MTB Suspension Tuning DAQ
Critical Design Review (CDR)

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Abstract

This Critical Design Review (CDR) describes the current state of the ‘MTB Suspension Tuning DAQ’ senior design project. This project aims to quantify the suspension settings of mountain bikes (MTB) to improve the riding performance and reduce vibrational discomfort. A data acquisition system (DAQ) will collect data during a ride, which will be analyzed after the fact to suggest changes to the tuning parameters of the suspension. The CDR details the overall design and operation of the system and justifies the design choices made. Further, the plans for manufacturing and testing the verification prototype are laid out and explained.

Since the Preliminary Design Review, most of the progress has been on the electrical systems in the DAQ. The new sensors were selected, and circuits were designed to integrate them into a new iteration of the DAQ. Finally, a new PCB schematic was created, which will be sent off for manufacturing after approval of this CDR. To go along with the electrical system, new code was written to communicate with the new sensors. The next steps involve manufacturing the PCBs, soldering on the electrical components, validating the prototype, and designing the tuning algorithm.

Table of Contents

1. Introduction

In this CDR report, the full design of the Mountain Bike Data Acquisition System is described. The purpose of the DAQ is to collect data during a mountain bike ride. This data will then be processed to recommend tuning changes to improve the performance of the suspension in reducing vibration and increasing bike speed.

Since PDR, many changes have been made to the electrical system of the DAQ, as well as the firmware and the housings. The scope of our project now focuses on building a data acquisition system to start collecting data and justifying our metrics. Section 2 (System Design) describes the design in its entirety, and the way in which it will function. Section 3 (Design Justification) explains why decisions were made about the new design. Section 4 (Manufacturing Plan) goes on to explain how the verification prototype will be produced, from the procurement of materials to the final assembly of created components. Finally, Section 5 (Design Verification Plan) continues to describe how the prototype will be tested to verify that it meets our previously laid out specifications.

After CDR, the remainder of the project will be spent creating the prototype, developing the recommendation algorithm, and field testing. Due to issues with the provided DAQ this project was based around, the scope of this project changed somewhat. Most of this quarter was spent troubleshooting and redesigning the firmware and hardware of the DAQ system, rather than focusing on the algorithm and figures of merit as planned. The Spring Quarter will be mostly spent testing and tuning. As we test, we will be able to iterate and improve our algorithm until it demonstrably improves the bike's speed and comfort.

2. System Design

The MTB DAQ System is a modular, portable system that is compatible with any bike a person would ride off roads or on mountains. The system consists of one central unit and two auxiliary sensor units that can be mounted in several different locations on a bike. By strapping on the sensors and main unit and connecting them with cables, data can be collected with the press of a button without impeding the user's ability to ride their mountain bike down their favorite trail. Our system can functionally be broken down into 6 subsystems:

1. Mount & Protect Unit
2. Power Unit
3. Interface with Rider
4. Collect Data
5. Store Data
6. Interpret Data

To mount our system components, sensors will be inserted into custom designed 3D printed housings made of PLA, shown in Figure 1. The printed circuit board containing the sensor and associated circuitry slides into a slot until the unit is fully enclosed and snug within the housing, at which point the holes in the PCB align with holes in the housing and screws are inserted to fix it in place. The angled outer surface opposite the screws provides two points of contact with the fork housing and seat stay for each respective sensor.

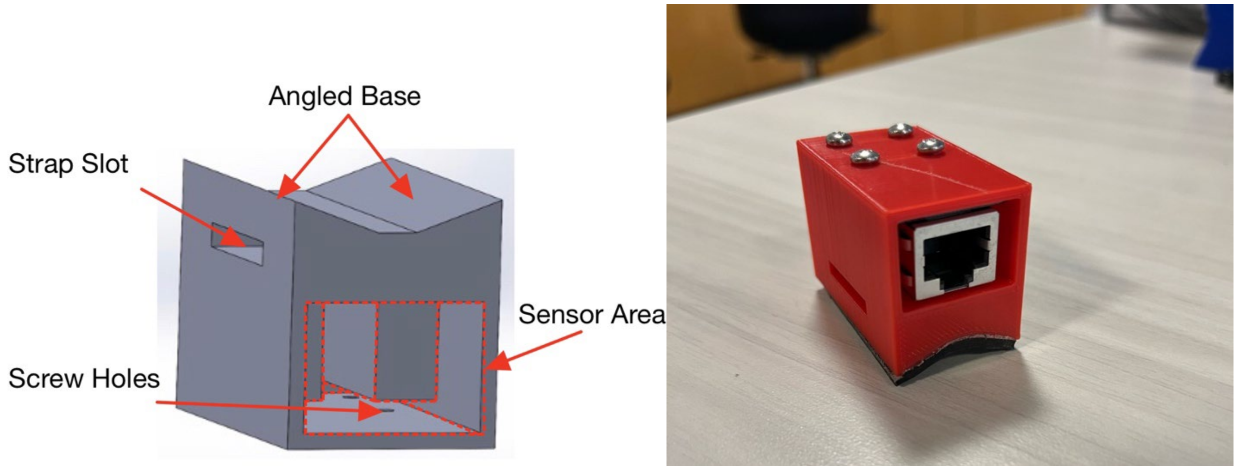


Figure 1: Accelerometer CAD and Housing with Accelerometer PCB Inserted

The rear sensor on the seat stay contains an accelerometer only, while the front sensor on the fork housing contains an accelerometer and a hall effect sensor. This component senses the presence of the spoke magnet clipped to the front wheel and sends a signal when the magnetic fields interact. This will record angular speed of the wheel and, with the diameter of the wheel, can be used to calculate the velocity of the bike assuming a no slip condition between the wheel and ground. These accelerometer positions can be seen in Figure 2.

Figure 2: Accelerometers Positioned at the Fork and Seat-stay Respectively

As shown in Figure 3, The main unit is mounted to the center of the bike frame with two screws fastening the housing to the water bottle bosses. This unit contains the main board with accelerometer and gyroscope, microcontroller, ethernet ports, Micro SD card slot, and USB Mini B port for charging. It also contains a connected User Interface board with LED indicators, record button, and display screen. Additionally, 5 batteries are connected in parallel to supply power to the unit. Specifications for all electronic components can be found in Appendix A.

Figure 3: Mounted Main DAQ System on Bike Frame

During operation, the rider flips the power switch to turn on the main unit and then holds the bike still on flat ground while the accelerometers calibrate so their biases can be calculated. Once the rider is ready, they press the record button to begin data collection, which increments the log count on the display screen, creates a new file on the SD card, and lights up an LED to indicate recording is in progress. All 3 accelerometers, the gyroscope, and the hall effect sensor then start sending data through ethernet cables and PCB traces back to the microcontroller in the main unit, which sends this data to the SD card to store in memory. The system will continue to collect data until the record button is pressed again, at which point the file will be closed and the LED will turn off.

Once the data is collected and stored on the SD card, it is later processed on a PC with MATLAB using metrics that will be developed by this team next quarter.

Firmware

All code responsible for running the program used for data collection during operation was written in MicroPython. The communication protocol used is SPI for all accelerometers and the hall effect sensor because of their high data output rate, while the gyroscope will necessarily use its manufacturer configured I2C protocol to send data back to the microcontroller. Using a FIFO buffer for all sensor data, the MCU will write the data to the SD card using SDIO where it will be stored in a binary format to save memory.

Cost and Budget

In Table 1 below, the costs associated with each category of component is listed, along with estimated shipping and tax costs, for **two verification prototypes** to be built, as requested by our sponsor. A more specific breakdown of the project budget can be seen in Appendix B.1.

Table 1. Project Cost and Budget

System	**Component**	**Cost**
Housings	Housings	$12.00
	Housing Straps	$16.50
Electronics	Sensors	$44.00
	Electrical Components	$4.00
	Update PCBS	$88.00
Mechanical	Mounting Hardware	$5.00
	Spoke Magnet	$10.00
Shipping + Tax	-	$90.00
Total Cost		$269.50
Project Budget		$500.00
Funding Left		$230.50

3. Design Justification

At the request of our sponsor, our designs for the sensor housings and system design are to be created with the intent of collecting riding data, without the concerns for a product to be used by other customers. Because of this, our design justification will be based on the specifications needed to effectively collect data for metric testing, without the concerns of uncommon failure modes that can occur when it is being used by a mass audience.

3.1 Housing Design Justification

With this in mind, we designed the sensor and main DAQ housings to be 3D printed with PLA filament. Under normal operation, there will be no significant mechanical stresses applied to the housings or system itself, so FEA and Stress analysis were not included in our analyses. Our main failure modes would be that which affects the quality of data collection, rather than what would affect the function of the system based on the use of a mass audience. The sensors we selected are rated to have a large shock tolerance that can be shown from their respective datasheets (Appendix A).

To justify our housing design in terms of the quality of data collection, we had to ensure the housing would not slip during operation and the rubber pad wouldn't dampen the accelerations to a great extent. To ensure this, we subjected the accelerometers and housings to a shake table test. Comparing both orientations, horizontal and vertical, as well as testing with and without the rubber pads, we confirmed that the rubber pads add enough friction between the housings and the frame to eliminate potential slip and does not dampen the accelerations to a significant effect. These orientations can be seen in Figure 4.

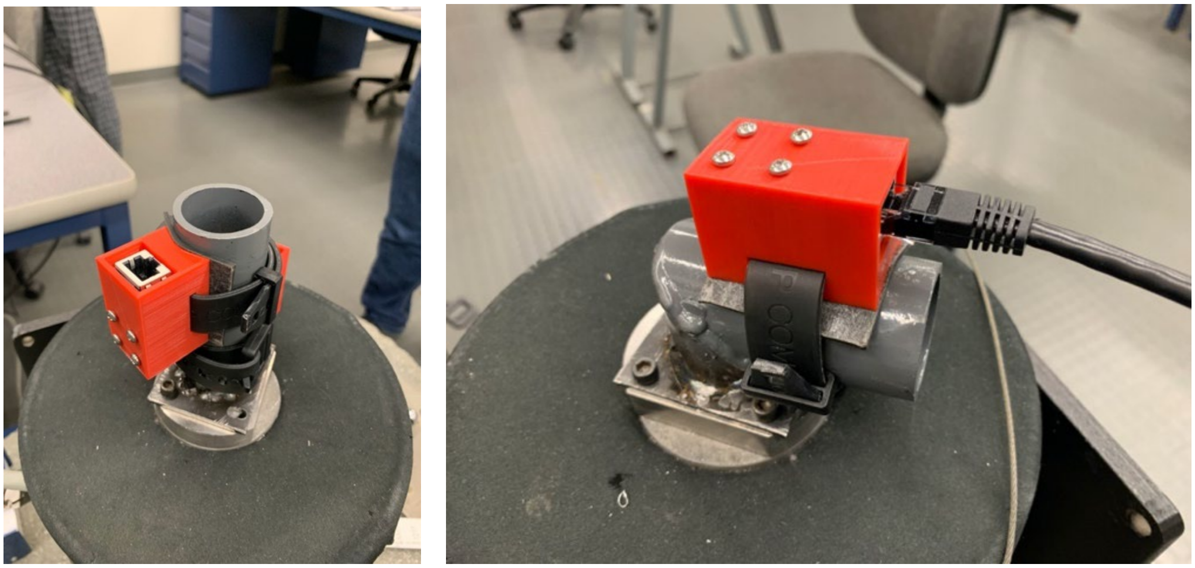


Figure 4: Accelerometer Vertical and Horizontal Positions Respectively for Lab Testing

Figure 5 shows the similarities between the accelerometers in a horizontal position, both being subjected to 20hz on the shake table. The accelerometers show offsets that our team will calibrate in future tests to make the data relevant.

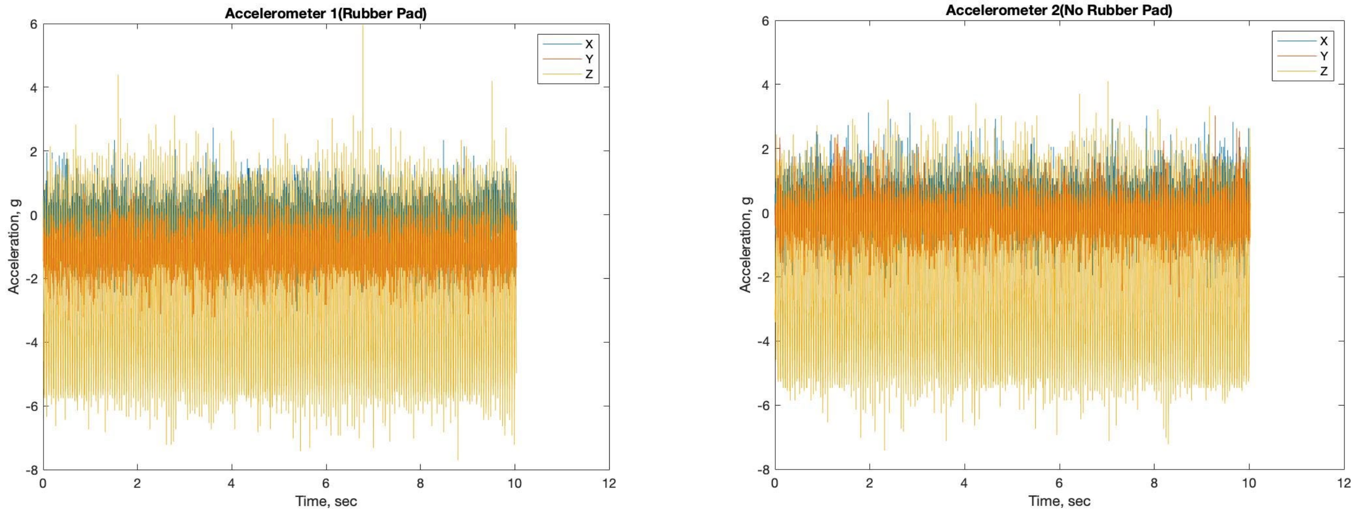


Figure 5: Accelerometers in Vertical Position Subjected to 20Hz on the Shake Table

Currently, DAQ systems made for mountain bikes are similarly designed in the way they mount their housings to the bike's frame. Instead of the fastening band that our design implements, other DAQ systems often used wire ties. The intended audience for the other DAQ systems is for professional use, so they did not design them with the mass audience in consideration. Wire ties are similar to our band design, except we incorporated a less permanent attachment due to the constant testing we will have to do with our system.

3.2 Sensor Data Collection Justification

Similar to the housings, the way the sensors collect data is also a design that needs to be justified. This design includes the MicroPython code used to drive the sensors and the sensor selection itself. We did not have to design more code to drive the accelerometers because Steven Waal's version of the accelerometer driver works as is intended, collecting data at a rate of 1600Hz. This was justified through multiple field tests and lab tests using the accelerometer to collect data.

The gyroscope was the new sensor added and was selected based on its output frequency range and the fact that it is 3-axis. The specifications of the gyroscope are shown in Appendix A. The gyroscope is collecting data at a slower rate than the accelerometers because the angular velocity is not rapidly fluctuating. We planned to verify that our driver works with the selected gyroscope by breadboarding it onto a Nucleo and collecting accurate data from it. However, due to shipping problems we did not have the necessary components to complete this bench test and will proceed with the test after this review. Although our system does not use a Nucleo as a microprocessor, the code can be modified to fit our intended system and microcontroller.

Continuing with the accelerometers, we tested in a range from 0hz to 1600hz to verify that the given accelerometers were able to accurately collect and transmit data on files that we can process through MATLAB. The following data is taken from the accelerometers in the horizontal position at rest.

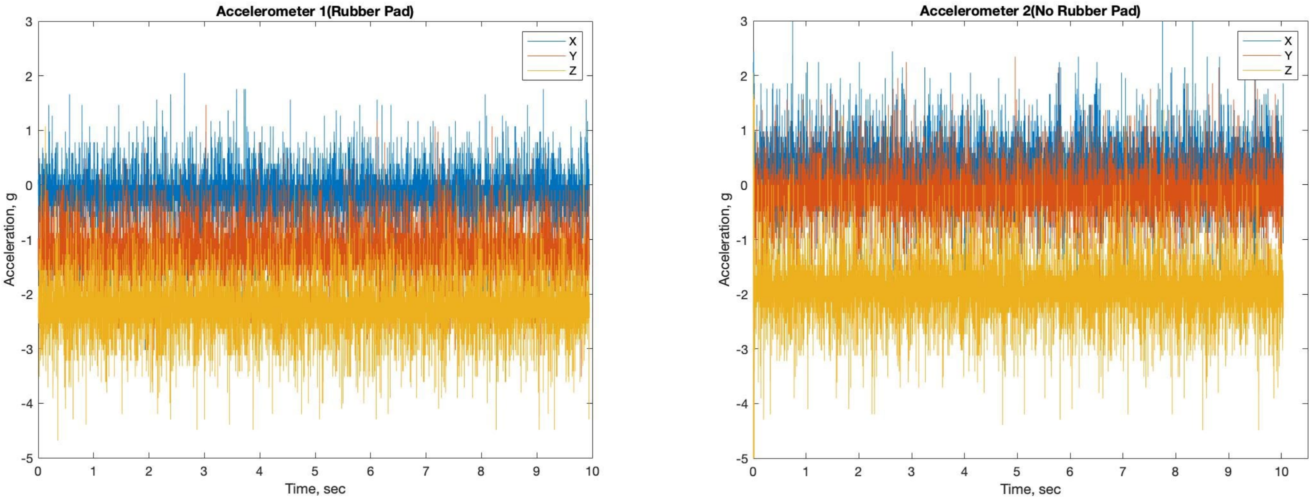


Figure 6: Accelerometer Data Taken at a Rest Position

As shown in Figure 6, the data displays the biases of both the accelerometers. Since both tests were taken when the accelerometers were at rest, the magnitude of their accelerations should be equal to 1g, however both accelerometers show biases in each axis. We will have to calibrate the accelerometers in a perfectly horizontal position to ensure accurate data is being collected and to make use of previous data taken.

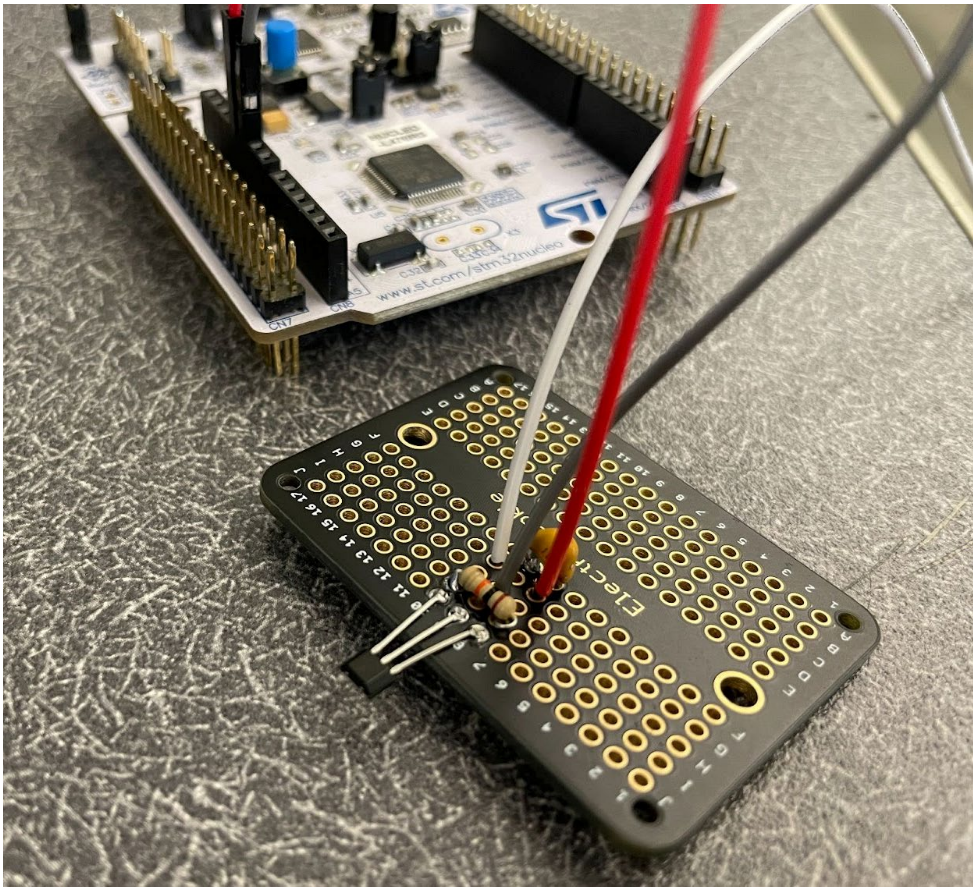


Figure 6. Hall Effect Sensor on Breadboard, Powered by STM32 Nucleo-L476RG Prototyping Board [5]

A prototype circuit was also made to verify the function of the Hall effect sensor. For this, we attached the sensor and all other components in the circuit to a solderable breadboard. The output and ground pins were attached to a voltmeter, and a magnet was passed in front of the sensor. As the magnet approached the sensor, the voltmeter read a value of 5V, and as the magnet departed, the voltmeter read 0V. The sensor and circuit functioned the way we designed them to, but not perfectly.

3.3 Safety, Maintenance and Repair Consideration

The safety of the user and the securement of the device is an important consideration that our team took into consideration. The team reviewed the safety of the design by creating a Failure Modes and Effects Analysis, which is attached in Appendix D. Using this process, our team can determine how the design will fail, how these failures can affect the customers and the most critical potential issues. Because our objective with our design is to create this DAQ solely as a testing device, most of our failures will be software related and not affect the user's safety.

Some safety precautions include the design of small form factors for the housings to ensure no interference between the user's path and the housings. There will be no exposed conductors and wire ties are used to keep the ethernet cables attached to the bikes frame.

In order to protect the device from potential damage, we added housings with a thickness that is tolerable to potential crashes from riding the bike. These housings will protect the electronic components from external damage, as the sensors are already tolerable to shock. Other protective measures include a video demonstrating how to properly install the DAQ onto a mountain bike as well as a written manual on how to operate the device, which will be available with the verification prototype.

With our current design, there should be no need for maintenance within the system. However, in the case that bugs and software problems occur, there will be well documented code and documentation on the design of the DAQ system that the user can reference.

3.4 Unresolved Issues and Concerns

There are concerns related to the current DAQ design that we cannot ignore for future iterations of the design. The power supply design to the DAQ is not the most efficient. Most of our problems came from the insufficient power supply to the DAQ. The main board was designed to have batteries connected in parallel to supply the power. This would cause the rechargeable batteries life to drain faster than if it was powered by a singular battery. The power supply will need to be altered in our final iteration of the board design.

We found several issues during the Hall Effect Sensor verification test. The first was the proximity of the magnet to the sensor; the magnet had to be between 0.5 to 1 inch for the sensor to toggle on. This obviously leads to issues with the mounting of the system, as it allows little clearance for the spokes and sensor to pass by each other while still picking up velocity data. A second issue was with our selection of a latch-type sensor. The sensor turns on with a positive magnetic field and continues to stay there, only turning off again in the presence of an equal negative magnetic field. This means the magnet must be oriented so both poles can be read, which reduces the magnetic field’s strength at the sensor and lowers the range of the circuit. We could also have a second magnet to turn off the sensor, but this is clearly not ideal either. We will continue to test with the other type of Hall effect sensors, which only output the measured intensity of a magnetic field, instead of latching on and staying there. While these issues exist, the underlying concepts were proven to work by this testing. Further experimentation with the Hall effect circuit will occur after CDR.

4. Manufacturing Plan

The following section presents the manufacturing processes that will be required in order to build the verification prototype. This includes the procurement of materials/components, manufacturing of custom parts, outsourcing of part manufacturing, and lastly, the assembly process.

4.1 Procurement

The manufacturing of materials and components consists of a variety of electrical components, sensors, 3D printed parts, and mounting hardware. Ronan is the elected purchaser of the components, however, the team and sponsor will hold component reviews prior to purchasing to ensure the components are accurately selected.

The electrical components (resistors, capacitors, crystals, etc.) will be purchased through a supplier called Digikey. With their wide variety of products, every electrical component can be purchased through them. Prior to purchasing components, each manufacturer will be researched to ensure the component is high quality.

The mechanical hardware will be purchased at a variety of suppliers. The OneUp straps used to secure the sensor housings to the bike will be purchased directly through them on their website. The spoke magnet that attaches to the rim will be purchased on the REI website. The remaining mounting hardware (screws and bolts) will be purchased through McMaster.

The final iteration of 3D printing will take place in the ME Department using the Formlab 3+ printer. In order access this high-quality printer we will need to pay for a maintenance fee ($10) and technician fee ($45). We have selected a specific Formlabs material called “Tough 200 Resin” which will be purchased directly through Formlabs ($175). The product spec sheet supplied by Formlabs can be found in the Appendix A.

4.2 Manufacturing

The fabrication of the updated main PCB and updated Accelerometer + Hall Effect PCB will be manufactured by JLC PCB. This manufactured was selected based on their capability to produce high quality boards with a very short turn around and low price. One of the team members as well as Steven Wahl have used this manufacturer in the past and had good experiences with JLC PCB as well.

As stated in section 4.1, our housings will be manufactured with a Formlabs 3+ printer. The Formlabs 3+ printer uses Low Force Stereolithography (LFS) which is an advanced form of SLA printing that uses a flexible tank and linear illumination to turn liquid resin into the desired part. This print style was selected due to its excellent surface finish, part accuracy, and material strength/stiffness, all of which will make a finished look product but at a lower cost. The printer is located in the ME Department and we will be working with a shop technician to have the parts properly printed.

Lastly, the software development must be procured. The process of developing this code includes Steven Wahl's original code (modifying it for the new board pinouts) as well as utilizing code from our ME 305 and 405 scripts for the gyroscope. Psuedo code has been developed for the new sensors and the code can be validated using the nucleo/breakout boards during the manufacturing process for the PCBs. This allows the team to stay on track during the 1–2-week lead time for the PCB manufacturing.

4.3 Assembly

The surface mounting (SMT) of the components onto the board will be hand soldered by the team. The team has prior experience with soldering of electrical components on PCBs and is confident that components will be properly placed on the board. To ensure the boards are reliable, a rigorous quality control (QC) plan will be put into place. This QC plan begins with in-circuit testing using the designed access points in the board and comparing these values to Eagle Simulations as well as hand-calculations.

If the hand assembly is not successful, JLC PCB has the capability to do so. Their outgoing quality control (OQC) includes visual inspection, solder paste inspection (SPI,) x-ray inspection, and automated optical inspection. Their capabilities are much greater than that of hand soldering the components, however, their price to do so is another cost that could be avoided.

Once the PCBs have had all components soldered to the board, they will be mounted to the housings. The OneUp straps will be put through the sensor housings, ready to be placed on the bike. When the user is ready to collect the data, all that is necessary is to buckle down the sensors and tighten the through bolts on main DAQ housing.

5. Design Verification Plan

After completion of the verification prototype, we will need to identify if it meets all of our design specifications. For a full table of specifications and testing, see the Design Verification Plan in Appendix E.

Size — Main Hub and Peripheral Housings

The physical dimensions of the system are very important to its function, as they should not interfere with the rider's ability to operate the bicycle. We selected a maximum size for the hub of 12.5 cm long, 7.5 cm wide, and 2.5 cm thick. For the sensor housings, we want a maximum of 4 cm for length, width, and thickness. Measuring these will simply involve using a ruler or calipers to find each dimension.

Weight

Since the DAQ is targeted towards competitive riders, minimizing the weight of the entire system is crucial. More weight translates to a slower ride and more effort to ride the bike. Our specification for the entire system is a maximum mass of 500g, which weighs roughly 1.1 lbf. Testing the weight of the system will only require a weight scale, and it does not need to be particularly precise.

Cost

To differentiate from similar products, keeping our product affordable was a key focus. We want our entire system to cost less than $150. While the current prototype design will be made of the more expensive Formlabs resin, the final version would be made of a cheaper, more mass-producible material and process. We will be able to calculate this directly from our budget. See Appendix B for the entire budget.

Battery Life

The system should be able to operate on a single charge long enough for the rider to get in a day's worth of rides. The DAQ will mainly be used on downhill portions of trails, which makes up a fraction of the entire ride duration. We specified a minimum battery life of one hour. We can estimate the battery life by measuring the current consumed by the device using a multimeter. The battery operates at a (near) fixed voltage and multiplying by current gives the wattage of the device. Battery capacity is given in Watt-hours, which we can divide by the wattage to find roughly how long the batteries will last.

Ingress Protection

While riding, the DAQ will experience somewhat harsh environmental conditions. We defined an ingress protection level of IP54. This means that the system is protected against dust interfering with the DAQ's functionality. It also means that the system will be able to withstand splashes of water. We chose these specifications because they represent actual conditions that the DAQ might reasonably go through during operation.

To test the ingress protection specification, we will first remove the internal electronics from the DAQ and replace them with paper. Then we will splash the system with water and dust and observe if the paper is wet or any dust entered. If the inside is dry and dust-free, the test is successful.

Foolproof Operation

The system should not be complicated to operate. We will give the verification prototype to various "customers" and provide them with basic operation instructions. If they run into any issues with how to use the DAQ, this will count as an unsuccessful test.

Maximum Recording Storage

The system needs to have enough storage to contain data from multiple rides. We decided on a minimum of 8 gigabytes, which corresponded to well over 20 hours of recording time. Testing this specification will only require examining the SD card used for data storage.

Mounting Universality

The DAQ is not specific to any model of bike and should be able to fit across a range of frame geometries. We will test the system's universality by trying to mount it on a multitude of bicycles. We can find a variety of bikes either through a biking-related club, a bike shop, or individual personal bikes.

Aesthetics

The appearance of the DAQ system should be attractive to potential customers. This is a subjective criterion which we can test by surveying potential customers. If over 80% of those surveyed agree that the system is visually appealing, this specification is considered met.

Suspension Tuning Recommendation

The overall purpose of this product is to produce suspension tuning recommendations which increase the bike's performance. To test this, we will ride the bike on a trail with the suspension tuned randomly. After riding, we will adjust the suspension based on the DAQ's recommendation and test again. We can run this test at different 'untuned' configurations to ensure the system works for a range of test cases. If the average speed increase of the bike is 5% or more, this specification will be marked a success.

5.1 Uncertainty Analysis

To ensure the validity of our data, we will need to estimate the uncertainty of the sensors. We will not need the data to be extremely precise in our application, as the vibrations and rotations are going to have high nominal values. The uncertainty of the sensors will likely be negligible compared to our data. However, we will still analyze the uncertainty of the sensors to be sure any variation in data not attributed to actual vibrations is not significant.

MEMS devices, including the accelerometers and gyroscope in our system, have many sources of error. These are listed on the manufacturer's datasheets, along with typical values of uncertainty for each source of error. Error arises from the construction of the devices, as well as from noise, misalignment, and offset due to temperature.

From the datasheets, the estimated maximum uncertainty of the accelerometers and gyroscope were calculated. The conditions were assumed to be stationary with one axis oriented perpendicular to gravity, and at 25°C, the defined ambient temperature for both manufacturers. Uncertainty was also calculated for every angle to be measured in this calibration test. If the uncertainty at zero is sufficient to characterize the entire range of data, we may use the zero data point to calibrate the system as needed. These calculations can be seen in Appendix C. To compare against these uncertainties, we will take measurements with the devices at different known angles over a period of time. The devices will not be moving, allowing us to examine the fluctuations in readings. This will be compared against the estimated maximum uncertainty at zero. This will give us a basic idea of how the devices are performing, and if they meet the expected uncertainty specifications.

A full description of the test procedures is laid out in Appendix I.

6. Conclusions

This report documents and presents our progress towards completing the MTB DAQ system. Our team has encountered difficulties with getting the previous design of the data acquisition system to work properly over the past few weeks, making the verification of working sensors and circuit design our team's focus for our structural prototype. Our team verified the collection of accelerometer data through the shake table test and found a potential bias in both accelerometers. The hall effect sensor was tested for usable range and verified circuit design. The gyroscope was unable to be tested due to shipping problems, so the bench test to verify data collection could not be performed.

The next steps include analyzing the lab test data to calibrate the sensors and eliminate the biases, installing the gyroscope to our designed circuit and verify its data collection, and to complete the design of the Main DAQ PCB. With the permission of our sponsor, we will commit to our purchasing, building and test plans.

7. References

[1] Accelerometer datasheet: *https://www.analog.com/media/en/technical-documentation/data-sheets/ADXL375.PDF*

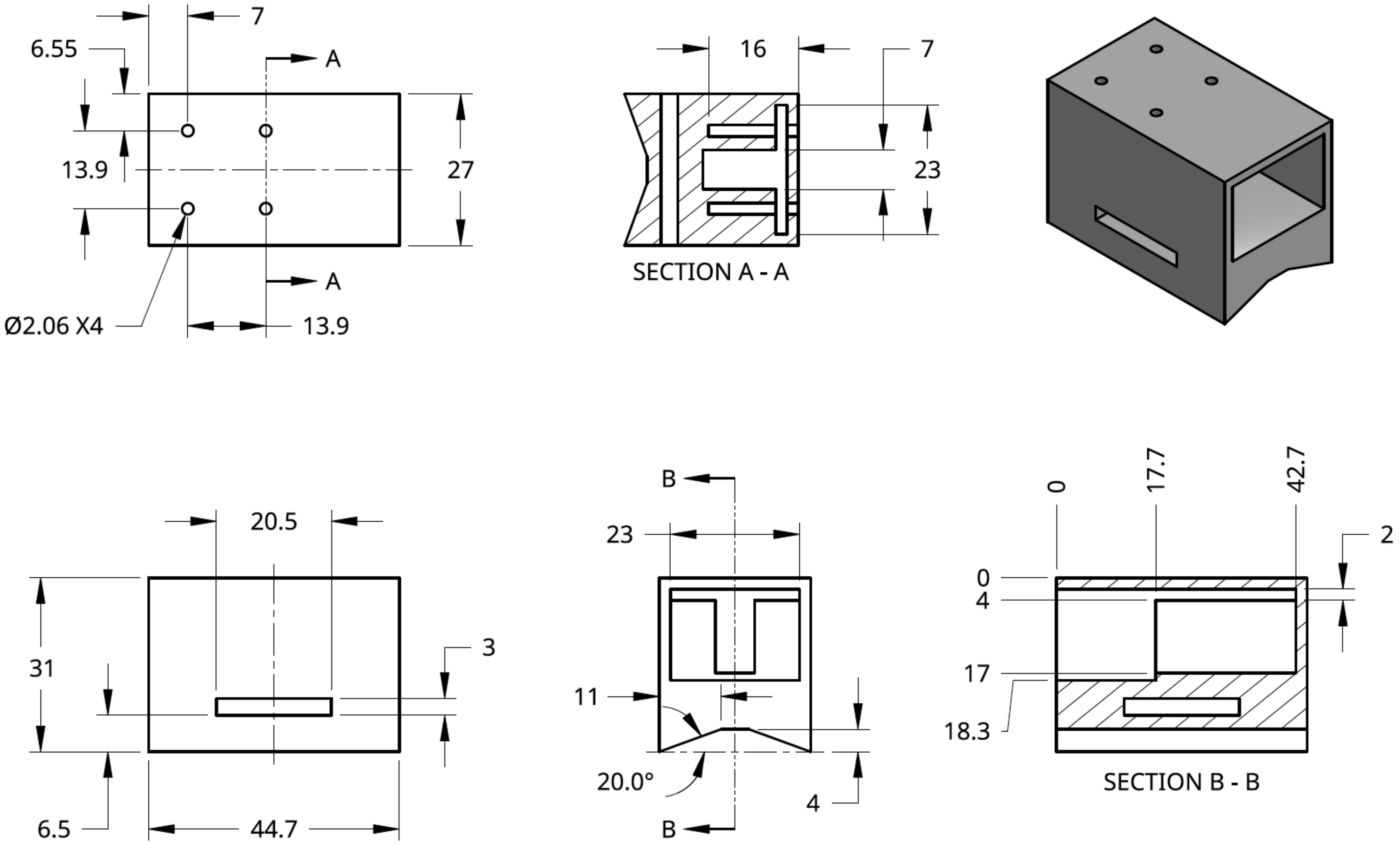
[2] Gyroscope Datasheet: https://invensense.tdk.com/wp-content/uploads/2015/02/PS-MPU-3050A-00-v2-7.pdf

[3] Hall Effect Sensor Datasheet: https://www.digikey.com/en/htmldatasheets/production/2007903/0/0/1/aps12205luaabu.html?site=US&lang=en&cur=USD

[4] Formlabs 3+ Tough 2000 Resin Specifications Table:

https://formlabs-media.formlabs.com/datasheets/2001340-TDS-ENUS-0P.pdf

Appendix A. Drawing and Specs Package



SECTION A - A

SECTION B - B

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS

LENGTH = ±0.1mm
ANGULAR = ±0.1 °

SURFACE FINISH √

DO NOT SCALE DRAWING

BREAK ALL SHARP EDGES AND REMOVE BURRS

THIRD ANGLE PROJECTION

	NAME	DATE
DRAWN	JOHN RINGROSE	02/27/2022
CHECKED	DYLAN RUIZ	02/27/2022
APPROVED	RONAN SHAFFER	02/27/2022

MATERIAL
PLA

FINISH
Black

TITLE
Sensor Housing

NOTES

REVISION 1: INITIAL RELEASE
REVISION 2: REMOVAL OF BASE SNAP RIBS, FLIPPED ORIENATION OF SENSOR

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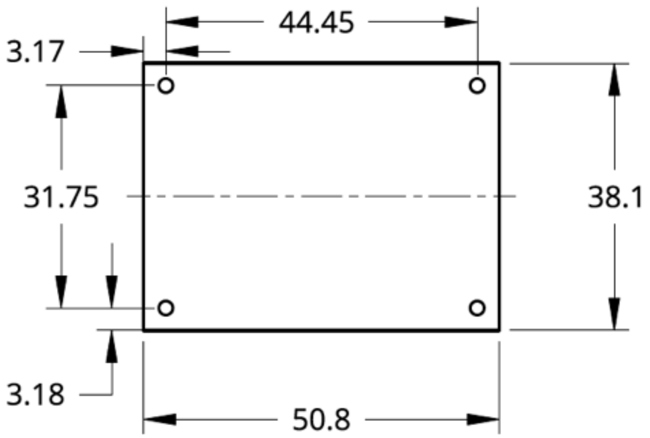

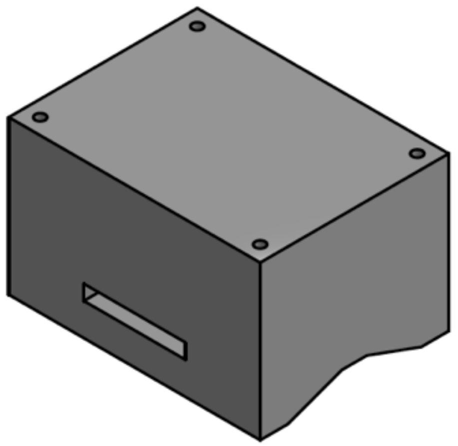

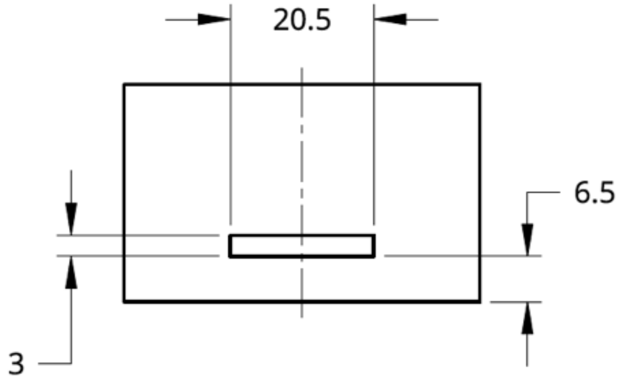

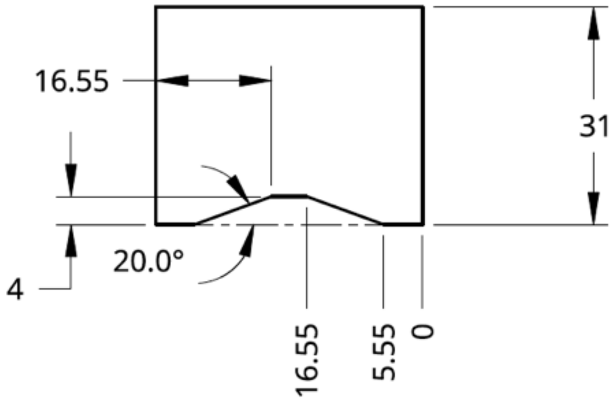

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	CHECKED	DYLAN RUIZ	02/27/2022
	APPROVED	RONAN SHAFFER	02/27/2022
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BREAK ALL SHARP EDGES AND REMOVE BURRS			
THIRD ANGLE PROJECTION	MATERIAL PLA	FINISH BLACK	

CADENCE PROTO MOUNT

NOTES

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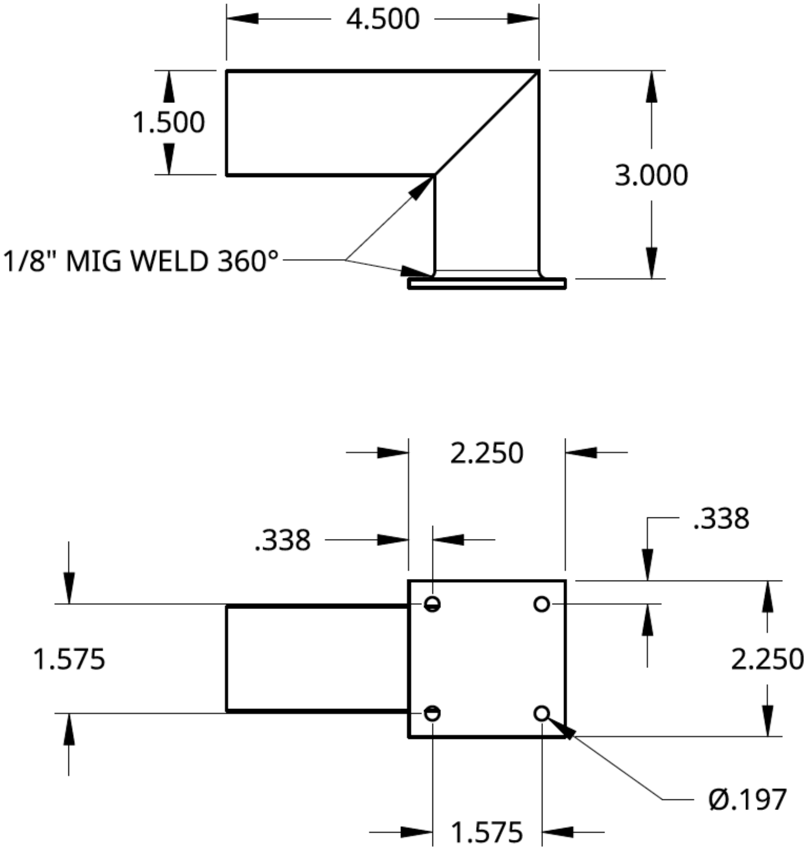

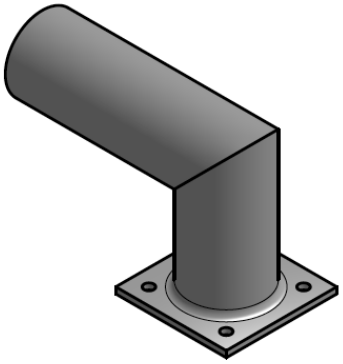

UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES

ANGULAR = ±1 °
FRACTIONAL = ±1/32

SURFACE FINISH √

DO NOT SCALE DRAWING

BREAK ALL SHARP EDGES AND
REMOVE BURRS

THIRD ANGLE PROJECTION

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CHECKED	RONAN SHAFFER	02/27/2022
APPROVED	DYLAN RUIZ	02/27/2022

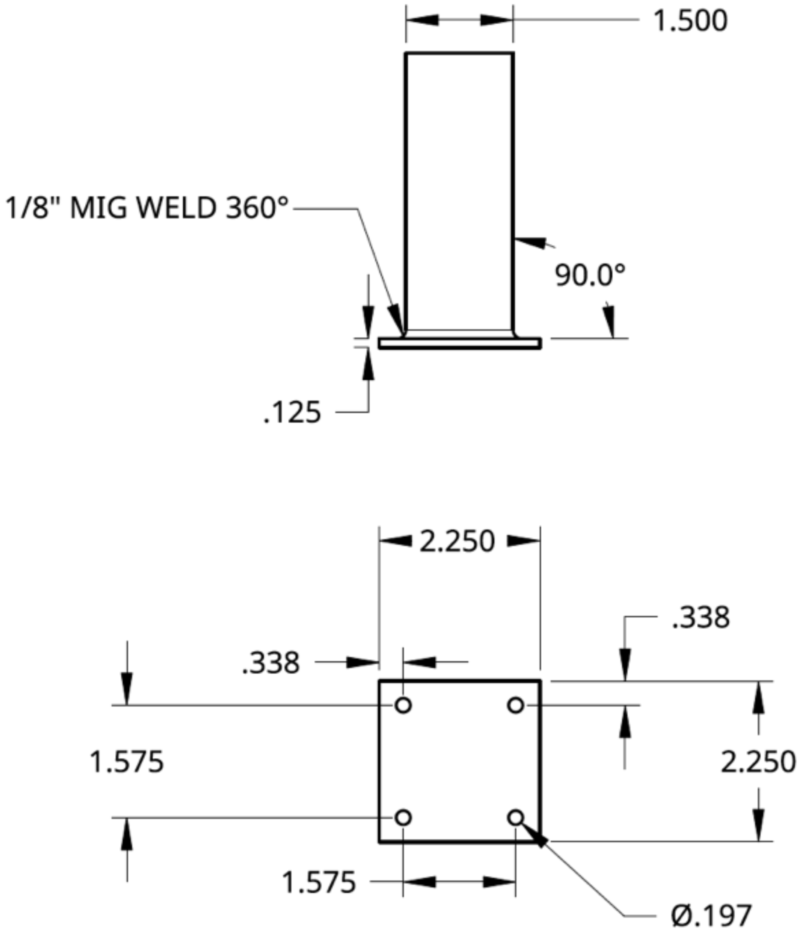
MATERIAL: STEEL
FINISH: GREY PAINT

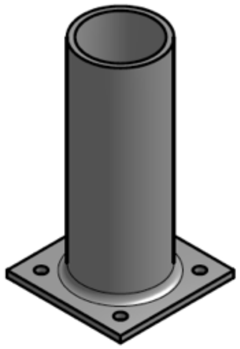
TITLE
HORIZONTAL SHAKE TABLE MOUNT

NOTES

REVISION 1: INITIAL RELEASE
REVISION 2: CHANGE HOLE SPACING TO CORRECT DIM (4mm x 4mm)

SIZE: A
DWG NO. 1002
REV. 2
SCALE 1:2.5
WEIGHT
SHEET 1 of 1





UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

ANGULAR = ±1 °
FRACTIONAL = ±1/32

SURFACE FINISH

DO NOT SCALE DRAWING

BREAK ALL SHARP EDGES AND REMOVE BURRS

THIRD ANGLE PROJECTION

	NAME	DATE
DRAWN	JOHN RINGROSE	02/02/2022
CHECKED	RONAN SHAFFER	02/27/2022
APPROVED	DYLAN RUIZ	02/27/2022

MATERIAL: STEEL

FINISH: GREY PAINT

TITLE

VERTICAL SHAKE TABLE MOUNT

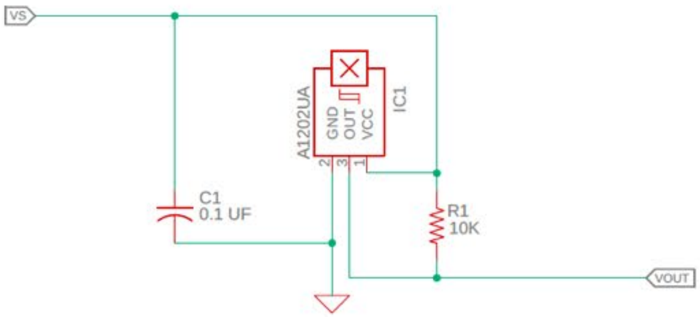
NOTES

REVISION 1: INITIAL RELEASE
REVISION 2: CHANGE HOLE SPACING TO CORRECT DIM (4mm x 4mm)

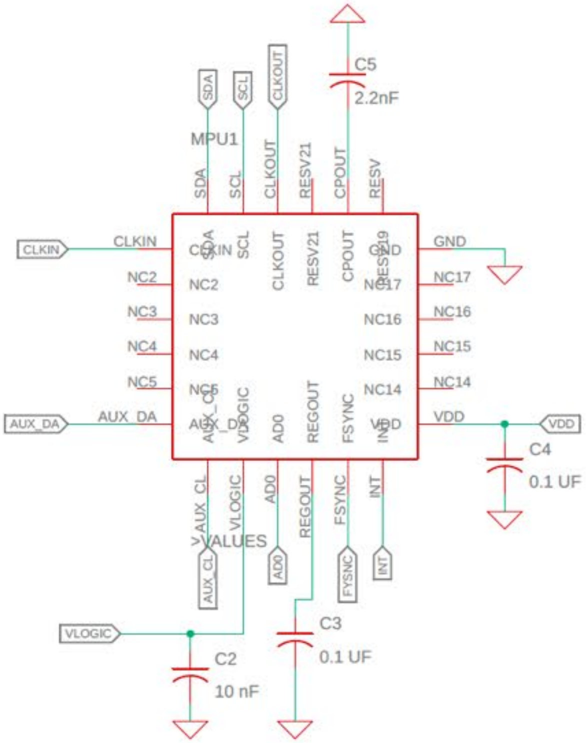
SIZE	DWG NO.	REV.
A	1003	2

SCALE	WEIGHT	SHEET
1:2.5		1 of 1

Hall Effect



Gyro



DRAWN BY:
JOHN RINGROSE

TITLE: Structural Prototype

Document Number: 2001

REV: 1

Date: 02/07/2022

Sheet: 1/1

SPECIFICATIONS

T_A = 25°C, V_S = 2.5 V, $V_{DD\ I/O}$ = 2.5 V, acceleration = 0 *g*, C_S = 10 µF tantalum, $C_{I/O}$ = 0.1 µF, output data rate (ODR) = 800 Hz, unless otherwise noted.

Table 1.

Parameter	Test Conditions/Comments	Min	Typ[1]	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range[2]		±180	±200		*g*
Nonlinearity	Percentage of full scale		±0.25		%
Cross-Axis Sensitivity[3]			±2.5		%
SENSITIVITY	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}[2, 4]	ODR ≤ 800 Hz	18.4	20.5	22.6	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}[2, 4]	ODR ≤ 800 Hz	44	49	54	mg/LSB
Sensitivity Change Due to Temperature			±0.02		%/°C
0 *g* OFFSET	Each axis				
0 *g* Output for X_{OUT}, Y_{OUT}, Z_{OUT}		−6000	±400	+6000	m*g*
0 *g* Offset vs. Temperature			±10		m*g*/°C
NOISE	X-, y-, and z-axes		5		m*g*/√Hz
OUTPUT DATA RATE AND BANDWIDTH[5]	User selectable				
Output Data Rate (ODR)[4, 6]		0.1		3200	Hz
SELF-TEST[7]					
Output Change in Z-Axis			6.4		*g*
POWER SUPPLY					
Operating Voltage Range (V_S)		2.0	2.5	3.6	V
Interface Voltage Range ($V_{DD\ I/O}$)		1.7	1.8	V_S	V
Supply Current					
Measurement Mode	ODR ≥ 100 Hz		145		µA
	ODR ≤ 3 Hz		35		µA
Standby Mode			0.1		µA
Turn-On and Wake-Up Time[8]	ODR = 3200 Hz		1.4		ms
TEMPERATURE					
Operating Temperature Range		−40		+85	°C
WEIGHT					
Device Weight			30		mg

[1] Typical specifications are for at least 68% of the population of parts and are based on the worst case of mean ± 1 σ distribution, except for sensitivity, which represents the target value.

[2] Minimum and maximum specifications represent the worst case of mean ± 3 σ distribution and are not guaranteed in production.

[3] Cross-axis sensitivity is defined as coupling between any two axes.

[4] The output format for the 1600 Hz and 3200 Hz output data rates is different from the output format for the other output data rates. For more information, see the Data Formatting at Output Data Rates of 3200 Hz and 1600 Hz section.

[5] Bandwidth is the −3 dB frequency and is half the output data rate: bandwidth = ODR/2.

[6] Output data rates < 6.25 Hz exhibit additional offset shift with increased temperature.

[7] Self-test change is defined as the output (*g*) when the SELF_TEST bit = 1 (DATA_FORMAT register, Address 0x31) minus the output (*g*) when the SELF_TEST bit = 0. Due to device filtering, the output reaches its final value after 4 × τ when enabling or disabling self-test, where τ = 1/(data rate). For the self-test to operate correctly, the part must be in normal power operation (LOW_POWER bit = 0 in the BW_RATE register, Address 0x2C).

[8] Turn-on and wake-up times are determined by the user-defined bandwidth. At a 100 Hz data rate, the turn-on and wake-up times are each approximately 11.1 ms. For other data rates, the turn-on and wake-up times are each approximately τ + 1.1 ms, where τ = 1/(data rate).

3 Electrical Characteristics

3.1 Sensor Specifications

Typical Operating Circuit of Section 4.2, VDD = 2.5 V, VLOGIC = 2.5 V, T_A=25°C.

Parameter	Conditions	Min	Typical	Max	Unit	Notes
GYRO SENSITIVITY						
Full-Scale Range	FS_SEL = 0		±250		°/s	4, 7
	FS_SEL = 1		±500			4, 7
	FS_SEL = 2		±1000			4, 7
	FS_SEL = 3		±2000			4, 7
Gyro ADC Word Length			16		Bits	3
Sensitivity Scale Factor	FS_SEL = 0		131		LSB/(°/s)	1
	FS_SEL = 1		65.5			3
	FS_SEL = 2		32.8			3
	FS_SEL = 3		16.4			3
Sensitivity Scale Factor Tolerance	25°C	-6	±2	+6	%	1
Sensitivity Scale Factor Variation Over Temperature	-40°C to +85°C		±2		%	8
Nonlinearity	Best fit straight line; 25°C		0.2		%	6
Cross-Axis Sensitivity			2		%	6
GYRO ZERO-RATE OUTPUT (ZRO)						
Initial ZRO Tolerance	25°C		±20		°/s	1
ZRO Variation Over Temperature	-40°C to +85°C		±0.15		°/s/°C	8
Power-Supply Sensitivity (1-10 Hz)	Sine wave, 100mVpp; VDD = 2.2 V		0.2		°/s	5
Power-Supply Sensitivity (10 – 250 Hz)	Sine wave, 100mVpp; VDD = 2.2 V		0.2		°/s	5
Power-Supply Sensitivity (250 Hz – 100 kHz)	Sine wave, 100mVpp; VDD = 2.2 V		4		°/s	5
Linear Acceleration Sensitivity	Static		0.1		°/s/*g*	6
GYRO NOISE PERFORMANCE	**FS_SEL=0**					
Total RMS Noise	DLPFCFG = 2 (100 Hz)		0.1		°/s-rms	1
Low-frequency RMS noise	Bandwidth 1 Hz to 10 Hz		0.033		°/s-rms	1
Rate Noise Spectral Density	At 10 Hz		0.01		°/s/√Hz	3
GYRO MECHANICAL FREQUENCIES						
X-Axis		30	33	36	kHz	1
Y-Axis		27	30	33	kHz	1
Z-Axis		24	27	30	kHz	1
GYRO START-UP TIME	**DLPFCFG = 0**					
ZRO Settling	to ±1°/s of Final		50		ms	5
TEMPERATURE RANGE						
Specified Temperature Range		-40		85	°C	2

Notes:

1. Tested in production
2. Based on characterization of 30 parts over temperature on evaluation board or in socket
3. Based on design, through modeling and simulation across PVT
4. Typical. Randomly selected part measured at room temperature on evaluation board or in socket
5. Based on characterization of 5 parts over temperature
6. Tested on 20 parts at room temperature
7. Part is characterized to Full-Scale Range. Maximum ADC output is [2^{16} / (Sensitivity x 2)]
   Example: For Sensitivity of 131 LSB/(°/s), [2^{16} / (131 x 2)] = ±250 °/s.
8. Based on characterization of 48 parts on evaluation board or in socket

ELECTRICAL CHARACTERISTICS: Valid over full operating voltage and ambient temperature range, unless otherwise noted

Characteristics	Symbol	Test Conditions	Min.	Typ.[1]	Max.	Unit[2]
ELECTRICAL CHARACTERISTICS						
Forward Supply Voltage	V_{CC}	Operating, $T_J < 175°C$	2.8	–	5.5	V
Supply Current	I_{CC}	V_{CC} = 5.5 V	–	2	4	mA
Output Leakage Current	I_{OUTOFF}	V_{OUT} = 5.5 V, $B < B_{RP}$	–	–	10	μA
Output Saturation Voltage	$V_{OUT(SAT)}$	I_{OUT} = 5 mA, $B > B_{OP}$	–	50	500	mV
Output Current	I_{OUT}	Recommended value used during characterization	–	5	–	mA
Output Short-Circuit Current Limit	I_{OM}	$B > B_{OP}$	30	–	60	mA
Power-On Time[3]	t_{ON}	$V_{CC} \geq 2.8$ V, $B < B_{RP}$(min) – 10 G, $B > B_{OP}$(max) + 10 G	–	–	25	μs
Power-On State, Output[3]	POS	$V_{CC} \geq V_{CC}$(min), $t < t_{ON}$	Low			–
Chopping Frequency	f_C		–	800	–	kHz
Output Rise Time[3][4]	t_r	$R_{PULL\text{-}UP}$ = 1 kΩ, C_L = 20 pF	–	0.2	2	μs
Output Fall Time[3][4]	t_f	$R_{PULL\text{-}UP}$ = 1 kΩ, C_L = 20 pF	–	0.1	2	μs
MAGNETIC CHARACTERISTICS						
Operate Point	B_{OP}	APS12205	5	22	40	G
		APS12215	15	50	90	G
		APS12235	100	150	180	G
Release Point	B_{RP}	APS12205	–40	–22	–5	G
		APS12215	–90	–50	–15	G
		APS12235	–180	–150	–100	G
Hysteresis	B_{HYS}	APS12205 (B_{OP} – B_{RP})	10	45	80	G
		APS12215	30	100	180	G
		APS12235	200	300	360	G

[1] Typical data are are at T_A = 25°C and V_{CC} = 5 V, and are for initial design estimations only.
[2] 1 G (gauss) = 0.1 mT (millitesla).
[3] Guaranteed by device design and characterization.
[4] C_L = oscilloscope probe capacitance.

Tough 2000 Resin Material Properties Data

	METRIC[1]		IMPERIAL[1]		METHOD
	Green[2]	Post-Cured[3]	Green[2]	Post-Cured[3]	
Mechanical Properties					
Ultimate Tensile Strength	29 MPa	46 MPa	4206 psi	6671 psi	ASTM D 638-14
Tensile Modulus	1.2 GPa	2.2 GPa	174 ksi	329 ksi	ASTM D 638-14
Elongation at Break	74 %	48 %	74 %	48 %	ASTM D 638-14
Flexural Properties					
Flexural Strength	17 MPa	65 MPa	2465 psi	9427 psi	ASTM D 790-15
Flexural Modulus	0.45 GPa	1.9 GPa	65 ksi	275 ksi	ASTM D 790-15
Impact Properties					
Notched IZOD	79 J/m	40 J/m	1.5 ft-lbf/in	0.75 ft-lbf/in	ASTM D256-10
Unnotched IZOD	208 J/m	715 J/m	3.9 ft-lbf/in	13 ft-lbf/in	ASTM D256-10
Thermal Properties					
Heat Deflection Temp. @ 1.8 MPa	42 °C	53 °C	108 °F	127 °F	ASTM D 648-16
Heat Deflection Temp. @ 0.45 MPa	48 °C	63 °C	118 °F	145 °F	ASTM D 648-16
Coefficient of Thermal Expansion	107 µm/m/°C	91 µm/m/°C	59 µin/in/°F	50 µin/in/°F	ASTM E 831-13

[1] Material properties can vary with part geometry, print orientation, print settings, and temperature.

[2] Data was obtained from green parts, printed using Form 2, 100 µm, Tough settings, washed and air dried without post cure.

[3] Data was obtained from parts printed using Form 2, 100 µm, Tough 2000 settings, and post-cured with a Form Cure for 120 minutes at 80 °C.

Appendix B.1 Project Budget

Vendor (name, website, phone, or fax)	**Product Name** (paste the exact product title, include all text)	**Part Number**	**Qty**	**Price/Ea**	**Total**	**Design Location**	**Payment**	**Date Purchased**	**Currently Located**
Digikey	MPU-3050	1428-1001-1-ND - Cut Tape (CT)	2	$ 8.26	$ 16.52	Main DAQ	Reimburse	2/3/2022	In Hand
Digikey	APS12205LUAA	620-1964-ND	2	$ 0.98	$ 1.96	Fork Sensor	Reimburse	2/3/2022	In Hand
Digikey	LP402535JU+PCM+2 WIRES 50MM	1908-LP402535JU+PCM+2WIRES50MM-ND	8	$ 9.49	$ 75.92	Main DAQ	Reimburse	2/3/2022	In Hand
Digikey	BATTERY LITHIUM 3.7V 1.2AH	1528-1838-ND	2	$ 9.95	$ 19.90	Main DAQ	Reimburse	2/3/2022	In Hand
Arrow	Accelerometer Triple ±200g 2.5V/3.3V 14-Pin LGA T/R	ADXL375BCCZ-RL7	2	$ 11.24	$ 22.48	Main DAQ/Front/Rear	Reimburse	2/3/2022	In Hand
Jenson USA	ONEUP COMPONENTS EDC GEAR STRAP	TL186J05	2	$ 16.50	$ 33.00	Fork/Rear Sensor	Reimburse	2/3/2022	In Hand
My Bike Shop	MSW Universal Speed Sensor Spoke Magnet	**EC3311**	2	$ 5.00	$ 10.00	Front Wheel Spoke	Reimburse	2/3/2022	In Hand
JLC PCB	Sensor PCB	Custom	2	-	$ 34.00	Fork Sensor	Reimburse		
JLC PCB	Main DAQ PCB	Custom	2	-	$ 54.00	Main DAQ	Reimburse		
FormLabs	Housings	Custom	4	-	$ 100.00	Main DAQ/Sensors	Reimburse		
Shipping/Handling/Tax					$ 97.00				
Total					$ 464.78				
Project Budget					$ 500.00				
Budget Remaining					$ 35.22				

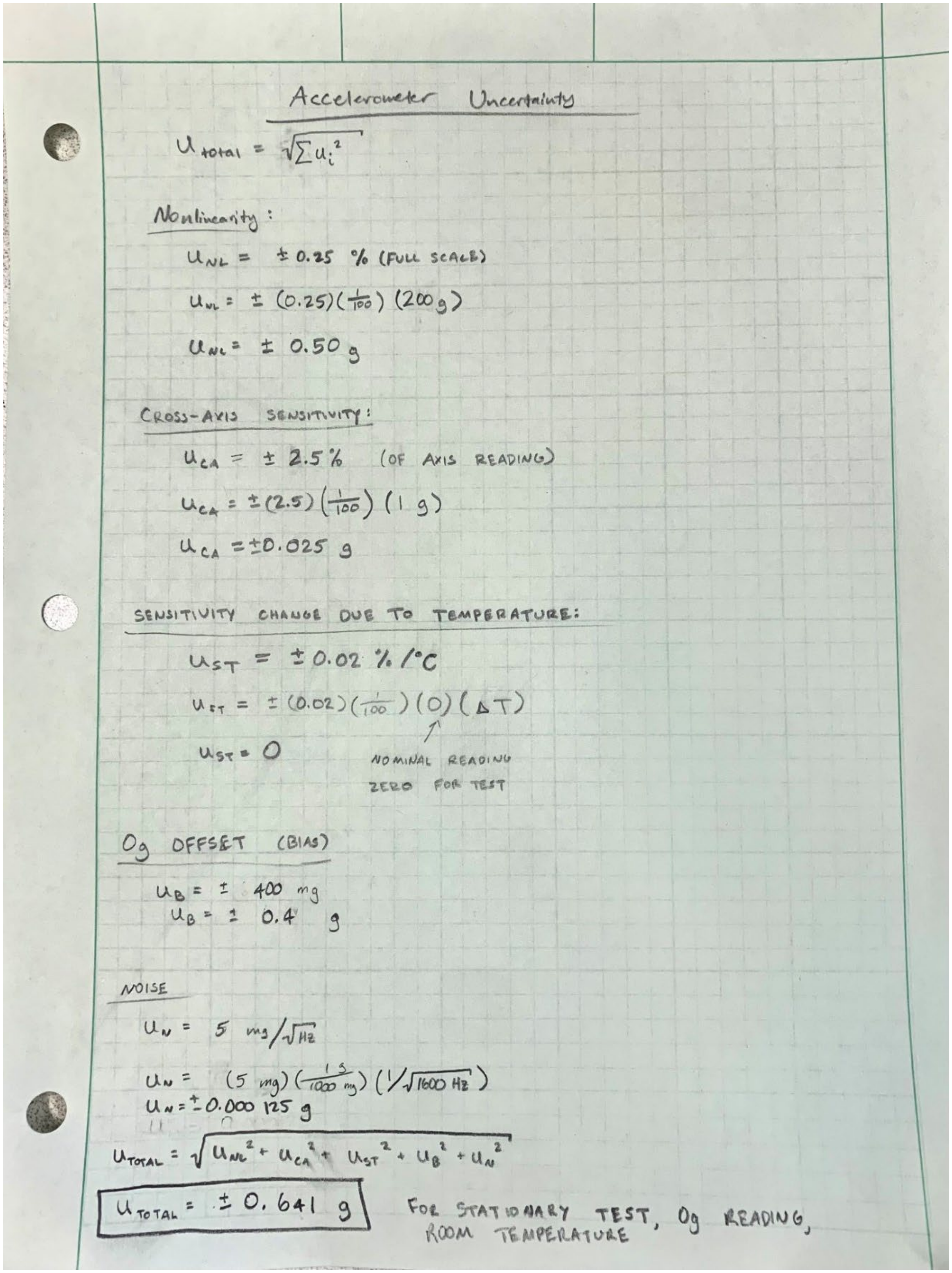
Appendix B.2: Bill of Materials

MTB DAQ

Indented Bill of Material (iBOM)

Assy Level	**Part Number**	**Descriptive Part Name**					**Qty**	**Part Cost**	**Source**	**URL**	**More Info**
		Lvl0	*Lvl1*	*Lvl2*	*Lvl3*	*Lvl 4*					
0	100000	Final Assy							------		
1	110000		Main DAQ						------		
2	111000			Housing			1	$ 1.50	custom		Maintanence
2	111100				Bolts		1	$ 0.59	McMaster		item 45792A
2	111400			PCB					------		
3	111410				Gyroscope		1	$ 1.50	custom		vac-formed PET
3	111420				Accelerometer		1	$ 2.15	McMaster		item 98725
3	111430				Nucleo		1	$ 0.30	McMaster		item 48005
					RJ45 Ports						
					Batteries		4				
2	111600			Cables					------		
3	111610				Ethernet Cables		2	$ 0.35	McMaster		item 48250
3	111620		Rear Sensor						------		
4	111621			Housing			1	$ 1.50	custom		mold in ABS
4	111622				Strap		1	$ 0.50	Bearing Inc.		item 27-100
2	111700				Screws				------		
3	111710			Accelerometer			1	$ 7.00	custom		machined aluminum
3	111720			PCB			1	$ 2.50	Bendix		item US259874
1	120000		Front Sensor				1	$ 1.50	custom		mold in ABS
				Housing							
	TL186J05			Strap			1	$ 16.50	Oneup	Link	OTS
					Screws						
				Accelerometer			1				
1				Hall effect sensor				$ 0.98	DigiKey	Link	OTS
1	207107			Spoke magnet			1	$ 10.40	REI	Link	OTS
				PCB							
1	130000						4	$ 0.72	Home Depot		#3-1/2-in
	Total Parts						**19**	**$ 47.99**			

Appendix C. Uncertainty Propagation



Accelerometer Uncertainty

$u_{total} = \sqrt{\sum u_i^2}$

Nonlinearity:

$u_{NL} = \pm 0.25\ \%$ (FULL SCALE)

$u_{NL} = \pm (0.25)(\frac{1}{100})(200\,g)$

$u_{NL} = \pm 0.50\ g$

CROSS-AXIS SENSITIVITY:

$u_{CA} = \pm 2.5\ \%$ (OF AXIS READING)

$u_{CA} = \pm (2.5)(\frac{1}{100})(1\ g)$

$u_{CA} = \pm 0.025\ g$

SENSITIVITY CHANGE DUE TO TEMPERATURE:

$u_{ST} = \pm 0.02\ \%/^{\circ}C$

$u_{ST} = \pm (0.02)(\frac{1}{100})(0)(\Delta T)$

$u_{ST} = 0$

NOMINAL READING ZERO FOR TEST

0g OFFSET (BIAS)

$u_B = \pm 400\ mg$

$u_B = \pm 0.4\ g$

NOISE

$u_N = 5\ mg/\sqrt{Hz}$

$u_N = (5\ mg)(\frac{1\ g}{1000\ mg})(1/\sqrt{1600\ Hz})$

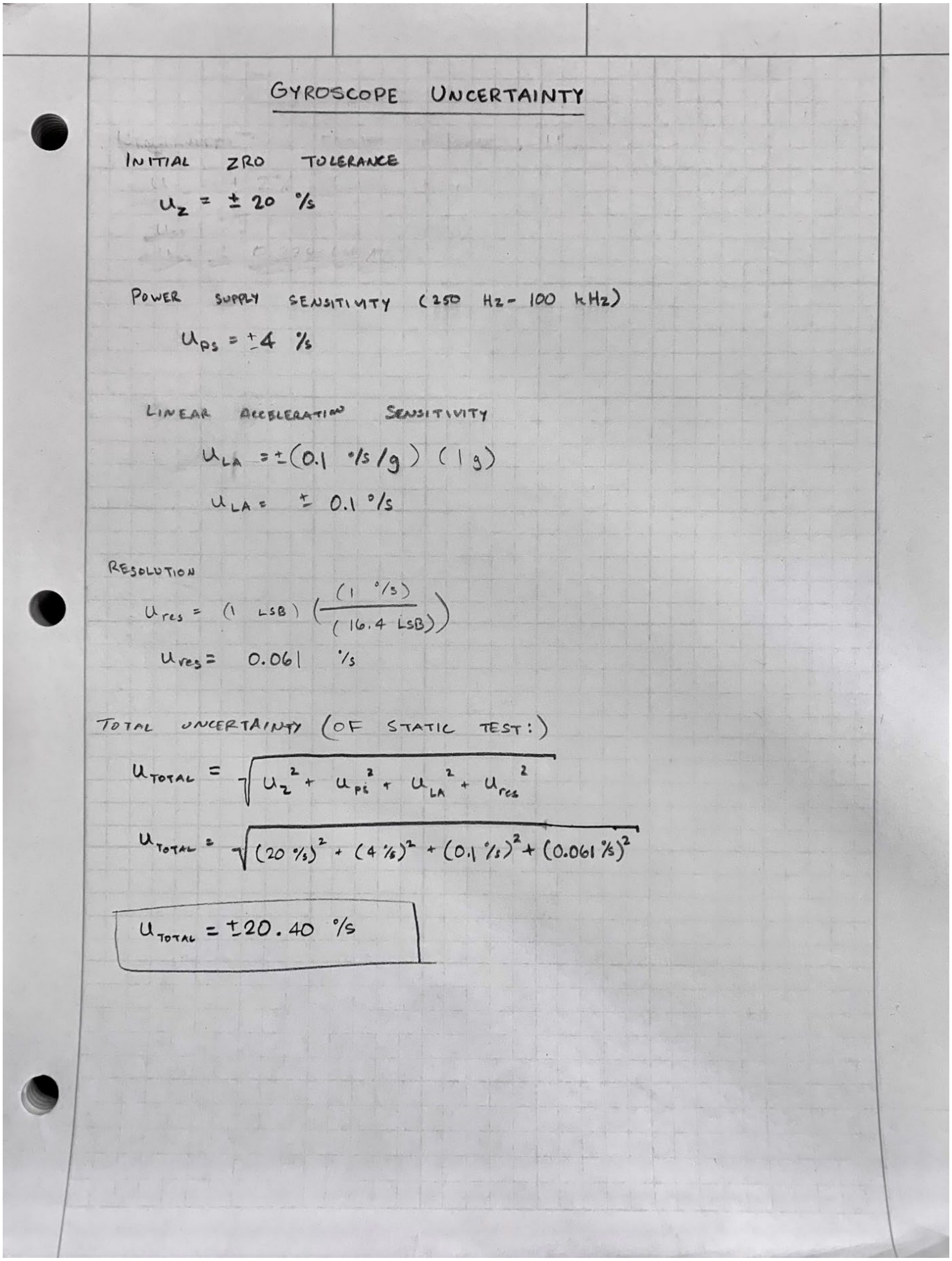
$u_N = \pm 0.000\,125\ g$

$u_{TOTAL} = \sqrt{u_{NL}^2 + u_{CA}^2 + u_{ST}^2 + u_B^2 + u_N^2}$

$\boxed{u_{TOTAL} = \pm 0.641\ g}$

FOR STATIONARY TEST, 0g READING, ROOM TEMPERATURE

Fig. Uncertainty estimation for stationary accelerometer, with axis oriented along 0g axis, at ambient temperature (25 °C). Uncertainty values from manufacturer's datasheet [Appendix A].



GYROSCOPE UNCERTAINTY

INITIAL ZRO TOLERANCE

$$u_z = \pm 20\ ^\circ/s$$

POWER SUPPLY SENSITIVITY (250 Hz - 100 kHz)

$$u_{ps} = \pm 4\ ^\circ/s$$

LINEAR ACCELERATION SENSITIVITY

$$u_{LA} = \pm(0.1\ ^\circ/s/g)(1\ g)$$

$$u_{LA} = \pm\ 0.1\ ^\circ/s$$

RESOLUTION

$$u_{res} = (1\ \text{LSB})\left(\frac{(1\ ^\circ/s)}{(16.4\ \text{LSB})}\right)$$

$$u_{res} = 0.061\ ^\circ/s$$

TOTAL UNCERTAINTY (OF STATIC TEST:)

$$u_{TOTAL} = \sqrt{u_z^2 + u_{ps}^2 + u_{LA}^2 + u_{res}^2}$$

$$u_{TOTAL} = \sqrt{(20\ ^\circ/s)^2 + (4\ ^\circ/s)^2 + (0.1\ ^\circ/s)^2 + (0.061\ ^\circ/s)^2}$$

$$\boxed{u_{TOTAL} = \pm 20.40\ ^\circ/s}$$

Fig. Uncertainty estimation for stationary accelerometer at ambient temperature (25 °C). Uncertainty values from manufacturer’s datasheet [Appendix A].

Appendix D. FMEA

Team F11												Action Results			
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
Algorithm / Interpret Data	Incorrect Interpretion of Data	1. Uncomfortable Rider 2. Slower Trail Time	7	1. Improper filter of Sensor data 2. Irrelevant Metric 3. Inaccurate data	1.Industry & Technical Research 2. Iterative implementation, testing and redesign	7	Comparative testing between run times	8	1	Iterate through testing and editing of algorithm parameters until they result in real-world improvements in performance.	Entire team. Final algorithm: April 18				
Main DAQ / Store Data	Unusable data	No tuning recommendation	8	1. SD card full 2. SD card not formatted properly 3. Data corrupted 4. SD card damaged	1. Design & order PCB from manufacturer 2. Test EE components	3	1.Test System for maximum run time 2. Start-up alert if SD error	3	4	Main DAQ redesign (along with UI)	Entire team. Target completion March 7.				
Sensors / Measure Data	Inaccurate measurement	1. Uncomfortable Rider 2. Slower Trail Time	6	1. Sensor miscalibration 2. Too fast sampling rate 3. Too slow sampling rate 4. Sensor damage	1. Robust autocalibration software design 2. Design & order PCB from manufacturer 3. Test EE components 4. Iterative implementation, testing and redesign	4	1. Calibrate on testing setup with known data 2. Trail testing 3. Post-test data analysis	7	2	Create test setups to compare data to known measurements (i.e. accelerometer angles). Develop procedure to automatically calibrate sensors on bike. Validate data with trail testing and analysis.	Theo. Target completion January 25.	Perforned Shake Table Lab Test February 22.			
Housings / Protect DAQ & Sensors	Sensor/PCB damage	1. Uncomfortable Rider 2. Slower Trail Time	7	1. Water ingress 2. Dust/debris ingress 3. Destructive impact	1.Industry & Technical Research 2. Iterative implementation, testing and redesign 3. Purchase or design waterproof connection point	6	System testing	6	5	Iterate through stress testing and adjusting geometry of housing to improve.	Dylan. Initial waterproofing concepts January 27.				
Main DAQ / User Interface	Unresponsive UI	Difficulty operating	6	1. Button sticks 2. Button connection broken 3. LED breaks 4. Character display breaks	1.Industry & Technical Research 2. Iterative implementation, testing and redesign	3	System testing by design team and users	3	8	Main DAQ redesign including button UI for the time being.	Whole team is responsible, March 7th Target Completion				
Main DAQ / Power DAQ	Improper power supply	Unresponsive system	7	1. Battery damaged 2. Battery supplies too high voltage 3. Battery supplies too low voltage 4. Circuit disruption	1.Industry & Technical Research 2. Iterative implementation, testing and redesign	8	System testing	4	3	Research/explore issues with power supply in current DAQ, and design new board to fix them.	Max. Target completion: March 7th.	Researched potential battery replacement for future design of Main DAQ.			
Housings / Mount Sensors & DAQ	Sensor moves from desired position	1. Bad tuning recommendation 2. Interference with rider's motion	6	1. Mount slips on bike 2. Mount detaches from bike 3. Mount interferes with rider's motion	Trail testing	6	Trail testing	7	6	Attach housings to bike, test on trail, and observe any movement. Adjust design if needed.	Ronan. Target completion: January 7.	Attached housings to bike. Rode trails with them attached.			
	Sensor / Housing movement independent of bike	1. Uncomfortable Rider 2. Slower Trail Time	6	1. Rubber Pad Dampens Vibrations 2. Strap to bike too loose. 3.Screws fixing sensors to housing insufficient	1. Trail testing 2. Lab testing	4	Trail testing	7	7	Mount accelerometers to a shake table in lab, observe results. Adjust design if needed.	Ronan. Target completion: Feb 22.	Shake Table test conducted.			
Cables / Data Transmission	Connection Loss / Cable Damage	Unresponsive system	6	1. Connection is disrupted (wires disconnect, are damaged, etc.) 2. Cable is damaged during crash	1. Secure design of Ethernet cable snap 2. Strapping cables to frame out of way 3. System start-up connection error alert	3	System start up connection error test	7	9	Implement cable lock, not within the scope of our project	Stretch goal, only work on it if all other aspects within scope are completed.				

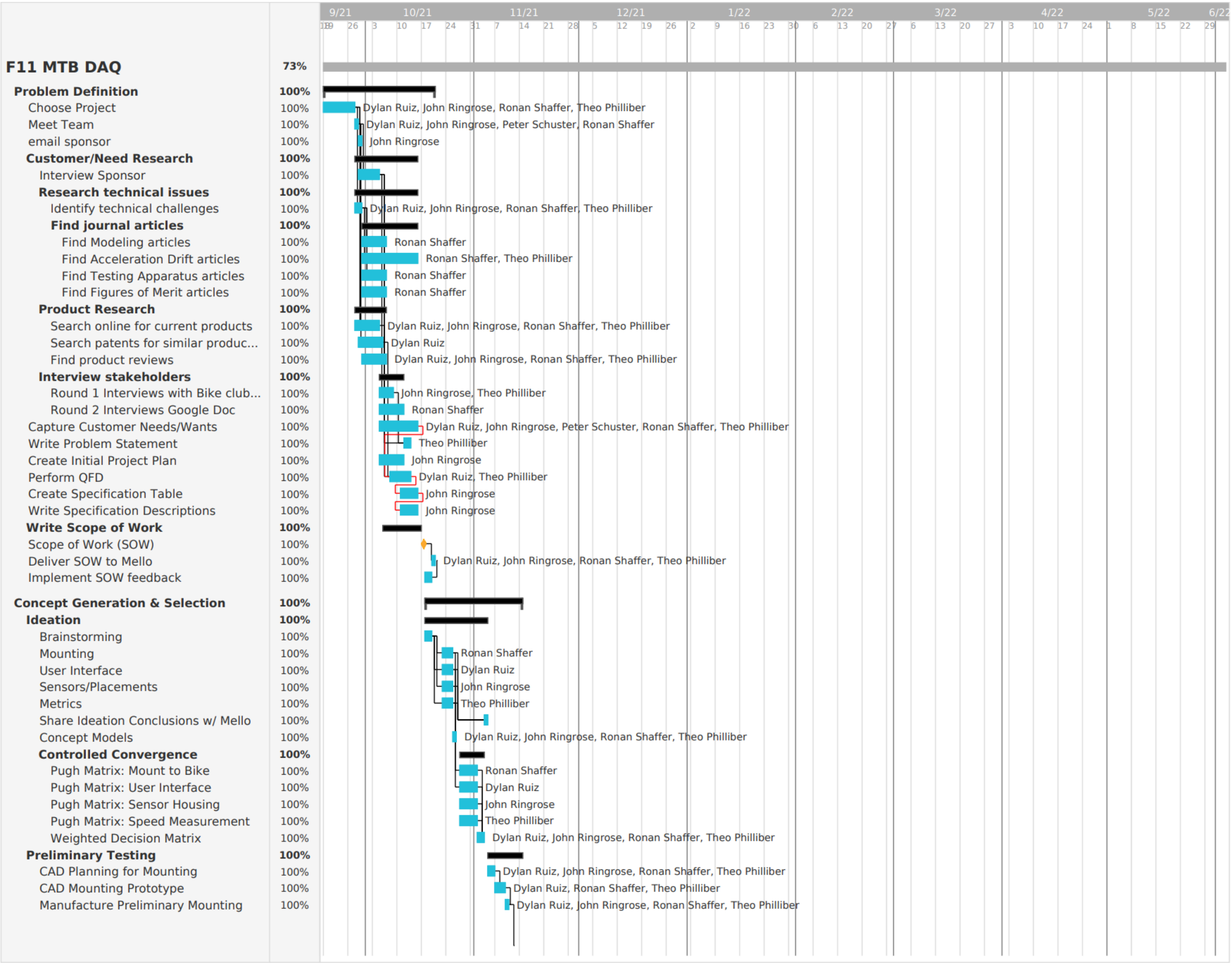
Appendix E. Design Verification Plan

DVP&R - Design Verification Plan (& Report)

Project: F11 - MTB DAQ
Sponsor: Dr. Joseph Mello
Edit Date: 2/18/2022

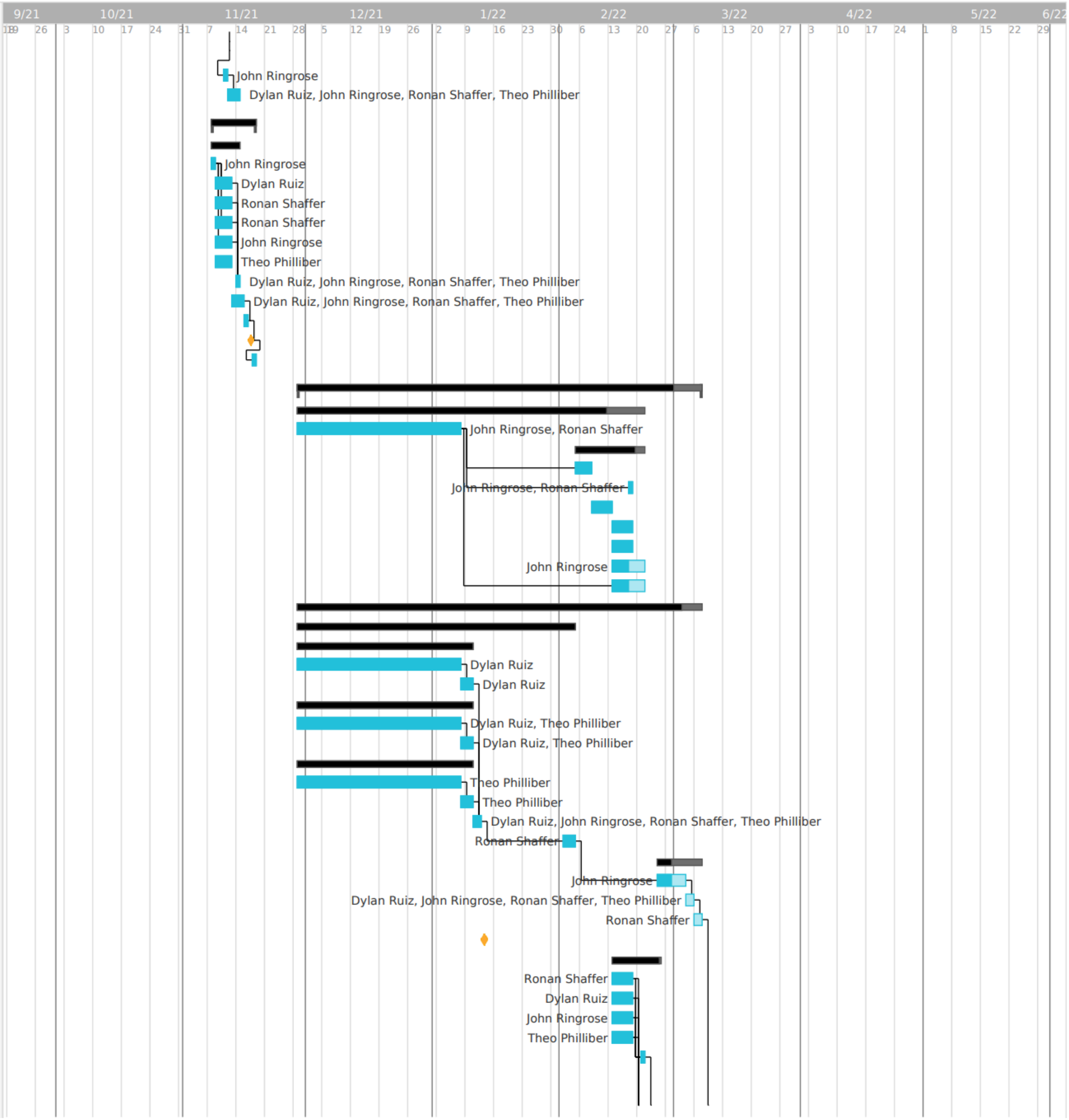
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
1	Main Hub Size	Measure physical dimensions of main hub.	Lengths	5"x3"x1" or less	Calipers or ruler	SP/FP	Theo	4/18/2022			
2	Sensor Housings Size	Measure physical dimensions of peripheral sensor housings.	Lengths	1.5"x1.5"x1.5" or less	Calipers or ruler	SP/FP	Theo	4/18/2022			
3	Weight	Weigh entire system (hub, sensors, cables, straps) on scale.	Mass	500g or less	Weight Scale	SP/FP	Ronan	4/18/2022			
4	Cost	Add up entire cost of final system	Dollars	Under $150	None	None	Ronan	4/18/2022			
5	Battery Life	Turn on and run system for target battery life, see if it runs out of power.	Hours	1 Hour or more	None	FP	Dylan	4/18/2022			
6	Ingress Protection	Remove internal electronics from housings and replace with paper. Spray with moderate amount of water, and toss dust at system. See if either has penetrated housings.	Pass/Fail	No water or dust in system	Water, dust	FP	Dylan	4/18/2022			
7	Foolproof	Give system to users with provided manual/instructions, see if they run into any issues.	Pass/Fail	100% pass by user testing (no issues)	Customer Survey	FP	Max	4/18/2022			
8	Maximum Recording Storage	Check maximum storage capacity of SD card	Gigabytes	8 gb or more	None	SP	Max	4/18/2022			
9	Mounting Universality	Attempt to attach system to variety of bikes.	Pass/Fail	System fits on 100% of bikes	Variety of bikes	SP/FP	Theo	4/18/2022			
10	Aesthetics	Survey potential customers, asking if they find the system visually appealing	Pass/Fail	Over 80% Approval	Customer Survey	FP	Ronan	4/18/2022			
11	Suspension Tuning Recommendation	Test the system on a mountain biking trail, adjust according to tuning recommendations, and ride again.	Trail Time	Over 5% faster	Bike trail, bike	FP	Max	4/18/2022			

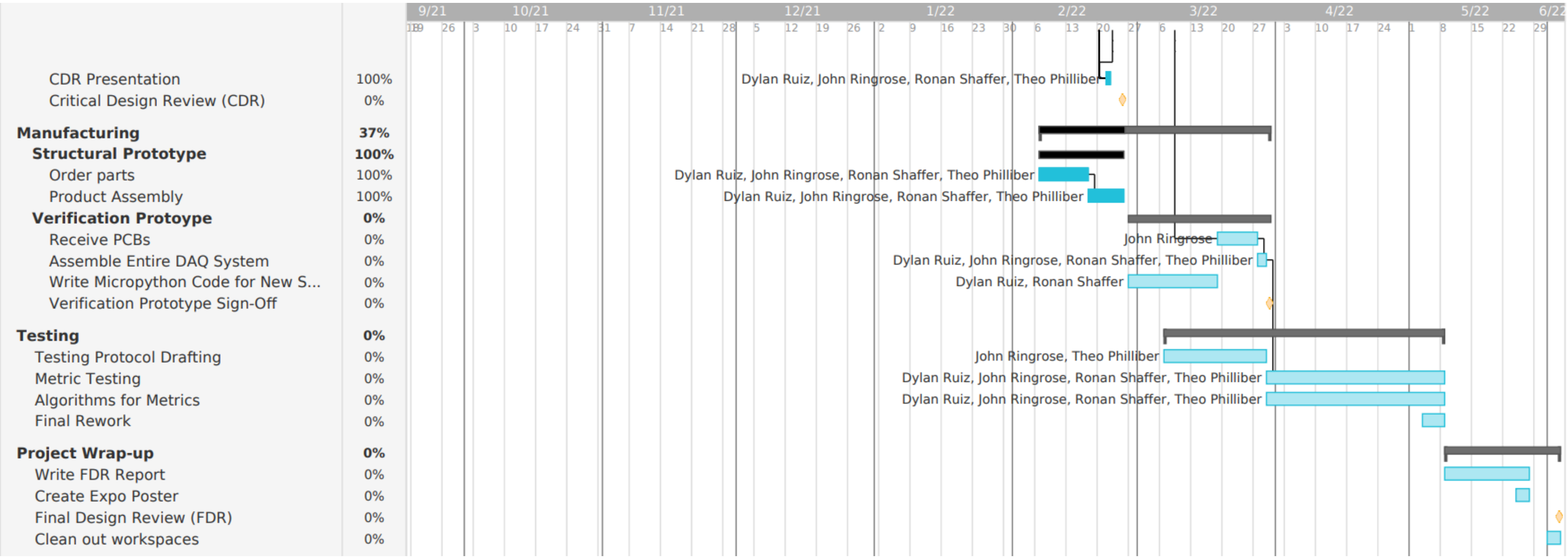
Appendix G. Gantt Chart



F11 MTB DAQ	**73%**	
Problem Definition	**100%**	
Choose Project	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Meet Team	100%	Dylan Ruiz, John Ringrose, Peter Schuster, Ronan Shaffer
email sponsor	100%	John Ringrose
Customer/Need Research	**100%**	
Interview Sponsor	100%	
Research technical issues	**100%**	
Identify technical challenges	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Find journal articles	**100%**	
Find Modeling articles	100%	Ronan Shaffer
Find Acceleration Drift articles	100%	Ronan Shaffer, Theo Philliber
Find Testing Apparatus articles	100%	Ronan Shaffer
Find Figures of Merit articles	100%	Ronan Shaffer
Product Research	**100%**	
Search online for current products	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Search patents for similar produc...	100%	Dylan Ruiz
Find product reviews	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Interview stakeholders	**100%**	
Round 1 Interviews with Bike club...	100%	John Ringrose, Theo Philliber
Round 2 Interviews Google Doc	100%	Ronan Shaffer
Capture Customer Needs/Wants	100%	Dylan Ruiz, John Ringrose, Peter Schuster, Ronan Shaffer, Theo Philliber
Write Problem Statement	100%	Theo Philliber
Create Initial Project Plan	100%	John Ringrose
Perform QFD	100%	Dylan Ruiz, Theo Philliber
Create Specification Table	100%	John Ringrose
Write Specification Descriptions	100%	John Ringrose
Write Scope of Work	**100%**	
Scope of Work (SOW)	100%	
Deliver SOW to Mello	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Implement SOW feedback	100%	
Concept Generation & Selection	**100%**	
Ideation	**100%**	
Brainstorming	100%	
Mounting	100%	Ronan Shaffer
User Interface	100%	Dylan Ruiz
Sensors/Placements	100%	John Ringrose
Metrics	100%	Theo Philliber
Share Ideation Conclusions w/ Mello	100%	
Concept Models	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Controlled Convergence	**100%**	
Pugh Matrix: Mount to Bike	100%	Ronan Shaffer
Pugh Matrix: User Interface	100%	Dylan Ruiz
Pugh Matrix: Sensor Housing	100%	John Ringrose
Pugh Matrix: Speed Measurement	100%	Theo Philliber
Weighted Decision Matrix	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Preliminary Testing	**100%**	
CAD Planning for Mounting	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
CAD Mounting Prototype	100%	Dylan Ruiz, Ronan Shaffer, Theo Philliber
Manufacture Preliminary Mounting	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber

Mount to bike	100%
Prelim Testing Day	100%
PDR	**100%**
Write PDR Document	**100%**
Revise SOW	100%
Concept Development sect	100%
Concept Design sect	100%
Concept Justification sect	100%
Project Management sect	100%
Rest of PDR (Intro/Conclusion/etc)	100%
Incorporate Peer Feedback	100%
Create Presentation	100%
PDR Presentation	100%
Preliminary Design Review (PDR)	100%
Present PDR to Mello	100%
Detailed Design & Analysis	**93%**
Metric Selection	**89%**
Ideate/Research Metrics	100%
Metric Testing	**86%**
Build Test Rig	100%
Lab Test	100%
Write Gyro Driver	100%
Test New Sensors	100%
Breadboard Gyro to Nucleo for T...	100%
Field Test	50%
Analyze Data	50%
Circuit Board Additions	**95%**
Sensor Additions	**100%**
Gyro and Accelerometers	**100%**
Background Research/Determi...	100%
Add Parts to CAD	100%
Potentiometers	**100%**
Background Research/Determi...	100%
Add Parts to CAD	100%
Speed Sensor to Wheel	**100%**
Background Research/Determi...	100%
Add Parts to CAD	100%
Design Review for Sensors	100%
Buy Sensors and Parts	100%
Board Rework	**32%**
CAD Design	50%
Design Review for Board	0%
Outsource Board Manufacturing	0%
Interim Design Review (IDR)	100%
Critical Design Review (CDR)	**96%**
System Design Section	100%
Design Justification Section	100%
Manufacturing Plan Section	100%
Design Verification Plan Section	100%
Create CDR Presentation	100%





CDR Presentation	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Critical Design Review (CDR)	0%	
Manufacturing	**37%**	
Structural Prototype	**100%**	
Order parts	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Product Assembly	100%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Verification Protoype	**0%**	
Receive PCBs	0%	John Ringrose
Assemble Entire DAQ System	0%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Write Micropython Code for New S...	0%	Dylan Ruiz, Ronan Shaffer
Verification Prototype Sign-Off	0%	
Testing	**0%**	
Testing Protocol Drafting	0%	John Ringrose, Theo Philliber
Metric Testing	0%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Algorithms for Metrics	0%	Dylan Ruiz, John Ringrose, Ronan Shaffer, Theo Philliber
Final Rework	0%	
Project Wrap-up	**0%**	
Write FDR Report	0%	
Create Expo Poster	0%	
Final Design Review (FDR)	0%	
Clean out workspaces	0%	

Appendix H. Design Hazard Checklist

CDR Design Hazard Checklist F11 MTB DAQ

Y	N	
○	●	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
●	○	2. Can any part of the design undergo high accelerations/decelerations?
●	○	3. Will the system have any large moving masses or large forces?
○	●	4. Will the system produce a projectile?
○	●	5. Would it be possible for the system to fall under gravity creating injury?
○	●	6. Will a user be exposed to overhanging weights as part of the design?
○	●	7. Will the system have any sharp edges?
○	●	8. Will any part of the electrical systems not be grounded?
○	●	9. Will there be any large batteries or electrical voltage in the system above 40 V?
●	○	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
○	●	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
●	○	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
●	○	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
○	●	14. Can the system generate high levels of noise?
●	○	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc.?
○	●	16. Is it possible for the system to be used in an unsafe manner?
○	●	17. Will there be any other potential hazards not listed above? If yes, please explain on the reverse.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The design will undergo high accelerations based on the way the user of the design rides the bike the design is attached to.	When testing, we will have an experienced rider wear safety protection while being mindful of riding the bike safely.	11/20/2021	11/20/2021
The system itself will not be large in mass, but it is attached to a bike that will be moving fast. A fast-moving bike can be a hazard to spectators.	When testing, we will spectate the rider from a safe place. We will have a specified segment the rider will take when testing, allowing us to know the path the rider will take.	4/08/2022	
There is currently a battery within the main DAQ system.	Currently, this hazard is low-risk due to the housing of the main DAQ providing protection from the electrical components.	11/20/2021	11/20/2021
The user will have to be riding a mounting bike to use this design.	There will be a cautionary notice before the use of the device listing this hazard. Since this hazard is not affected by our design, this is the most we can do	1/11/2022	
The manufacturing process will include PCB rework. There are hazards with the tools used such as a solder.	The people manufacturing will be trained in safety precautions before operating the tools.	2/19/2022	2/19/2022

Appendix I. Accelerometer Calibration Test Description

Theo Philliber, Dylan Ruiz

Max Ringrose, Ronan Shaffer

2/28/2022

Experimental Planning Worksheet

Project Title: MTB DAQ (F11)

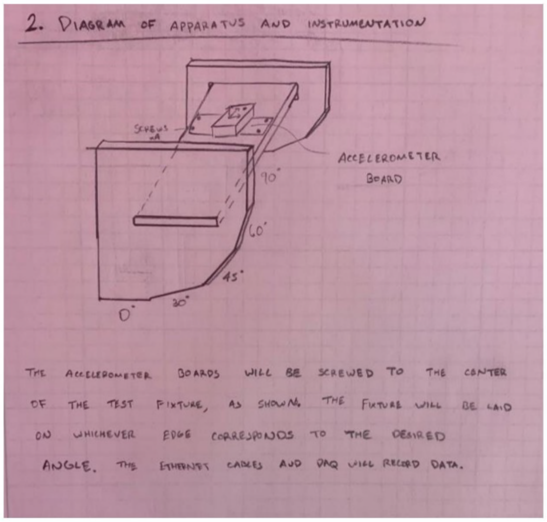
Description:

This preliminary experiment will be to test the performance of the accelerometers. We will take data from each accelerometer at known angular orientations and compare the expected output to the actual outputs. This will give us an idea of the biases and errors present in each sensor and allows us to determine if we need to calibrate or adjust each accelerometer in the firmware.

1. *Desired Results with Required Uncertainty*

The results of this test will be accelerometer data. The raw output of each sensor is in bits, which are then multiplied by a sensitivity (g/LSB) provided by the manufacturer. The manufacturer also provides some uncertainty values in the specifications. From these, we can determine the expected value and uncertainty at each angular setpoint, seeing if our data falls within that range. Our data will have its own uncertainty, caused by the resolution error of the known angles and statistical uncertainty.

2. *Diagram of apparatus and instrumentation*



2. DIAGRAM OF APPARATUS AND INSTRUMENTATION

THE ACCELEROMETER BOARDS WILL BE SCREWED TO THE CENTER OF THE TEST FIXTURE, AS SHOWN. THE FIXTURE WILL BE LAID ON WHICHEVER EDGE CORRESPONDS TO THE DESIRED ANGLE. THE ETHERNET CABLES AND DAQ WILL RECORD DATA.

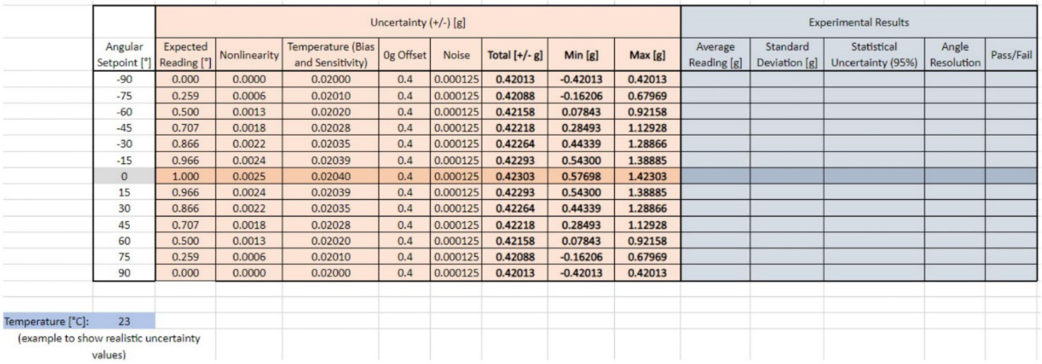
3. *Priority list of measurements to be undertaken*

The only measurement taken will be the acceleration data of each sensor at each angular orientation.

4. *Schedule Including calibration, zero/tare, baseline, repeats*

First the fixture will be oriented at 0 degrees. The sensor will be allowed a few seconds (around 5-10) to settle, after which 10 readings will be taken across a period of 10 seconds. Next, the fixture will be moved to 15 degrees, and the readings will be taken. This continues for all angles, positive and negative, and the entire process is repeated once more. The whole process is repeated for all sensors.

5. *Data analysis equations/spreadsheet with uncertainty*



	Uncertainty (+/-) [g]								Experimental Results				
Angular Setpoint [°]	Expected Reading [°]	Nonlinearity	Temperature (Bias and Sensitivity)	0g Offset	Noise	Total [+/- g]	Min [g]	Max [g]	Average Reading [g]	Standard Deviation [g]	Statistical Uncertainty (95%)	Angle Resolution	Pass/Fail
-90	0.000	0.0000	0.02000	0.4	0.000125	**0.42013**	**-0.42013**	**0.42013**					
-75	0.259	0.0006	0.02010	0.4	0.000125	**0.42088**	**-0.16206**	**0.67969**					
-60	0.500	0.0013	0.02020	0.4	0.000125	**0.42158**	**0.07843**	**0.92158**					
-45	0.707	0.0018	0.02028	0.4	0.000125	**0.42218**	**0.28493**	**1.12928**					
-30	0.866	0.0022	0.02035	0.4	0.000125	**0.42264**	**0.44339**	**1.28866**					
-15	0.966	0.0024	0.02039	0.4	0.000125	**0.42293**	**0.54300**	**1.38885**					
0	1.000	0.0025	0.02040	0.4	0.000125	**0.42303**	**0.57698**	**1.42303**					
15	0.966	0.0024	0.02039	0.4	0.000125	**0.42293**	**0.54300**	**1.38885**					
30	0.866	0.0022	0.02035	0.4	0.000125	**0.42264**	**0.44339**	**1.28866**					
45	0.707	0.0018	0.02028	0.4	0.000125	**0.42218**	**0.28493**	**1.12928**					
60	0.500	0.0013	0.02020	0.4	0.000125	**0.42158**	**0.07843**	**0.92158**					
75	0.259	0.0006	0.02010	0.4	0.000125	**0.42088**	**-0.16206**	**0.67969**					
90	0.000	0.0000	0.02000	0.4	0.000125	**0.42013**	**-0.42013**	**0.42013**					

Temperature [°C]: 23
(example to show realistic uncertainty values)

6. *Expected results (control curves)*