difficult to view this file in paper format however links will be added later in the documentation for a digital representation.

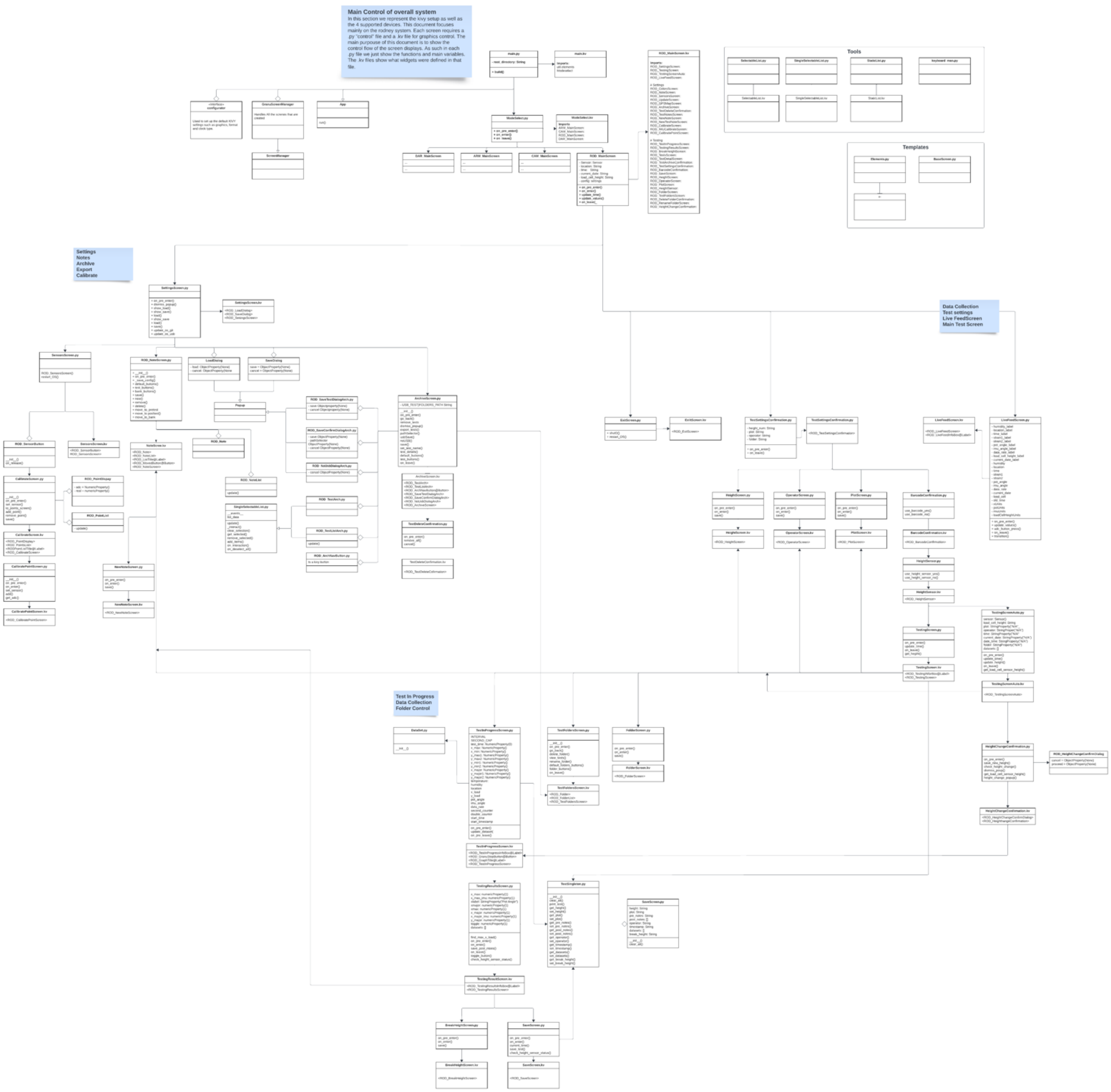


Figure 5: UML flowchart

The following images show screen shots of the current GUI configuration. The first image shown below is what the user will see upon powering up the device. The lab that we are working for wanted to build an all-in-one system incorporating our new Rodney design. This package presentation will focus on the Rodney software.

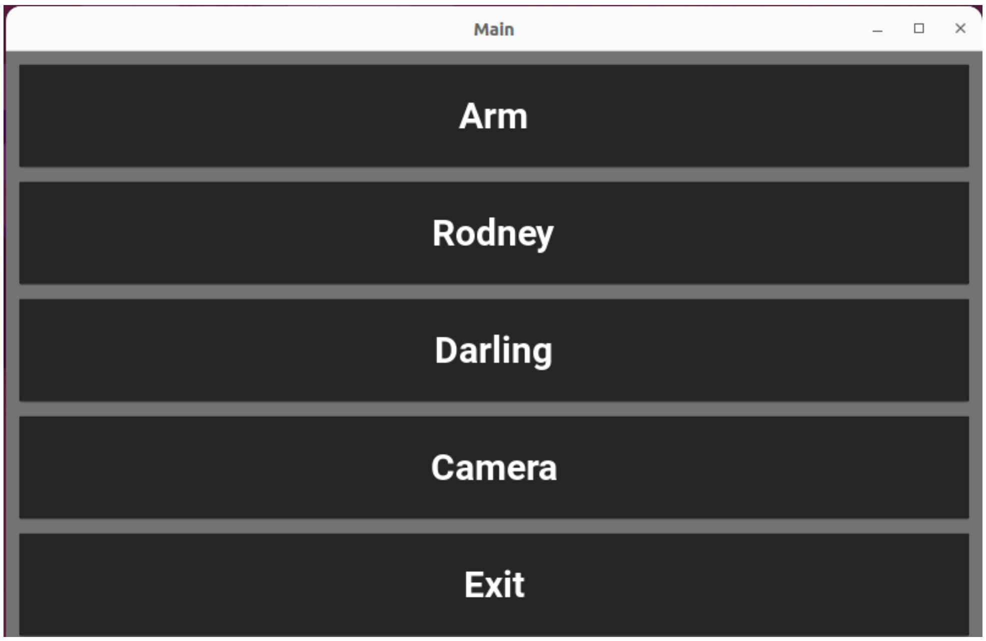


Figure 6: Mode Select Screen, first option on power up the GUI.

The following image is the main control menu of the Rodney device. The settings option is used for calibrating the different sensors. The collect data is where a user can perform field testing of corn stalks. The live feed screen button is for validating that we are receiving a signal from the various sensors.

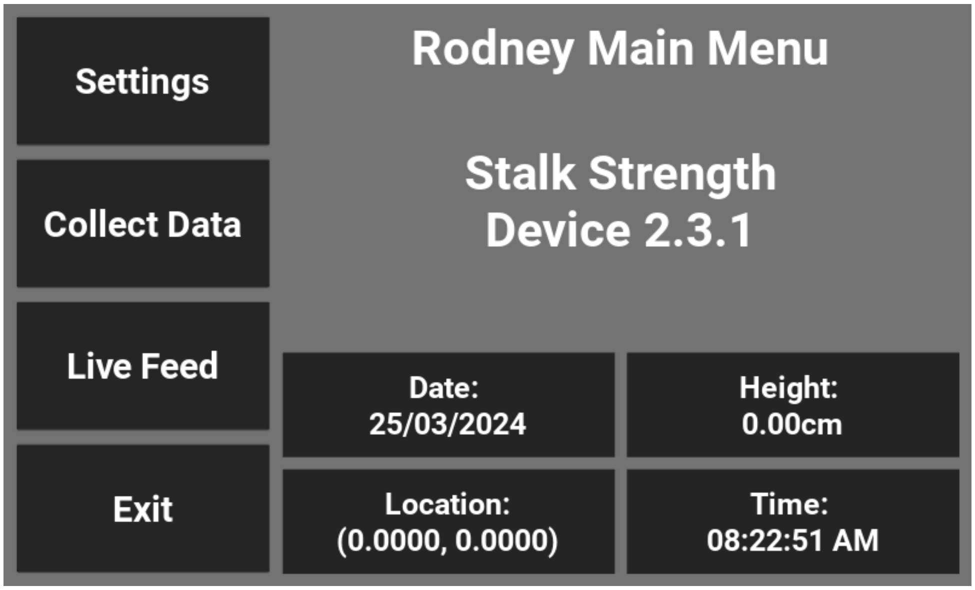


Figure 7: Main screen of Rodney Device

In the following image we have an example of the live feed screen. It shows the 4 different strain gauges along with the 2 encoders used on the whiskers. The top row is just general information including the current sampling frequency.

Figure 8: Live Feed screen showing the different sensors live readings.

This final image is us dynamically testing applying a load in both the X and Y direction of the device. In the image we are rapidly changing the direction of force applied, along with the amplitude to verify that the device is able to handle quick changes.

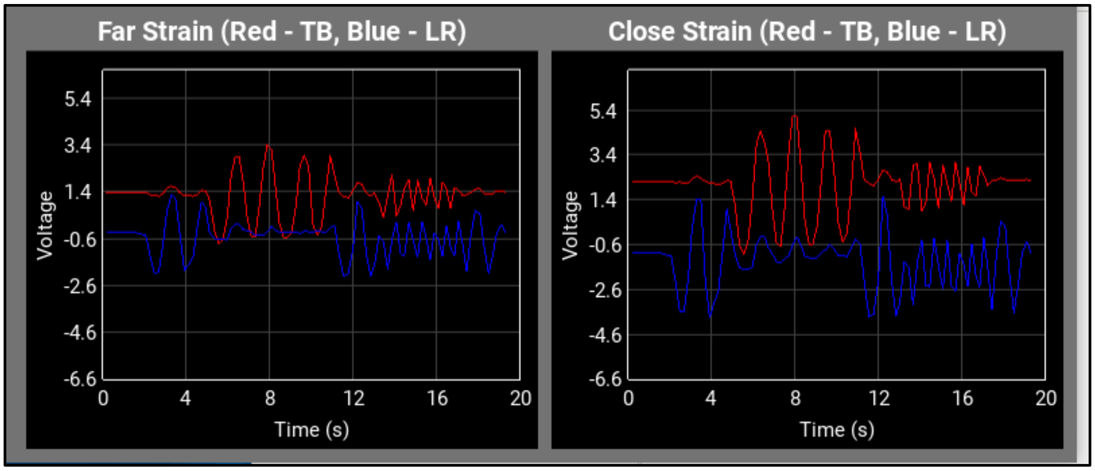


Figure 9: Live plotting during manual testing of the strain gauges.

Artifact ID: PS-1	Artifact Title: Performance Summary	
Revision: 00	Revision Date: 1 MARCH 2024	
Prepared by: Gustavo Oliveira	Checked by: Jeremy Read	
Purpose:		

Revision History			
Revision	Revised by	Checked by	Date
00	Gustavo Oliveira	Jeremy Read	30 NOV 2023
01	Gustavo Oliveira	Jeremy Read	25 MAR 2024

We used the following subsystems in our validation: Rodney, Whiskers, PCB, and Software.

Rodney

We performed 4 separate tests on Rodney to validate its effectiveness:

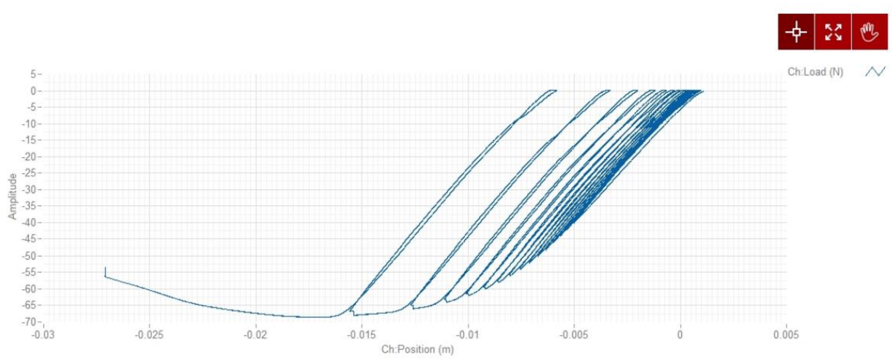
<u>3 Point Bending</u>

To test the material properties of Rodney we performed 3-point bending testing on the circular tubing used to construct the Rodney. The material properties of the beam are important to both use as constants in our beam bending calculations that determine the stress in the corn stalk, as well as to determine the robustness of Rodney to plastic deformation under use. The results of each of the 3 tests can be seen below.

Figure1: 3-Point bending test results

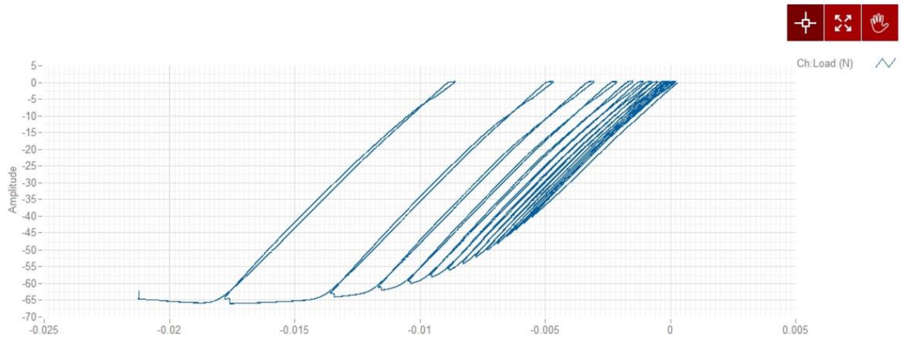
Specimen details

Specimen ID	Date	Time	Type	Gauge Length
half_inch_rodney_3_12072023_103317	12/7/2023	10:33 AM	None	1in

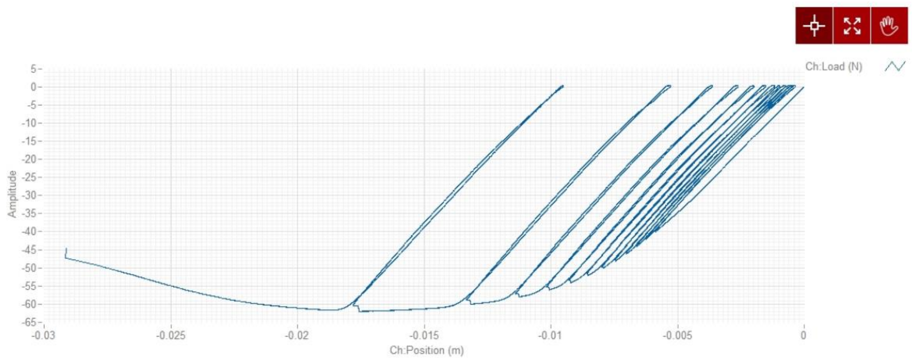


Specimen details

Specimen ID	Date	Time	Type	Gauge Length
half_inch_rodney_2_12072023_102743	12/7/2023	10:27 AM	None	1in



Specimen ID	Date	Time	Type	Gauge Length
half_inch_rodney_1_12072023_102307	12/7/2023	10:23 AM	None	1in



This figure shows the three individual 3-point bending tests performed on the circular tubing used for Rodney. The results indicate that Rodney failed consistently at approximately 70N of applied force, and from visual inspection it was determined that the mode of failure was buckling. This corresponds to a yield strain of approximately 0.3% in the beam before failure.

<u>Assembly fit</u>

To validate the mechanical design and fabrication of the Rodney system we performed an assembly test to fit together all the components. This involved individually assembling the guarding used for Rodney onto the mounting plate at each possible mounting angle. After ensuring the fit of the guarding to the mounting plate we assembled the Rodney measurement system and attached it to guarding. Finally, after validating the fit of the measurement system to the guarding we tested the fit of the complete system. Upon ensuring the complete fit of the system in all possible configurations we determined that our mechanical tolerances, and dimensions were correct for Rodney.

<u>System Calibration and Validation</u>

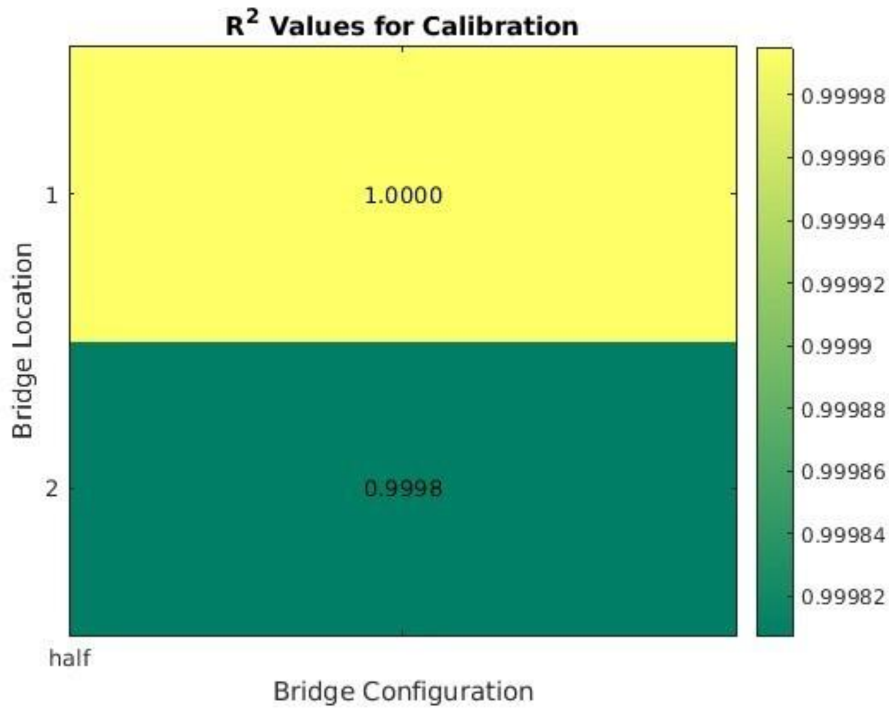
To validate the mounting of the strain gauges on the beam, and the sensitivity of the system to force inputs from multiple orientations we performed a calibration to determine the nominal strain gauge resistances, the mounting locations of the strain gauges, and the resistor values in the Wheatstone bridge. To perform this calibration, we fixed Rodney to a rigid surface, and hung masses of known weight from specified distances along the beam. We then gathered static data from these known masses, and using a Monte-Carlo optimization we determined the values of each of the above listed constants. The results of this calibrations can be seen in the table below.

Table 1: Calibration values for Rodney System

c1x	0.0053
c2x	0.0057
k1x	0.0849
k2x	0.0254
d1x	0.0912
d2x	0.1115
c1y	0.0054
c2y	0.0057
k1y	0.0653
k2y	0.0341
d1y	0.0954
d2y	0.1023

From these calibrations we can determine not only the exact values of the calibration coefficients, but also the functionality of the system. After performing the monte-carlo optimization on the calibration values we can obtain a R^2 fit for the accuracy of the calibration which can be seen below.

Figure 2: Calibration R^2 values for Rodney



This figure shows the R^2 values for the calibration of the Rodney system. The bridge location refers to the direction of the strain gauges, Bridge 1 is in the X orientation, and Bridge 2 I in the Y orientation.

Dynamic Testing

We assembled Rodney and integrated it with the Amiga Robot platform. This allowed us to simulate a cornfield experience by allowing Rodney to run in the lab and deflect PVC pipes that were mounted into a wooden block.

Figure: Synthetic Corn Field

The Amiga robot platform with Rodney attached will drive by the synthetic corn field and deflect it and provide measurements. We do not have final values for the stalk stiffness because we need to do post processing to get the flexural stiffness from the voltage readings.

Whiskers

We performed 3 separate tests on the Whiskers to validate its effectiveness:

Potentiometer Characterization

To ensure that the Potentiometers used for the Whiskers were accurate, and corresponded to an accurate angle we characterized the relationship between voltage output and potentiometer angle and built a calibration for it. The fit we found for the front and back Whiskers can be seen in the table below.

Table 2: Calibration Results for the Whisker Potentiometers

	Front Whisker	Back Whisker
m	-0.0121	0.0119
c	279.947	-21.296

This table shows the linear calibration fits that map between voltage values and approximate whisker angles.

This characterization was then tested to ensure that the maximal and minimal range of values was within the expected range of values from 0 to 90 degrees. We found that the potentiometers were accurate to this range and were able to continue testing.

Software Integration

To perform the software integration, we attached the Whiskers to the onboard ADCs and added sensors for them in the software. We tested moving the whiskers while looking at live data plots in the software to ensure that the values being read from it were accurate.

Dynamic Validation

To validate the Whiskers when mounted to a robot we attached the Whiskers to an Amiga Robot Platform and ran dynamic tests using the whiskers to ensure that the measured angles were accurate to the real angles the Whiskers reached. We ran a test where we drove the amiga straight forward and ensured that the Whiskers read a constant angle that was the same as the expected angle. The plot of this data can be seen below.

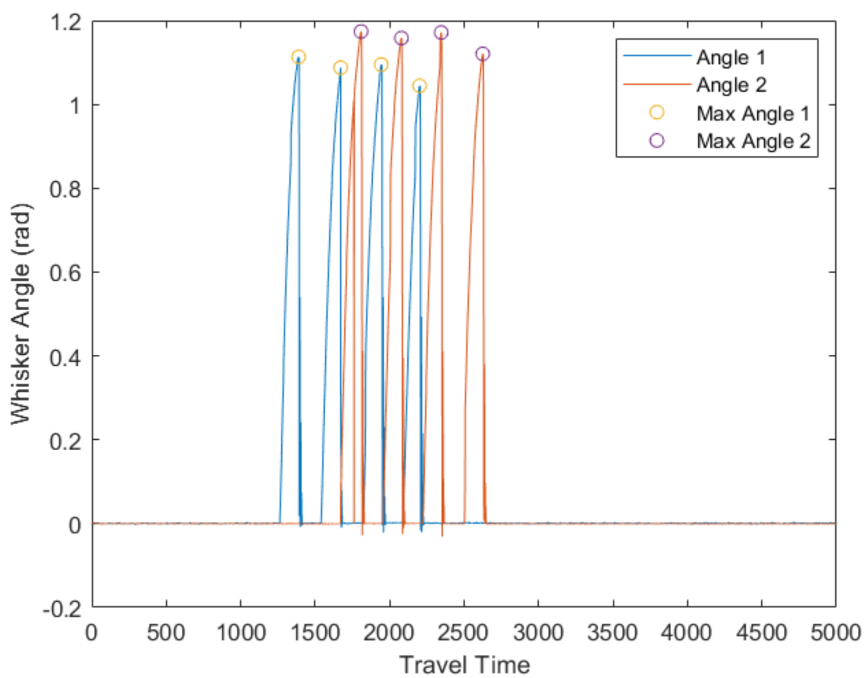


Figure 3: Whisker Dynamic Testing Validation Results

This figure shows the measured angular values in real time of the whiskers on our validation test. The expected value for this test is 1.18.

PCB

We performed 3 separate tests on the PCB to validate its effectiveness:

Calibration

To calibrate the PCB, we used an automatic software calibration found in our ADC package that calibrates our ADCs. To calibrate them we take a zero-voltage reading from them and gather calibration offsets for the ADC. We use this calibration when reading from the Strain Gauges.

Continuity

To ensure that the PBC was functioning properly across all traces we performed continuity tests using a multi-meter and ensured that all traces that were supposed to be connected were connected.

MUX

To ensure that we could read values from our MUX we set up a test system using a Raspberry Pi Pico and ran sample provided code to read ADC values. After ensuring that this works, we transferred this code to our main software system which uses the Raspberry Pi 4.

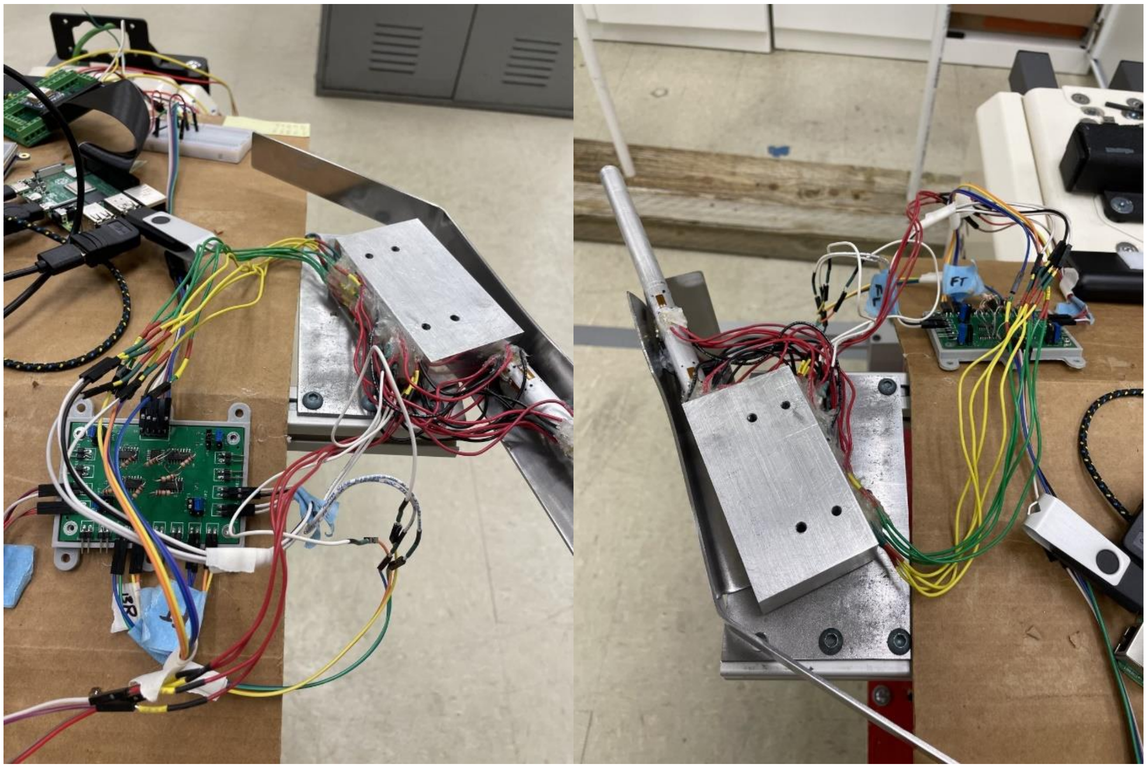


Figure 3: Images of the PCB attached to the Rodney device and reading values.

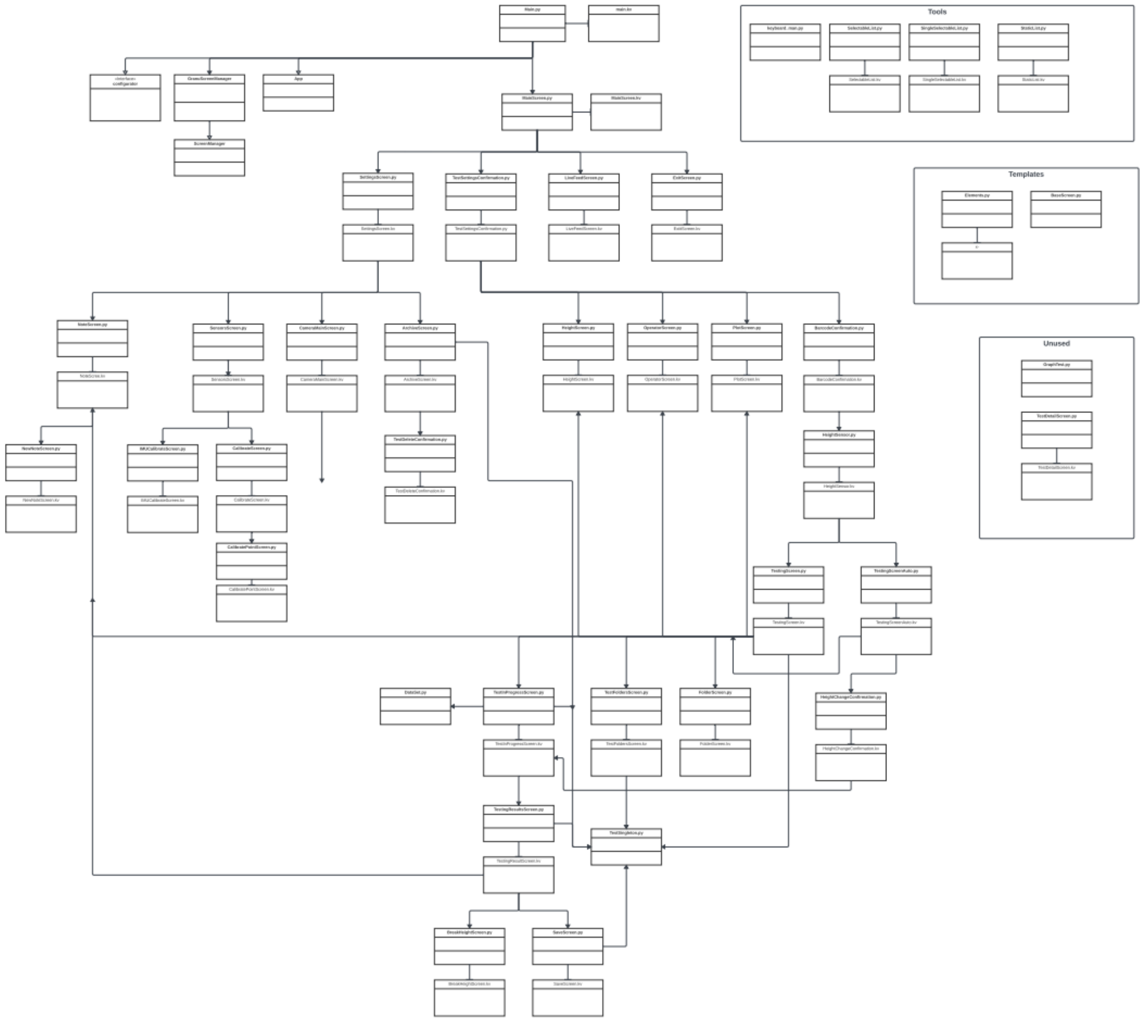
Software

We performed a single test on the Software to validate its effectiveness:

After ensuring that all parts of the software functioned properly without causing errors though system testing, we tested our system for the system requirement matrix values. In the below graph we show how we were able to measure the ease of learning how to use the new software package.

Measurement	Metric	Process	Results	Final Result (AVG)
Clicks to get data	Number of Clicks	Counted Number of Clicks from startup to collecting data	15,18,12,11,17	15 Clicks
Lag between Clicks	Time in seconds	Timed the time between clicking the screen and Reaction	.4,.5,.6, .3,.7	.5 Seconds
Professional Look	Opinion of Sponsor	Asked our sponsor if they approved of the design	Approved	Approved by Dr. Cook
Time to Learn how to use	Time in Minutes	Taught other team membes who didn't have experience timed the result	8,10,12,8,12	10 minutes
Active Branches	Number of Branchs	Deleted Unecessary Branch Counted remaining	3	3 Branches
Receiving Data to Graphing on display	Time in seconds	Timed the time between clicking the screen and Reaction	.05, .15, .1, .12,.9	.1 Seconds

Here is the flow diagram of the UML software



Artifact ID: REM-1	Artifact Title: Requirement Matrices	
Revision: 03	Revision Date: 05 FEB 2024	
Prepared by: Nathan Ludlow & Ryan Hall		Checked by: Landon Beutler
Purpose: A definition of system requirements, along with desired values for objectives		

Revision History			
Revision	Revised by	Checked by	Date
01	Nathan Ludlow	Gustavo Oliveira	29 NOV 2023
02	Caleb Price	Landon Beutler	30 NOV 2023
03	Ryan Hall	Gustavo Oliveira	05 FEB 2024
04	Ryan Hall		03 MARCH 2024

* Both System and Subsystem Matrices

Arifact ID	Artifact Title
RM-001	Requirements Matrix
Revision: D	Date: 3/11/2024
Team: R.E.A.P.E.R	
Prepared By: Gustavo	
Checked By: Jeremy	

#	Market Requirements	Importance (optional)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Market Ratings: Rating	Artifact ID
	Performance Measures		Time to detach	Number ot stalks to mesaure per minute	Overall footprint	Unit cost	Percent error to stalk stiffness	Waterproof rating	Mulitple communication interfaces	Looks Proffessional	Height of drop survived onto dirt	Low unit weight	Time to learn to use device	Battery life	Repeatability Error	Height of corn it can measure	Device storage capacity (GB)	Power Consumption	Man Hours To Manufacture			
	Units		min	stalks/min	m^3	USD	Percent error	IP Rating	# communication interfaces		m	kg	min	hours	% Variation	cm	GB	W	hr			
1	Measures Force and Distance of Bending	9					*								*							
2	Device is Accurate	9					*															
3	Easy to Use Interface for Mounting	8	*																			
4	Measures Quickly	8		*																		
5	Versatile Data Communication Interface	7							*													
6	Durable Against Outdoor Environment	6						*														
7	Affordable	6				*																
8	Can Measure Corn of Different Heights	7														*						
9	Device Lasts a Long Time	5						*			*			*			*	*				
10	Device is Visually Appealing	5								*												
11	Easily Manufacturable	4																	*			
12	Easy Assembly	4	*																			
13	User Friendly	4											*									
14	The Device is Portable	1			*									*								
15	Device is Low Weight	1										*										
	Importance (optional)		1	9	3	5	8	2	1	6	3	1	3	4	9	6	2	2	1			

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Ideal Values		Lower Acceptable Limit	-	30	-	-	-	IP53	1	Doesn't still look like a prototype	0.25	-	-	4	-	-	10	-	-	
		Ideal	3	120	0.15	$1,500	5%	IP 68	3	No internal components shown	1	5	15	12	10%	15-100	64	10	5	
		Upper Acceptable Limit	15	-	0.5	$3,500	25%	-	-	-	-	10	60	-	20%	30-80	-	100	40	
		Target	8	60	0.3	$2,000	20%	IP 65	2	Minimize exposed internal components	0.5	17	30	8	15%	25-90	60	40	15	
		Stretch		120			10%		3		0.6	12	25	10	20%	20-100	128	25	12	
Real Values	Predicted	Artifact																		
		Value	10	45	0.01	1500	20	IP53	1	Yes	0.5 m	5	15	10	10	30-80	64	75	7	
	Measured	Artifact																		
		Value	10	60	0.005	405		IP53	I2C	Yes	1m	3	10				16		3	

Revision History

Rev.	Date.	By	Approval	Description	ECO
A	9/11/2023	Team		Initial release	
B	9/20/2023	Dr Cook		Updated requirements to better match sponsors desires	
C	9/25/2023	Landon & Ryan		Matched performance measures to market requirements and ranked Performance Measu	
D	2/21/2024	Gustavo	Caeleb	Added performance measures	
E	3/11/2024	Gustavo	Jeremy	Finalized	

Artifact ID: MDP-1	Artifact Title: Model Definitions and Prototypes	
Revision: 01	Revision Date: 30 NOV 2023	
Prepared by: Nathan Ludlow		Checked by: Ryan Hall
Purpose: To define the testing procedures, and results from testing of our initial prototypes.		

Revision History			
Revision	Revised by	Checked by	Date
01	Nathan Ludlow	Ryan Hall	30 NOV 2023
02	Ryan Hall		01 MARCH 2024

The prototype used for our testing and results is the square tube strain gauge design as introduced in the Executive Summary. We present here the methods, results, and analysis of these results below.

Methods

To gather data for the strain gauge prototype we used an initial prototype with a square tube as shown in Figure 22. This device is referred to as the “Dogbone” and comes from previous work in the Crop biomechanics laboratory we are working for. The setup for strain gauges and gathering data from them can be found in the System Architecture Definition. Since corn is not currently in season it is not possible to test the system on actual corn stalks and for this reason, we opted to build a testing rig. We constructed a testing rig out of a wooden base with PVC tubing mounted vertically in it to simulate corn stalks. From previous testing in the lab, it was found that the stiffness of PVC is comparable to that of corn stalks, which is the reason behind using PVC for our testing rig. We mounted the Dogbone device to the Amiga Farm NG platform, and to perform testing we drove the Amiga along the side of the testing rig and gathered data from trials as seen in Figure 23.

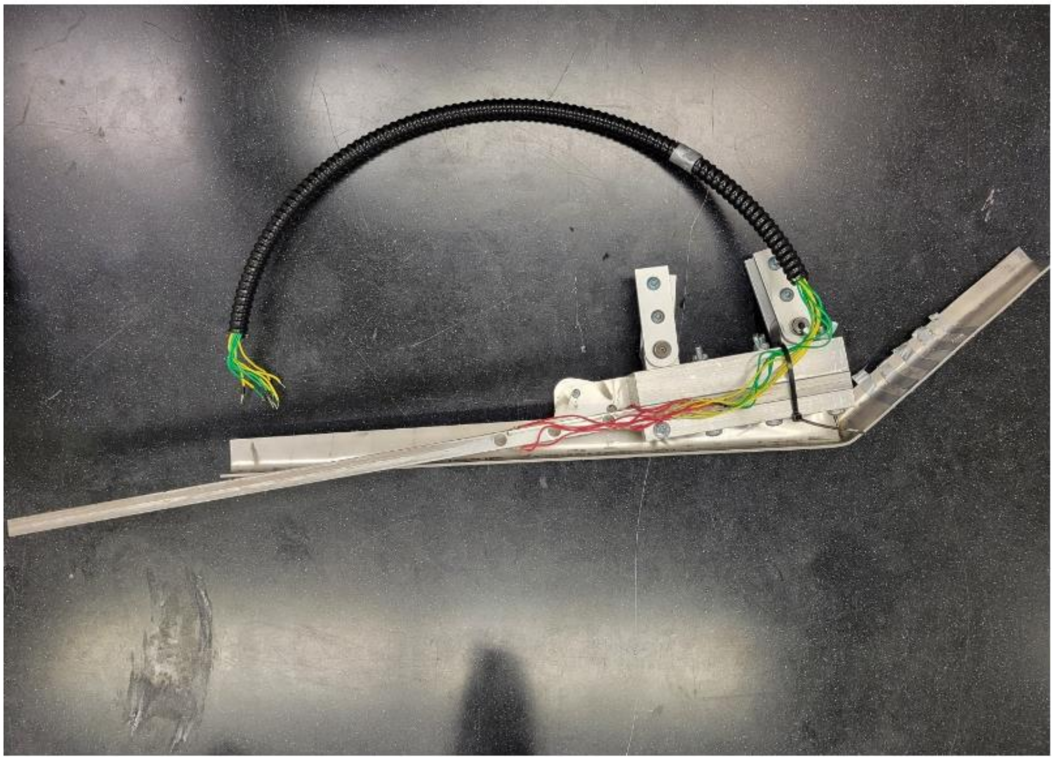


Figure 22: Dogbone device as viewed from above.

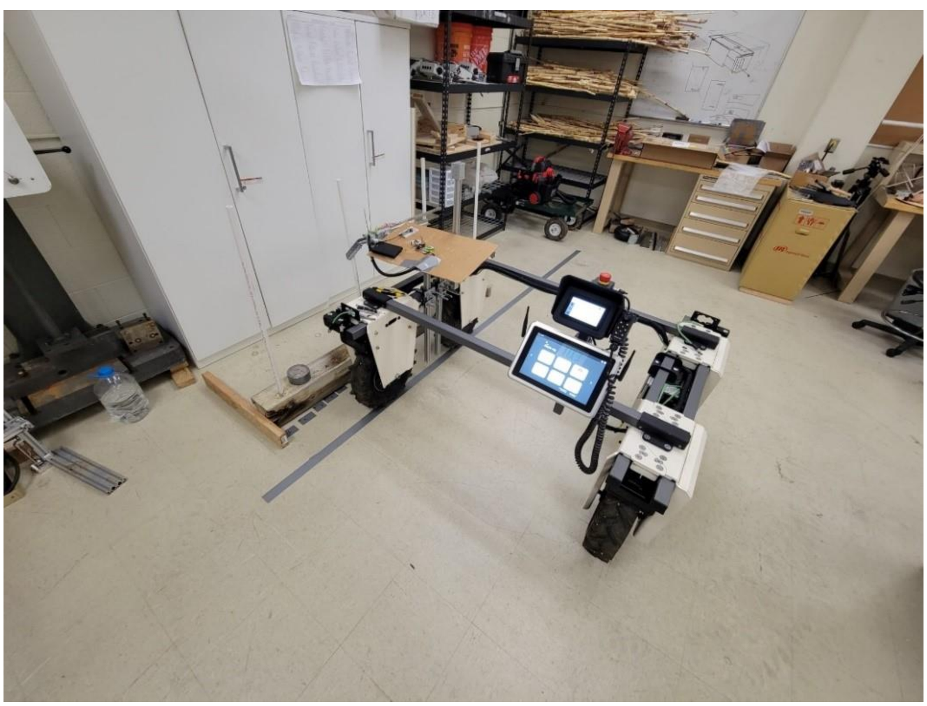


Figure 23: Image of the testing setup used to gather data.

To analyze and validate the accuracy of the data we took the strain gauge readings and processed them into stiffness values. The approach used to do this is mathematically derived in the next section. These equations were derived from the work of another master's student in the Crop Biomechanics Laboratory, and their writeup of the derivation is included below for reference:

Derivation of Equations:

The strain along a cantilever beam undergoing bending is related to the bending moment using basic cantilever beam bending equations as shown in Equation 1.

$$\varepsilon = \frac{My}{EI} \tag{1}$$

Here E is the Young's modulus of the beam, I is the moment of inertia, and y is the distance from the neutral axis. At the beam's surface, y is half the thickness of the beam. When a force F is applied at a distance x from the cantilever's base, the resulting bending moment experienced by a strain gauge mounted on the beam's surface a distance d from the base is given by:

$$M = F(x - d_i) \tag{2}$$

Thus, the expression for the strain experienced by the strain gauge is given by

$$\varepsilon_i = \frac{y}{EI} F(x - d_i) \tag{3}$$

We assume the strain gauge is being read using an amplified Wheatstone bridge configuration. The equation for the voltage read by the Wheatstone bridge is a function of the strain at that point.

$$V_i = \frac{V_s G g n}{4} \varepsilon_i \tag{4}$$

Here V_s is the supply voltage, G is the gauge factor of the strain gauge, g is the amplification gain, and n is a variable relating to the Wheatstone bridge configuration. For quarter, half, and full Wheatstone bridge configurations, n equals 1, 2, or 4, respectively. If we plug in the strain found from the beam bending equation, we can get an expression for the voltage in terms of the input force and distance.

$$V_i = \frac{V_s G g n}{4EI} F(x - d_i) \tag{5}$$

We can group the constants in the front of the equation into one term, and we will add a noise term to the end to arrive at our governing strain gauge equation:

$$V_i = k_i F(x - d_i) + c_i \tag{6}$$

Here k has the theoretical value.

$$k = \frac{V_s G g n y}{4EI} \tag{7}$$

In typical load cells, the force F is unknown, while the application distance x is fixed. Thus, equations (5) and (6) can be used to solve for the unknown force when the Wheatstone bridge voltage is measured. However, this equation is insufficient if both the force and application distance are unknown. This can be resolved by mounting two strain gauges on the beam at locations d_1 and d_2. We now have two different strains being measured by the two Wheatstone bridges, both of which correlate to the same force and application distance.

We can set up a system of equations and solve it to find the unknown force and distance. First, we take two instances of equation (6), solve them for F, and set them equal:

$$V_1 = k_1 F(x - d_1) + c_1 \tag{8}$$
$$V_2 = k_2 F(x - d_2) + c_2 \tag{9}$$

This value of x can be plugged back into equation (8) to solve for F. It should be noted that solving for x first instead of F is also possible, though it results in a polynomial expression for F and is generally less convenient. Also, either the first or second Wheatstone bridge in equation (8) can be used to solve for F, since the result for each is equivalent.

Once the force and application distance are known, the deflection of the cantilever beam at the point of force application can also be calculated using the standard cantilever beam bending equation:

$$x = \frac{k_2 d_2 (V_1 - c_1) - k_1 d_1 (V_2 - c_2)}{k_2 (V_1 - c_1) - k_1 (V_2 - c_2)} \tag{10}$$

$$F = \frac{k_2 (V_1 - c_1) - k_1 (V_2 - c_2)}{k_1 k_2 (d_2 - d_1)} \tag{11}$$

Using this equation, we wrote code that would process the strain values into stiffnesses for trials run gathering data from the Dogbone system. We first clipped the data from the teach trial into separate stalk measurements to analyze each stalk individually. The plotted results from each stalk can be found in the Testing Plots artifact. A summary of the results can be found in Table 1.

Table 4: Stiffness values measured from our PVC testing rig using the Dogbone device.

	Stalk 1	Stalk 2
Pass 1	37.03 N/m	33.02 N/m
Pass 2	35.76 N/m	32.50 N/m
Pass 3	34.36 N/m	32.28 N/m

The actual stiffness of PVC has been tested by the lab using a standard 3-point bending test. The mean stiffness is 24.8 N/m with a standard deviation of 0.46. The minimum measured stiffness was 23.8 N/m with a maximum of 25.3 across the testing. Comparing these results with the measured stiffness values from the Dogbone system we can clearly see that there is a large bias error in our system. However, this bias offset is normal across all previous measurement devices used in the lab in the field and was smaller than the error from the Arm prototype. The reliability of the system in producing consistent results for stiffness was determined to be very high as generally the error in sensory measurements for agricultural robotics is much higher than measured in our system.

Our research primarily utilized the Dogbone concept for initial testing phases. As of now, testing on the Rodney system remains incomplete, primarily due to the pending arrival of parts necessary for our Printed Circuit Board (PCB), which is crucial for gathering sensor measurements. Despite this, we have managed to conduct preliminary tests focusing on sensitivity analysis and the signal-to-noise ratio of the sensor in its existing configuration. The data acquired, although preliminary, suggests that the results from our current prototype system fall within an anticipated range, reinforcing our expectation of its functionality once full-scale testing begins.

Rodney First Prototype

We created our first verision of the Rodney device which uses the circular beam concept to measure the forces at multiple angles. This sensor was used to collect most of our dynamic testing results.

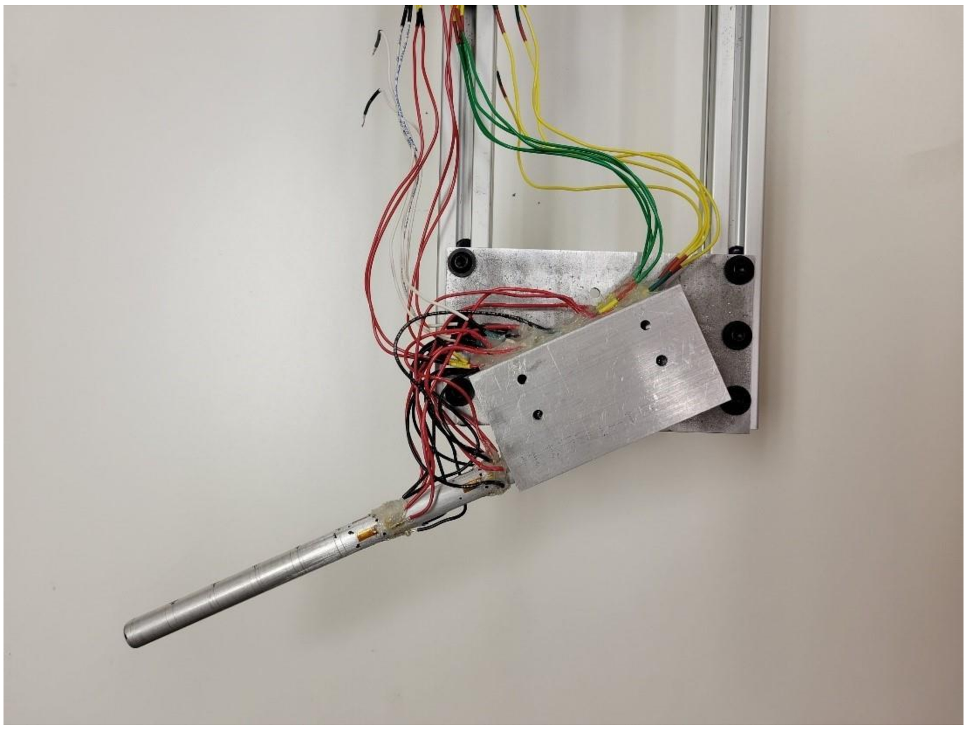


Figure 24: First Rodney prototype

The sensitivity analysis testing for Rodney was based on theoretical results, derived from the fundamental equations we outlined earlier. A critical aspect of both the Dogbone and Rodney devices is the angle at which the device is positioned relative to the robotic platform's base while navigating along corn rows. This angle influences the deflection distance and speed of the corn stalks. Even minor deviations in this angle can significantly alter measured stiffness values. Such deviations can arise from various factors, including mounting inaccuracies, flex in the mounting system, and deviations in the robot platform's steering alignment. To minimize these error sources, our sensitivity analysis focused on identifying initial mounting angles that exhibit minimal sensitivity to angular variations when calculating stiffness. Figure 24 illustrates this analysis. It is evident that angles near 45 degrees demonstrate lower sensitivity, as do smaller forces in the system. However, mounting the sensor at a 45-degree angle is impractical due to the excessive frictional forces it would generate between the sensor and the corn stalk. Consequently, the maximum feasible angle for mounting the sensor is 25 degrees, which we plan to implement in our final design. This angle selection not only complies with the sensor's physical limitations but also reduces the overall forces in the Rodney device, thereby enhancing accuracy.

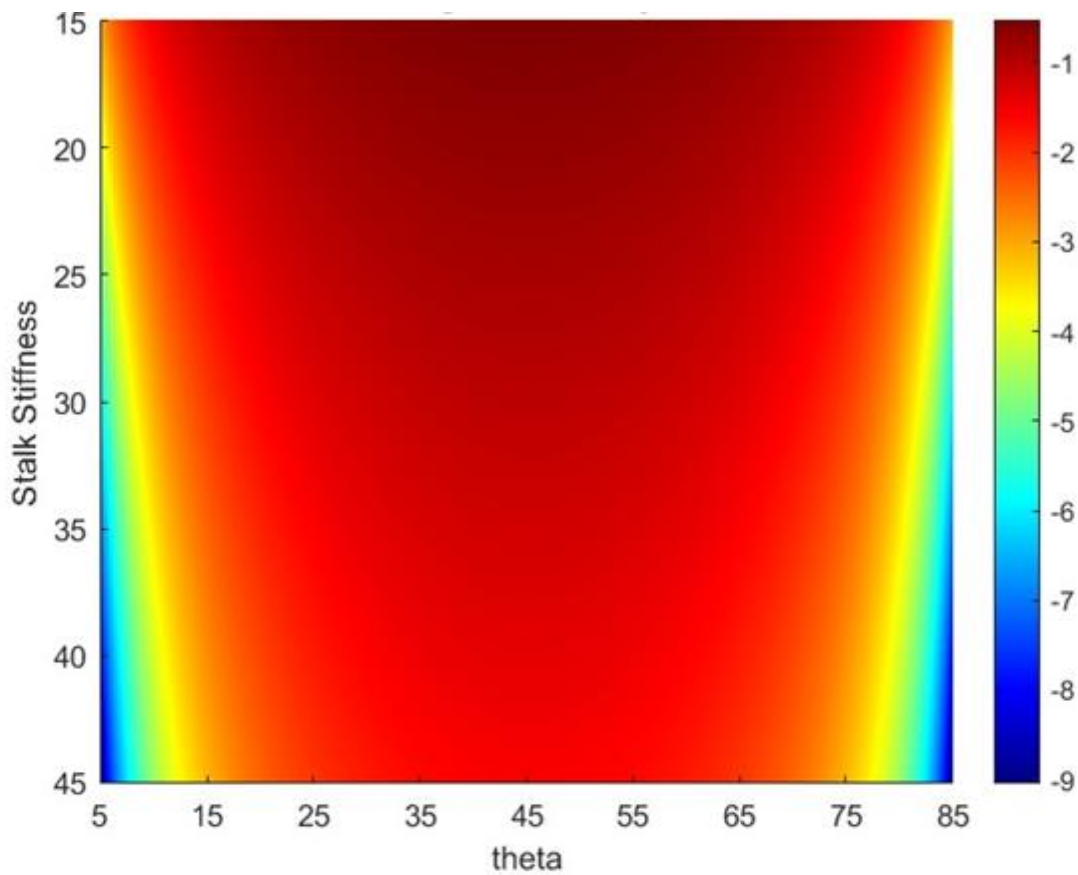


Figure 24: Spectrogram of the stiffness measurement sensitivity to changing angle in the y (driven by Rodney mounting and steering) at various stalk stiffness. A low sensitivity indicates that measurement inaccuracies due to steering would be minimal.

Our testing on signal to noise ratio analysis for Rodney includes initial testing on the physical system to determine the smallest signal we are able to read. Two representations of our signal to noise ratio are pictured below. The measurement zone of our prototype Rodney device are between 1 and 3 inches, which is the range that we tested within. As you can see from Figure 25 the trends of noise in our measured voltage with a 0.25kg weight at one inch reflect the noise with no weight attached, indicating that the signal to noise ratio is approximately equal at both locations. In Table 5 we include numerical measured values of the signal to noise ratio indicating that our measurement system will be capable of measuring the stalk stiffness.

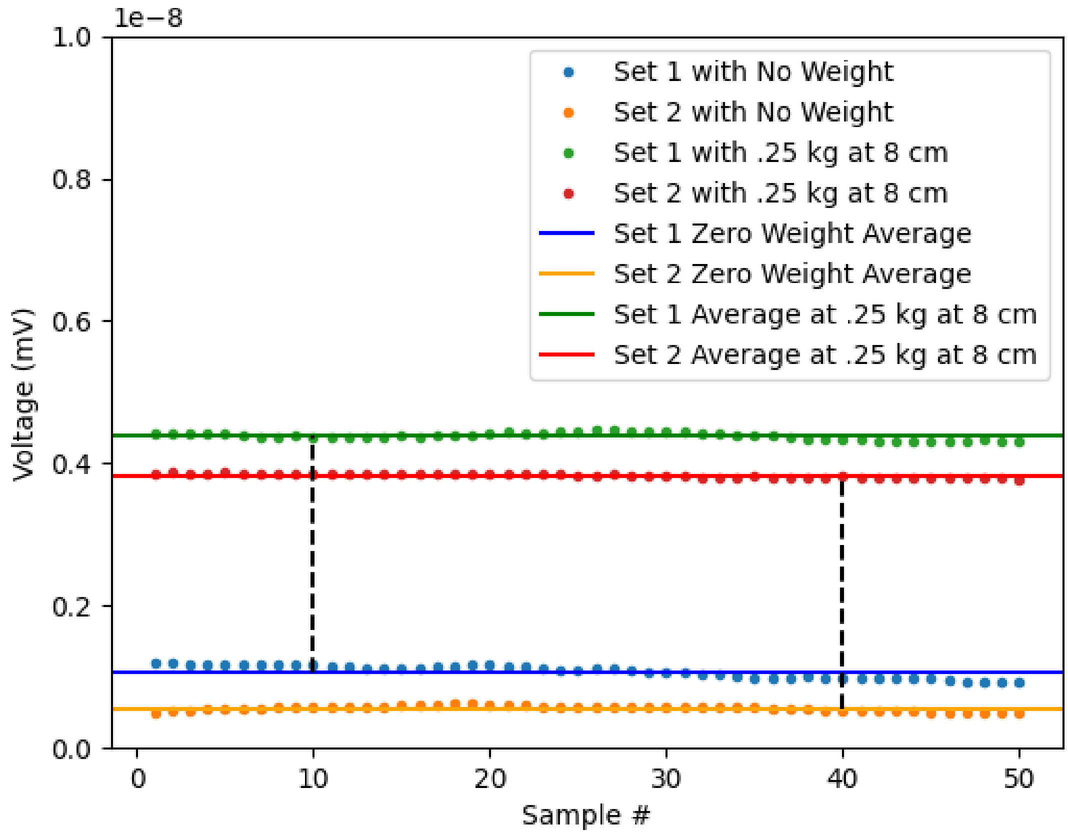


Figure 25: Signal to noise comparison for Rodney. The blue and yellow lines are the voltages measured by the strain gauges with no applied load. The green and red lines are the voltages measured when a .25 kg weight is applied 8 cm from the strain gauge set B.

Table 5: Results from the signal to noise comparison tests for Rodney.

	Set 1		Set 2	
	0 kg	.25 kg at 8 cm	0 kg	.25 kg at 8 cm
Average Voltage	1.07E-09	4.38E-09	5.57E-10	3.83E-09
Standard Deviation	8.53E-11	4.65E-11	3.51E-11	2.61E-11
Gap to Noise Ratio	38.774		93.237	

Rodney Final Model

The measurment portion of the final Rodney model is the same as the origional design. We adjusted the housing to be better with strain relief and cabel management.

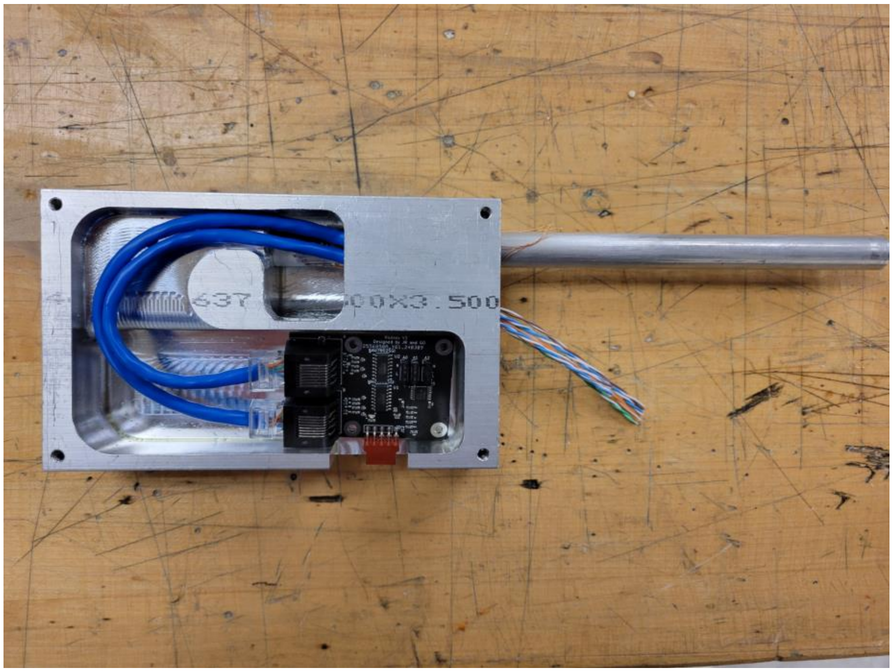


Figure 26: Final Rodney Housing

This model reduces the length that the wires have to travel to reach the processing unit. Additionally, the housing has a cover that can be placed on it to allow for better waterproofing. This design will have similar results to the first iteration of the Rodney Device.

Whisker Model

The Whiskers, developed as a subsystem for data collection with the Rodney device, serve to address the sensitivity of Rodney to the angle of impact on the corn stalk. Comprising two blocks equipped with encoders, the Whiskers enable us to employ trigonometry in calculating the angle at which the corn stalk passes the sensor, enhancing the accuracy of data collection.

Figure 26: First prototype of the whisker models

PCB Model First Iteration

We've crafted a custom PCB specifically tailored to our system, incorporating essential connections for our Wheatstone bridges. Additionally, it seamlessly manages analog-to-digital conversion and streamlines transfer to the Raspberry Pi through the I2C communication protocol. Strategically mountable near the sensor, this device minimizes errors typically associated with analog signal travel over extended distances.

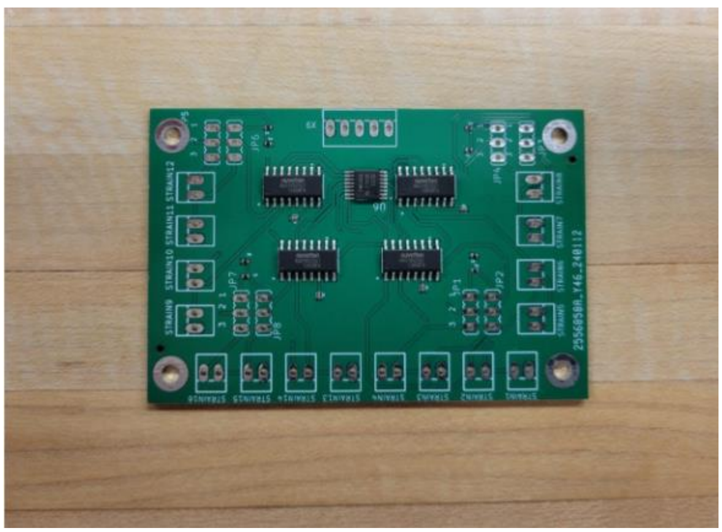


Figure 27: First iteration of Data Collection PCB

PCB Model Final Iteration

We wanted to save space on our package, so we took the PCB design and shrunk the board. Additionally we changed connections to ethernet ports for better cabel managment and signal isolation. This device works the same as the pervious iteration, but has been optimised for our system.

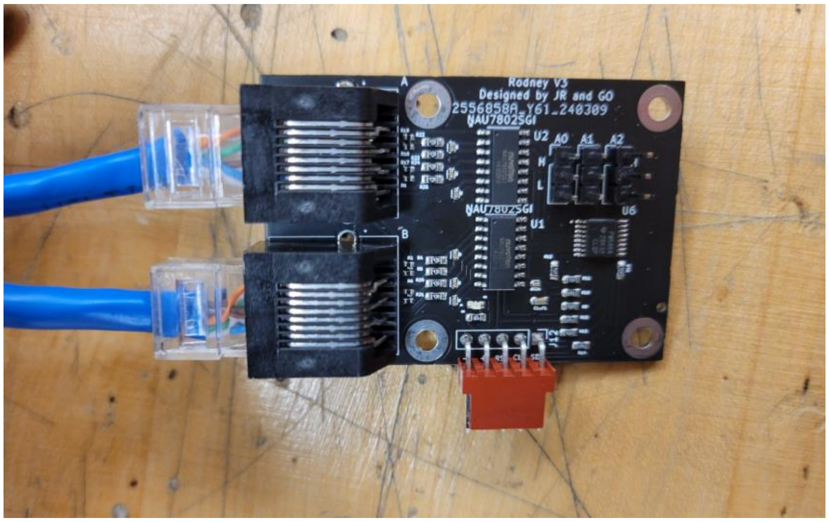


Figure 28: Final of Data Collection PCB

Sofware Model

The software model is designed around a Kivy-based Graphical User Interface (GUI) which serves as the primary interaction point for users. The base of this model was inherited from Darling software developed by the Crop Bio Mechanics lab at Brigham Young University. The interface offers intuitive navigation and seamless user experience. Its purpose is to facilitate efficient control and management of the system, providing users with comprehensive tools to oversee various processes and functionalities. At its core, the software adeptly processes data, handling inputs and outputs with precision and speed. Through its cohesive integration of the GUI and robust data processing capabilities, the model stands poised to streamline user interactions and optimize system performance. Below is an example of the Rodney main menu screen.

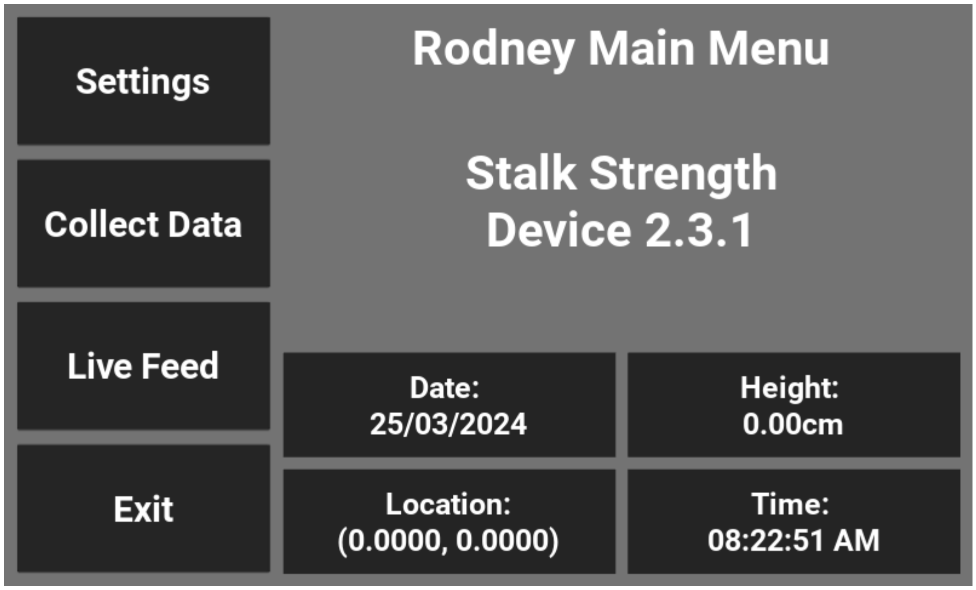


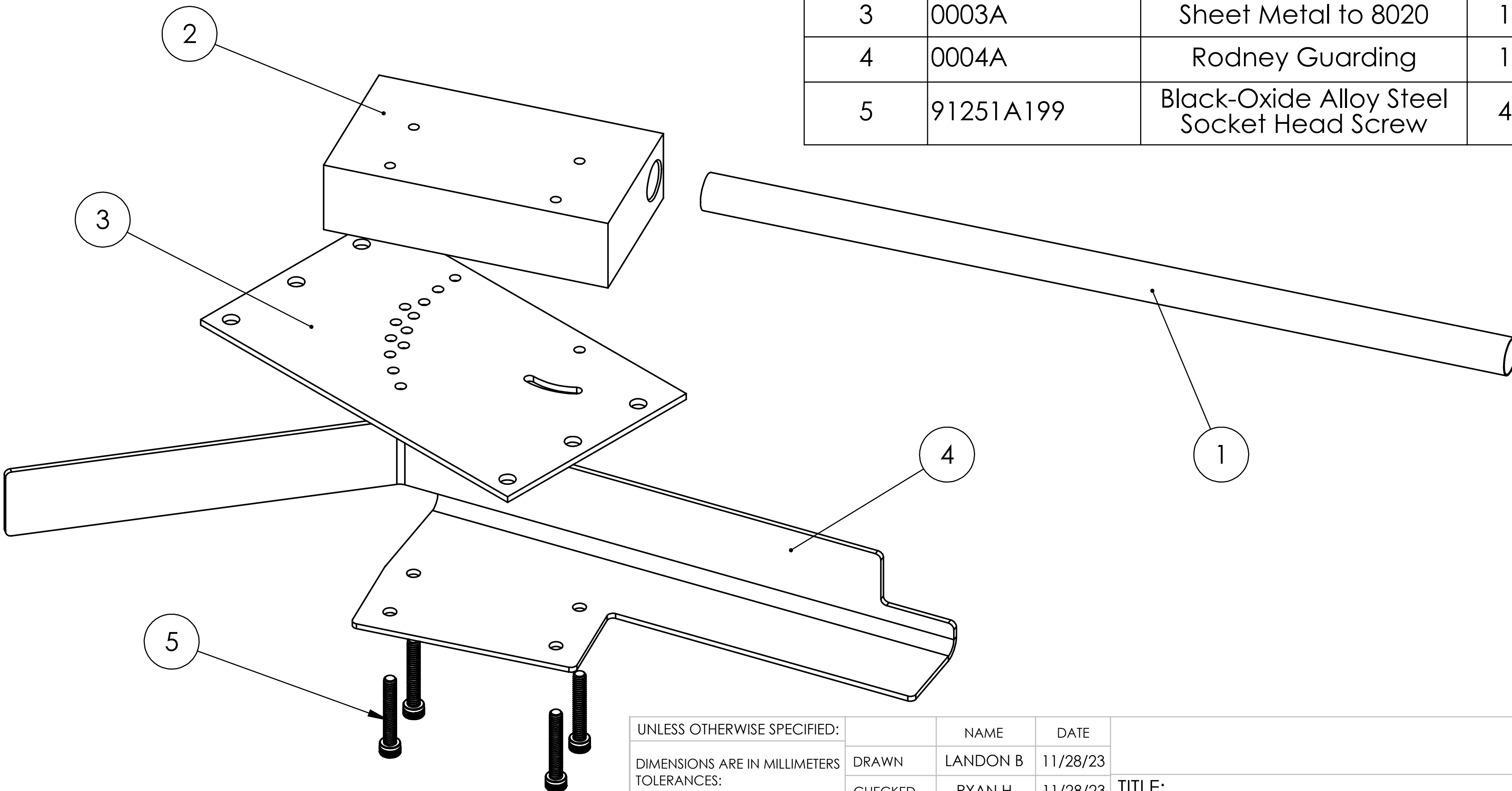
Figure 29: Final Rodney graphical user interface

Artifact ID:	Artifact Title:
SDP-1	System Design Package
Revision: 01	Revision Date: 25 MAR 2024
Prepared by: Gustavo Oliveira	Checked by: Ryan Hall
Purpose: Package of all the design files	

Revision History			
Revision	Revised by	Checked by	Date
01	Gustavo Oliveira	Ryan Hall	25 MAR 2024

2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	0001A	Rodney Circular Tube	1
2	0002A	Rodney Mounting Block	1
3	0003A	Sheet Metal to 8020	1
4	0004A	Rodney Guarding	1
5	91251A199	Black-Oxide Alloy Steel Socket Head Screw	4



B B

A A

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INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

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CHECKED	RYAN H	11/28/23
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Rodney Exploded View

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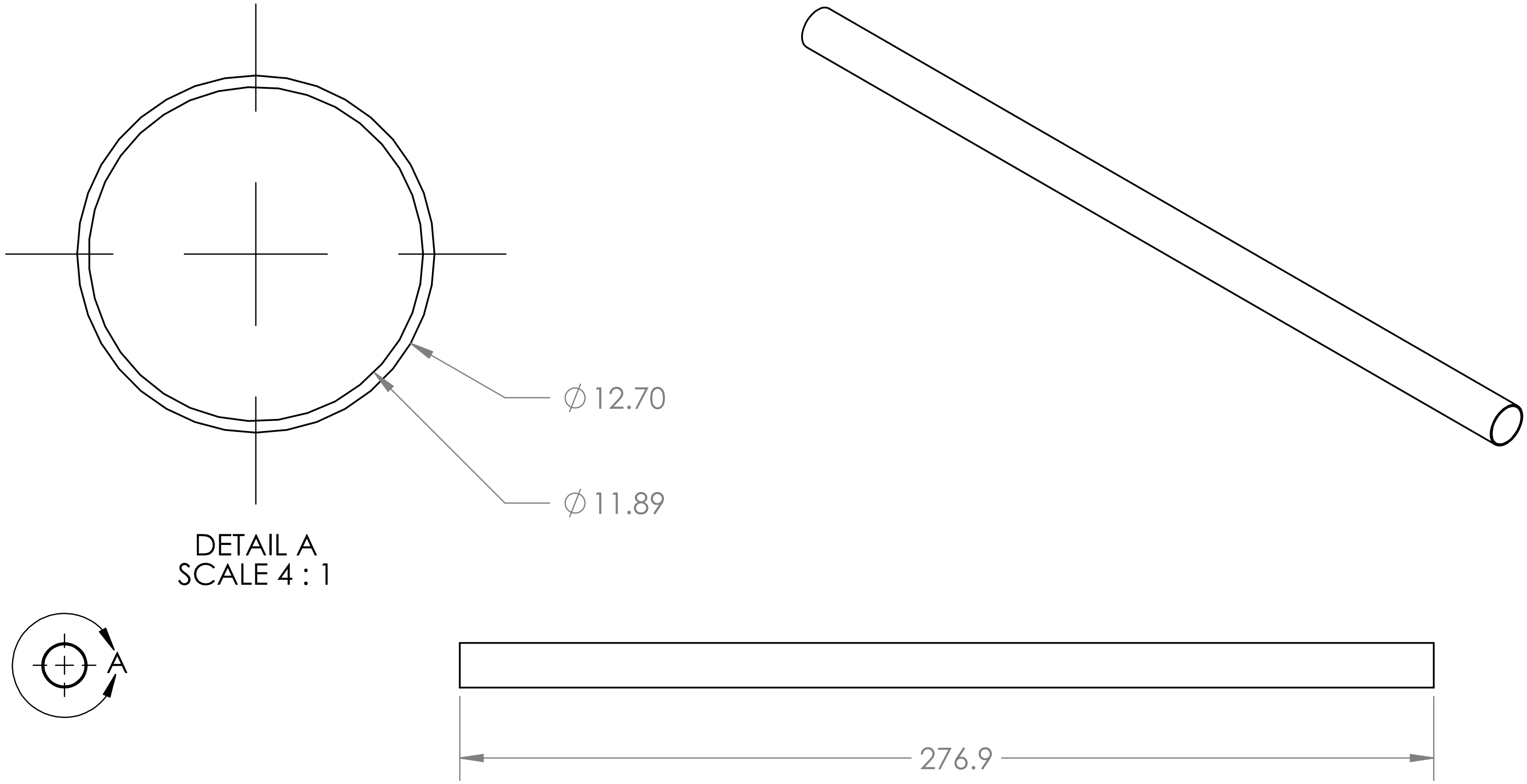
2 1



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Rodney Circular Tube

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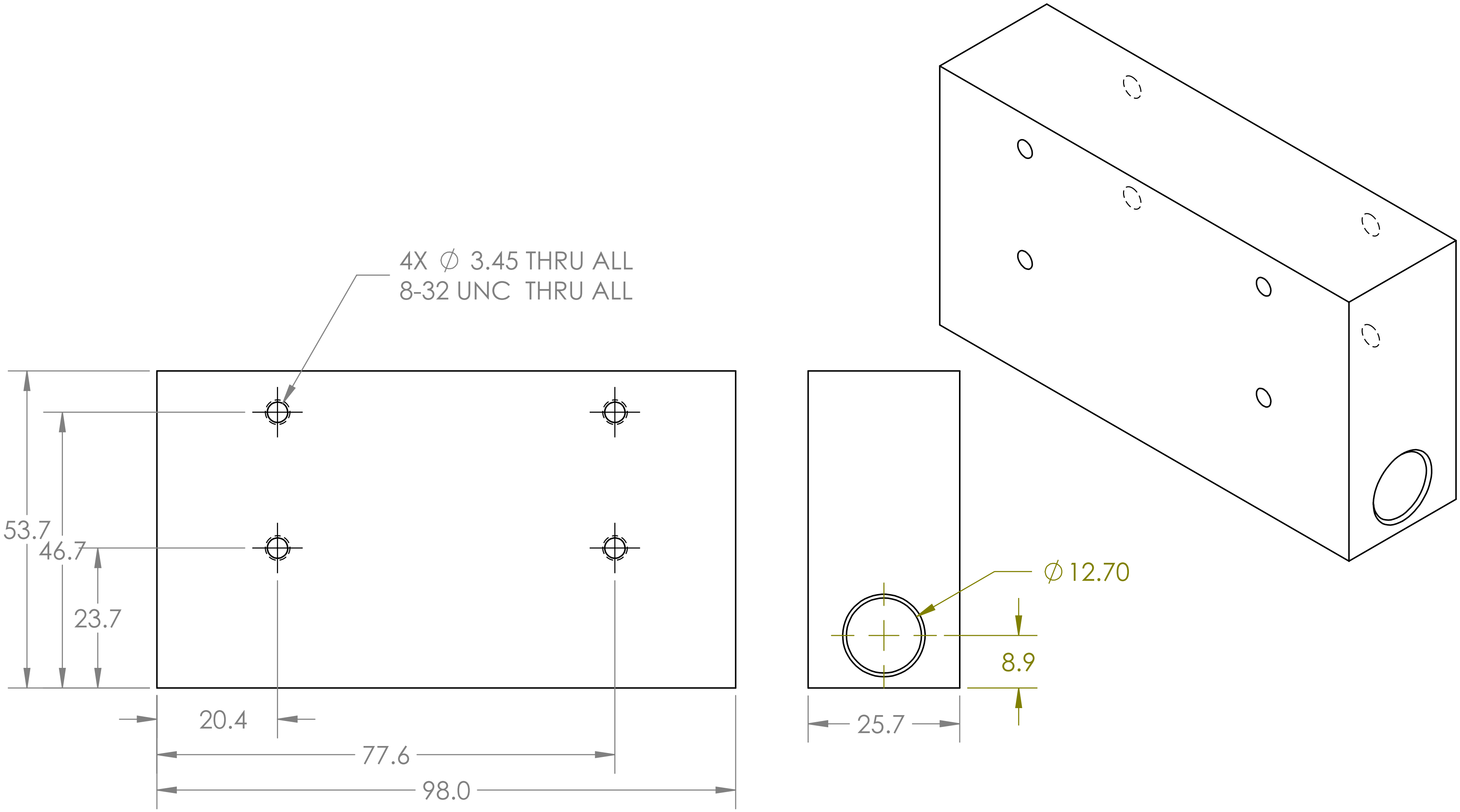

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RODNEY MOUNTING BLOCK

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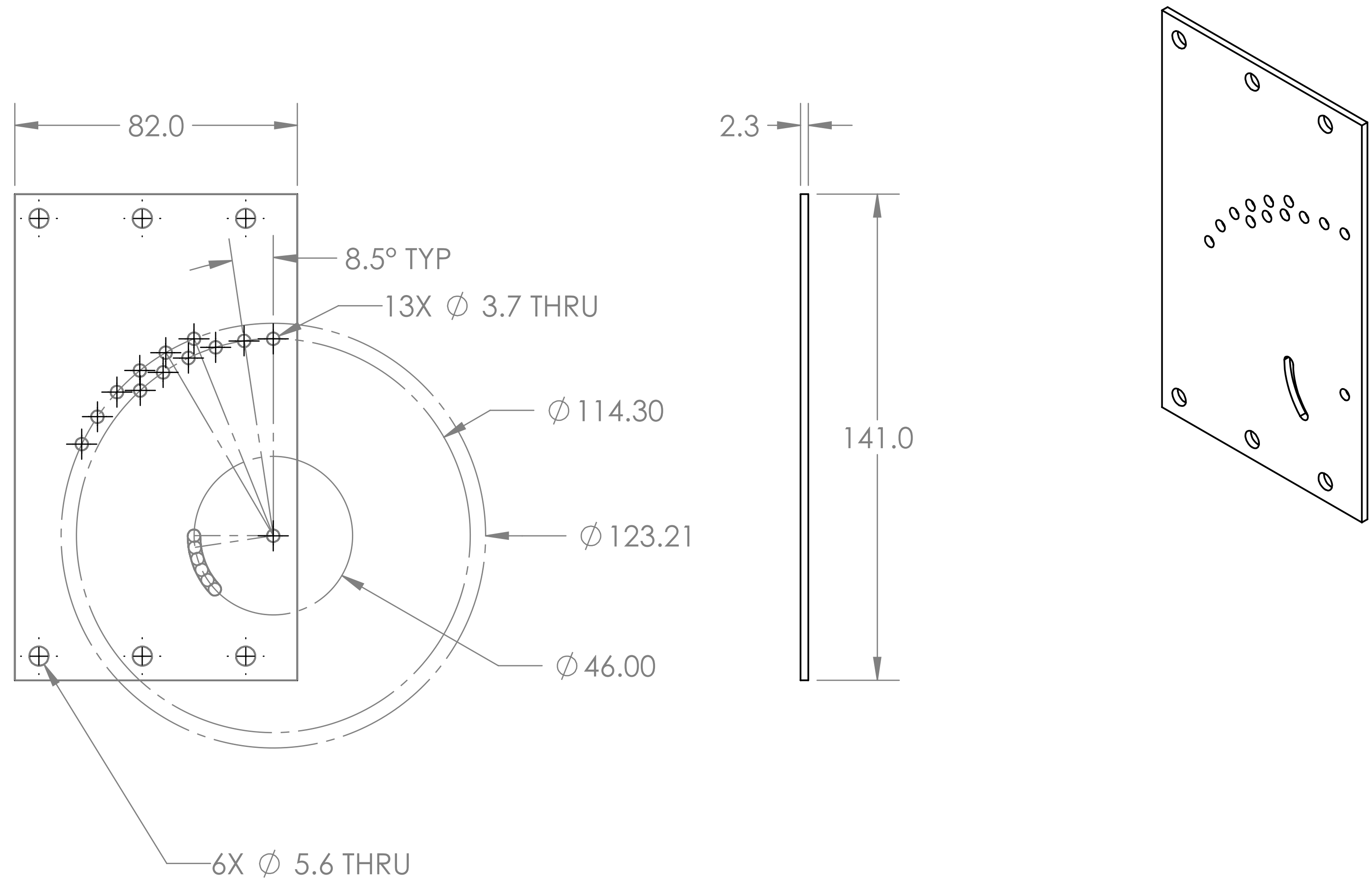

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	MFG APPR.			
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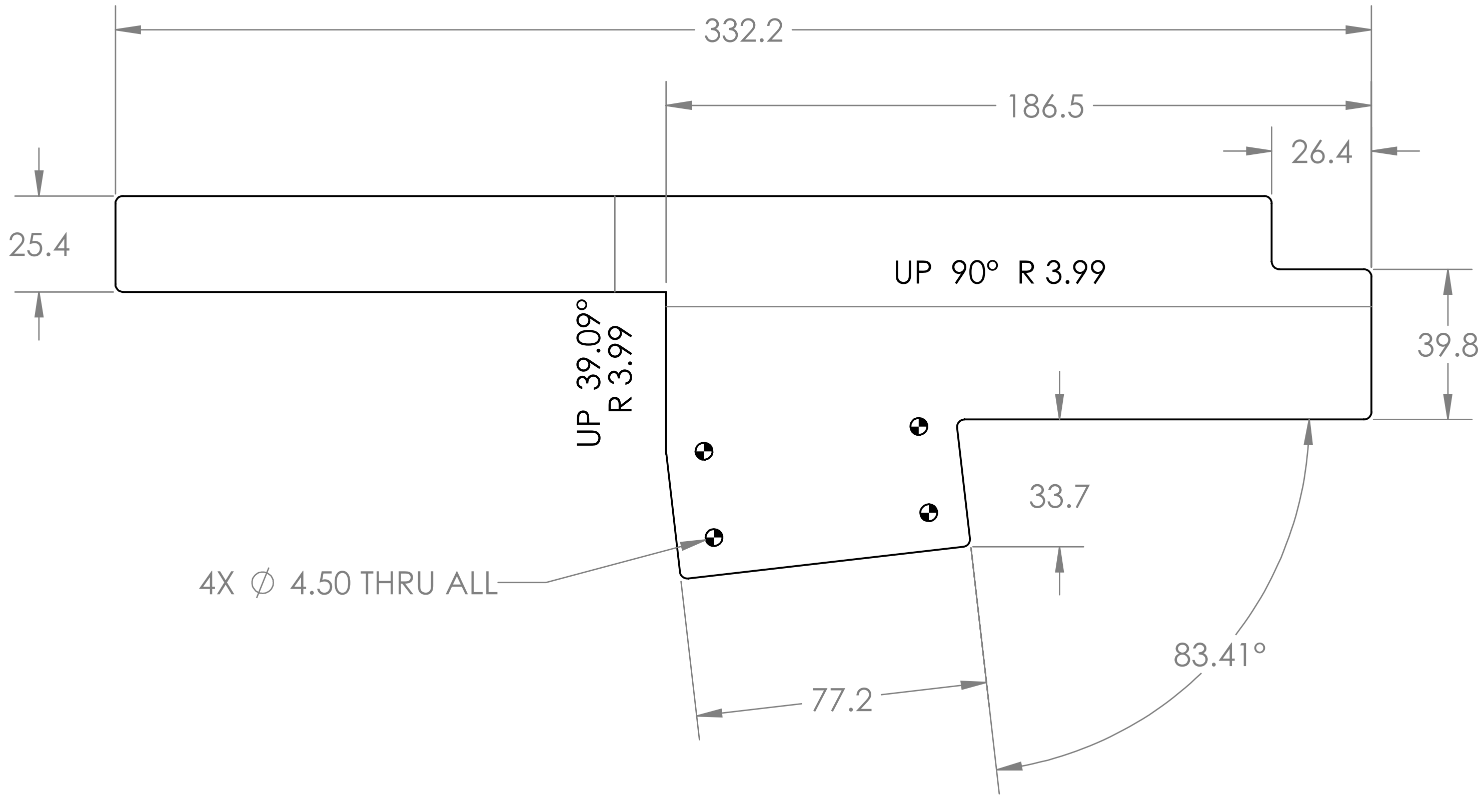

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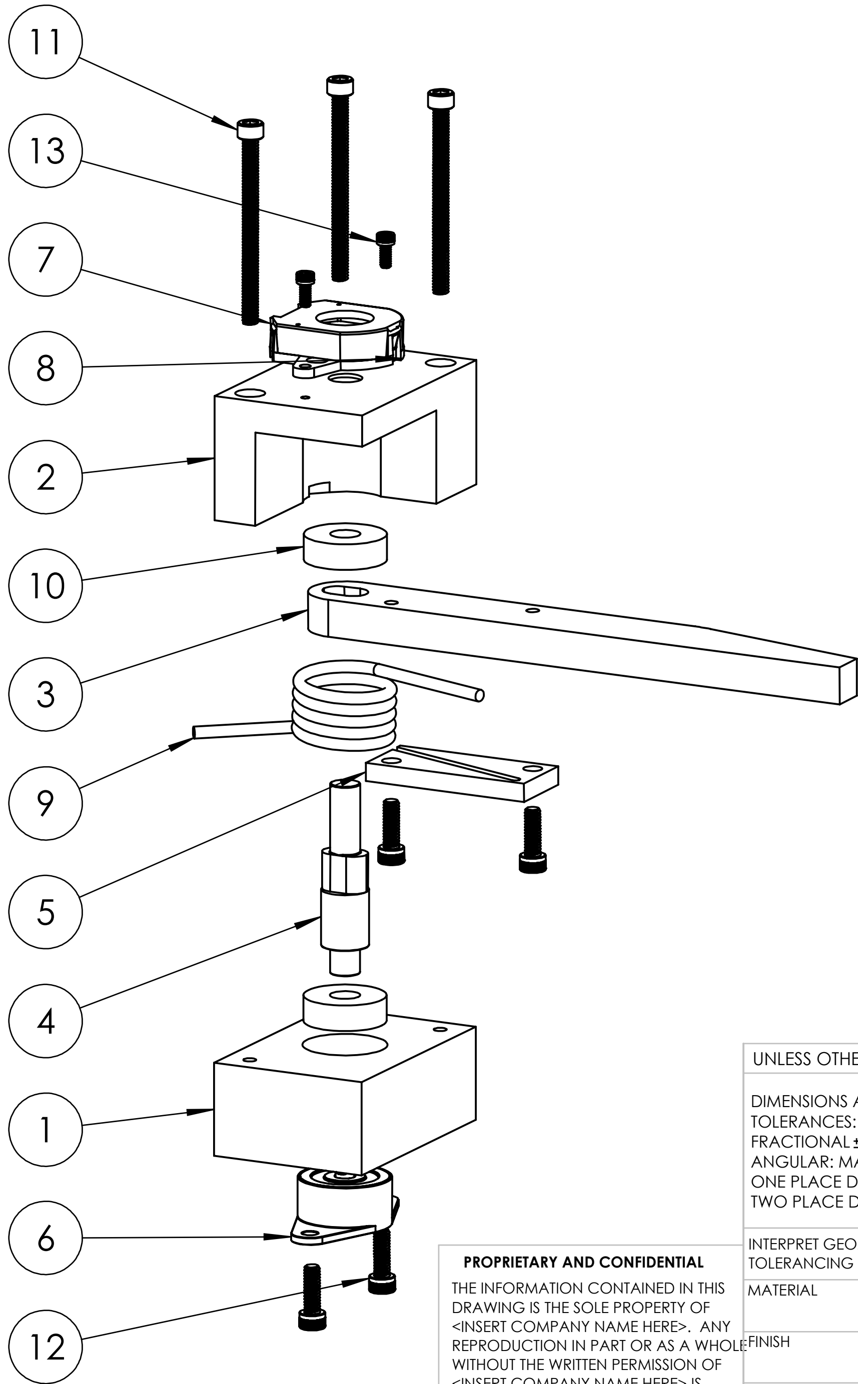

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2	0011A	Top	1
3	0012A	Arm	1
4	0013A	Shaft	1
5	0014A	Spring Cover	1
6	6597K126	Rotary Speed Limiter	1
7	AMT-203_303	Rotary Encoder	1
8	AMT-X03	Endoder Mount Wide	1
9	9271K123	Torsion Spring	1
10	0018A	608-2R Bearing	2
11	90044A113	2" 8-32 Socket Head Screw	3
12	91251A194	.5" 8-32 Socket Head Screw	4
13	91251A106	.25" 4-40 Socket Head Screw	2

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MATERIAL

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	NAME	DATE
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CHECKED	RYAN H	2/22/24
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

R.E.A.P.E.R

TITLE: Whisker Exploded View

SIZE A | DWG. NO. 003 | REV A

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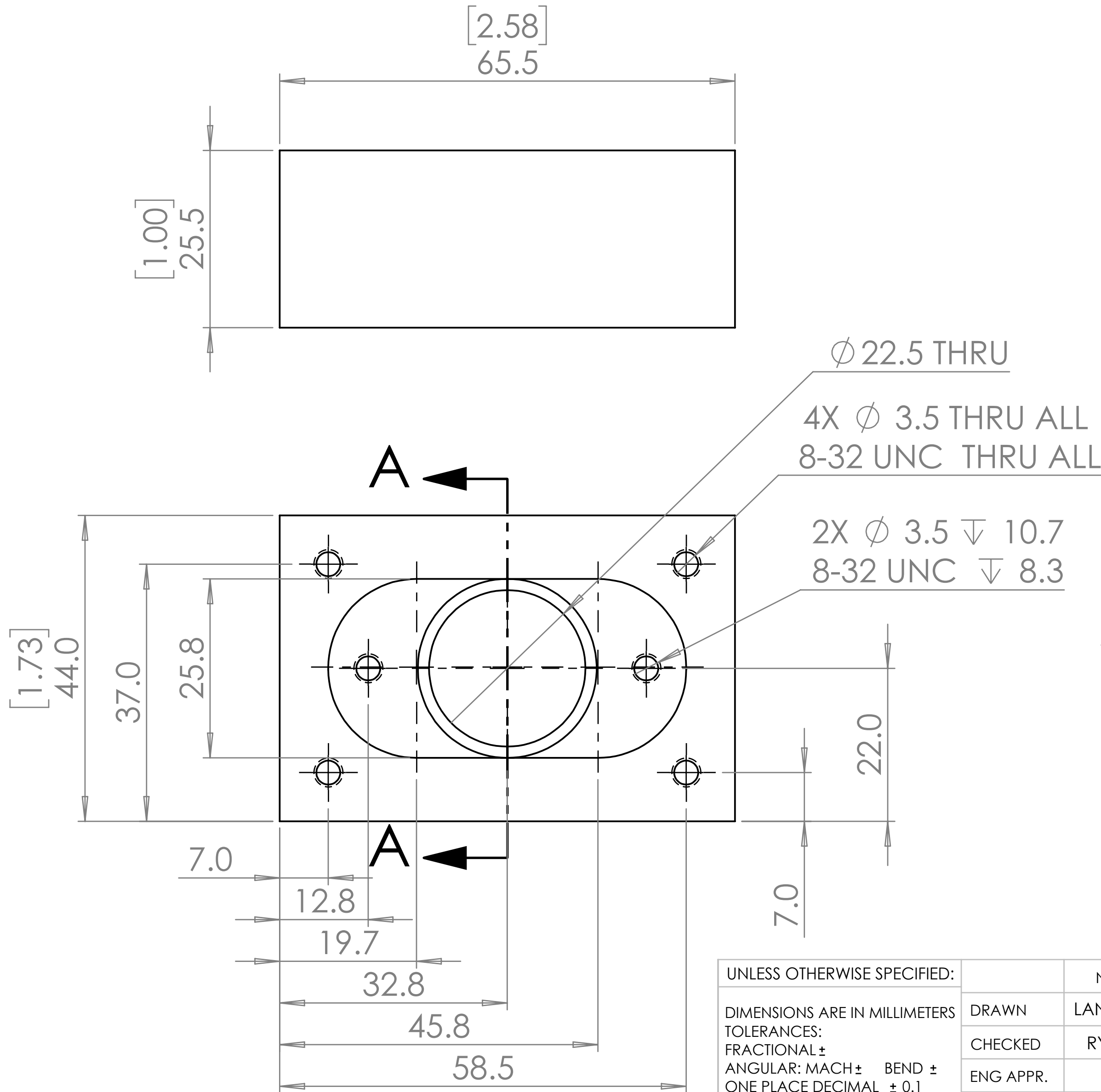

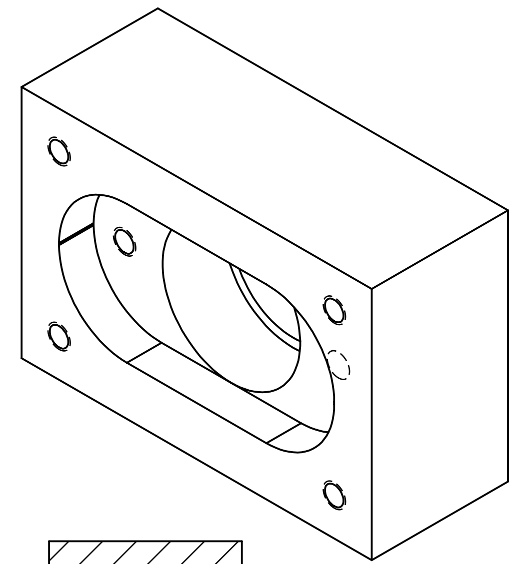

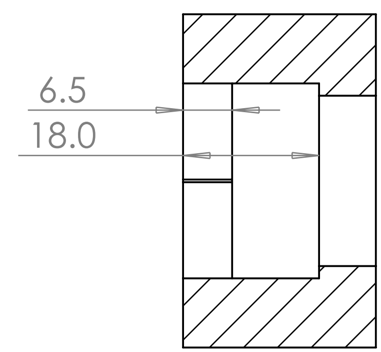

SECTION A-A

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MATERIAL Aluminum	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

R.E.A.P.E.R

TITLE:

Whisker Base

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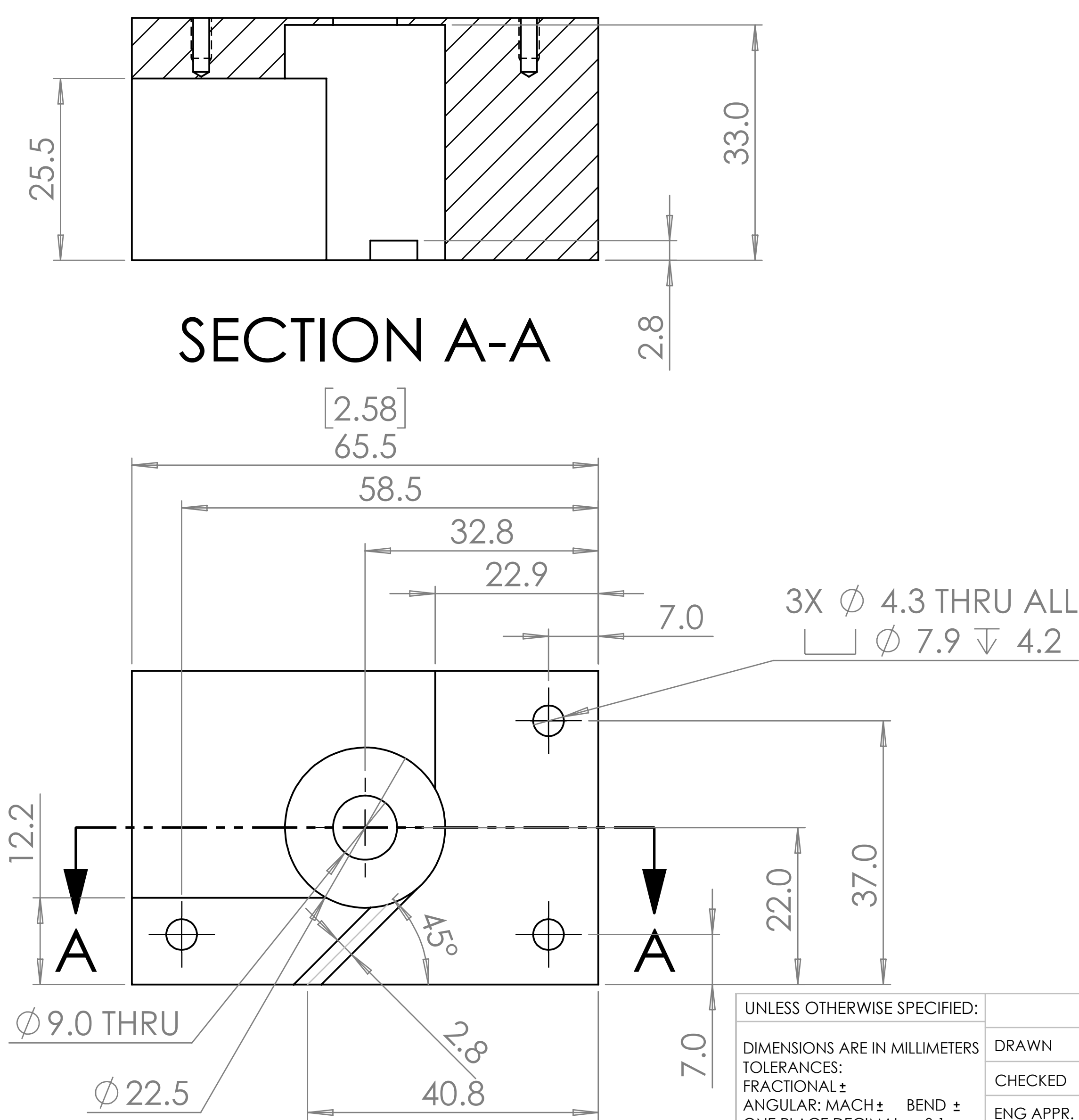

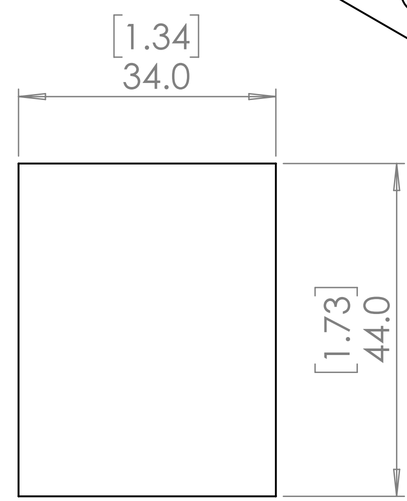

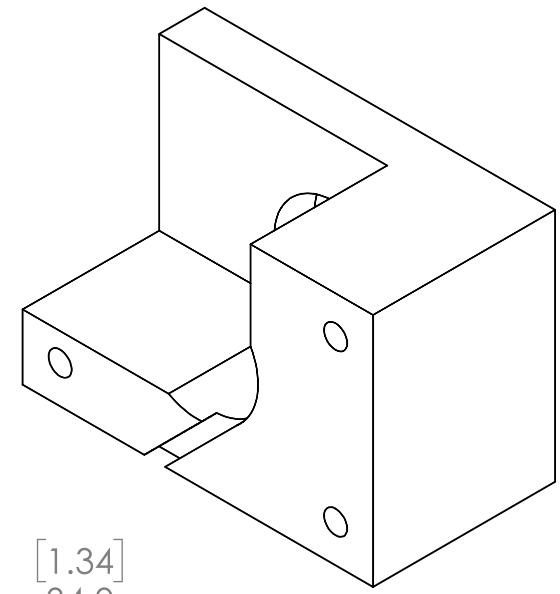

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	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Aluminum	COMMENTS:		
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R.E.A.P.E.R

TITLE:

Whisker Top

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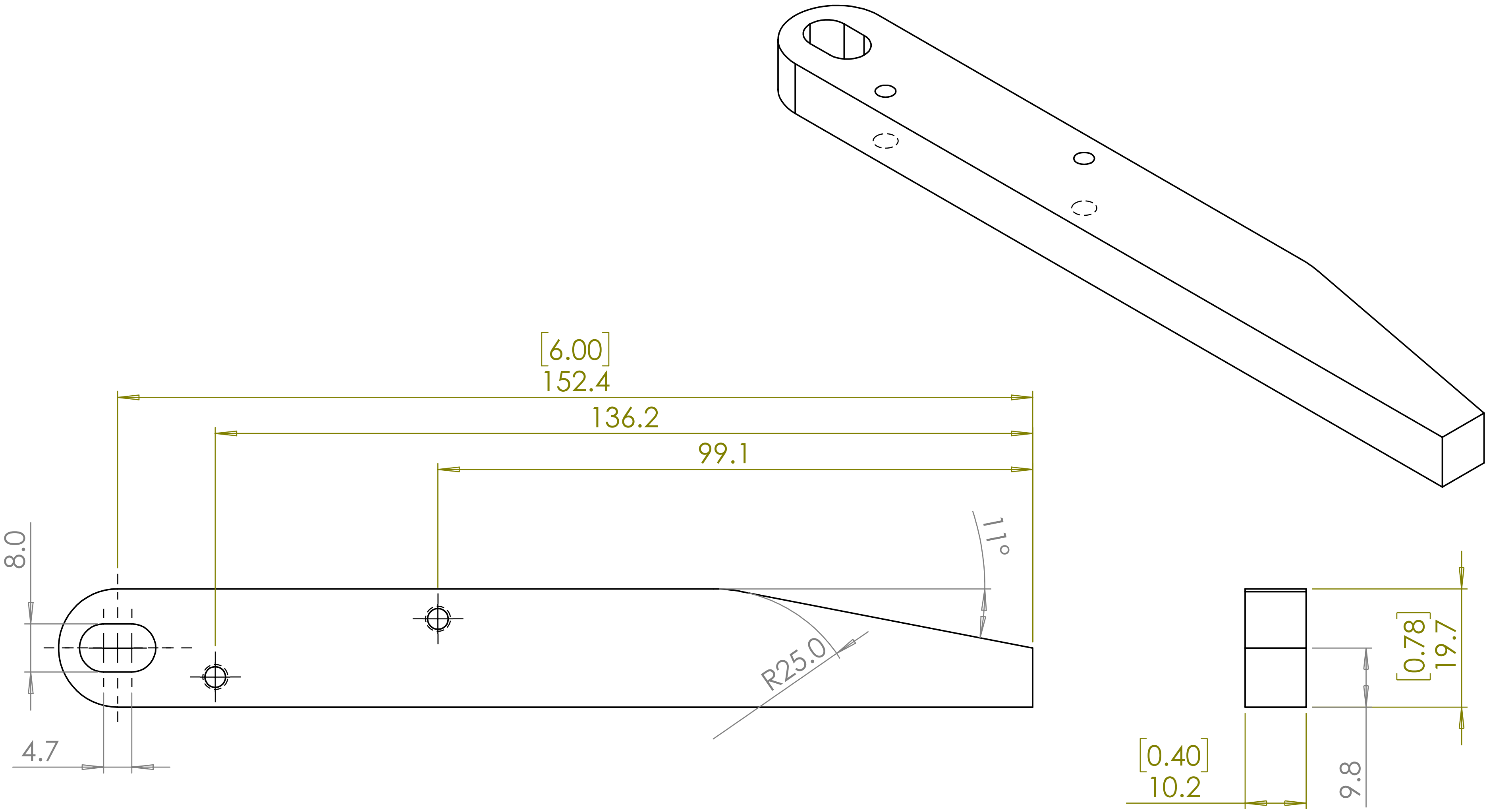

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MATERIAL Aluminum	COMMENTS:		
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TITLE:

Whisker Arm

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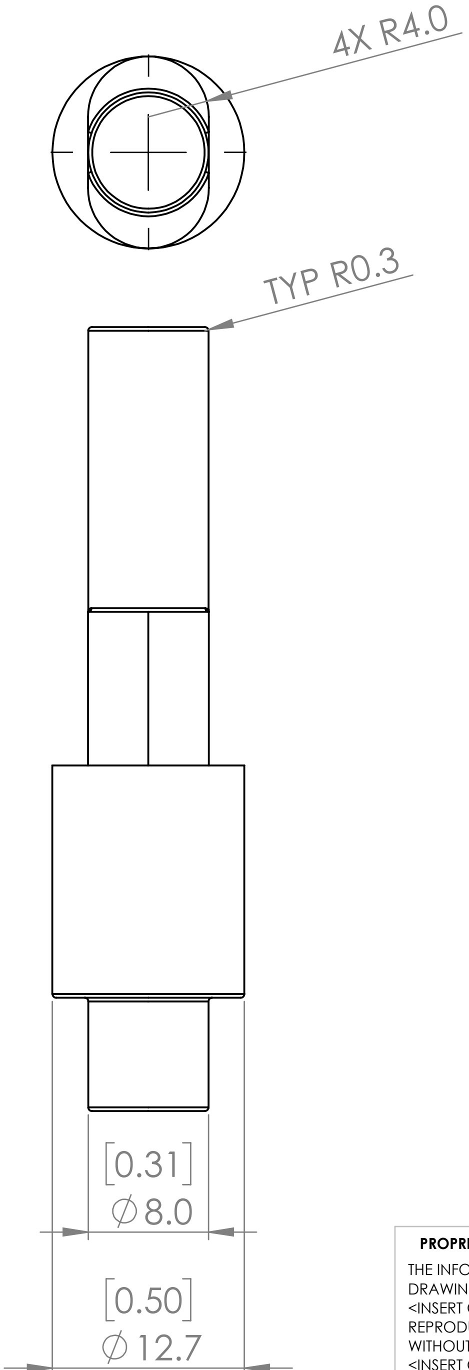

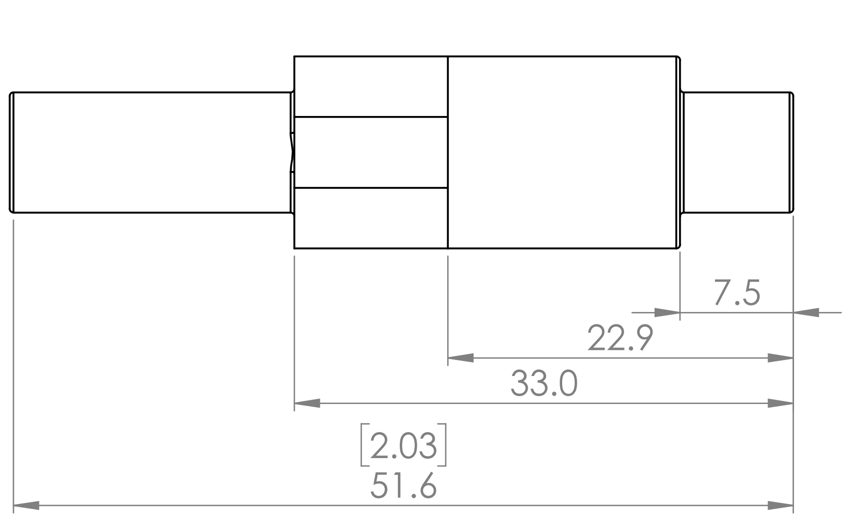

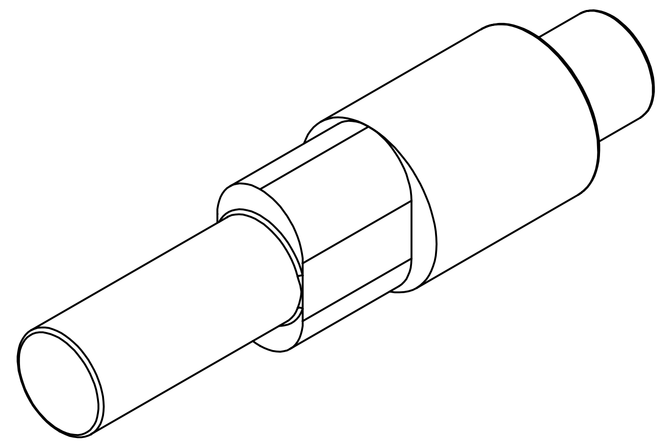

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	MFG APPR.		
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TITLE:

Whisker Shaft

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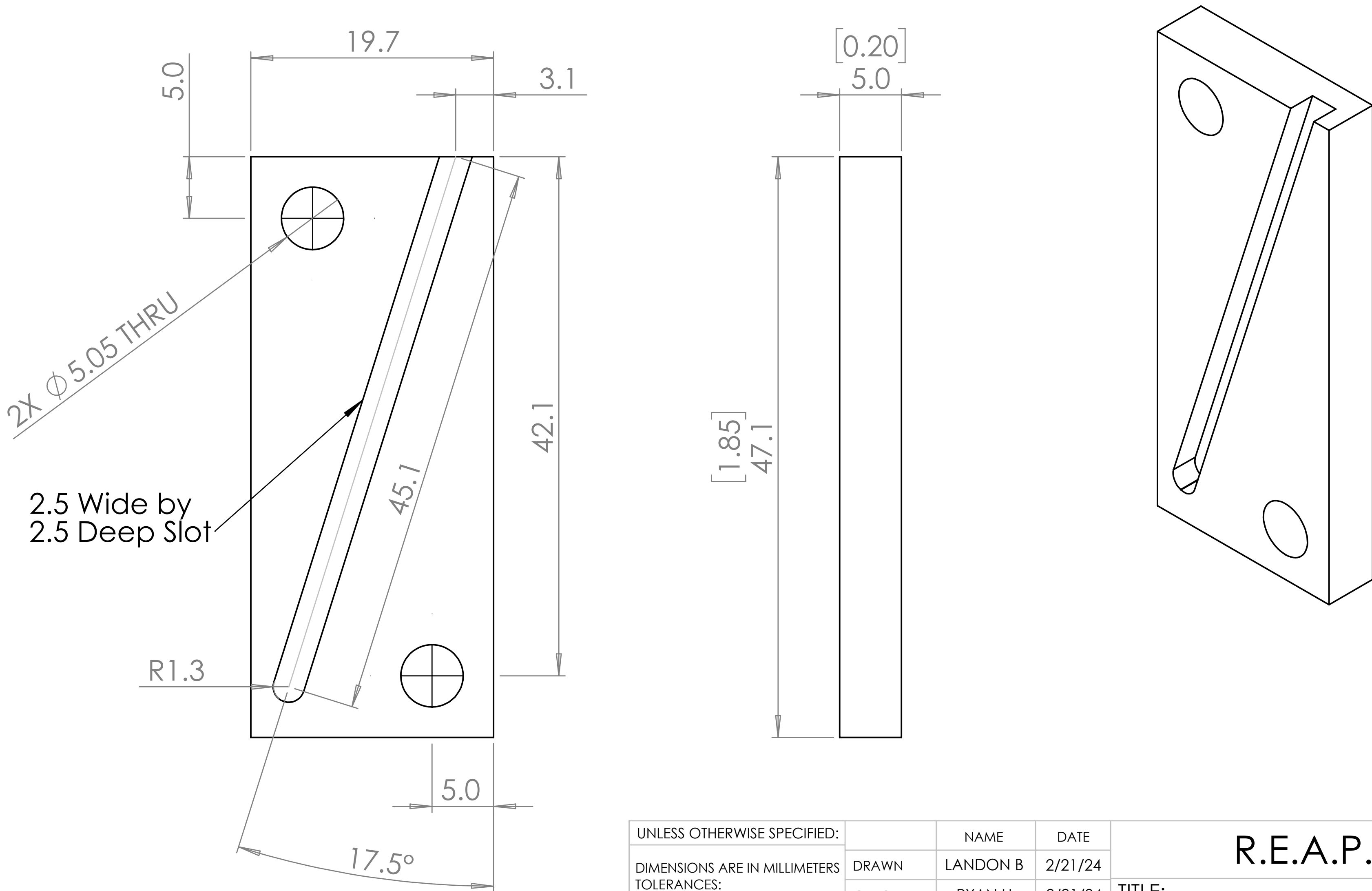

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± 0.1 deg
ONE PLACE DECIMAL ± 0.1
TWO PLACE DECIMAL ± 0.05

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	LANDON B	2/21/24
CHECKED	RYAN H	2/21/24
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

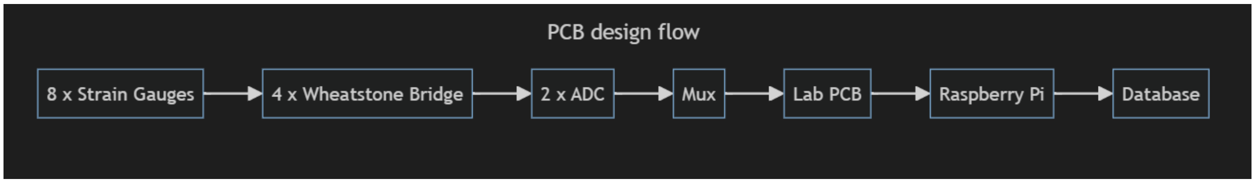
R.E.A.P.E.R

TITLE:

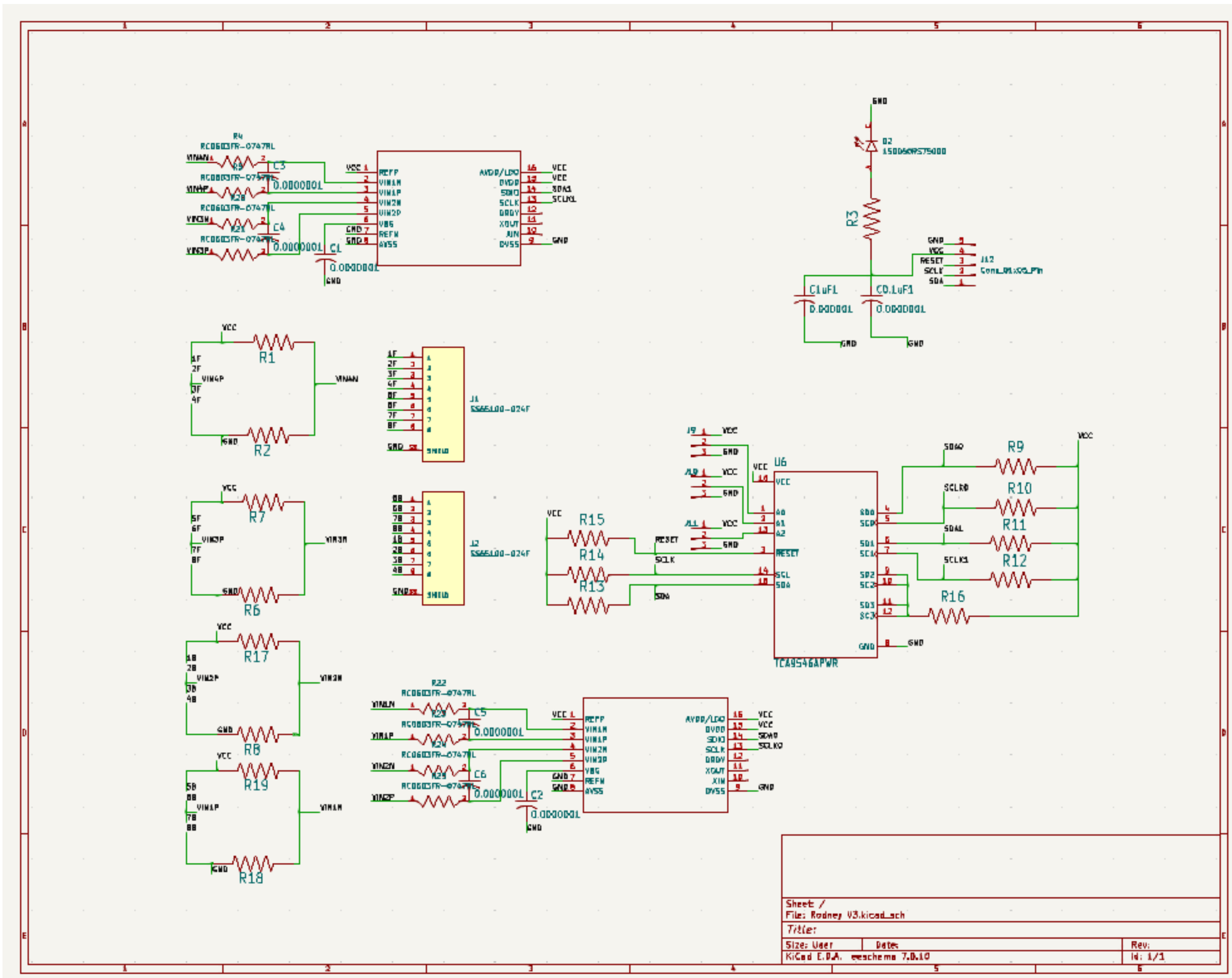
Spring Cover

SIZE	DWG. NO.	REV
A	0014A	A

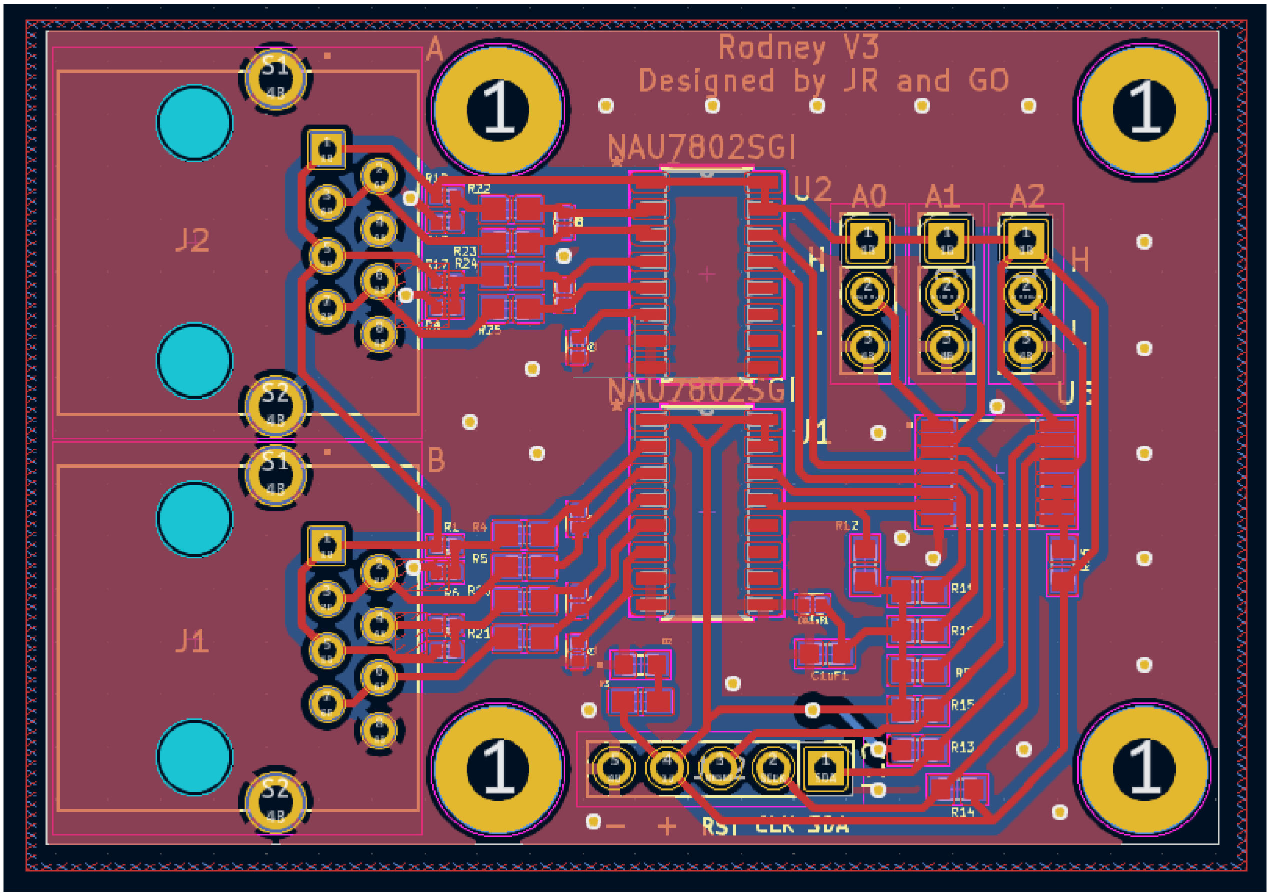
SCALE: 2:1 WEIGHT: SHEET 1 OF 1



PCB design flow
8 x Strain Gauges
4 x Wheatstone Bridge
2 x ADC
Mux
Lab PCB
Raspberry Pi
Database



R1
R2
R7
R6
R17
R8
R19
R18
R15
R14
R13
R9
R10
R11
R12
R16
R3
U6
TCA9546APWR
Sheet: /
File: Rodney V3.kicad_sch
Title:
Size: User
Date:
Rev:
KiCad E.D.A. eeschema 7.0.10
Id: 1/1


Rodney V3
Designed by JR and GO
NAU7802SGI
NAU7802SGI
U2
A0
A1
A2
J2
J1
A
B
RST CLK SDA

Arifact ID	Artifact Title	Revision:	Date:
BOM-001	RODNEY BOM	4	2/22/2024
Team: R.E.A.P.E.R.			
Prepared By: Landon Beutler		Checked By: Nathan Ludlow	

Revision History

Rev.	Date.	Changed By	Checked By	Description	ECO
A	11/30/2023	Landon B	Jeremy R	Initial release	
B	1/16/2024	Landon B	Nate L	Added Parts for casing and whiskers	
C	2/2/2024	Landon B	Nate L	Updated whisker parts and added part numbers	
D	2/21/2024	Landon B	Nate L	Added Pricing, description, and part number to several pa	
E	3/22/2024	Jeremy R	Gustavo O	Updated PCB parts and Cost	

Part No.	Part Name	Description	Qty	Drawing	Revision	Build/Buy	Material	Supplier	Supplier Part No.	Purchase/Stock Cost	% Complete
001	*Rodney Mechanical*	*Assembly*	*1*	*001*	*A*	*Build*	*N/A*	*N/A*	*N/A*	*221.6968*	*90*
0001A	Rodney Circular Tube	1/2" Dia. 12" Length	1	0001A	A	Buy	Alu TBD	McMaster	89965K491	11.33	100
0002A	Rodney Mounting Block	4 Hole Mount and Casing	1	0002A	A	Build	Alu TBD	N/A	N/A	6.4	100
0003A	Sheet Metal to 8020	6 Hole Pattern	1	0003A	A	Build	Steel TBD	N/A	TBD	5	100
0004A	Rodney Guarding	Impact Protection	1	0004A	A	Buy	Steel TBD	Oshcut	ZM83	48.18	100
0005A	Steel Socket Screw	8-32	8	N/A	A	Buy	Steel TBD	McMaster	91251A199	1.6608	100
0006A	T-Slotted Framing	1/4 - 28	58	N/A	A	Buy	Steel TBD	McMaster	98697A770	68.556	100
0007A	Button Head Hex	1/4 - 28	58	N/A	A	Buy	Steel TBD	McMaster	91255A553	12.1452	100
0008A	Waterproof Top	Lid for Casing with Gasket Inset	1	0008A	A	Build	Alu TBD	N/A	N/A	10.78	90
0009A	Case Gasket	Seals Casing	1	0009A	A	Build	TPU	N/A	N/A	1.11	10
0023A	Strain Gauges	DAOKI 350 ohm High Precision Pressu	8	N/A	A	Buy	N/A	Amazon	BF350-3AAA	8.91	100
0024A	Solder Pads	Isolate Strain Measurements	8	N/A	A	Buy	N/A	Mouser Electroni	951-SP900S-0(	16.18	100
0022A	4-40 Bolt	0.25" 4-40 Socket Head Screw	3	N/A	A	Buy	Steel	McMaster	91251A106	0.3348	100
0025A	Cable	CAT5e Ethernet	1	N/A	A	Buy	N/A	Amazon	8233T33	31.11	100
003	*Whisker Mechanical*	*Assembly*	*2*	*003*	*A*	*Build*	*N/A*	*N/A*	*N/A*	*109.322*	*100*
0010A	Whisker Base	Encases Damper	1	0010A	A	Build	Alu	Prototyping Lab	N/A	4	100
0011A	Whisker Top	Encases shaft, spring, and encoder mo	1	0011A	A	Build	Alu	Prototyping Lab	N/A	4	100
0012A	Whisker Arm	Contacts stalks	1	0012A	A	Build	Alu	Prototyping Lab	N/A	3	100
0013A	Whisker Shaft	Base for arm	1	0013A	A	Build	Steel	Prototyping Lab	N/A	2	100
0014A	Spring Cover	Holds spring in arm	1	0014A	A	Build	Alu	Prototyping Lab	N/A	2	100
0015A	Whisker Damper	Prevents hard impact and oscilation	1	N/A	A	Buy	N/A	McMaster	6597K132	34.265	100
0016A	Whisker Encoder	Measures stalk deflection	1	N/A	A	Buy	N/A	Arrow Electronic	AMT203S-V	48.425	100
0017A	Encoder Mount	Wide Base encoder mount	1	N/A	A	Buy	N/A	Arrow Electronic	AMTX03	0	100
0018A	Whisker Spring	Resets tracking for next stalk	1	N/A	A	Buy	Stainless	McMaster	9287K186	10.775	100
0019A	Bearing	608-2RS Scateboard Bearing	2	N/A	A	Buy	Steel	Amazon	608 - 2RS Ball	0.857	100
0020A	8-32 Bolt	2" 8-32 Socket Head Screw	3	N/A	A	Buy	Steel	McMaster	90044A113	1.6944	100
0021A	8-32 Bolt	0.5" 8-32 Socket Head Screw	4	N/A	A	Buy	Steel	McMaster	91251A194	1.1136	100

0022A	4-40 Bolt	0.25" 4-40 Socket Head Screw	2	N/A	A	Buy	Steel	McMaster	91251A106	0.4464	100
002	*PCB*	*Assembly*	*2*	*S-2*	*B*	*Build*	*N/A*	*JLCPCB*	*N/A*	*$91.23*	*100*
0026A	Resistor	By JLCPCB	8	N/A	B	Buy	N/A	JLCPCB	RESC1005X40	N/A	100
0027A	Resistor	By JLCPCB	8	N/A	B	Buy	N/A	JLCPBC	RESC1608X50	N/A	100
0028A	Resistor	By JLCPCB	8	N/A	B	Buy	N/A	JLCPCB	RESC1608X55	N/A	100
0029A	1x3 Selector Header	By Hand	3	N/A	B	Buy		ELC	PinHeader_1x(	$0.27	100
0030A	Capacitors	By JLCPCB	7	N/A	B	Buy		JLCPCB	CAPC1005X55	N/A	100
0031A	Resistor Led	By JLCPCB	1	N/A	B	Buy		JLCPCB	R_0201_0603N	N/A	100
0032A	Green Led	By JLCPCB	1	N/A	B	Buy		JLCPCB	LED_150060R	N/A	100
0033A	1x5 Molex	By Hand	1	N/A	B	Buy		ELC	PinHeader_1x(	$0.15	100
0034A	MUX	By JLCPCB	1	N/A	B	Buy		JLCPCB	SOP65P640X1	N/A	100
0035A	ADC	By JLCPCB	2	N/A	B	Buy		JLCPCB	NAU7802SGI	N/A	100
0036A	Ethernet Port Fem	By Hand	2	N/A	B	Buy		ELC	BEL_SS65100-	$3.07	100
0037A	Capacitor Filtering	By JLCPCB	1	N/A	B	Buy		JLCPCB	CAPC1608X90	N/A	100

Artifact ID:	Artifact Title:
CF-1	Computer Files
Revision: 00	Revision Date: 05 FEB 2024
Prepared by: Ryan Hall	Checked by:
Purpose: To show the results of our prototypes	

Revision History			
Revision	Revised by	Checked by	Date
00	Ryan Hall	Caleb Price	05 FEB 2024
01	Caleb Price	Ryan Hall	04 MARCH 2024

The software package is quite large. The easiest way to view all of the computer files is to gain access to the projects repository. Below is a link to the github repository. In order to view this repo you must get permission from Dr. Cook from Brigham Young university.

https://github.com/byu-crop-biomechanics-lab/FIELDAQ-Software-and-Electronics

Artifact ID:	Artifact Title:	
IFD-1	Interface Definitions	
Revision: 01	Revision Date: 23 FEB 2024	
Prepared by: Nathan Ludlow	Checked by: Ryan Hall	
Purpose: To define how the various subsystems interface.		

Revision History			
Revision	Revised by	Checked by	Date
01	Nathan Ludlow	Ryan Hall	12 DEC 2023
02	Ryan Hall	Landon Beutler	15 FEB 2024
03	Nathan Ludlow	Ryan Hall	23 FEB 2024
04	Ryan Hall	Nathan Ludlow	04 MARCH 2024

	Software	PCB	Whiskers	Rodney
Rodney			●	
Whiskers	●			
PCB	●			
Software				

Figure 35: Interface matrix for Rodney. Shows which subsystems interface with each other.

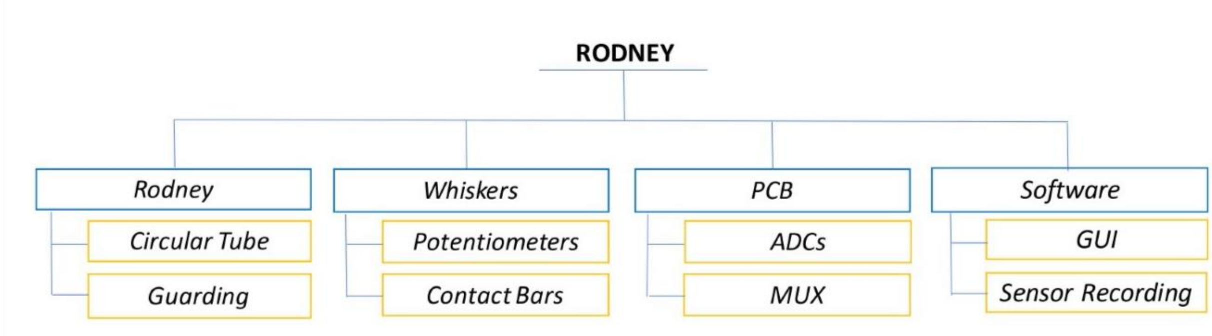


Figure 36: Structural decomposition of the Rodney. Lists the various sub-systems with their components.

Table 6: Interface definition table for Rodney. Defines the individual subsystems, their interface functions, their key performance measures, and the team responsible for it.

Interface Between	Interface Functions	Performance Measures	Responsibility
Rodney	Rigidly fix the circular tube in place To press against corn stalks Guarding prevents corn from deflecting certain parts of the sensor package. Attaches to mounting block. interface with strain gagues	Angle of Deflection <2 degrees 0.2% < Yield strain < 0.4% 10,000 Cycles <Failure Correctly reads values at over 100Hz	Mechanical Hardware Team
Whiskers	Contacts all corn stalks in a field Reads potentiometer values in real time	Over 95% of stalks contacted Samples at greater than 100Hz	Mechanical Hardware Team
PCB	Converts analog voltage readings into binary values Add Terminals to PCB so they can interact with the sensors	Samples/Second with 24-bit resolution Percentage of terminals converted to new type 0-100 percent	Electrical Hardware Team

Software	Coding interface that allows the user to select which device he is using and collect data	60Hz refresh rate, clean, easy to use, works outside	Software Hardware Team
	Responsible for coding and making sure the data is measured and displayed accurately	0 bugs, works 100% of the time, able to process data real time	

Artifact ID: TR-1	Artifact Title: Test Procedures and Results	
Revision: 00	Revision Date: 05 FEB 2024	
Prepared by: Nathan Ludlow	Checked by:	
Purpose: To show the resting procedures and results of each of our subsystems		

Revision History			
Revision	Revised by	Checked by	Date
00	Ryan Hall		05 FEB 2024

Our complete system testing has not yet been completed and as such the following document includes testing only from individual subsystems.

Rodney

We performed 3 separate tests on Rodney to validate its effectiveness:

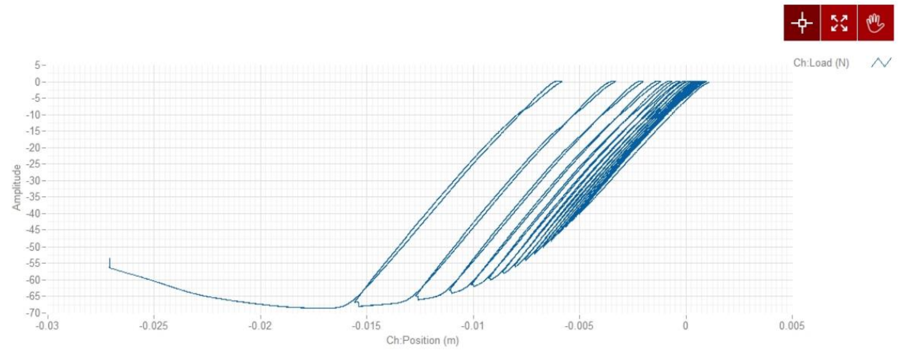
<u>3 Point Bending</u>

To test the material properties of Rodney we performed 3-point bending testing on the circular tubing used to construct the Rodney. The material properties of the beam are important to both use as constants in our beam bending calculations that determine the stress in the corn stalk, as well as to determine the robustness of Rodney to plastic deformation under use. The results of each of the 3 tests can be seen below.

Figure1: 3-Point bending test results

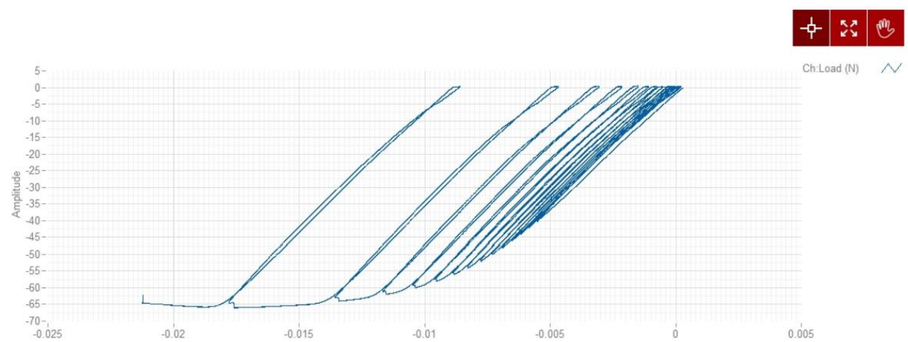
Specimen details

Specimen ID	Date	Time	Type	Gauge Length
half_inch_rodney_3_12072023_103317	12/7/2023	10:33 AM	None	1in

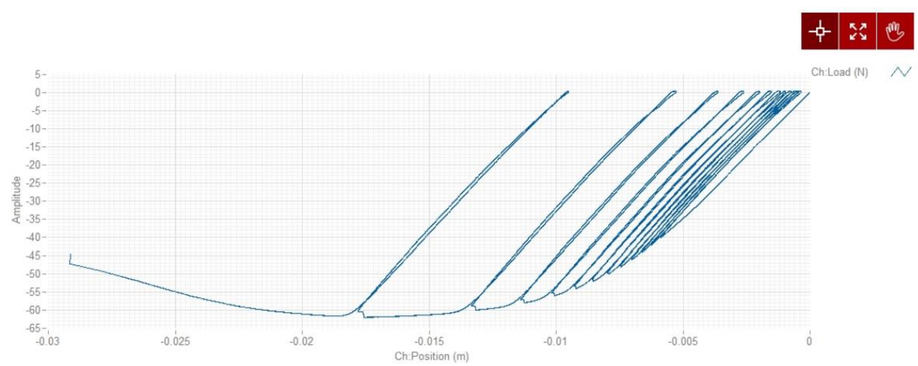


Specimen details

Specimen ID	Date	Time	Type	Gauge Length
half_inch_rodney_2_12072023_102743	12/7/2023	10:27 AM	None	1in



Specimen ID	Date	Time	Type	Gauge Length
half_inch_rodney_1_12072023_102307	12/7/2023	10:23 AM	None	1in



This figure shows the three individual 3-point bending tests performed on the circular tubing used for Rodney. The results indicates that Rodney failed consistently at approximately 70N of applied force, and from visual inspection it was determined that the mode of failure was buckling. This corresponds to a yield strain of approximately 0.3% in the beam before failure.

Assembly fit

To validate the mechanical design and fabrication of the Rodney system we performed an assembly test to fit together all the components. This involved individually assembling the guarding used for Rodney onto the mounting plate at each possible mounting angle. After ensuring the fit of the guarding to the mounting plate we assembled the Rodney measurement system and attached it to guarding. Finally, after validating the fit of the measurement system to the guarding we tested the fit of the complete system. Upon ensuring the complete fit of the system in all possible configurations we determined that our mechanical tolerances, and dimensions were correct for Rodney.

System Calibration and Validation

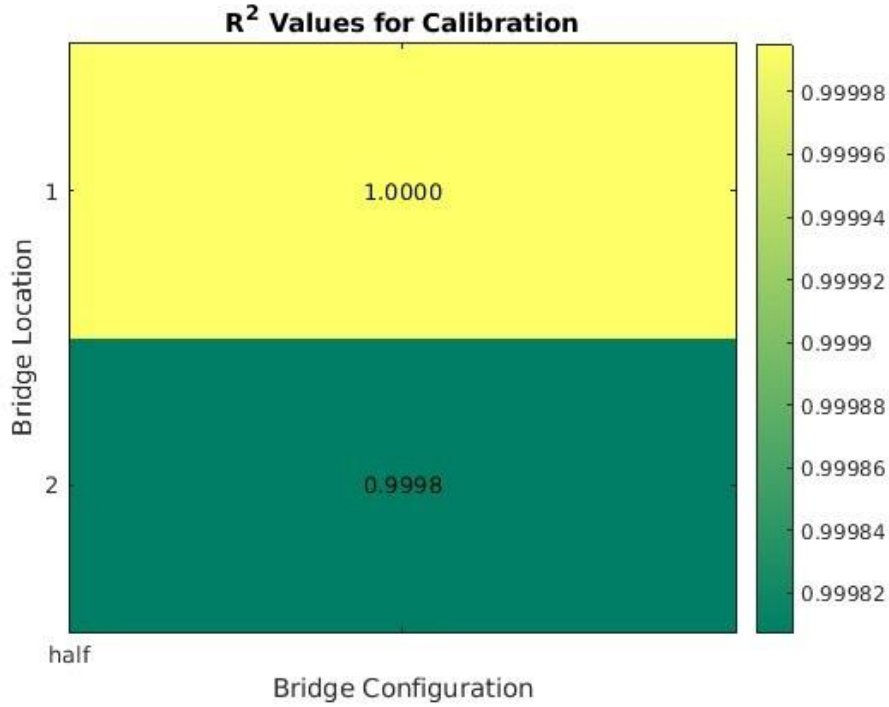
In order to validate the mounting of the strain gauges on the beam, and the sensitivity of the system to force inputs from multiple orientations we performed a calibration to determine the nominal strain gauge resistances, the mounting locations of the strain gauges, and the resistor values in the Wheatstone bridge. To perform this calibration, we fixed Rodney to a rigid surface, and hung masses of known weight from specified distances along the beam. We then gathered static data from these known masses, and using a Monte-Carlo optimization we determined the values of each of the above listed constants. The results of this calibrations can be seen in the table below.

Table 1: Calibration values for Rodney System

c1x	0.0053
c2x	0.0057
k1x	0.0849
k2x	0.0254
d1x	0.0912
d2x	0.1115
c1y	0.0054
c2y	0.0057
k1y	0.0653
k2y	0.0341
d1y	0.0954
d2y	0.1023

From these calibrations we can determine not only the exact values of the calibration coefficients, but also the functionality of the system. After preforming the monte-carlo optimization on the calibration values we can obtain a R^2 fit for the accuracy of the calibration which can be seen below.

Figure 2: Calibration R^2 values for Rodney



This figure shows the R^2 values for the calibration of the Rodney system. The bridge location refers to the direction of the strain gauges, Bridge 1 is in the X orientation, and Bridge 2 I in the Y orientation.

Whiskers

PCB

We used the software to check that we could read from each ADC through the mux. Once the values changed consistently, we knew the ADCs were responding correctly.

Software

In the below graph we show how we were able to measure the ease of learning how to use the new software package.

Measurement	Metric	Process	Results	Final Result (AVG)
Clicks to get data	Number of Clicks	Counted Number of Clicks from startup to collecting data	15,18,12,11,17	15 Clicks
Lag between Clicks	Time in seconds	Timed the time between clicking the screen and Reaction	.4,.5,.6, .3,.7	.5 Seconds
Professional Look	Opinion of Sponsor	Asked our sponsor if they approved of the design	Approved	Approved by Dr. Cook
Time to Learn how to use	Time in Minutes	Taught other team membes who didn't have experience timed the result	8,10,12,8,12	10 minutes
Active Branches	Number of Branchs	Deleted Unecessary Branch Counted remaining	3	3 Branches
Receiving Data to Graphing on display	Time in seconds	Timed the time between clicking the screen and Reaction	.05, .15, .1, .12,.9	.1 Seconds

Artifact ID:	Artifact Title:
ST-1	Software Testing
Revision: 00	Revision Date: 21 FEB 2024
Prepared by: Caleb Price	Checked by: Gustavo Oliveira
Purpose: To Analise the ease of use of the new software system	

Revision History			
Revision	Revised by	Checked by	Date
00	Caleb Price	Gustavo Oliveira	21 FEB 2024
01	Ryan Hall	Jeremy Read	22 FEB 2024

In the below graph we show how we were able to measure the ease of learning how to use the new software package.

Measurement	Metric	Process	Results	Final Result (AVG)
Clicks to get data	Number of Clicks	Counted Number of Clicks from startup to collecting data	15,18,12,11,17	15 Clicks
Lag between Clicks	Time in seconds	Timed the time between clicking the screen and Reaction	.4,.5,.6, .3,.7	.5 Seconds
Professional Look	Opinion of Sponsor	Asked our sponsor if they approved of the design	Approved	Approved by Dr. Cook
Time to Learn how to use	Time in Minutes	Taught other team membes who didn't have experience timed the result	8,10,12,8,12	10 minutes
Active Branches	Number of Branchs	Deleted Unecessary Branch Counted remaining	3	3 Branches
Receiving Data to Graphing on display	Time in seconds	Timed the time between clicking the screen and Reaction	.05, .15, .1, .12,.9	.1 Seconds

Project Success Agreement

07 Dec. 2023

Revision 1.2

A device for rapidly measuring maize stalk stiffness and strength

Project Sponsors:

BYU Crop Biomechanics Laboratory

Capstone Team 9: R.E.A.P.E.R

Nathan Ludlow

Caleb Price

Ryan Hall

Landon Beutler

Jeremy Reed

Gustavo Olivera

Ira A. Fulton College of Engineering

Brigham Young University

Product Success Agreement

Artifact ID:	Artifact Title:
PSA-1	Project Success Agreement
Revision: 02	Revision Date: 07 DEC 2023
Prepared by: Gustavo Oliveira	Checked by: Jeremy Read
Purpose: Written summary of our project requirements, goals, and motivations.	

Revision History			
Revision	Revised by	Checked by	Date
00	Gustavo Oliveira	Jeremy Read	29 NOV 2023
01	Gustavo Oliveira	Jeremy Read	30 NOV 2023
02	Nathan Ludlow	Ryan Hall	07 DEC 2023

Project Background:

Rodney is a sensor package meant to measure corn stalk stiffness. Dr. Cook is our sponsor. Our team will improve upon the work of previous teams in designing a device that can measure corn stalk stiffness non-destructively. We will be manufacturing this device to share with other universities, and each university has its own robot, so the device will have a standard mounting system so all universities can use it easily.

Project Scope

The final product will be a sensor package that will be a product ready to release to the market. The intended market will be scientists growing corn, and farmers who would like data regarding crop harvesting. The package will include the following.

- An integrated sensor package that can measure the flexural stiffness of corn stalks.
- A mounting interface which will allow the sensor to connect to various robots for use in the field.
- An electronic package that allows the product to collect and transfer data recorded to a Raspberry Pi.
- A software package that will allow the user to visualize and collect data more easily.

Product Requirements

Key Success Measures

Measure	Stretch Goal	Excellent Performance (A)	Good Performance (B)	Fair Performance (C or lower)	Lower Acceptable Limit	Ideal	Upper Acceptable Limit
Measures Force and Bending Distance	Variation of 5%	Variation of 15-50%	Variation of 50-70%	Variation of 70-90%	Variation of 95%	Variation of 0%	90%
Device Accuracy	10% error	20-30% error	30-40% error	40-50%	60%	0%	N/A
Quick measurements	2 stalk/sec	1 stalk/sec	.5 stalk/sec	.25 stalk/sec	.125 stalk/sec	5 stalk/sec	N/A
Affordable	$1750	$2000	$2500	$3000	N/A	$2000	$3500

While our project permits a relatively high final error margin, this approach is deemed suitable given its context. In the realm of agricultural robotics, especially for our product's application, obtaining more precise data for each corn stalk is not only extremely challenging in our context but also unnecessary. This is due to the vast amount of data we will be collecting across an entire corn field. With the device analyzing thousands of stalks, a normally distributed measurement error around the true value enables us to accurately determine the average stalk stiffness for the entire field, despite the higher error margins in individual assessments. Enhancing the precision for each stalk measurement would entail a significant reduction in sampling speed, an alteration incompatible with our project's objectives. Such a slowdown would extend the time needed to survey a single field to several days, which is impractical. Therefore, we argue that the accepted level of measurement error is justifiable and has been acknowledged as reasonable by our project sponsor.

Approval Signatures

The following agree to the bounds and procedures of the Project Success Agreement (PSA)

Nathan Ludlow — 12/11/23

Nathan Ludlow — Date

Jeremy Read — 12/11/23

Jeremy Read — Date

Caleb Price — 12/11/23

Caleb Price — Date

Gustavo Olivera — 12/11/23

Gustavo Olivera — Date

Ryan Hall — 12/11/23

Ryan Hall — Date

Landon Beutler — 12/11/23

Landon Beutler — Date

Douglas Cook — 12/12/23

Douglass Cook - Coach — Date

Douglas Cook — 12/12/23

Douglass Cook - Sponsor — Date

Brady Davies
Brady Davies (Dec 13, 2023 12:18 MST) — Dec 13, 2023

Brady Davies – Capstone Instructor — Date

BYU Capstone Team 9 PSA for Signature

Final Audit Report 2023-12-13

Created:	2023-12-13
By:	Lisa Barrager (lc38@byu.edu)
Status:	Signed
Transaction ID:	CBJCHBCAABAAO05XkzLXwqwKF3bii1ThjoRAmEETBwb2

"BYU Capstone Team 9 PSA for Signature" History

Document created by Lisa Barrager (lc38@byu.edu)

2023-12-13 - 3:29:11 PM GMT- IP address: 128.187.112.3

Document emailed to brady_davies@byu.edu for signature

2023-12-13 - 3:29:38 PM GMT

Email viewed by brady_davies@byu.edu

2023-12-13 - 7:18:34 PM GMT- IP address: 128.187.116.16

Signer brady_davies@byu.edu entered name at signing as Brady Davies

2023-12-13 - 7:18:53 PM GMT- IP address: 128.187.116.16

Document e-signed by Brady Davies (brady_davies@byu.edu)

Signature Date: 2023-12-13 - 7:18:55 PM GMT - Time Source: server- IP address: 128.187.116.16

Agreement completed.

2023-12-13 - 7:18:55 PM GMT

Artifact ID:	Artifact Title:	
VDS-1	Vendor Data Sheets	
Revision: 01	Revision Date: 04 MARCH 2024	
Prepared by: Nathan Ludlow	Checked by: Ryan Hall	
Purpose: To define how the various subsystems interface.		