Adaptive Wheel Alignment System for Vehicles

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1. Motivation

The choice of this project reflects our enthusiasm for automotive mechatronics and the need for a more accessible and versatile system for improved vehicle handling, comfort, safety, and efficiency, particularly under dynamic driving conditions. While simple and cost-effective, traditional passive suspension systems offer limited adaptability to changing terrain or driver input. Our interest in developing an adaptive wheel alignment system is rooted in its potential to optimise camber and toe angles in real time, enhancing performance in a way that passive systems cannot.

We were especially inspired by recent advances in active suspension technology, such as those by Mercedes-Benz and Audi, and by academic works demonstrating that adaptive control of wheel geometry can yield significant improvements in handling and stability

2. Overview

2.1 Significance of the Project

The proposed project aims to address a critical challenge in vehicle dynamics: maintaining optimal wheel alignment in varying real-world conditions. While passive systems use fixed geometry, our adaptive system actively modifies camber and toe angles in response to sensor inputs and vehicle motion. Such real-time alignment has the potential to:

- Improve cornering grip and vehicle stability by optimising contact patch geometry. Thus, reducing uneven tyre wear, enhancing cost-efficiency and safety.
- Leverage machine learning to model complex relationships between vehicle states and optimal alignment settings, enabling data-driven prediction of camber and toe angles for enhanced adaptability and performance.

The core academic value lies in bridging the gap between theoretical alignment models and the predictive capabilities of machine learning. By simulating vehicle behaviour across various conditions, we aim to identify how camber and toe angles can be optimally tuned in real-time based on input from virtual sensors. If successful, this can contribute to the future development of embedded control systems and smart chassis technologies.

2.2 Description of the Project

In most vehicles today, wheel alignment settings such as camber and toe angles are fixed or manually adjusted and do not change while the vehicle is in motion. However, real-world driving involves constant changes: cornering, braking, uneven roads, or varying speeds. In such cases, having a system that can actively adapt these alignment angles in real time could significantly improve vehicle stability and how much grip the tyres have.

Our project aims to simulate such a system. We are designing a model that can estimate whether the current camber and toe angles are optimal based on sensor data like tyre temperature, vehicle speed, and steering input. Then, using machine learning, the system will predict the ideal alignment angles under those conditions.

The main problem we are addressing is that current passive alignment systems cannot respond to dynamic changes during driving, which limits performance and safety. Our goal is to build a virtual control system that learns how to adjust alignment parameters for better overall stability and cornering, using data-driven methods.

The scope of the project includes:

- Building a dynamic vehicle simulation in Carsim or Matlab SimMechanics that responds to changes in suspension geometry.
- Developing a machine learning model that can predict optimal camber and toe settings based on these inputs.

- Testing this adaptive system through simulation to evaluate stability improvements.

While no physical system will be built, this simulation-based study will show the potential of real-time alignment systems and how they might be implemented in future vehicles.

2.3 Background of the Project

The stability, safety, and efficiency of modern vehicles are directly influenced by suspension and wheel alignment systems. Traditional fixed-geometry suspension setups, while reliable, do not optimally adapt to dynamic road and driving conditions. Active Suspension Systems (ASSs) have therefore gained significant attention in both academia and industry for their potential to improve ride comfort and handling. According to a recent review by Luo et al. (2021) [2], ASSs are now seeing a resurgence in commercial viability due to their compatibility with electric and autonomous vehicles. These systems are designed not only to stabilise the chassis and reduce vibrations but also to integrate with other vehicle subsystems like steering, braking, and high-level control modules. However, such systems currently appear only in high-end vehicles like those from Mercedes-Benz (Active Body Control) and Audi (Predictive Active Suspension), and are not implemented in most conventional or lower-end vehicles.

Parallel to this, some research efforts have proposed mechanical solutions for real-time wheel alignment. For example, Gnanasekaran (2021) [1] describes a system that uses double wishbone suspension arms with telescopic actuators to dynamically control camber and toe angles. The system, governed by a closed-loop PID controller using sensor feedback, showed notable improvements in both simulation and physical prototype testing. Nevertheless, these methods do not incorporate any predictive logic or learning capabilities.

Current active alignment technologies lack integration with predictive models or machine learning approaches. No known system or implementation attempts to predict wheel alignment settings based on road condition sensing (e.g., wet/dry surfaces, incline, or cornering) or tire parameters. The proposed project aims to investigate this gap by exploring a machine learning-based approach to determine camber and toe settings in real-time using simulated and sensor-based inputs. While it does not aim to replicate commercial suspension systems, it will explore data-driven decision-making as a means of improving dynamic wheel alignment.

3. Methodology

3.1 Design Phase

Our proposed solution is a real-time predictive system that recommends optimal camber and toe angles based on current road conditions. The system integrates surface state data, such as wet or dry surfaces, road incline, and cornering angles, into a machine learning model trained on both simulated and collected data. This model predicts the ideal alignment settings to enhance vehicle stability.

Unlike fixed or manually adjustable systems, our approach enables adaptive control in response to real-time driving scenarios. In contrast to purely mechanical or rule-based methods, it learns from a wide range of road-vehicle interactions, providing greater precision and adaptability. Importantly, this solution is not limited to high-end vehicles; it is designed to be scalable and cost-effective enough to benefit low-end vehicles as well, making advanced alignment control more widely accessible.

3.2 Implementation Phase

The vehicle dynamics and data generation will be modelled using CarSim and MATLAB Simulink. CarSim will simulate vehicle behaviour under various road and driving conditions, from which input-output datasets (e.g., road surface → camber/toe) will be created.

A machine learning algorithm will be trained on this dataset. The trained model will then be embedded into the Simulink environment, where it will receive input signals in real-time and generate predicted alignment values. The model will then be validated through closed-loop simulations by adjusting alignment angles in real time and evaluating the effects on vehicle stability.

3.3 Testing Phase

The complete system—including the machine learning-based prediction model and control logic—will be implemented in Simulink and tested using the CarSim simulator. We will simulate a variety of road conditions and vehicle states (e.g., wet surfaces, inclines, sharp turns) and observe how the controller adapts the camber and toe angles in real time.

Key aspects to be tested include:

- Accuracy of the ML model in predicting optimal alignment angles
- Consistency of model output across repeated runs
- Stability improvement through real-time control

Testing will be done in phases—first validating the prediction output, then integrating the controller, and finally testing full closed-loop behaviour within CarSim. This allows us to verify system performance entirely in simulation, anticipating the lack of physical testing resources

3.4 Evaluation Phase

To evaluate the effectiveness of our system, we plan to compare the stability data across different simulation environments, including CarMaker and VI-CarReal Time or known optimal outcomes derived from existing vehicle dynamics theory. This validation method will help ensure that our results are consistent and not biased by a single simulation tool.

Key aspects to be evaluated include:

- Predicted camber and toe angles vs. fixed baseline settings
- Vehicle stability metrics such as yaw rate, lateral acceleration, and load transfer
- Robustness under noise or varying input combinations

Results will be presented using comparative graphs and simulation outputs. These visualisations will highlight the benefits of real-time adaptive alignment in terms of vehicle dynamics.

4. Features

- **Real-Time Adaptive Alignment:** Predicts optimal camber and toe angles dynamically based on road and vehicle data, unlike conventional fixed alignment systems.

- **Simulation-Driven Development:** The entire system is built and validated using professional automotive simulators like CarSim and VI-grade, ensuring realistic and accurate results.

- **Machine Learning-Based Control:** Uses a trained model for intelligent prediction rather than static lookup tables, enabling context-aware decision-making.

- **Vehicle Stability Enhancement:** Real-time adjustments improve cornering performance, reduce tire wear, and maintain safety on uneven or slippery roads.

- **Sensor Integration Readiness:** Designed with the potential to integrate physical sensors in future, making the system extendable to real vehicles.
- **Cross-Platform Evaluation:** Results validated across multiple simulation tools or a known mathematical model/theory for robustness and credibility.

5. Project Planning

Table 1: Project Planning Roadmap

	Task Description	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Selecting a Project Title														
2.	Literature Review and Background Study														
3.	Project Proposal Development & Presentation														
4.	Learning Simulation Software														
5.	Learning Machine Learning														
6.	Gathering Datasets from Simulation														
7.	Design & Development of Machine Learning Model														
9.	Mid-evaluation Presentation														
10.	Training the Machine Learning Model														
11.	Testing and Validation														
12.	Drafting Reports and Final Presentation														
13.	Final Demonstration														

6. Hardware and Software Requirements

- Matlab (SimuLink/SimMechanics)
- Carsim / IPG Carmaker
- VI-CarReal

No hardware will be required for this project.

7. References

[1] Kavitha, C., Shankar, S.A., Karthika, K., Ashok, B. and Ashok, S.D. (2019). Active camber and toe control strategy for the double wishbone suspension system. *Journal of King Saud University - Engineering Sciences*, [online] Available at: https://www.sciencedirect.com/science/article/pii/S1018363917302799

[2] Yu, M., Evangelou, S. and Dini, D. (2023). Advances in Active Suspension Systems for Road Vehicles. Engineering, [online] Available at: https://www.sciencedirect.com/science/article/pii/S2095809923003983

[3] Balázs Németh and Péter Gáspár (2015). LPV-based Variable-Geometry Suspension Control [online] Available at: https://www.sciencedirect.com/science/article/pii/S2405896315023721