

Development of an Instrumentation Setup for Measuring Off-Road Trail Profiles via Sensor-Data Fusion

John Crain and Mathew Clontz

School of Engineering + Technology, Western Carolina University

Introduction

Previous work on this project focused on using laser-based distance sensor arrays mounted along with an inertial measurement unit (IMU) on the front and rear wheel hubs of a mountain bike to estimate trail surface profiles. Each hub contained three distance sensors and one IMU which provide data to be used in an algorithm to calculate wheel height and obstacle dimensions through trigonometric relationships and numerical angle approximations.

The current sub-project involves the actual mechanical implementation of these sensors into the structure of the bicycle. Custom brackets were engineered to protect and align the sensors on a single-suspension gravel bike. Due to the nature of the data being collected and the sensors being used, it was important for the mounting structures to behave rigidly, while also providing damping between the bicycle frame and the mounting structures. The resulting data framework could enable high-resolution trail surface modeling for performance optimization and trail evaluation.

Methods

Two custom hub-mounted brackets were designed to fit around the bike's existing hardware, including the fork, axle, brake rotor, and drivetrain. These mounts positioned the sensors securely without interfering with moving parts. The three-sensor array will be mounted with a single cantilever arm that matches the sensors preexisting mounting system allowing for easier assembly. Each bracket also includes space for vibration-dampening foam to improve measurement stability. This streamlined design provides cleaner data and easier installation. Figure 1 displays a representative image the geometric setup used in the calculations for this project

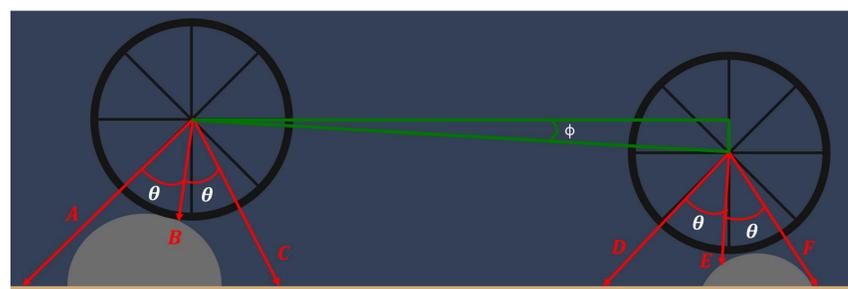
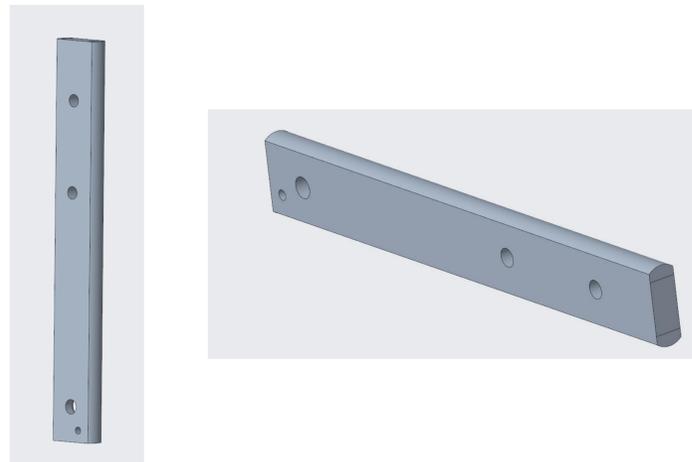


Figure 1: Geometric model of a bike tire on an obstacle, left, and a tire on another obstacle, right. Used to show the theory behind the physical model.

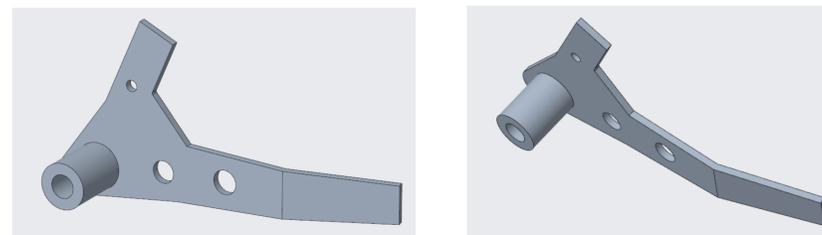
Results

While other team members continued work on algorithm development and the data collection electronics, the work presented here focused on the physical implementation of the instrumentation system. Due to variations in bicycle frame geometry and component configurations, the mounting hardware had to be custom-designed for the specific bicycle. For this project, the selected bicycle allowed the front sensor assembly to be installed on a fabricated plate secured to the front fork, extending as a cantilever from the side of the front hub.

The rear sensor bracket was constructed to interface with the cassette area and similarly cantilevers outward from the side of the rear hub. Both sensors are positioned on the right side of the bicycle to ensure consistent scanning conditions and minimize variability in the portion of the trail being measured. These mounting mechanisms were designed in SolidWorks and prototypes were printed with PLA on a Prusa Mk 4 printer. The complex nature of the bicycle geometry made it necessary to iterate the mount design prototypes to ensure a snug fit once damping foam was included.



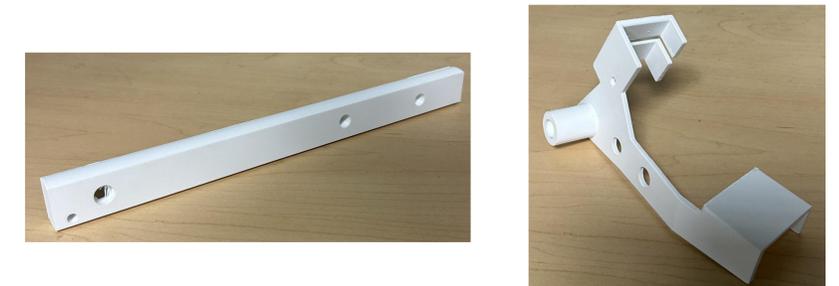
Figures 2 and 3: Shows the front fork mounting bracket design in CAD



Figures 4 and 5: Shows the rear axle mounting bracket in CAD



To reduce vibration transmission from the bicycle frame into the sensor assemblies, a layer of vibration-dampening foam was installed behind each mounting bracket. This foam acts as an isolator, absorbing high-frequency vibrations before they reach the sensors and thereby improving measurement stability and overall data quality, while protecting the electronics within the system.



Conclusions

This work is a subset of a greater project of which the goal is to develop a system which can measure the trail profile underneath the front wheel of a mountain bike. While other students are working on the development of the classification algorithm and the electrical setup, the present work focused on the mechanical implementation of the instrumentation scheme. The development of custom front and rear hub brackets enabled secure sensor placement while accommodating the constraints of a single-suspension mountain bike. These mounts were designed to improve data quality through enhanced stability and minimized mechanical interference. Together, with the other portions of this project, the mechanical setup of the instrumentation system described in this work represents a significant step towards the development of a robust system capable of measure off-road trail profiles.

Future stages of this work will likely bifurcate – one direction being the development of a slimmed down data collection system, and the other direction being the development of an off-road “cart” which can support a more extensive set of sensors. The current work will provide an excellent starting point for both future directions.

Acknowledgements

This research was supported by the School of Engineering + Technology at Western Carolina University and by a WCU Academic Projects Grant.

References

1. Alatoom, Y. I., Zihan, Z. U., Nlenanya, I., Al-Hamdan, A. B., & Smadi, O. (2024). <https://doi.org/10.3390/infrastructures9100179>
2. Farzad Mohammadi, Mohammad Reza Maleki, Jalal Khodaei, 2023. <https://doi.org/10.1016/j.still.2023.105678>
3. Baskent D, Barshan B. 1999. <https://doi:10.1177/02783649922066565>