MTB Suspension Tuning DAQ
Preliminary Design Review (PDR)

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Team
MTB – F11

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Abstract

This Preliminary Design Review (PDR) details the 'MTB Suspension Tuning DAQ' senior project, performed by four mechanical engineering students at California Polytechnic State University, San Luis Obispo. The project, under the guidance of Dr. Joseph Mello with the mechanical engineering department, 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. In this document, the initial concept development and design choices are described. It also lays out future steps if the PDR is approved.

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1.Introduction

The goal of this report is to document the selected design direction of the next iteration of Dr. Mello's Mountain bike (MTB) data acquisition system (DAQ). The next iteration of design will be supported by the findings in the first round of prototyping as well as the planned next steps to implement the new features of the system. Since the Scope of Work document was released, new features of the system were needed in order to succeed in developing the main goal of the system; that is to provide a user with tuning recommendations for their suspension settings based on metrics designed by the MTB DAQ team. Our team will develop our own metrics to characterize suspension behavior and evaluate a rider's performance resulting from their selected settings. Our first stage of research into these suspension metrics is outlined, as well as the team's upcoming goals for designing, building, and testing new system features.

Many metrics used in the industry of MTB and automotive racing are proprietary and not available to the public, thus we are proposing the time to test the current system with our prototype 1 housings and test the next iteration of the system once the design is validated.

2. Concept Development

The concept development process consists of organized and sequential steps that allow the selection of five system-level concepts. Concept ideation methods are used to produce ideas, both reasonable and unfeasible. These ideas are then implemented into Pugh Matrices for a specific function. Finally, the results of the Pugh Matrices inspired the creation of five system-level ideas for the MTB mounting system. These system-level ideas were evaluated through a weighted decision matrix to select the design direction of the MTB mounting system. To provide context for the main functions of system, a functional tree is composed below in Figure 1.

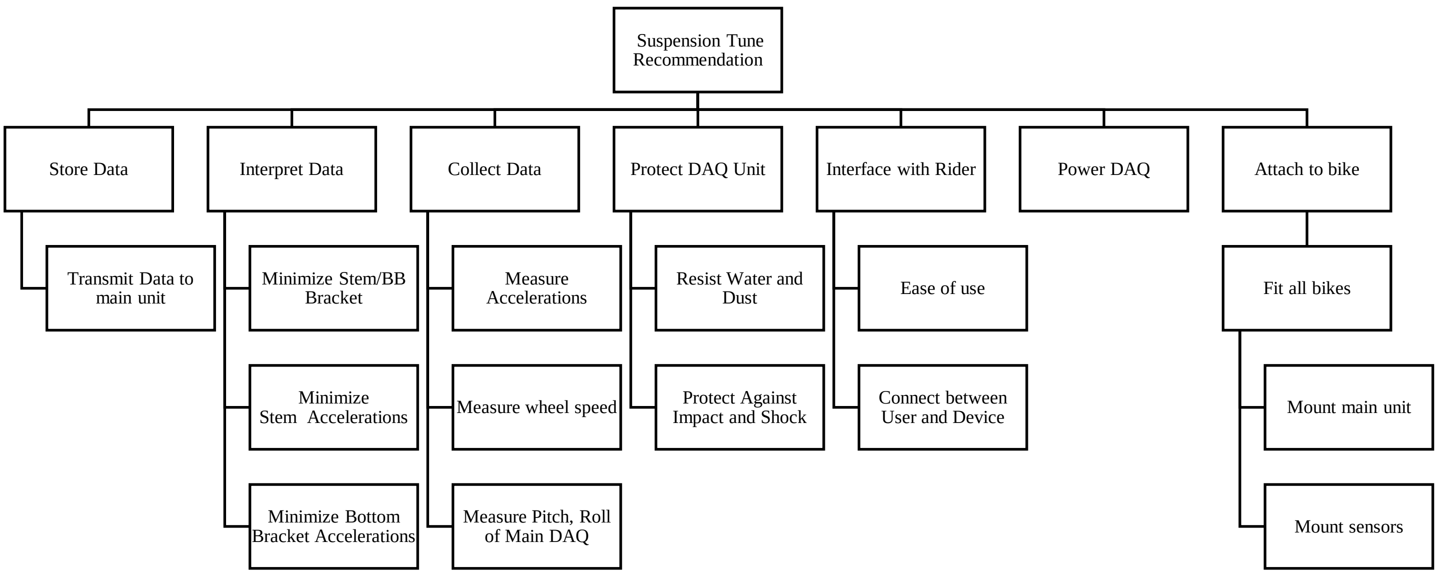


Figure 1. Functional Tree of the MTB DAQ System

2.1 Concept Ideation

To develop multiple ideas for each function, a functional tree divided the system level idea into subfunctions which the ideas were based on. Only functions relevant to the initial set-up of the MTB were referenced due to the priorities of preparing for preliminary testing. These functions include mounting to sensors to the bike, speed measurement, user interface, and sensor protection. The goal was to create 50 ideas per function through brainstorming, then select the best five ideas from each function to further evaluate in the Pugh Matrices. Using “How Might We” templates for the ideation, we generated ides that came to mind. Although, some of the ideas were more technical than others, such as ways to measure speed, which resulted in less ideas created overall. The top ideas are listed in Appendix A.

Using these top five ideas for each function, ideation models were developed mainly from cardboard, glue, and popsicle sticks to help visualize a few of the ideas, shown in Appendix A. These concept models were focused on the mounting portion of the functions, which consisted of the mounting of the sensors to the MTB and the housing for the sensors.

2.2 Pugh Matrices

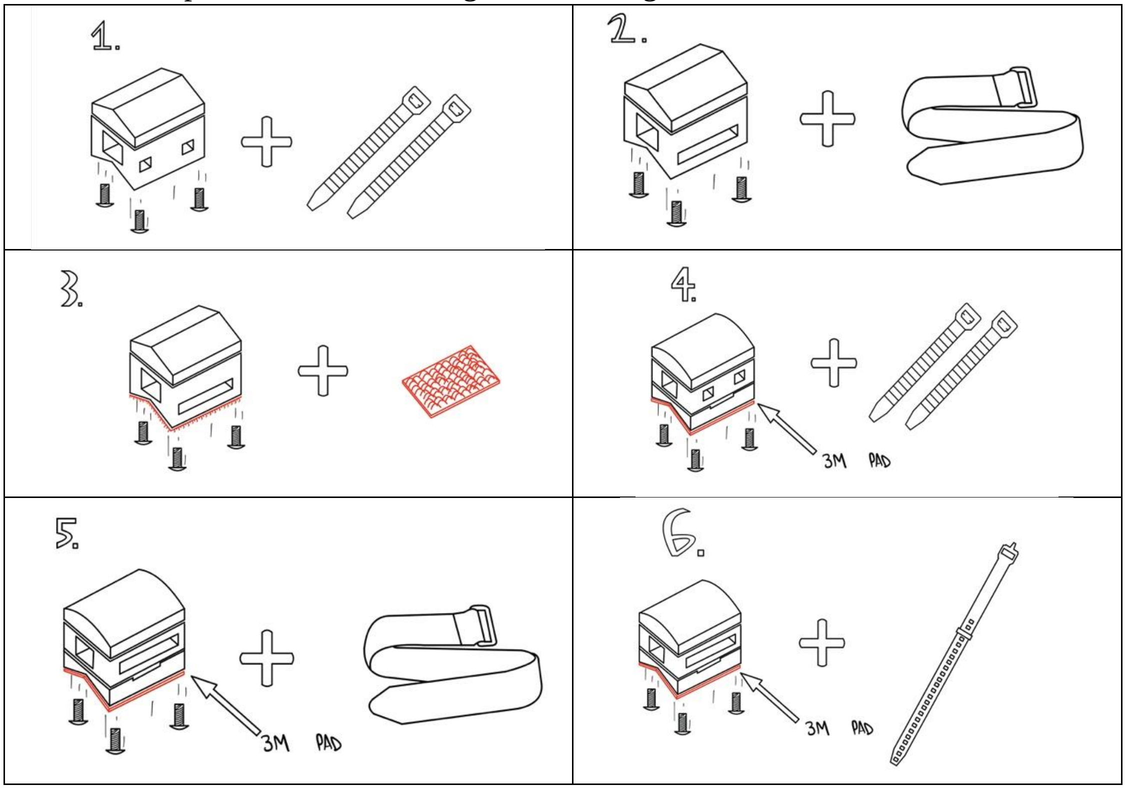
A Pugh matrix compares the different ideas for a certain function using a set of relevant criteria. One of the ideas is used as a "datum" to compare whether the other ideas are better or worse for a certain criterion. The values +, -, S are used to represent where the ideas compare to the datum for each criterion, with "S" being equal to the datum, "+" being better than the datum and "-" being worse than the datum. The scores are summed up for each solution, giving a rough idea of which solution will be the best, although it does not consider the importance of each criterion. The final concept ideas were determined using Pugh Matrices.

Each of the four Pugh Matrices in Appendix B were developed for one of the MTB DAQ system's functions: User Interface, Mounting Sensors to the Bike, Housing the Sensors and Measuring Speed of the Bike. Because the mounting of sensors to the bike were the priority, only the ideas for mounting and housing the sensors were used to create the top five system level concepts. The other two functions are independent of the mounting and can incorporate virtually any idea. From the Pugh matrices related to mounting, it was found that permanent attachments to the bike, such as welding or adhesives, were unfavorable due to the effects it would have on the bike's frame. Instead, Velcro and tie straps proved to be more efficient. Also, a tapered base was more favorable than a rounded base because it ensures at least two points of contact to a variety of bike frames.

2.3 Top Five System Level Concepts

Using the results from the two relevant Pugh Matrices, six concept level ideas were created. The concept level ideas incorporated the combinations of the top two ideas from the sensor housing Pugh Matrix and the top three ideas from the mounting to bike Pugh Matrix. These six concept level ideas can be seen in table 1 of the next page

Table 1. Six Concepts for Sensor Housings & Mounting Methods



Each of these concept models provided a unique way of housing and mounting the sensors to the bike. All the concepts use a tapered base that allows the housing to mount to multiple diameters within a range. Concept 1 utilizes zip ties, a cheap and accessible product, to mount the housing to the bike. The housing has a lid that can be opened to insert the accelerometer and utilizes screws to secure the accelerometer board to the housing. Concept 2 is the same design as Concept 1 except it uses a Velcro strap instead of zip ties, which is better for reusability. Concept 3 uses a Velcro pad to mount the housing to the bike instead of zip ties or a Velcro strap. Concept 4 consists of a lid with a hinge, zip ties and a rubber pad to both increase the stability through friction and protect the bike from scratches. Concept 5 is the similar to Concept 4 substituting the zip ties for a Velcro strap. Finally, Concept 6 is similar to both Concept 5 and Concept 4 but uses a OneUp strap to mount the housing to the bike. The OneUp strap is an off-the-shelf part made of a UV stabilized polyurethane strap.

2.4 Weighted Decision Matrix

The weighted decision matrix in Appendix C compared the six mounting concepts against each other using a set of criteria and weights developed through team consensus. Each design was rated 1-10 for each criterion based on how well it satisfied the criterion, with a rating of 10 indicated the design perfectly met the criterion to the highest standard. The rating of each criterion was also multiplied by each of the criterion's weight, creating a total score for each criterion. The total scores for each criterion were then summed up for each design to determine the best design based on our specifications.

Each team member filled out their own decision matrix based on their best judgement. This first step was done individually to minimize the impact of peer pressure among team members. The final decision matrix was created based on the average of all the team members matrices. The best concept, determined by the highest score in the decision matrix, was Concept 6 due to its high rankings in the most important criteria. These criteria include durability, vibrational dampening, universality, and security. The second and third place concepts were Concepts 5 and 4 respectively. These designs both included the rubber base which seemed to be a big factor for the most important criteria. Although Concept 6 was determined to be the design direction for the mounting system, this is mainly based on theory and is subject to change based on the preliminary testing results.

3. Concept Design

Our selected concept design consists primarily of two newly designed parts: the sensor housing and the mounting platform. The purpose of the housing is to secure the accelerometer and ethernet port to protect the components from the outdoor conditions being operated in. The purpose of the mounting platform is to attach the housing to the bike. Our design also includes the data acquisition (DAQ) unit and the accelerometer sensors, designed and built by Steven Waal, the master's student whose work formed the basis of our project.

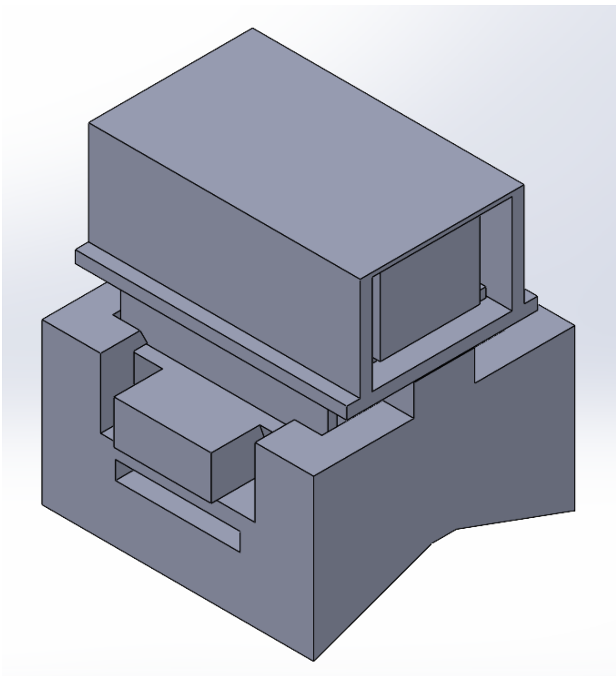


Figure 2. Assembly model of the sensor, housing, and platform fitting together

3.1 CAD Design of the Concept Prototype

The accelerometer sensor shown below in Figure 3 will measure acceleration data in XYZ directions; this data will be transmitted via ethernet cables to the main DAQ unit, where it will be stored on an SD card.

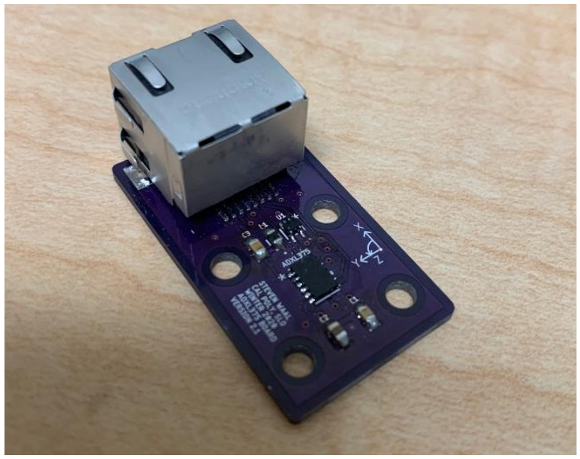


Figure 3. Picture of current accelerometer sensor

The sensor housing pictured below in Figure 4 features an internal chamber to fit the board, components, and port. The board will slide along the floor of the chamber into the slot, allowing the holes in the board and housing to align. M1 screws will go through the bottom of the housing up into the internal protrusions to prevent lateral movement of the sensor. The open face of the housing allows the user to insert/remove the sensor and to plug the ethernet cable into the port. The prongs on the bottom of the housing will be flexible and act as a buckle to clip to the platform. This will serve as an easy connection point to put the housing on and take it off the platform. To detach the housing from the platform, the buckle prongs are squeezed inward towards the center of the part until the lip no longer contacts the interfacing surface of the platform.

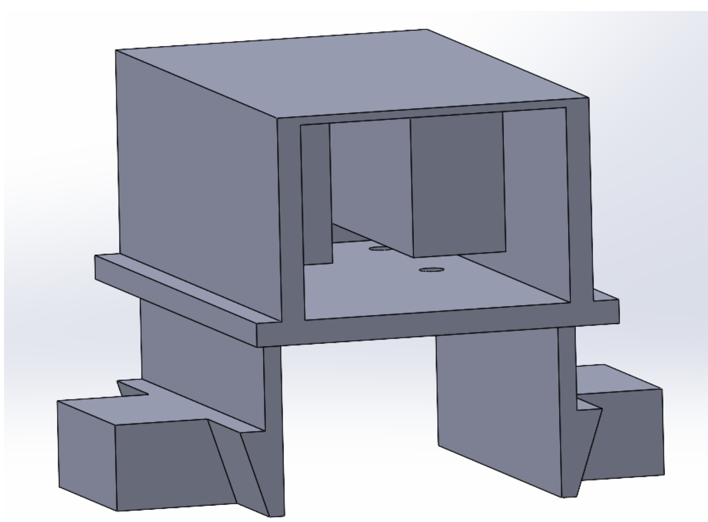


Figure 4. CAD model of sensor housing

The mounting platform depicted in Figure 5 receives the sensor housing prongs to prevent it from detaching upwards, with the centered uppermost surface sitting flush against the underside of the housing. The endcaps on either side of the buckle cavity prevent the housing from sliding laterally and detaching from the platform. The slot running underneath the floor of the buckle cavity will accommodate a polyurethane strap that will wrap around the bike fork or chain stay, securing the assembly to the bike. The angled surfaces on the underside of the platform will interface with the bike, providing two contact points. A thin rubber layer will be adhered to the angled surfaces of the platform, acting as a interface between the platform and the bike frame, to prevent vibrational chatter and dampen unwanted noise during data collection, as well as widen the contact surface and increase friction to secure the assembly to the bike.

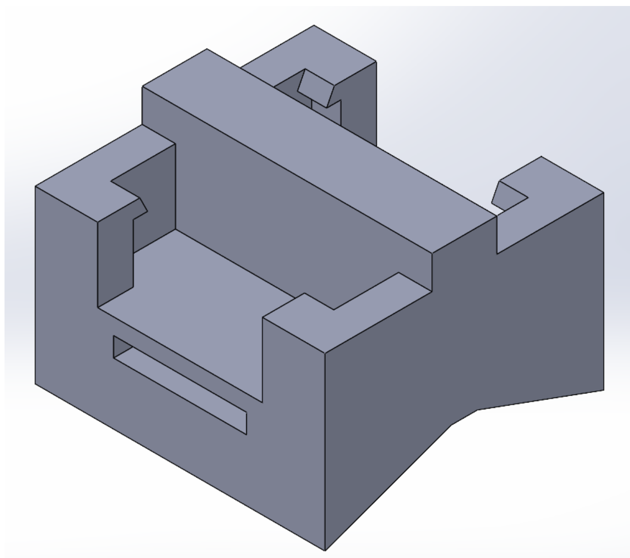


Figure 5. CAD model of platform mount

The main DAQ unit modeled below in Figure 5 consists of two ethernet cable ports for receiving accelerometer data, three LEDs to indicate the status of the system's power, charging, and recording functions, a record button to start and stop data collection, a 4-character display, a Micro SD card slot, and a USB Mini B port. Two M5X0.8 screws run through the unit to attach it to the water bottle bosses on the main frame of the bike. Two circuit boards are housed in the electronics enclosure: a UI board which connects to the LEDs, record button, and display, and the main board, which contains the rest of the electronic components including the microcontroller, crystal oscillators, power filtering circuit, battery charging circuit, Micro SD slot, ethernet ports, and USB port.

Figure 6. CAD model of the main DAQ housing

The housing and platform are both roughly 1 inch wide by 2 inches long, with the assembly sitting 2 inches high off the bike surface. One sensor will be mounted to the fork housing, close to the axle of the front wheel and the other will be mounted to the chain stay, close to the axle of the rear wheel. The DAQ housing is 5 in x 3 in x 1 in and will be mounted to the bike's main frame, close to the center of gravity of the bike-rider system.

3.2 Manufacturing and Materials of Concept Prototype

The accelerometer housing and platform components will be 3D printed with PLA using Ultimaker 3 and/or Ender 3 printers. These 3D printed parts will be used for preliminary testing to determine the viability of this manufacturing method. If the method and material yield good test results and are deemed reliable, durable, and safe enough to use for our project, we will continue to use the 3D printed parts throughout this project because of its manufacturing ease and cost savings. However, if these components do not yield good test results, other materials and manufacturing methods will be considered, most likely 6061 aluminum alloy and material removal machining methods such as CNC or manual milling, waterjet cutting, and drilling. The DAQ housing is made of aluminum with plastic endcaps that have cutouts for the cable ports and SD card slot.

Currently, the main DAQ unit is not fully defined and will be redesigned to include an accelerometer and gyroscope on its main board as well as additional ethernet ports to accommodate more sensors if we decide they are necessary to characterize suspension behavior. The DAQ housing will be redesigned to protect the electronics from water, dust, and debris entering through holes and gaps. If possible, the user interface will be redesigned to sit on the handlebars of the bike for easier access by the user, including an expanded, more modern display showing elapsed time during data collection and suspension adjustment recommendations afterwards to the user. However, this is a high-risk aspect of the design.

The final placement and sensor configuration are also not yet fully defined. Our team will decide if and where to add additional accelerometers to the bike if it's necessary. A more detailed explanation of options we are currently considering can be found in Section 5.

4. Concept Justification

We have demonstrated proof of concept with the first round of preliminary testing of the sensor housing/mount assembly. The first draft of the CAD model was 3D printed and assembled to examine the print quality of the chosen settings, specifically the orientation of the part on the build plate and the tolerances of the fit between the housing buckle and the platform lip.

Figure 7. Concept Prototype Housing for Accelerometer

The housing was printed with the open face of the chamber upwards to minimize overhanging features which are problematic when 3D printing. This minimized the number of overhanging supports and resulted in a cleaner surface finish and tighter tolerances. The holes that accommodate the screws going through the sensor PCB were undersized and printed parallel to the build plate which is not ideal but allowed for the larger overhanging features to come out more cleanly. The holes were then effectively tapped directly by inserting the screws which worked well to secure the sensor in the housing when mounted to the bike.

The platform was printed with the thru slot perpendicular to the build plate to eliminate the need for supports that would be difficult to remove and potentially interfere with the strap passing through it. However, the thin overhanging surface that catches the buckle protrusions on one side had more imperfections. Because this small surface is critical to the functionality of the snap-fit design, a second iteration of this print would orient the platform such that this lip is not overhanging. Regardless, the snap-fit worked reasonably well by simply pressing the housing into the platform until it clips in, with all interfacing surfaces between the parts sitting flush with each other. One important detail we learned of is that the center ridge of the platform was too wide and interfered with the heads of the screws in the housing.

This snap-fit design was intended to make it easier for attaching and detaching the sensors to the bike. However, while functional, we learned it was unnecessary to add this feature because of the ease with which the assembly can be strapped to the bike. The snap-fit prongs introduce a potential failure mode: being the thinnest features of the part, these prongs could yield from fatigue stress after enough cyclic loading from the squeezing action to buckle and unbuckle. With this realization, we will combine the housing and platform into one piece to reduce the number of parts needed and simplify the design. This way the form factor of the mount will be reduced and the clearance between the mount and the rider's shoe will be maximized, avoiding interference with the rider's motion. The system will also be lighter, easier to set up, and more robust and durable in the face of natural elements in an outdoor environment.

The angled surface of the bottom of the platform fits well onto the fork housing and seat stay, maintaining two points of contact with each component of the bike tested, and will fit any size and shape of fork housing and seat stay on the market.

The rubber pad between the platform and the bike significantly increased friction and, along with the polyurethane strap, this design fulfills the universal compatibility requirement from our design criteria.

The 3D printed PLA is waterproof and will protect from dust and debris, but we are still researching solutions to waterproof the electrical connections where openings in the housings of the sensors and main DAQ are necessary.

5. Future Work

In the coming weeks we will begin our first round of metric testing using the current state of the system along with our prototype 1 sensor housings. The three following subsections of this document give a brief introduction into each of the metrics we plan to test initially and how we will collect data per sensor locations. All possible sensor locations are depicted in Figure 7.

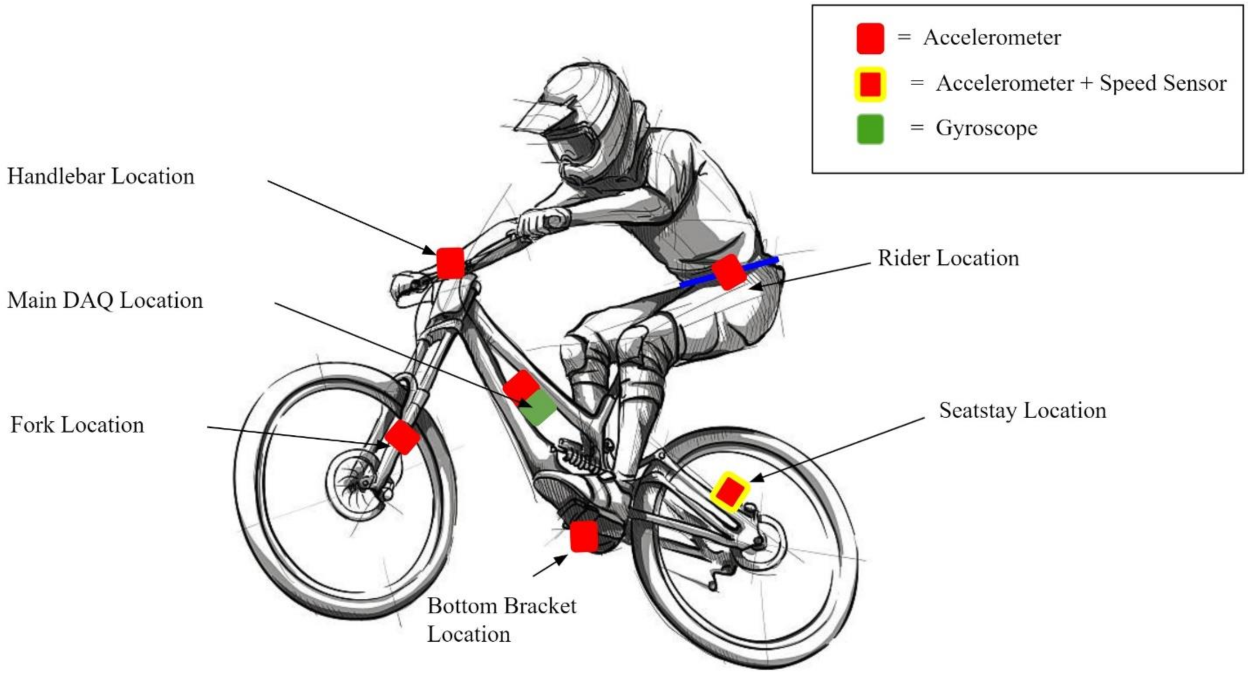


Figure 7. Sensor Types and Potential Locations

5.1 Suspension Balance Metric

One metric we will potentially use is a comparison of the front and rear axle behavior. Specifically, this figure would incorporate the root-mean-square values of measured accelerations at each location and compare the magnitude of each value for the instant of time that the measurements were taken. From this metric, we hope to determine whether the front fork or rear shock's spring rate or damping is too high or low relative to the other one. In this way, the suspension settings could be adjusted to minimize the difference in acceleration, and therefore reduce extraneous pitching motion, which may lead to a more balanced, smoother, faster ride.

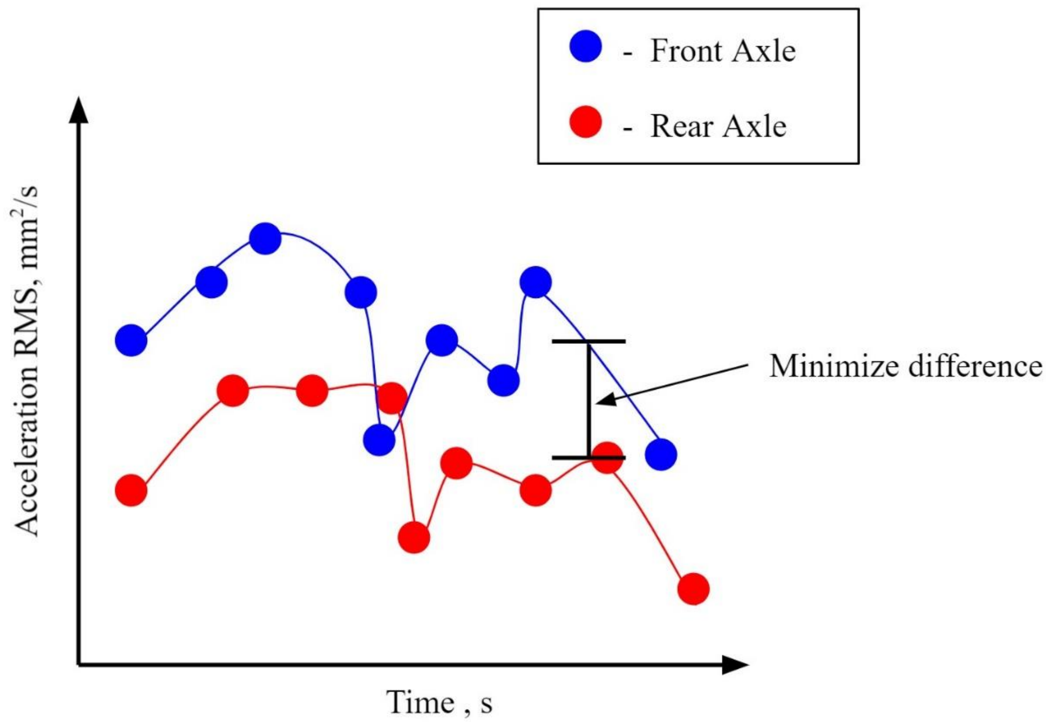


Figure 8. Plot demonstrating a comparison of RMS acceleration values for suspension balance

5.2 Rider Bike Metric

Another metric we will consider includes motion of the rider's body and compares it to the motion of the bike. While the rider's head position is being tracked in Figure 9, it could also be advantageous to track the motion of the rider's center of gravity with an accelerometer attached to a belt worn by the user. Body positioning is critical when biking competitively as it has a large effect on the rider's speed and control when navigating trail features. By collecting acceleration data of the rider's CG and comparing it to the bike frame's acceleration, we hope to analyze this motion in a suspension transmissibility context, similar to the next metric discussed below. Challenges for incorporating this metric include the added complexity of the rider's motion separate from the bike frame and the additional degrees of freedom that follow, as well as data transmission to the main DAQ which would be difficult with our current method using ethernet cables.

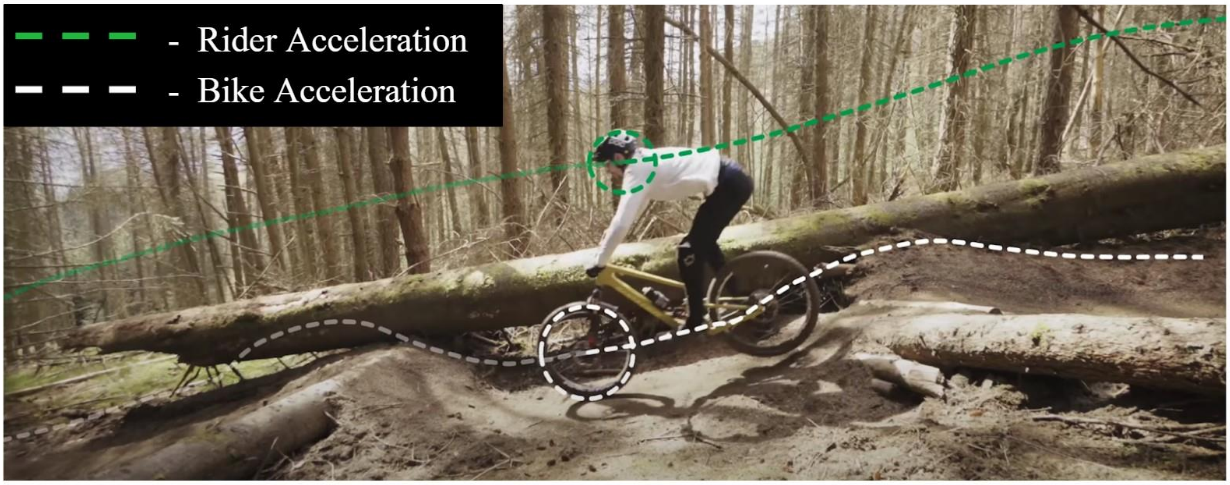


Figure 9. Positional/acceleration comparison of rider and bike

5.3 Handlebar/Fork Metric

The transmissibility of acceleration between the front axle and the handlebar is a metric that could lead to a more comfortable and faster ride. Ideally, the handlebar accelerations would be minimized as much as possible, allowing the user to experience less vibration and have more control during the ride. This may also help to reduce extraneous movement which could lead to a longer path traveled by the rider and therefore be slower. It could also provide more information pertinent to keeping the wheels contacting the ground, which is faster than when the bike and rider are airborne.

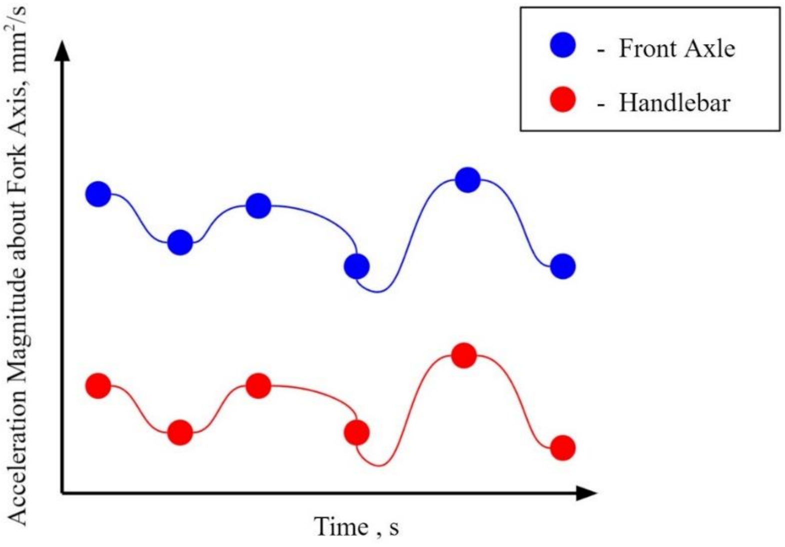


Figure 10. Example Plot of Handlebar and Front Axle Accelerations

Figure 8 represents an example plot of low transmissibility between the handlebar and front axle. The suspension will reduce or increase the transmissibility based on the selected settings. By minimizing the transmissibility, we can ensure the fork is not too stiff or bottoming out, as both cases would increase the transmissibility and cause discomfort, as well as contribute to a slower ride for the user.

We plan to assess the validity of each metric with an abundance of testing and data collection to see what correlates with faster ride times and more comfort and control experienced by the rider. Combining this with abundant background research on current techniques used in the racing industry and published methods in technical literature, we are confident in our ability to identify, develop, and implement meaningful metrics to quantify and evaluate suspension performance.

6. Project Management

The following subsection discusses what has been completed thus far and the planned tasks for the next major phase of this project: design and testing. This next quarter there will only be one main deliverable, the critical design review; therefore, the steps documented below will explain how we will reach the next design phase, engineering validation.

6.1 Design Process Timeline

At a high level our goals for the DAQ leading up to the CDR include round 1 of metric testing, adding sensors, an updated PCB, and updated main/sensor housings. To achieve these new features and metrics we will be working in parallel. This means each one of us will be owning a feature and leading the process. We will maintain the proper team dynamic by holding design reviews with the team and Dr. Mello. The major dates of the design phase are documented below in Table 2.

Table 2. Key Tasks Leading to CDR

Major Deliverables	Completion Date
New Component Research	1/6/22
New Component Selection	1/8/22
Round 1 Metric Testing	1/11/22
Interim Design Review	1/13/22
PCB Rework/ Redesign	1/14/22
PCB Review	1/21/22
DAQ Housing Redesign	2/2/22
Critical Design Review	2/11/22
Spring Break (2/19-2/27)	
Test Protocol Drafts	3/4/22

Component Testing	3/11/22
Round 2 Metric Testing	3/18/22

These new features will follow the same design path: research on sensors, selection of the new component, CAD implementation, PCB additions, programming, and component testing. We have come to understand that if we want a variety of options when determining metrics for tuning a MTB suspension, we do not want to be limited on the sensors we have available to us. A complete timeline for the entire project lifespan can be found on the Gantt chart in Appendix D. The following categories breakdown the processes we have followed and will follow through the different design phases of our device.

Concept | Ideation

After the completion of the SOW, we spent one week brainstorming and ideating on the main functions of the device. We generated over 100 ideas total for the functions we were brainstorming on. Then we turned our focus to the mount and housing for the accelerometers so that we could begin preliminary testing with the DAQ and gain experience. The next two weeks we preformed concepting activities and generated a few main concepts that boiled down to our main prototype. This process will continue throughout the lifespan of our project as this progression sets up for a smooth design phase.

Design | Prototype

After determining the main concept that would be prototyped, it was necessary to place an order on the off-the-shelf (OTS) parts that we were integrating into our system. By ordering these ahead of time, this allowed for us to take measurements on the OTS parts and begin the CAD work of the housing. After succeeding in the 3D printing of our housing we were able to mount it to the bike and perform our proof-of-concept tests. Following this process, we were able to find flaws in our design, but that is why we do create rapid prototypes. We plan to perform these steps again when adding new components and reworking our system.

Rework | Optimization

Following the completion of component testing, we will begin our investigation of tune metrics. This means that our system will need to be shook down to verify that the data we collect is reliable. During this process it is likely that we will have to rework our CAD/programs/PCB to correct our data collection. By giving ourselves time to make these corrections we should be able to achieve the level of data collection we desire. Once again, throughout the lifespan of our project we will rework our design until we deem the quality we desire has been achieved.

7. Conclusions

This Preliminary Design Review describes the development of the initial MTB Suspension Tuning DAQ concepts and prototype development. It details the specifications and design requirements, and how the selected concept meets them. The document then goes on to describe the future plans and direction of the project if this current direction is approved. The next major steps after this PDR will be to begin testing the concept prototype and begin redesigning the DAQ components to create our full prototype system.

References

[1] S. R. Waal, “A Quantitative Approach to Tuning a Mountain Bike Suspension,” thesis, 2020.

[2] S. Hanly, “Top 12 vibration metrics to monitor & how to calculate them,” *enDAQ Blog for Data Sensing and Analyzing*. [Online]. Available: https://blog.endaq.com/top-vibration-metrics-to-monitor-how-to-calculate-them. [Accessed: 18-Nov-2021].

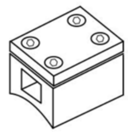
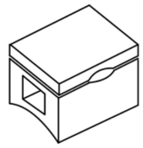
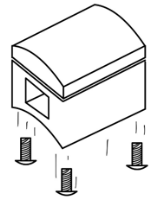
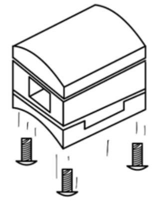
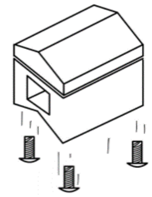
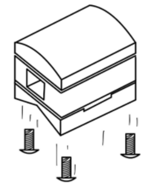
[3] S. J. Park and M. Subramaniyam, “Evaluating methods of vibration exposure and ride comfort in car,” *Journal of the Ergonomics Society of Korea*, vol. 32, no. 4, pp. 381–387, 2013.

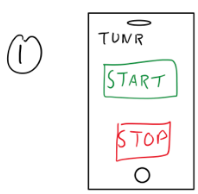
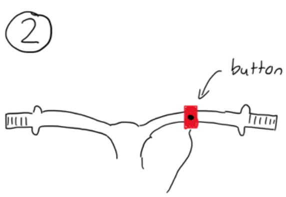
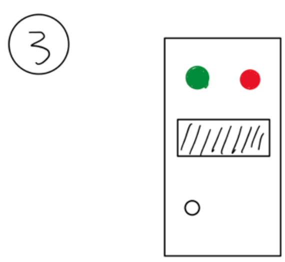
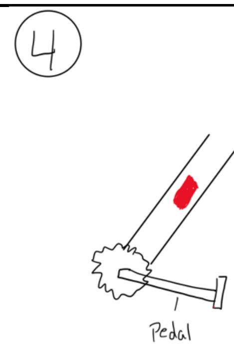
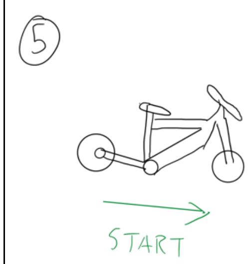
Appendices

Appendix A: Ideation Concepts (best ideas)

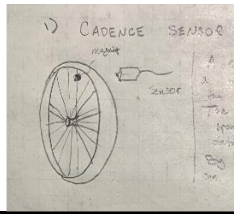
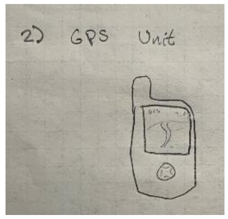
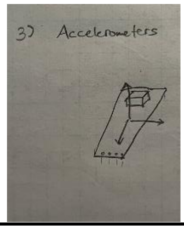
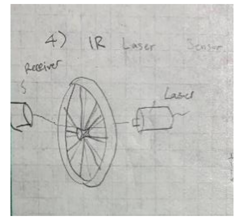
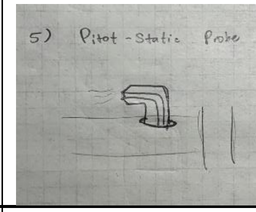
Sub-Functions	Idea
Attach Housing to Bike	Velcro
	Welding
	Adhesives
	C-Clamp
	Belt Loop
	Magnets
	Zip ties
	Rachet Strap
	Watch Band
	Glue
Measure Speed	GPS (phone)
	App (Strava)
	Timer Clock
	Integrate Acceleration
	Mechanical Speed Sensor
	Checkpoints with Time Intervals
	GPS onboard DAQ
	OTS sensor online
User Interface	Button on Handlebars to initiate/terminate
	iPhone App
	Sensor detection to initiate/terminate
	Touch Display on main device
	Foot button
	Link with Strava
	Link with Garmin
	Able to pause instead of terminating
	Two buttons to interface (start/stop; Keymark important times)
Housing	3d-Print
	Bottom Tapered
	Bottom Radial
	Hinged lid
	Locked lid
	Slide sensor through side
	Screws to hold board
	String to hold board
	Glue to hold board

Appendix B: Pugh Matrices

Sensor Housing							
Low Cost	+	-	+	-	+	+	S
Aesthetics	S	+	+	+	+	+	S
Manufacturability	+	+	-	-	-	-	S
Weight	+	+	+	+	+	+	S
# Of Parts	S	+	-	+	+	-	S
Waterproofing	+	+	+	+	-	+	S
Foolproof	S	-	-	+	+	+	S
Universal	-	-	-	-	+	+	S
Protection	-	-	+	+	+	+	S
Total	2	2	1	3	5	6	0

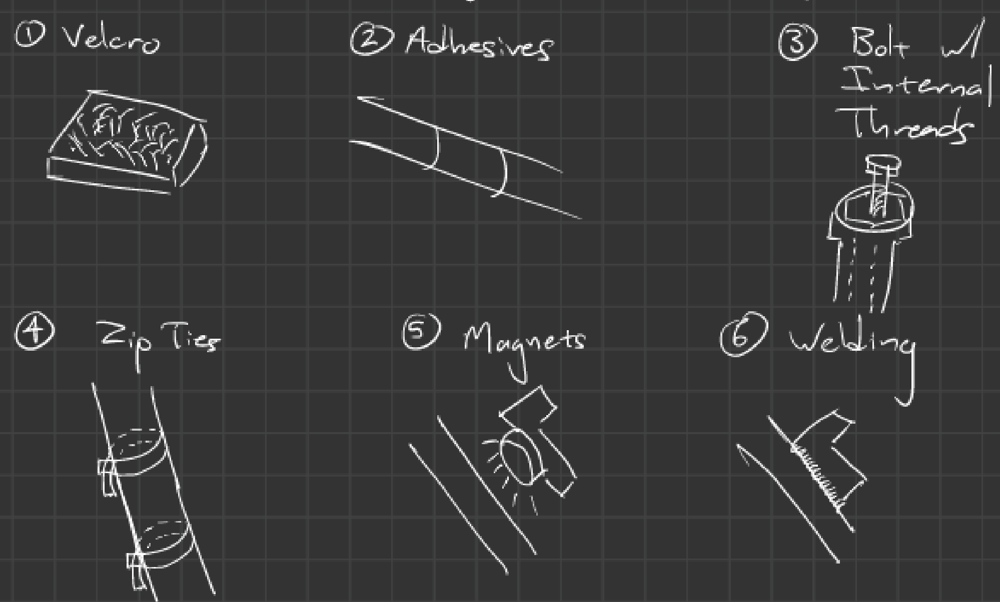
User Interface					
Weight	S	+	+	+	+
Low Cost	S	S	S	S	-
Water resistant	S	S	-	S	S
Simplicity	S	+	+	+	+
Universality	S	S	S	S	S
Durable	S	-	-	-	S
Aesthetics	S	-	-	-	-
Small Profile	S	+	+	+	+
Easy to Install	S	-	+	-	+
Total	0	0	1	0	1

Appendix B: Pugh Matrices (continued)

Speed Sensor	1. Cadence Sensor 	2. GPS Unit 	3. Accelerometer 	4. IR Laser Sensor 	5. Pitot-Static Probe 
Weight	S	-	S	S	+
Low Cost	S	-	-	S	+
Water resistant	S	+	+	-	-
Simplicity	S	+	-	S	-
Universality	S	+	-	S	-
Durable	S	+	+	S	-
Aesthetics	S	+	S	S	-
Small Profile	S	S	+	S	-
Easy to Install	S	+	S	S	-
Total	0	4	1	0	-5

Appendix B: Pugh Matrices (continued)

Pugh Matrix – Mounting Sensor Housing to Bike

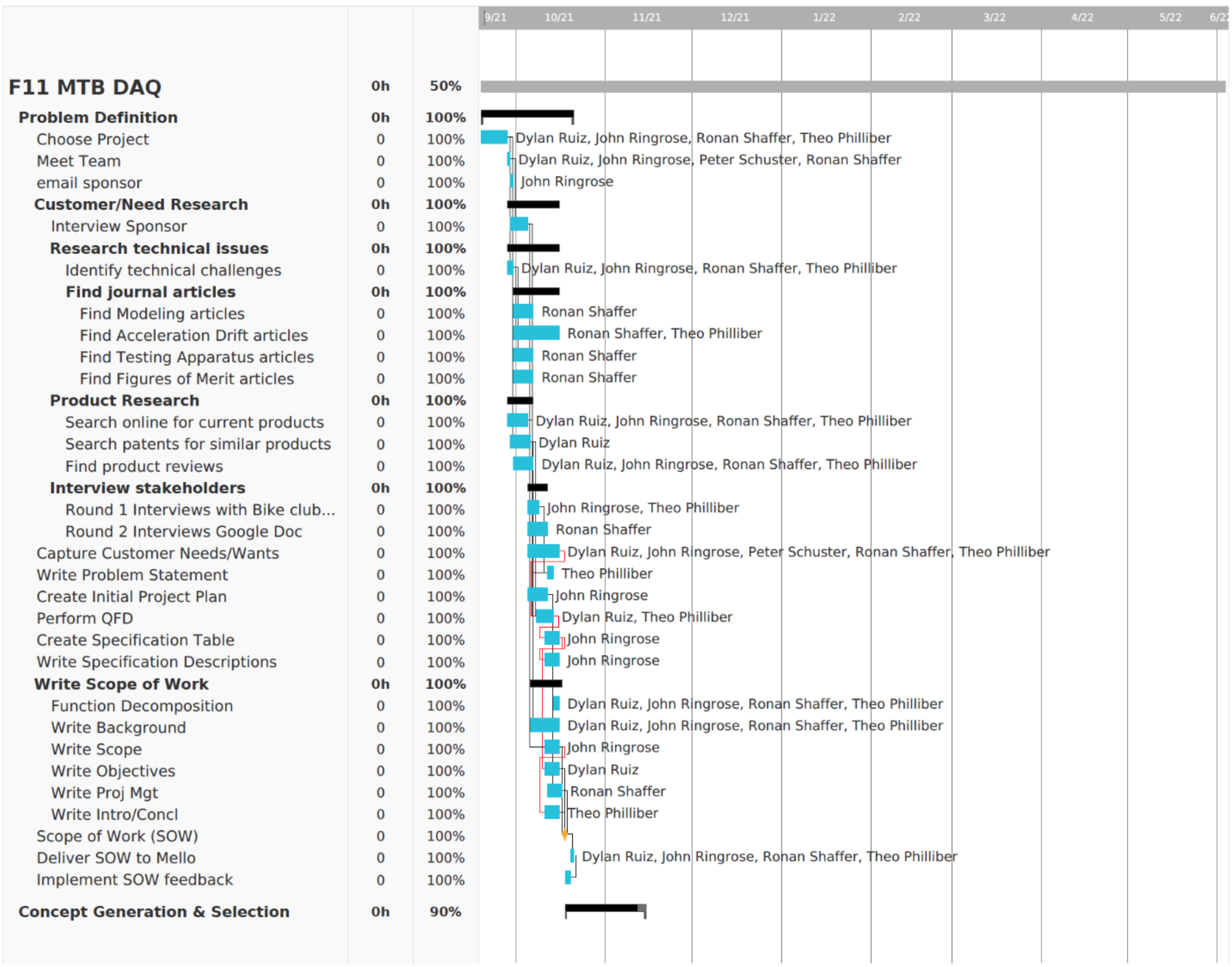


	④	①	②	③	⑤	⑥
Lightweight	DATUM	S	+	−	−	−
Low Cost	DATUM	S	−	−	−	−
Resistant to Water/Dust	DATUM	−	−	S	S	+
Mounting Universality	DATUM	+	+	−	−	+
Durable	DATUM	−	−	+	S	+
Aesthetics	DATUM	+	+	+	+	+
Ease of Installation	DATUM	+	+	−	+	−
TOTAL		0	1	−2	−1	1

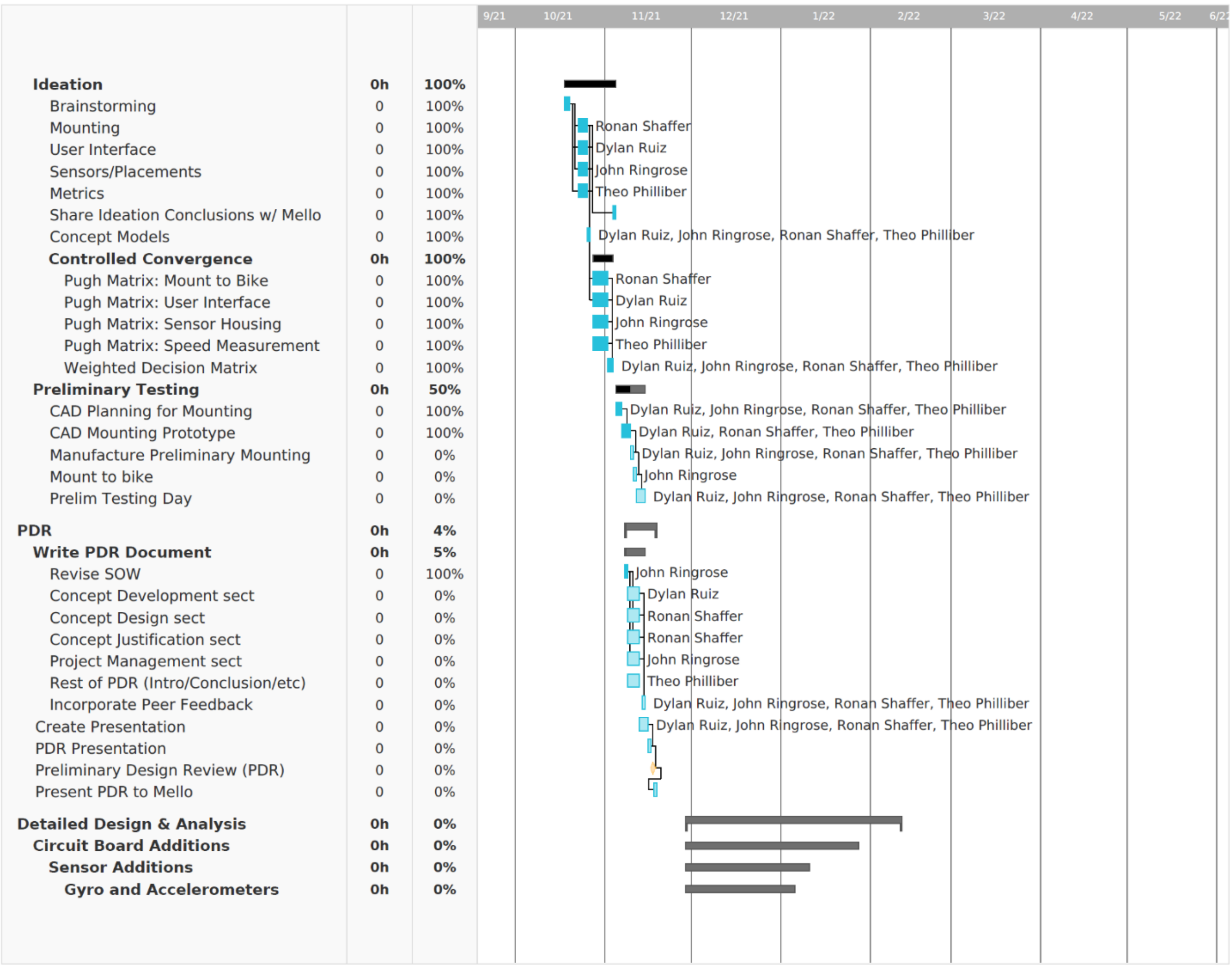
Appendix C: Weighted Decision Matrix

Final		Options											
		Design 1		Design 2		Design 3		Design 4		Design 5		Design 6	
Criteria	Weight	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Easy Installation	0.09	7.25	0.65	8.25	0.74	8.75	0.79	7.25	0.65	8.50	0.77	8.00	0.72
Waterproof	0.08	8.00	0.64	6.88	0.55	6.63	0.53	8.00	0.64	7.13	0.57	8.63	0.69
Durability	0.12	7.50	0.90	6.50	0.78	6.00	0.72	7.88	0.95	6.50	0.78	9.13	1.10
Vibrational Dampening	0.17	5.00	0.85	5.50	0.94	7.25	1.23	8.75	1.49	9.00	1.53	9.25	1.57
Universality	0.12	8.00	0.96	8.63	1.04	8.88	1.07	8.50	1.02	9.13	1.10	8.75	1.05
Security	0.12	7.00	0.84	6.38	0.77	4.75	0.57	8.50	1.02	8.13	0.98	8.75	1.05
Manufacturability	0.05	9.50	0.48	8.50	0.43	9.00	0.45	8.00	0.40	7.75	0.39	8.00	0.40
Number of Parts	0.06	7.50	0.45	8.00	0.48	8.00	0.48	6.25	0.38	6.13	0.37	6.25	0.38
Cost	0.05	8.50	0.43	8.13	0.41	8.75	0.44	6.75	0.34	6.25	0.31	5.50	0.28
Aesthetics	0.08	4.75	0.38	6.75	0.54	7.63	0.61	4.75	0.38	7.38	0.59	9.00	0.72
Weight	0.06	8.00	0.48	7.63	0.46	8.63	0.52	7.38	0.44	6.75	0.41	6.75	0.41
Total	1												
Sum		7.05		7.12		7.40		7.70		7.78		8.35	

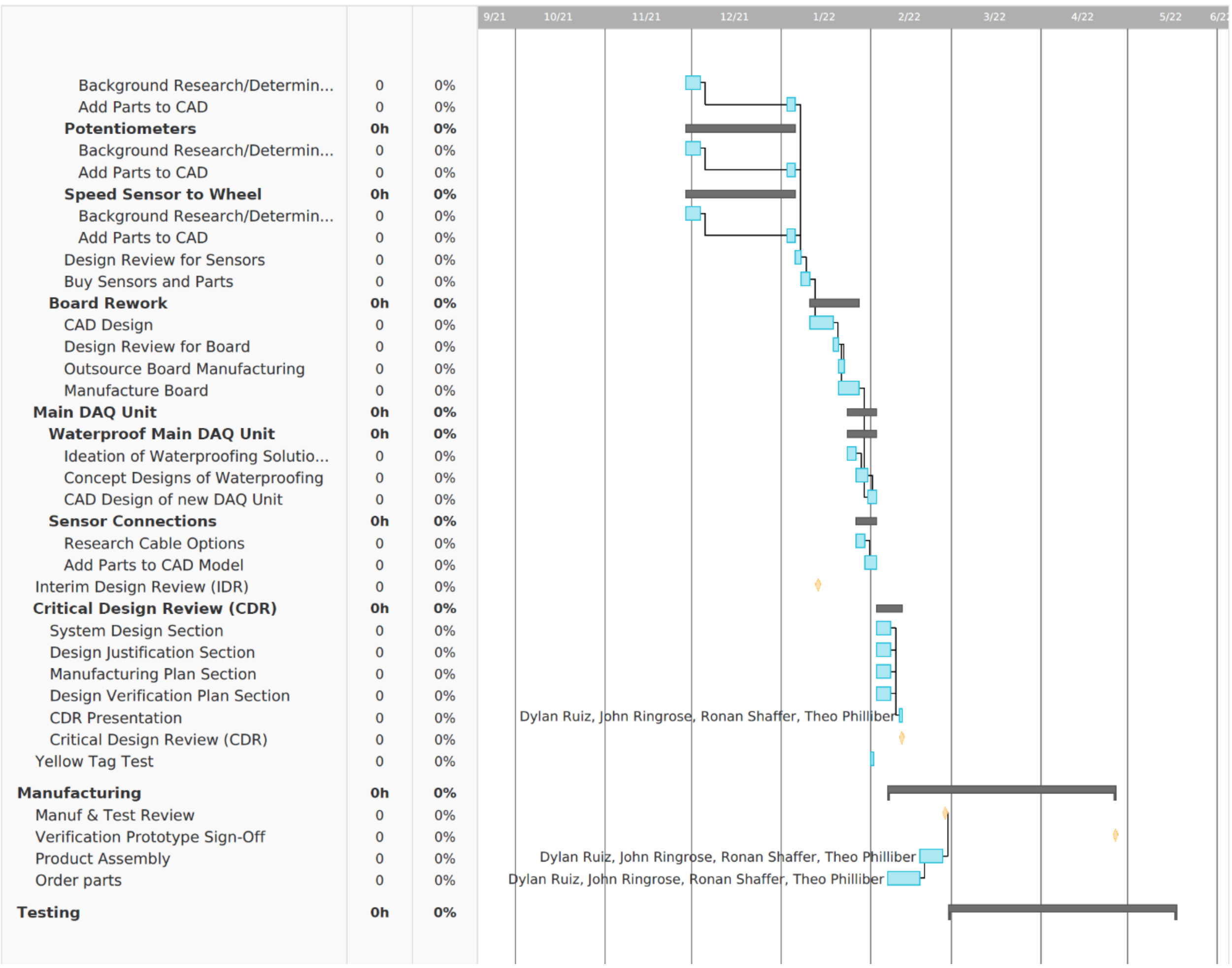
Appendix D: Gantt Chart



Appendix D: Gantt Chart (cont)

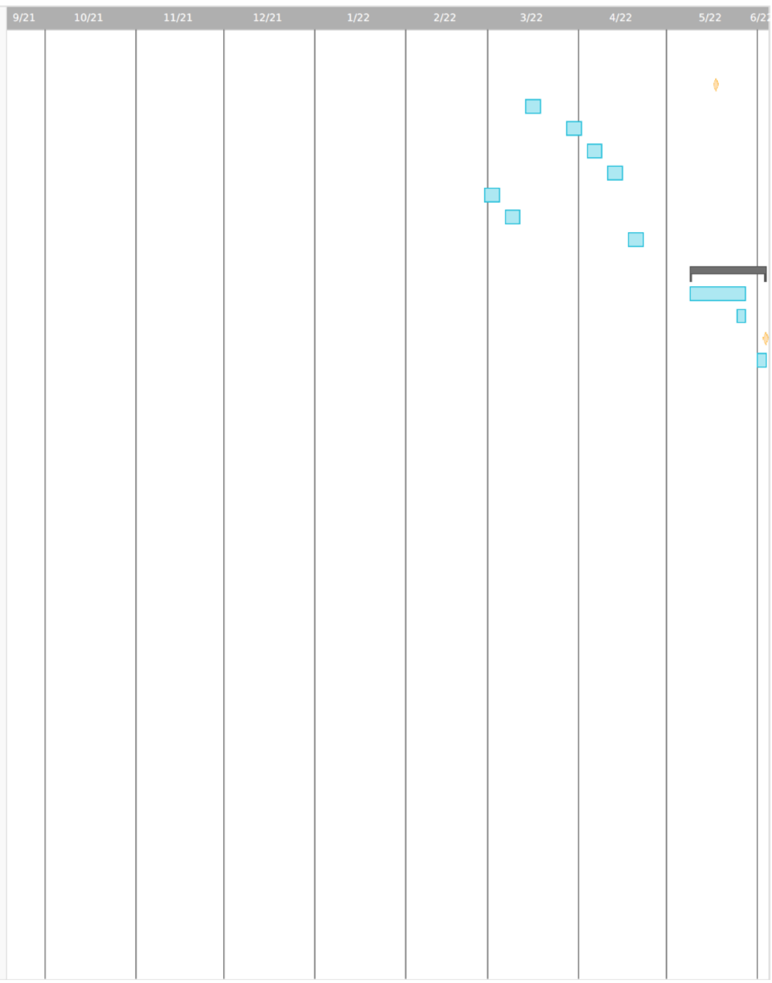


Appendix D: Gantt Chart (cont)



Appendix D: Gantt Chart (cont)

DVPR Sign-Off	0	0%
Validation Testing	0	0%
Summarize Test Results	0	0%
Rework	0	0%
Validation Testing Round 2	0	0%
Testing Protocol Drafting	0	0%
Component Testing	0	0%
Final Rework	0	0%
Project Wrap-up	**0h**	**0%**
Write FDR Report	0	0%
Create Expo Poster	0	0%
Final Design Review (FDR)	0	0%
Clean out workspaces	0	0%



Appendix E: Design Hazard Checklist

PDR 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 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	
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.	11/20/2021	
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	
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.	1/19/2022	

The device will be used in various environments.	The sensors and the main DAQ unit will be waterproofed for safer use.	2/2/2022	