

Literature Review of Current Motorcycle Dynamic Studies

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Abstract

This comprehensive literature review explores the historical roots and recent advancements in motorcycle dynamics research, tracing its origins to the late 19th century and highlighting significant developments in recent years. The study underscores a contemporary emphasis on constructing an advanced dynamics research and processing system, leveraging software tools such as 2D Race Data Recording, Ansys, VI-Bike Real Time, Adams, View-MATLAB, and Simulink co-simulation for high-performance outcomes. The primary research objective is to formulate an intricate motorcycle model that encompasses multiple facets of rider-motorbike dynamic simulation and its control system. Noteworthy progress in areas such as aerodynamics, suspension setups, rider aid, and safety considerations is actively integrated into the ongoing research. The document emphasizes the vital role played by observations from both the motorcycle and rider, exerting significant influence on the dynamic research landscape. In addition, the review provides detailed insights into specific advancements, including a focus on active steering assistance systems, computational fluid dynamics (CFD) aerodynamic simulations, AI-integrated safety systems by Damon Motorcycles, advanced control simulations for superbikes, and smartphone-based measurements of motorcycle dynamics. These diverse areas collectively contribute to the evolution of motorcycle technologies, addressing safety, performance, and rider comfort in the contemporary and future landscape.

1. INTRODUCTION

The motorcycle industry is undergoing a rapid transformation, propelled by an urgent need for innovation and a commitment to enhancing both safety and consumer appeal. Engineers find themselves at the forefront of this evolution, tasked with integrating cutting-edge technologies and pioneering upgrades to redefine the landscape of motorcycling. Noteworthy advancements include the adoption of novel materials, revolutionizing both ride comfort and handling dynamics. The infusion of inventive combinations and designs is capturing the attention of consumers, emphasizing a shift towards a more diverse and sophisticated market.

Control systems are increasingly becoming a standard feature, reflecting a broader industry trend towards the integration of smart technologies. This not only enhances the riding experience but also contributes to overall safety. Simultaneously, the resurgence of racing activities is injecting vitality into the industry, fostering a competitive environment that drives technological innovation. In the realm of multi-wheeled vehicles, motorcycles stand as unique entities with a single track, presenting a distinctive set of kinematic challenges. The intricacies of their dynamics set them apart, posing a more complex evaluation process compared to their counterparts. This distinctiveness is where the field of motorcycle dynamics emerges as a focal point for the latest advancements.

Looking ahead, the trajectory of motorcycle vehicle dynamics holds significant implications for the industry's future. As engineers continue to push boundaries, we anticipate a continued emphasis on safety, performance, and consumer-centric design. The evolution of materials, the exploration of innovative combinations, the integration of advanced control systems, and the resurgence of racing activities collectively shape a dynamic future for motorcycles. The ongoing advancements in motorcycle dynamics lay the groundwork for a new era, promising a diverse and technologically enriched landscape beyond the current horizon.

1.1 ACTIVE STEERING ASSISTANCE SYSTEM IN MOTORCYCLES

This research presents a comprehensive exploration of active steering assistance systems for powered two-wheelers (PTWs), addressing an underexplored area of motorcycle safety. The study focuses on three distinct systems – Motorcycle Curve Assist (MCA), Motorcycle Stabilization (MS), and Motorcycle Autonomous Emergency Steering (MAES). The authors aim to assess the applicability, effectiveness, and potential injury mitigation capabilities of these systems, providing valuable insights into their performance under various emergency scenarios.

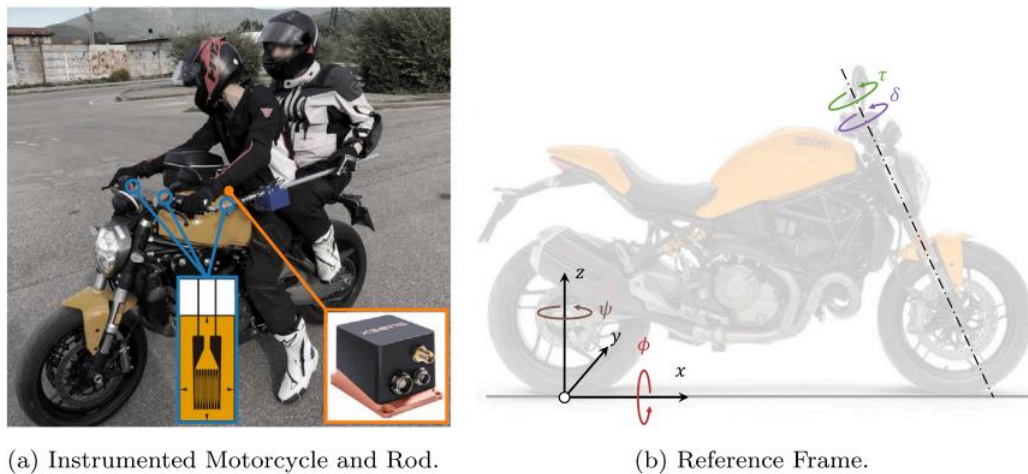


Figure 1: The experimental setup for the study involved a motorcycle equipped with instrumentation, including strain gauges positioned on both the handlebars and the rod, as indicated by the blue markings. Additionally, an Inertial Measurement Unit (IMU) was situated on the tank at the location highlighted in orange.

The research methodology involves a multi-faceted approach, combining Multiple Correspondence Analysis (MCA), Maneuver-Specific Evaluation (MS), and Knowledge-Based Methodology System (KBMS). The applicability of each system is meticulously evaluated through a categorization of crash scenarios, considering factors such as the nature of collisions and PTW involvement. The KBMS provides a quantitative metric for effectiveness, allowing direct comparison between the three systems. Additionally, the study employs an Innovative Dummy Compatibility Rating (IDCR) method to test the impact of these systems on real-world crashes. To further assess injury mitigation potential, experimental tests were conducted to evaluate the feasibility of changing a motorcycle's state of motion through external steering actions. The test involves significant external steering torque, and the rider's responses are analysed to determine the compatibility and effectiveness of the steering assistance systems.

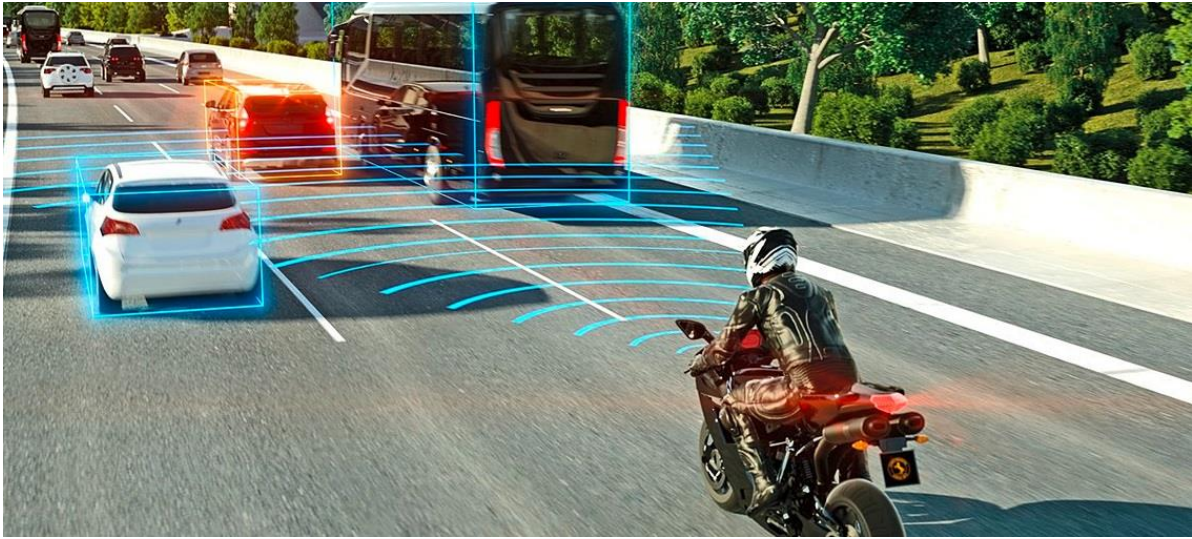


Figure 2: Advanced Driver Assistance System (ADAS)

The findings reveal nuanced characteristics of each steering assistance system. MCA, while highly applicable in bends, lacks consistency in crash scenarios, highlighting its specificity. MS demonstrates versatility but exhibits poor or negligible effects in certain situations. The most promising results emerge for MAES, which exhibits broad applicability across emergency scenarios and notable effectiveness in reducing injuries and preventing crashes. The KBMS metrics rank MAES as the most influential system, followed by MS and MCA. In the injury mitigation analysis, MAES intervention successfully prevents certain crashes and significantly reduces relative crash speed, indicating its potential to mitigate injury risks. However, the study acknowledges the need for further research to achieve statistical significance and a more comprehensive understanding of MAES's capabilities in different crash configurations.

The active steering assistance systems for PTWs offers valuable contributions to motorcycle dynamics and safety. The thorough methodology provides a nuanced understanding of the strengths and limitations of each system, with MAES emerging as the most promising candidate. The experimental test not only validates the feasibility of external steering actions but also underscores the importance of timely interventions to prevent crashes or mitigate their severity.

The study emphasizes the need for further research to investigate MAES's potential using detailed crash reconstructions and a more extensive sample size. The absence of a clear destabilizing effect during the experimental test suggests the potential safety benefits of active steering assistance systems. Overall, this paper lays a solid foundation for future studies in the realm of motorcycle safety, specifically focusing on the promising trajectory of active steering assistance systems.

This comprehensive assessment of steering assistance systems not only enhances our understanding of their applicability and effectiveness but also encourages further exploration and development in the field, potentially paving the way for advancements in motorcycle safety technologies.

1.2 COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATION OF AERODYNAMICS IN HIGH-PERFORMANCE MOTORCYCLES

The analysis of automobile aerodynamics from an external standpoint was one of the initial uses of applied computational fluid dynamics (CFD). This study focuses on investigating the aerodynamics of a motorcycle using CFD techniques. While CFD is a well-established technology in aerodynamics research and development, ensuring the precision and accuracy of results remains a challenge. Numerous factors, such as geometric intricacies, numerical mesh quality, turbulence model selection, and boundary condition specification, collectively influence the final outcomes. Therefore, conducting experimental validation or comparing results with published experimental data is considered a sound practice. The reference simulation in this study utilized the Delayed Detached Eddy Simulation (DDES) approach,

and results from accurately conducted DDES or Large Eddy Simulation (LES) simulations were used as benchmarks, including a margin of error that is similar to what is observed in experimental testing.

All simulations employed ANSYS Fluent software (version 2020 R1) on the High-Performance Computing infrastructure provided by the National Centre for Nuclear Research. The MotoStudent class motorcycle CAD model from Warsaw University of Technology, including a 3D scan representing the rider's posture, was used. Non-essential components affecting aerodynamics were simplified, ensuring a realistic geometry representation.

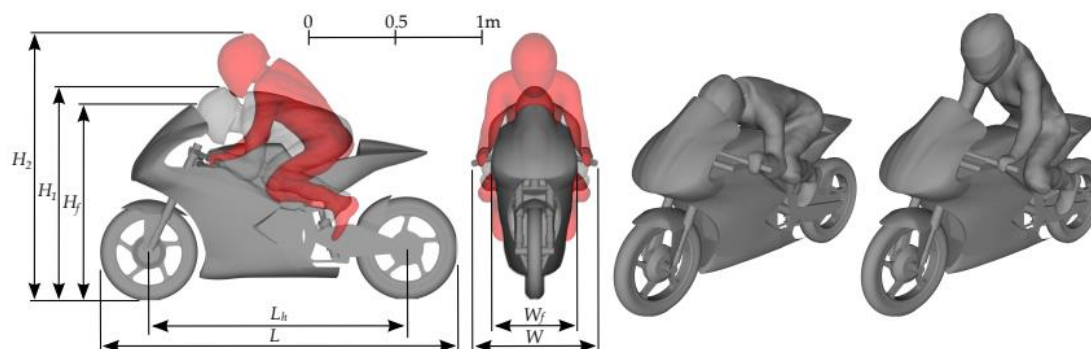


Figure 3. A sports motorcycle from the MotoStudent category, designed in CAD with two riding configurations.

Starting with the bike's geometry, the study proceeded to define the domain and boundary conditions for computational work based on established standards for mathematical modeling. This ensured clear visibility of flow structures behind the moving motorcycle without boundary interactions. Output values obtained post-processing were comparable to wind tunnel results at Warsaw University of Technology under near-maximum capacity operation.

The Ansys mesh generation methodology was then applied, studying various aerodynamic drag coefficient values. The study delved into Reynolds-Averaged Navier-Stokes (RANS), Scale-Adaptive Simulation (SAS), and DDES turbulence modeling methods, conducting assessments and comparative analyses.

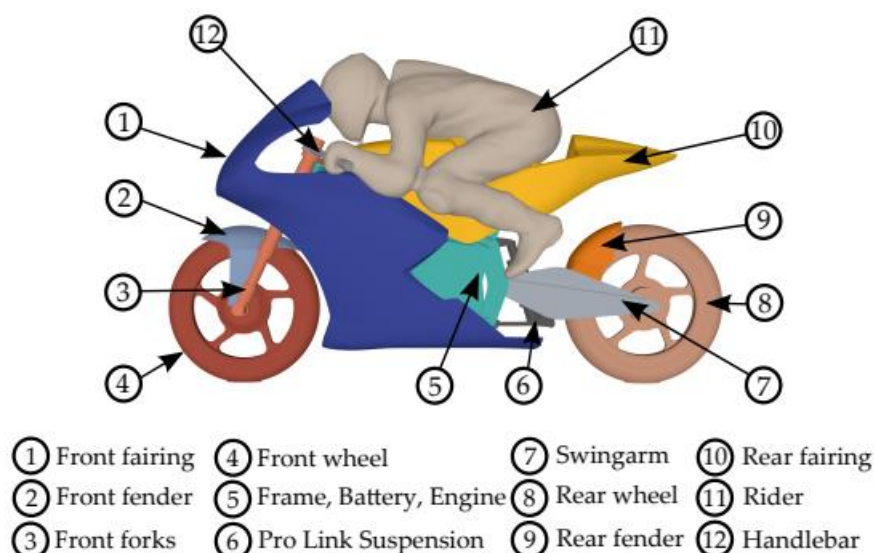


Figure 4. Highlighted components of the analysed geometry.

The drag coefficient and drag values obtained from all turbulent models displayed resemblances with minor differences. As a result, an assessment of aerodynamic drag involving both the motorcycle and the rider was conducted. By exploring different rider positions and model modifications, the study identified potential performance improvements using comprehensive CFD simulations.

1.3 DAMON MOTORCYCLE'S CoPilot™: SAFETY THROUGH AI – INTEGRATION

In the ever-evolving landscape of motorcycle technology, Damon has emerged as a trailblazer with its CoPilot™ Advanced Warning System for Motorcycles (AWSM).

Motorcycling, while a common form of transportation globally, is inherently riskier than other modes. Acknowledging this, Damon positions AI as the next frontier in motorcycle safety. The review begins by contextualizing the need for advancements, emphasizing the urgency to leverage technology to mitigate risks and enhance rider safety.

Damon's journey begins with a meticulous deconstruction of typical motorcycle journeys, analysing collision dynamics and understanding the unique challenges faced by riders. This foundational step establishes the groundwork for a safety system tailored to the specific nuances of motorcycle movements in varied traffic scenarios. Recognizing the successes of Advanced Driver-Assistance Systems (ADAS) in cars, Damon adapts these technologies for motorcycles. However, there is need for nuanced solutions due to the distinctive characteristics of motorcycles, such as lane-shifting, rider recognition, maneuverability, acceleration, braking, and interactions with other road users.

Development of CoPilot™ and AWSM:

Central to Damon's innovation is the CoPilot™ system, integrating advanced camera vision, object detection, and processor segmentation. The AWSM system, with its 360° protection, identifies and processes threats in real-time, delivering warnings through LED and haptic-vibration handlebar grips. This section highlights how Damon's technology responds to the specific challenges faced by motorcyclists during their journeys. A key strength of Damon's approach lies in its commitment to future-proofing the CoPilot™ system. The integration of 5G connectivity ensures rapid data transfer, facilitating continuous updates to improve rideability and safety features. Damon's system can track and process the movements of up to 64 objects simultaneously, showcasing its adaptability to evolving scenarios.



Figure 5: Damon Hypersport Motorcycle

Damon motorcycle's utilization of AI engines and big data, explaining how incident data is processed, algorithms are developed, and prediction models are continuously refined through machine learning. The seamless interaction between the AWSM system and the rider, coupled with over-the-air (OTA) updates, establishes a dynamic and responsive safety framework.

Damon's CoPilot™ system, bolstered by motorcycle AI integration, emerges as a groundbreaking solution to enhance motorcycle safety. With Damon's meticulous development process, they emphasize commitment to addressing the unique challenges faced by motorcyclists. With innovations like Shift™ complementing the safety features, Damon's

dedication to advancing motorcycle safety is poised to have a transformative impact on reducing accidents and injuries in the motorcycle dynamics landscape.

1.4 EXPLORATION OF SUPERBIKE DYNAMICS THROUGH ADVANCED CONTROL SIMULATIONS.

This research seeks to create a comprehensive model that combines different aspects of dynamic simulation, specifically focusing on the interaction between the rider-motorcycle system and its control system. Unlike previous studies that separately investigated these components, the authors developed an advanced tool using MATLAB/Simulink co-simulation and Adams/View. This tool accurately emulates the behavior of both the motorcycle and the rider, considering a specified trajectory and corresponding velocity profile.

The motorcycle was modelled using 15 bodies, incorporating flexibility into one of the two suspension groups for each body. Similarly, the virtual rider was modelled with 15 rigid structures. To accurately replicate the actual inertial properties of the motorbike, realistic models of each motorcycle component were created based on manufacturer specifications or experimental findings. The authors chose to simulate an entire lap at the Monza circuit, considering its diverse track conditions with hairpins, high curves, chicanes, etc. For high-performance motorcycles, aerodynamic force, especially drag, plays a crucial role, directly influencing acceleration and braking. The research involves a multibody model of a motorcycle, introducing a variable force applied horizontally along the bike's longitudinal plane to the rider's centre of gravity. The investigation takes into account factors such as drag, the rider's passive impedance, and data from trajectory sensors.

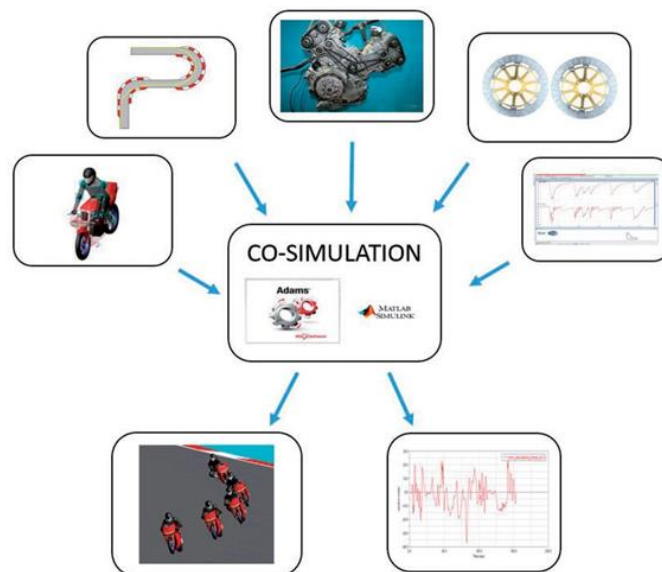


Figure 6. Diagram illustrating the logical sequence of instruments.

The researchers created a tool, as shown in Figure 6, that can accurately simulate the dynamics of the motorcycle-rider system. This tool is designed to follow any predefined route with a specified velocity profile, faithfully replicating engine performance and braking. The all-encompassing methodology is visually represented in the logic chart of the instruments and the flow diagram of the control system, as depicted in Figure 7.

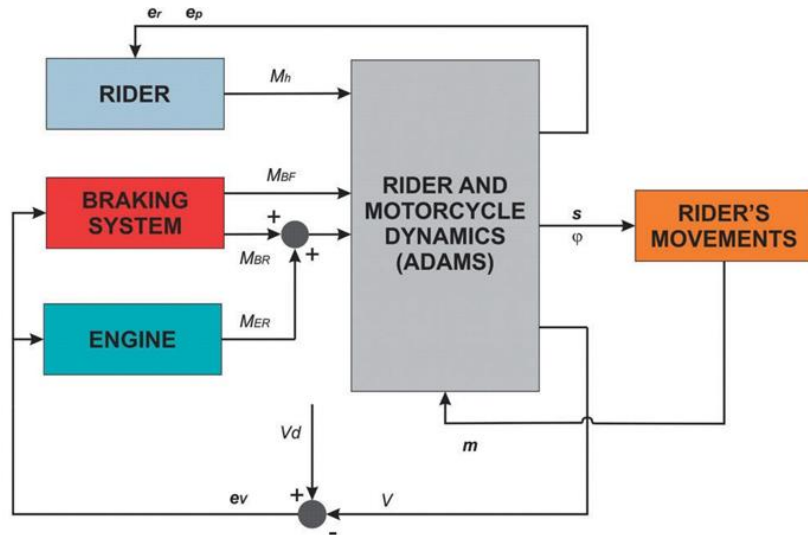


Figure 7. Diagram depicting the flow of a control system.

In the co-simulation, Adams software calculates the model's dynamics equations, while Simulink processes control system data, necessitating data exchange between the two programs. Figure 7 details the extended control system, with the Adams model as the main component. The 'Rider' block calculates the torque required for handlebar turning, the 'Braking System' block determines brake torque for rear and front wheels, the 'Engine' block calculates rear-wheel torque, and the 'Rider's motion' block computes rider movement. Building upon an existing model, the researchers devised a control system for the motorcycle-rider interaction. They employed widely applicable co-simulation software (MATLAB/Simulink and Adams/View) to perform a comprehensive lap simulation on the Monza racetrack. This analysis aimed to understand the genuine influence of rider movements on bike dynamics, engine, and brake performance, as well as the overall drag on the system. The resulting model is adaptable, enabling trajectory adjustments to simulate various racetracks.

1.5 MEASUREMENT OF MOTORBIKE DYNAMICS UTILIZING SMARTPHONE TECHNOLOGY

In the contemporary landscape of smartphones, essential hardware sensors like accelerometers, gyroscopes, and magnetometers, often accompanied by GPS receivers, are commonly integrated. Luxmeters, microphones, proximity sensors, and barometers further augment the sensory capabilities. Applications access sensor data through standardized interfaces within the operating system. Notably, the accuracy of these built-in sensors varies, prompting the authors to employ diverse devices for their research.

The research delves into the foundational aspects of motorcycle lateral dynamics, applicable coordinate systems, and provides a comprehensive overview of smartphone sensors. Particularly, the discussion revolves around computing the roll angle of a motorcycle using sensor data.

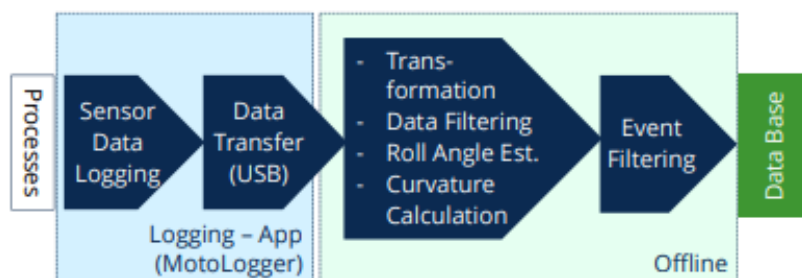


Figure 8. The configuration of measurement chain involving a mobile application and conditions for offline processing.

The measurement chain, as illustrated in Figure 8, outlines the phases of online data measurement and offline postprocessing. A specialized 'Moto Logger' program, tailored for Android and iOS smartphones, facilitates reliable on-bike data collection. Raw data is then transferred to a computer for subsequent processing in a MATLAB environment. The object-oriented MATLAB programming simplifies tasks such as coordinate transformation, data filtration, roll angle estimation, and course angle calculations, accommodating various rides.

To validate the procedures for measuring motorcycle dynamics, the authors compare the smartphone measurement chain with a high-precision inertial measurement unit (IMU), employing a BMW R1200 GS Adventure motorcycle for experimentation (see Figure 9). Two test tracks were used for data collection and analysis.

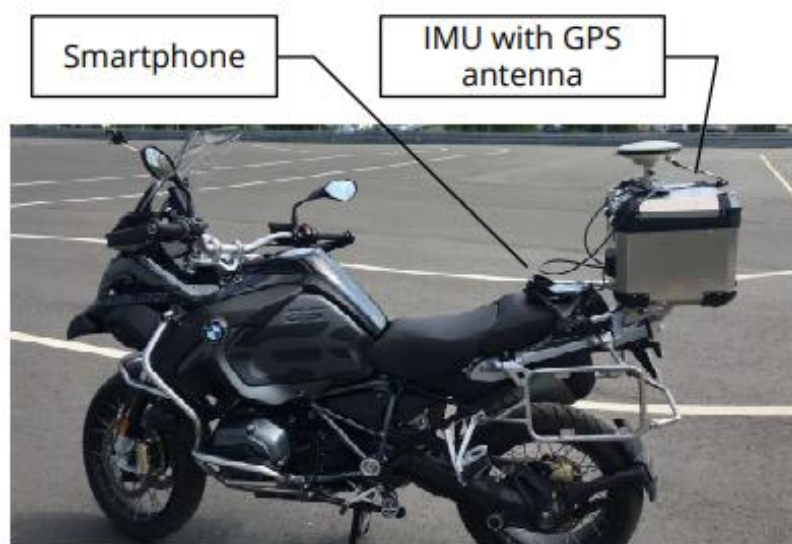


Figure 9. BMW R1200 GS equipped with a dual data acquisition system for testing.

Comparison of data from the Inertial Measurement Unit (IMU) and smartphones reveals slight variations attributed to GPS discrepancies. Subsequent research omits the use of the IMU. The findings from simulations and data collections highlight minor variations due to GPS discrepancies, with the research meticulously detailing GPS errors and factors influenced by different smartphones.

In recent years, there has been a growing emphasis on smartphones as research tools. Significantly, the authors introduce a groundbreaking measuring toolchain, utilizing smartphones for researching driving lean angles on a broad scale. This innovative approach enables the exploration of lean angles within larger rider collectives, offering a portable measuring instrument at a cost-effective price point, utilizing private bikes for research purposes.

2. CONCLUSION

The literature review provides a comprehensive exploration of advancements in motorcycle dynamics, encompassing various aspects such as active steering assistance systems, aerodynamic simulations, AI integration for safety, advanced control simulations of superbikes, and smartphone-based measurements. Notable contributions include a detailed assessment of steering assistance systems, emphasizing the promising trajectory of Motorcycle Autonomous Emergency Steering (MAES) as a groundbreaking solution for injury mitigation.

The document underscores the evolving landscape of motorcycle technology, with Damon's CoPilot™ Advanced Warning System standing out as a trailblazing AI-driven safety solution. The integration of AI, 5G connectivity, and over-the-air updates in Damon's system exemplifies a commitment to future-proofing and continuous improvement in motorcycle safety technologies.

Additionally, advanced control simulations and comprehensive CFD aerodynamic simulations contribute to refining the understanding of motorcycle dynamics. The research involving smartphone-based measurements introduces a

cost-effective and portable toolchain, enabling extensive exploration of motorcycle lean angles on a larger scale. Looking ahead, the document hints at the transformative impact on motorcycles after 2035, anticipating a different era with significant technological advancements. Electric motorcycle brands like Damon Hypersport, with patented safety mechanisms and switchable rider position ergonomics, exemplify the direction towards enhanced rider comfort, safety, and performance.

In summary, the reviewed literature points towards a future where motorcycles will witness substantial changes driven by technological innovations. The ongoing research and developments discussed in the document lay the groundwork for a promising evolution in motorcycle dynamics, with a focus on rider ergonomics, safety enhancements, and overall performance.

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