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University of Wales Trinity Saint David - School of Engineering.

Advancing Motorcycle Dynamics: A Measurement Platform for Analysing Rider Input and Motorcycle Response in High-performance Environments.

Contemporary Powertrain design (ACFA7004)

2023 - 2024

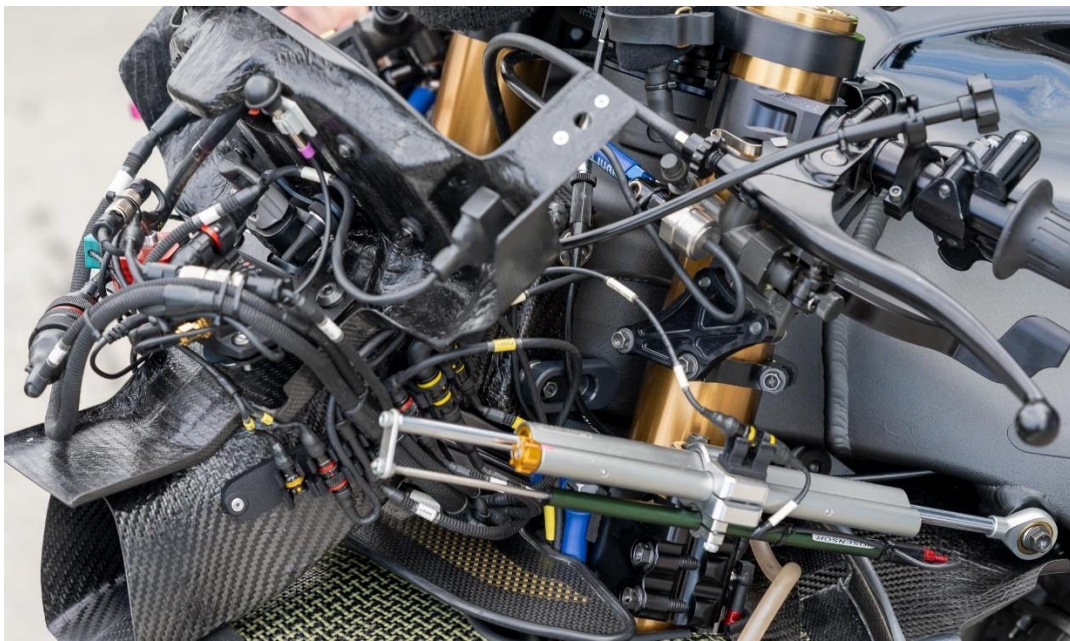


Figure 1: WSBK Electronics (MCnews.com.au, 2023)

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2 Introduction

The realm of motorcycle dynamics and rider input has been rigorously explored in recent research, with significant contributions such as (Przibylla, 2018) development of a steering torque measurement platform, and their subsequent analysis in 2020 on the physically applied steering torque (Przibylla, 2020). These studies identified and assessed factors controlling dynamic behaviour and steering performance. Further expanding on this, (Bartolozzi, Savino and Pierini, 2023) introduced comprehensive input measurements using handlebars and IMU in controlled tests to develop a steering torque model. (Bartolozzi *et al.*, 2023) continued this exploration by integrating measurements from handlebars, footpegs, and seats to investigate the influence of different riding styles on motorcycle response, concluding that steering torque is the primary input, whereas applying pressure on footpegs or shifting weight over the saddle has minimal effect.

2.1 Research Problem

Despite extensive studies, there remains ambiguity in the racing community—including riders, engineers, and coaches—about the effective methods of steering a motorcycle. Conventional wisdom and prior research suggest that motorcycles are primarily controlled through the application of torque at the handlebars (Cossalter, 2006). However, training methods still advocate for alternative steering methods, such as applying force on the footpegs or using body weight shifts, which have not proven effective as standalone steering techniques (Bartolozzi *et al.*, 2023; Harrison, 2023; Daemen, 2024). This research aims to dissect these conventional teachings under dynamic, high-performance conditions to explore how the body might be utilized differently in motorcycle steering and to determine if alternative effective methods exist.

2.2 Context and Necessity of Research

This investigation is crucial for refining high-performance riding techniques and coaching strategies. By understanding the actual dynamics and potential of varied body inputs under racing conditions, we can enhance both rider performance and safety. The goal is to establish a clearer, empirically backed understanding of how different body usages influence motorcycle control and to challenge or validate current training paradigms.

2.3 Research Question

“How does body usage by riders influence motorcycle response and rider input in high-performance environments, and what implications does this have for existing theories and training methods related to motorcycle control?”

2.4 Major Issues and Sub-Problems

The primary challenge addressed by this research is the discrepancy between taught riding techniques and their actual effectiveness from a vehicle dynamics perspective. There exists a significant gap in measured, empirical data regarding

the effects of these techniques, leading to potential inefficiencies or misconceptions in rider training.

2.5 Variables

Independent Variables: These include the testing trajectory in controlled environments, and the specific types of rider inputs being examined, ranging from isolated to combined steering methods.

Dependent Variables: The study will measure the effect of these inputs on rider performance, vehicle response, and trajectory over racing circuits, with a particular focus on how body usage influences the steering control of the motorcycle.

2.6 Hypothesis

The working hypothesis is that while various body movements are taught to influence motorcycle steering, the effective control still primarily involves counter steering through the handlebars, potentially aided by different muscular engagements or body movements to facilitate this action.

2.7 Boundaries of Proposed Research

The scope of this research will focus on input measurements and analysis. While aiming to include high-level, world championship riders for a comprehensive understanding, the extent of public data and the number of participants may limit the breadth of empirical conclusions that can be confidently generalized across all levels of rider skill.

By addressing these aspects, this research intends to contribute to the field of motorcycle dynamics and rider training, optimising current practices based on robust, scientifically validated data.

3 Methodology

The following part will describe the methodology planned to be undertaken for completion of this study.

3.1 Measurement Platform

The Aprilia RS660 Trofeo is the motorcycle chosen for the project and as a platform for the measurement equipment and testing. The 660cc parallel twin, is one of the leading mid-range Sportbikes currently on the market, both as a road bike and race bike. With an outstanding weight/ power ratio at 153kg with 105hp and 67Nm, an excellent adjustable electronics package including Anti-wheelie, cornering - ABS, Traction control, Engine brake and a high performance geometry package. With the already high performance road version, the trofeo includes Andreani front fork cartridges, An Ohlins AP948 racing rear shock absorber. Racing rearsets, clip-ons, triple clamp, An SC project racing exhaust, racing air filter for high performance on track (Aprilia, 2024). A roadgoing version is also available to the University at the time of the project, with racing triple clamps, clip-ons, rearsets, exhaust, race mapping in order to allow calibration of the measurement system and data recording on the road. The rear sets and clip-ons allow the possibility to swap the sensor equipped bars, footpegs between the race and road motorcycles in order to decrease cost of sensors and ease of measurement.



Figure 2: RS660 Sensor placement representation (Iatrakis, 2024)

3.2 Data Logging System

A Data Logger from 2D Debus & Diebold Meßsysteme GmbH (2D Debus & Diebold Meßsysteme GMBH) will be used, this system allows connection and integration with the Aprilia RS660's Controller Area Network (CAN). This allows data streams from inbuilt sensors of the motorcycle to be read. These channels are initially raw channels with no true meaning, through testing, Andrew Harrison, A member of staff and lecturer at the university has been able to decipher the meaning of important channels allowing analysis of RPM, Wheel speeds, Throttle position, Gear Position, Coolant temperature. The roadgoing version allows reading of brake pressure through the CAN system as the ABS system is still present. External suspension potentiometers are installed using bespoke designed mounts, Brake pressure sensors are also added for analysis. In order to measure the dynamic attitude and position of the motorcycle, a xNAV200 GNSS/INS from Oxford Technical Solutions Ltd., a highly accurate dual antenna GPS and inertial measurement unit, provided by the university, will be used. The underseat area of the RS660 offers a empty place large enough to position all the data logging equipment and also allows the IMU to be mounted as close to the combined centre of gravity of the motorcycle and rider (Przibylla, 2018).

3.3 Setup For Rider Input Measurement

To measure the strain inside the handlebars and on the footpegs, and calculate the forces applied by the rider, bonded metallic strain gauges will be installed on the handlebar tubes and footpegs. This way, the strain measured inside the handlebar tubes and footpegs can be related to the force applied by the rider. Due to their small size and versatility in placement, high accuracy these are the most applicable compared to the previously mentioned strain measurement methods.

The handlebar strain gauges will be placed on 4 positions/ axis 90 degrees from each other, with one axis in line with the steering axis to allow ease of measurement of the steering torque, measured through the second axis.

Steering torque is the torque that is acting around the front assembly of a motorcycle and its steering head, where the magnitude of the torque that is applied by the rider is equal to the resultant of all moments that are generated by the forces which are acting on the front section with either misaligning or aligning influence on the steering (Cossalter, 2006). The centrifugal force of the front section, the lateral force on the front wheel and the gyroscopic effect of the front wheel are having an aligning influence for example, whilst the weight force of the front section, the normal load on the front wheel and the twisting torque of the front tire have a misaligning influence, as shown in *Figure 1* below (Cossalter, 2006).

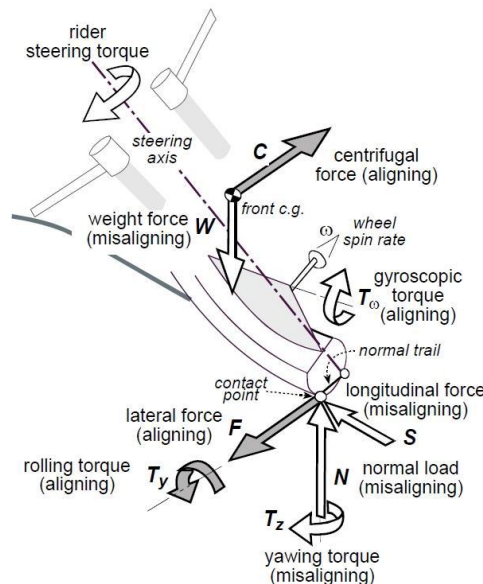


Figure 3: Equilibrium of the front frame (Cossalter, et al., 2010)

The same method will be applied to the footpegs where placement of four strain gauges placed 90° around the footpeg can be used to differentiate and determine the direction and magnitude of the resultant force on the footpeg.

In order to measure pressure distribution on the seat, pressure pads are available to accurately determine pressure distribution on the seat, due to budget restrictions this might be unavailable to the author for use. An alternative method is using thin pressure strips placed between the subframe and seat support on either side of the seat to measure the that way.

In order to measure muscle exertion, relatively simple Electromyography sensors are available for the public. The sensors measure muscle activity through the electric potential of the muscle, commonly referred to as surface electromyography (EMG or sEMG for short). When the human brain tells a muscle to flex, it sends an electrical signal to the muscle to start recruiting motor units (the bundles of muscle fibres that generate the force behind muscles). The harder the muscle is flexed, the more motor units are recruited to generate greater muscle force. The greater the number of motor units, the more the electrical activity of your muscle increases. Products such as the MyoWare 2.0 Muscle Sensor (MyoWare) analyse the filtered and rectified electrical activity of a muscle and output a signal (0-VIN volts, where VIN signifies the voltage of the power source) that represents how hard the muscle is being flexed.

3.4 Strain Measurement

If an external force is applied to a material, the internal resistance of the material to the deformation that is caused by the force is called stress and the formula for stress is given as (Twigg, 1996):

$$\text{Stress} = \frac{\text{Force}}{\text{Cross - Sectional Area}} = \sigma = \frac{F}{A}$$

Strain is the fractional change of dimension of the material under an applied force and can be calculated as follows (Bird, 2012):

$$\text{Strain} = \frac{\text{Change in Length}}{\text{Original Length of the material}} = \varepsilon = \frac{\Delta l}{l}$$

According to Hooke's Law, the deformation of an elastic material under load is directly proportional to the load that is producing it and, since stress is directly proportional to the load and strain directly proportional to the deformation, stress is proportional to strain (Stephens, 1970). Hence, for any given material, the gradient of the linear relationship between stress and strain, i.e. the ratio of stress to strain, is a constant and it is called Young's Modulus of Elasticity, which has the formula (Stephens, 1970):

$$\text{Youngs Modulus} = \frac{\text{Stress}}{\text{Strain}} = E = \frac{\sigma}{\varepsilon}$$

However, Hook's Law only applies below the limit of proportionality, beyond which a material behaves in a non-linear elastic manner until it reaches its elastic limit,

from where it can no longer return to its original shape after the removal of external forces, which means that the elastic region is exceeded and the material has reached plastic deformation that will eventually result in failure (Bird, 2012).

Strain gauges consist of metallic foil that is arranged in a grid pattern and bonded to a carrier, which is a thin backing that is directly attached to the test specimen, in this case the outside of the handlebar tubes and the footpegs. The strain that is experienced by the strain gauge material linearly changes the electrical resistance within the strain gauges, which is measured at two leads that are attached to each strain gauge.

The electrical configuration of strain gauges is based on a Wheatstone bridge, to measure small changes in resistance (National Instruments, 2016).

A Wheatstone bridge is the electrical equivalent of two voltage dividers in parallel, with four resistive arms and an exciting voltage that is applied across the bridge. The voltage is measured between the middle nodes of the two voltage dividers (National Instruments, 2016).

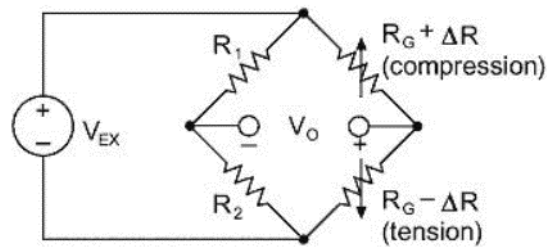


Figure 4: Half Wheatstone Bridge (National Instruments, 2024)

The Wheatstone bridge configurations that will be used will consist of a half-bridge and full-bridge configuration. A half-bridge means that two of the resistive components are active elements. In this case, two strain gauges opposite each other and two resistors, installed on the components, are wired in the Wheatstone bridge. A full Wheatstone bridge uses four active components to measure the strain. Either four strain gauges or two 'double strain gauges' are used. A double strain gauge houses two grid patterns in one housing, acting as two strain gauges, but ensuring parallel measurement between the two grids, eliminating installation error when using two gauges. Using a full Wheatstone bridge offers double the measurement accuracy over a half-Wheatstone bridge. A half Wheatstone bridge would be used in positions on components where the bigger size of the double strain gauges is not feasible.

Higher quality strain gauges are manufactured with temperature compensation, meaning a change in the material temperature won't affect the reading of the strain (Cadence System Analysis, 2024). This means strain gauges need to be ordered depending on the material on which it will be used to measure.

Balanced Bridge Under Temperature Variations:

When the bridge is properly balanced, the output voltage at the midpoint between two resistive elements is equal and opposite to the output voltage at the midpoint between the other two, resulting in a net output of zero. If the resistive elements have similar temperature coefficients (meaning their resistance changes with temperature at a similar rate), then temperature fluctuations will affect all parts of the bridge similarly, keeping the bridge balanced and minimizing the impact on the measurement.

This means self-compensating strain gauges are only necessary in single Wheatstone bridges and half-Wheatstone bridges, as full Wheatstone bridges offer self-temperature compensation.

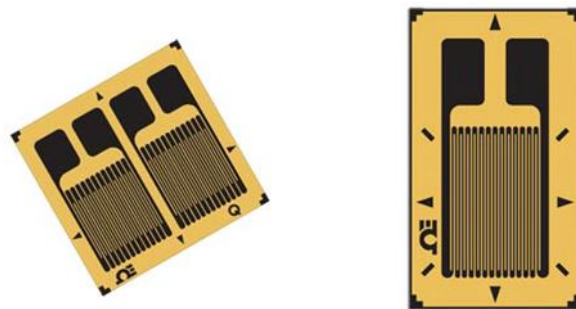


Figure 5: Double Linear Strain Gauge (Left) & Single Linear Strain Gauge (Right) (BesTech, 2024)

The surfaces will need prepping for bonding of the strain gauges, special attention will have to be given to placement of the strain gauges, being placed perfectly parallel and opposing each other in the same axis(Vishay Measurements Group, 2011) .

3.5 Strain Gauge Calibration Method

The calibration process starts in a controlled workshop setting, where all sensors undergo bench testing to establish their foundational accuracy. This involves using calibrated weights to achieve specific sensor readings that can be used for further detailed analysis.

(Przybylla, 2018; Werle and Diermeyer, 2022), have adopted a method of hanging weights from the handlebars to correlate with the measured strain. Calibration involves placing different weights, ranging from 5N to 50N, on both the middle and outer parts of the grip (Figure 6).

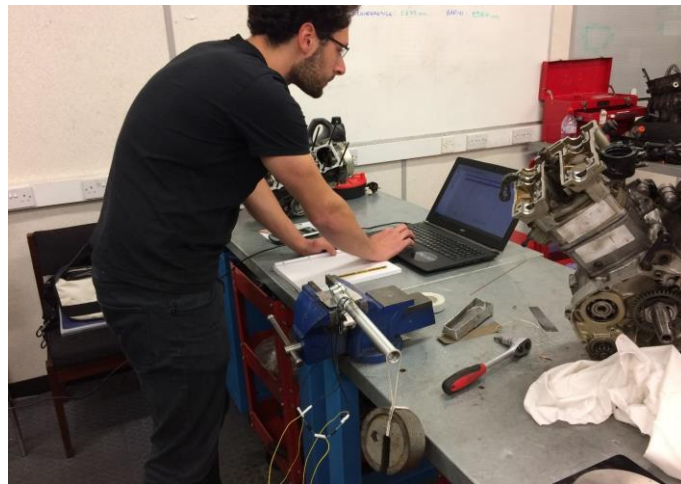


Figure 6: Bench Calibration Weight hanging method (Przybylla, 2018)

(Wahl *et al.*, 2020) shown an innovative calibration approach involves constructing a rig equipped with pulleys. This setup allows for the application of forces in a consistent and repeatable manner, facilitating the hanging of weights in the x-direction to simulate pushing and pulling forces (Figure 7). This enhances both the calibration accuracy and the scope of testing possibilities.

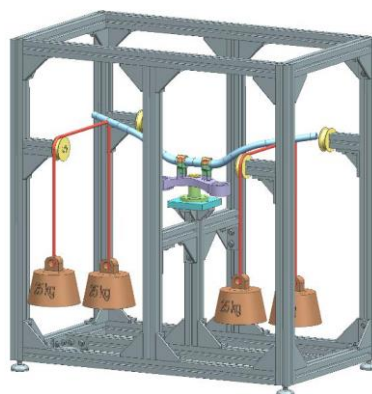


Figure 7: Test Bench for calibration. Weights at pulleys in front -> Pulling force (negative), weights at pulleys in the back -> pushing forces (positive) (Wahl et al., 2020)

While the second method, using the rig with pulleys, is preferred for achieving the most precise measurements, the initial method of direct weight application remains useful for final on-track calibrations. This ensures the system's accuracy is maintained right up until testing commences.

3.6 Testing Method

A testing procedure will be put in place to evaluate rider input under varying conditions, with a particular focus on track testing and controlled trials.

The initial process begins with bench testing in a controlled workshop environment to calibrate all sensors, ensuring the foundational accuracy of the system. Using calibrated weights in order to reach specific sensor values which can be used for further analysis.

Following bench testing, road riding sessions will be conducted to not only confirm the system's operational integrity in real-world scenarios but also to fine-tune sensor calibration based on dynamic rider inputs.

The testing strategy emphasizes controlled tests and high-performance track riding, designed specifically to assess the impact of rider inputs across a spectrum of riding conditions.

controlled testing sequences will be implemented to gain a deeper insight into the sensor data under various operational scenarios, facilitating a comprehensive analysis regarding rider input to motorcycle response.

The final phase of the testing methodology involves high-performance track riding, in order to analyse behaviour at high speeds and under extreme conditions.

These stages allow for a nuanced understanding of how rider actions influence motorcycle performance, enabling detailed analysis and optimization of both rider technique and vehicle setup, providing valuable insights for enhancing performance and safety.

3.7 Controlled Test Manoeuvres

Typical manoeuvres in controlled data sets include steady corners, lane changes, and slalom. These were also employed by Bartolozzi M. & Przybilla A. in their research on estimating motorcycle steering torque through experimental validation, which also looked into manoeuvrability implications. The fundamental approach of this research is similar to the topic we are investigating, making it a valuable reference for comparing results and methodologies.

However, additional research is necessary to determine if there are any industry standards concerning motorcycle testing manoeuvres, which would further validate and standardise our experimental approaches.

Table 1: List of dataset manoeuvres. (Bartolozzi M., 2023)

Type	Geometry
Steady Corner	Centreline radius 15 m
Steady Corner	Centreline radius 12.5 m
Lane Change	3 m x 14 m
Lane Change	2.75 m x 5.5 m
Slalom	Cone Spacing 7m

4 Timing Plan

Research into motorcycle steering and stability modes, rider behaviour, 'how' do they think they control the motorcycle. Research into the existing technology available for measuring forces or torques and assessment of the applicability of different force and torque transducers.

An in depth discussion with Micro-Measurements, a highly reputable manufacturer of high-precision strain measurement equipment, has been had, to discuss these available products and find an applicable solution. With direct regards to the application and conditions of use, a strain gauge type has been selected for use on the measurement platform. Bonding and installation solutions have also been discussed.

Before installation of the Force measurement equipment, the base data recording system will be installed, Design and construction of mounting methods for suspension potentiometers is required, additional information of data from the motorcycle will be recorded through a connecting between the CAN system of the motorcycle and the Data logger, providing info such as throttle position, brake pressure, rpm, gear, traction control modes etc.

Time will be spent practicing and perfecting the installation method using spare parts and strain gauges, to avoid installation errors on the high quality parts that will be used during the measurement and data collection.

After installation of the final sensor setup, on the handlebars and footpegs, the sensors will require calibration, measuring strain in a controlled method in order to calibrate the measurement method for accurate results and analysis. The processing method of raw data will require the derivation of mathematical formulae to result in useful data regarding the parameters of interest.

After installation of the data logger, sensors and strain gauges, an Inertia Measurement Unit (IMU), with dual antenna GPS is installed, to provide additional, highly accurate data of vehicle position and dynamic attitude.

Before testing the complete setup, all equipment must be installed securely onto the motorcycle, all sensors need to be recalibrated.

Time will be spent testing on public roads, initially to 'dial in' and further calibrate the system and maths, with further measurement during controlled tests, carrying out simple manoeuvres and testing under high performance conditions on track.

Sorting and analysis of the data will be carried out after each test, analysing what information is gained and what can be done the next time testing. Analysis into further work possible with this system will also be required.

Table 2: Timing Plan (Iatrakis, 2024)

Planned Timing																																				
	March				April				May				June				July				August				September											
week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4								
Key dates		Visit																																		
	Literature + Research Proposal																Thesis Drafting								Review and Revision				Final Submission Prep				Submission + Viva			
Tasks	System Spec + Component procurement																																			
					System Assembly				Calibration testing				Controlled + Track testing																							
													Data Analysis																							

5 Potential Risks and Failures

With a technically demanding project, it's important to recognize the inherent risks. Potential failure modes have been identified and corresponding mitigation strategies to ensure the project can adapt to challenges and maintain progress toward research objectives.

5.1 Material failure

The risk of material failure in sensors or motorcycle components is addressed by selecting high-quality, industry-standard sensors and materials known for their durability and performance. Regular pre-test inspections and stress testing will be conducted to identify any potential weaknesses before full-scale testing begins.

5.2 Human error

Misinterpretation of data, incorrect sensor setup, or procedural errors can lead to flawed conclusions. Practice will be put into ensuring correct training and instalment of sensor installation on the measurement platform. Leveraging the expertise of highly experienced staff, the project incorporates supervision and mentoring to significantly mitigate human error, ensuring precision and reliability in all phases of the project.

5.3 Financial Risk

Most required instruments are readily available and have been in use by the Motorcycle engineering Department at UWTSD. With Strain gauges being the only purchase cost, but at high cost, a lower cost gauge type will be used for initial proof of concept in order to optimize the process and installation, to then in a later stage, higher quality cost strain gauges will be requested for purchase on the final measurement system.

5.4 Data System reliability

Reliability of the used data system is paramount, data loss or corruption can be detrimental to the project. High quality, often used and proven data systems will be used in order to ensure quality measurement and storage of recorded data. Consistent data monitoring will be employed to quickly identify and address any anomalies during testing.

5.5 Vehicle and Equipment Failure

The aim is to minimize the risk of catastrophic failure through diligent maintenance and monitoring, as high-intensity testing can lead to unforeseen breakdowns of the used motorcycles and systems. In the event of a critical failure of the data systems, we have provisions to quickly replace or repair the affected components, leveraging the technical resources available within our department. Should the motorcycle itself suffer a catastrophic failure, we have access to alternative vehicles that can be instrumented to ensure continuity of the research project.

5.6 Environmental factors

Weather conditions are a notable environmental risk, which can significantly impact the feasibility of track riding sessions. The availability of wet racing tires ensures that, even in adverse conditions, testing can proceed without significant delays, allowing for valuable data collection under a range of environmental scenarios. This flexibility in our testing approach not only enhances the robustness of our data but also maximizes the utilization of scheduled track days, ensuring that our project remains on schedule and within budget.

5.7 Testing Procedures

Part of the commitment of ensuring the safety and reliability of the project, rigorous testing procedures have been established, underpinned by comprehensive risk assessments in alignment with university guidelines. These risk assessments cover a broad spectrum of scenarios, from routine travel in vehicles on public roads to the dynamic and high-speed environment of track testing and racing. Each phase, including transportation, setup, operation, and riding, is subject to a thorough evaluation to identify potential hazards and implement appropriate mitigation strategies, thereby ensuring the safety of all personnel involved and the integrity of the equipment.

6 Results

The principal aim of this research is to engineer a comprehensive measurement system that captures and analyses rider input alongside motorcycle dynamics. This platform will enable a precise quantification of how rider behaviours, including steering torque, body positioning, and manipulation of controls, directly influence motorcycle responses such as speed, motion transfer, and acceleration. This will be achieved through the employment of rigorously calibrated sensors and advanced data acquisition techniques, such as using weight rigs for exact calibration and conducting bench tests within controlled settings.

From the data amassed, sophisticated data processing will be applied. This will likely involve the implementation of time-series analysis to track the progression of inputs and responses over time, as well as deploying machine learning algorithms to detect patterns and forecast motorcycle performance across a variety of riding scenarios.

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