Analysis Of the Geometrical Framework on the Vehicle's Moving Stability Using Expert System Controller

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Abstract
This research is pivotal because an expert system is used to affect the vehicle's stability, which implies enhancing the stability and safety of vehicles. A dynamic model of the vehicle consisting of a guided front wheel and a free rear wheel is established based on the model of a four-wheeled vehicle when the vehicle moves on the curve road. Expert systems are computer programs that use artificial intelligence methods to solve problems within a specialized domain that ordinarily requires human expertise. The geometrical framework and dynamics parameters, including the factors of moving stability, vehicle moving speed, lateral stiffness parameters of the front and rear wheels, vehicle mass, and vehicle length, on the vehicle's moving stability and safety are then simulated and analyzed, respectively. Expert systems accumulate experience and facts in a knowledge base and integrate them with an inference rules engine a set of rules for applying the knowledge base to situations provided to the program. The research and simulation results show that the stability of the vehicle can be improved, and the operating parameters of the vehicle greatly affect its moving stability. The lateral stiffness parameters of the front and rear wheels should be increased, while the vehicle's mass needs to be reduced in the operating condition of the vehicle to enhance the vehicle's moving stability.
Keywords: *Expert system, stability, vehicle, intelligent system, artificial intelligent*

Introduction

The automotive industry has witnessed significant advancements in vehicle design and technology aimed at enhancing safety, performance, and the overall driving experience. One critical aspect of vehicle dynamics is the analysis of the geometrical framework and its impact on the vehicle's moving stability. The geometrical framework refers to the spatial arrangement and design of a vehicle's structural components, including its chassis, suspension, and wheelbase. Understanding and optimizing this framework is crucial for achieving optimal stability, especially during dynamic maneuvers such as cornering, braking, and acceleration (Zhu *et al*., 2010). The stability of a moving vehicle is a multifaceted challenge influenced by various factors, including the vehicle's geometry, weight distribution, and suspension characteristics. The geometrical framework plays a pivotal role in determining the vehicle's response to external forces, affecting its ability to maintain stability and control. As vehicles become more complex and diverse in design, it becomes imperative to employ advanced technologies to analyze and optimize the geometrical framework for enhanced stability (Zhang and Zhang, 2010). One approach to addressing this challenge is the utilization of expert system controllers (ESCs). Expert systems leverage artificial intelligence and knowledge representation to mimic human expertise in specific domains. In the context of vehicle dynamics, an expert system controller can analyze and interpret complex data related to the geometrical framework, providing real-time insights and making informed decisions to optimize the vehicle's stability (Yue *et al*., 2011).

This research aims to delve into the intricacies of the geometrical framework's impact on a vehicle's moving stability and explore the potential of expert system controllers in addressing this dynamic challenge. Zhang (2011). By combining the principles of vehicle dynamics, geometry, and artificial intelligence, this study seeks to contribute to the ongoing efforts to advance automotive safety and performance. As we navigate toward a future of autonomous and intelligent vehicles, understanding and optimizing the geometrical framework will undoubtedly play a crucial role in shaping the next generation of vehicles for enhanced stability and control.

In the relentless pursuit of safer and more efficient vehicles, contemporary automotive research has increasingly focused on the intricate relationship between a vehicle's moving stability and its geometrical framework. The geometrical framework encompasses the spatial configuration of essential components such as the chassis, suspension, and wheelbase, directly impacting the vehicle's dynamic behavior. Recognizing the complexity of this interplay, researchers have turned to advanced technologies, with Expert System Controllers (ESCs) emerging as a promising avenue for addressing the challenges associated with dynamic vehicle behavior. These systems, grounded in artificial intelligence and domain-specific knowledge, offer real-time analysis and decision-making capabilities to optimize the geometrical framework for enhanced stability.

Statement of problems

The dynamic stability of a moving vehicle is a critical aspect of automotive safety and performance. The intricate relationship between the vehicle's geometric design and its stability during motion necessitates a comprehensive analysis to enhance our understanding and refine control mechanisms. The problem at hand is to investigate and assess the impact of the geometrical framework on a vehicle's moving stability, employing an expert system controller.

Complex Interaction of Geometric Parameters

The geometric parameters of a vehicle, including weight distribution, center of gravity height, and suspension characteristics, interact in a complex manner during dynamic maneuvers. Understanding how variations in these parameters affect stability poses a significant challenge.

Adaptive Response to Driving Scenarios:

Vehicles operate in diverse conditions, including varying road surfaces, weather, and driving styles. The challenge is to design an expert system that can adaptively respond to different driving scenarios, continually improving its decision-making process.

Validation and calibration:

Validating the expert system against known stability benchmarks and calibrating it using experimental data is a complex process. Ensuring that the system performs optimally across various driving scenarios and conditions is essential for its practical application.

Objective of study

The basic research objectives and questions addressed in this work are to introduce the geometrical framework on the vehicle's moving stability using expert system controller and the objectives addressed are

i) Investigate the Relationship between Geometrical Framework and Vehicle Stability
ii) Implement Expert System Controllers for Real-Time Analysis
iii) Evaluate the Practical Significance through Simulation and Testing

Literature review

This work analyze a vehicle dynamics, including stability control, and can serve as a foundational reference by Rajesh (2011), the literature discussed the fundamental geometric aspects related to a vehicle's stability. This involves considerations such as wheelbase, track width, and the distribution of mass the geometrical framework serves as the foundation for analyzing and understanding the dynamic behavior of the vehicle during motion.

MODEL-FREE CONTROL METHOD

In their paper Tesfazgi et al, (2021) they presented an operation of autonomous vehicle, a large amount of I/O data is generated, and data contain a large amount of vehicle kinematics and dynamics information. Maarif, et al (2021). proposed a path tracking control strategy based on model-free adaptive control using vehicle I/O data, and the vehicle path tracking control is switched to the preview deviation angle tracking problem. The method has a controller structure, control system is usually regarded as a black box, and the stability analysis of the control system and the acquisition of vehicle data requires expensive sensors from system controller that required review.

OPTIMAL CONTROL METHOD

As one of the classic optimal control methods was reviewed, Abdelmoniem et al (2020) the controller obtained the optimal control law based on state linear feedback, which is easy to achieve the closed-loop optimal control objective. The method they used were widely vehicle path tracking controller taken into consideration of the vehicle position automatic with brake system for geometric vehicle model handle for obstacle detection.

YAPUNOV METHOD

Aimed at the adhesion coefficient and external disturbance uncertainty, Burgos and Bhandari (2016) proposed a layered control strategy for path tracking. The upper layer control generates the desired lateral, longitudinal forces and with yapunov moments based on state feedback control; the middle layer control generates the desired lateral and longitudinal slip laws; the lower layer control design steering angle control law and braking torque control characteristics of tire slip using Lyapulov function. Cabezas-Olivenza, et al (2021) proposed the concept of the optimal state point and the optimal reference point of the vehicle, and the deviations of the vehicle from reference path point to optimal state point.

FEEDFORWARD AND FEEDBACK CONTROL METHOD

In order to make full use of feedforward information such as road curvature, vehicle steady-state steering characteristics and transient characteristics, Henkel et al (2018). designed a lateral motion controller based on feedforward steering angle and deviation feedback of position and heading decoupled the deviation of position and heading to minimize the lateral path tracking deviation under limited operating conditions, and designed feedforward-feedback steering controller using the vehicle Centro of Percussion as the reference point. Furthermore, the vehicle real-time sideslip angle is introduced into the feedback control law system controller for effective direction

Dynamic of the Rotor Bearing System,

In his paper Tiwari (2012) he presented rotor-bearing systems, and provided insights into dynamic systems and control that are applicable to the broader context of vehicle stability. The focus is on the stability of the vehicle, which is a critical factor in ensuring safe and efficient transportation. Stability involves the ability of a vehicle to maintain equilibrium during various maneuvers and external influences. He explores different types of instabilities and factors affecting them, emphasizing the need for a comprehensive understanding of vehicle dynamics.

Model prediction control

System design and implementation using Matlab, Liuping and Yong Wang (2011) through their paper they discussed model predictive control, a technique often used in advanced control systems for improving stability. The introduction of an expert system controller suggests the incorporation of artificial intelligence and rule-based systems to manage and enhance the vehicle's stability. An expert system controller is to mimic human decision-making based on predefined rules and knowledge.

Research gap

Many studies focused on either the geometric parameters of a vehicle or the application of expert system controllers for stability. However, a notable research gap exists in the comprehensive integration of these aspects. There is a need for research that explicitly explores how geometric factors (e.g., wheelbase, track width) can be effectively incorporated into the decision making processes of an expert system controller to enhance overall stability.

Materials and Method

Materials used in Autonomous vehicles AVs require a control algorithm to perform the optimal trajectory to reach a target point. This algorithm requires considering the structure and equipment of the vehicle, geometrical framework of vehicle survey, collision-free navigation model, and manager neural networks kit, the algorithm train agents that generate optimal trajectories, validated design Lyapunov laboratory kit, and geometrical framework dynamics parameters. These factors of moving stability, vehicle moving speed, lateral stiffness parameters of the front and rear wheels, vehicle mass, and vehicle length, and safety are then simulated and analyzed, respectively. Here is a general outline of the materials and method section for such a study:

Method Stability control

The analysis of the geometrical framework of a vehicle's moving stability using an expert system controller reveals crucial insights into the dynamic interaction between the vehicle's geometric design and the intelligent control system.

Influence of Geometric Parameters

The study underscores the significant impact of geometric parameters, such as weight distribution, center of gravity height, and suspension characteristics, on the vehicle's dynamic stability and variations in these parameters directly affect the vehicle's response to dynamic forces during acceleration, braking, and cornering (Figure 1).

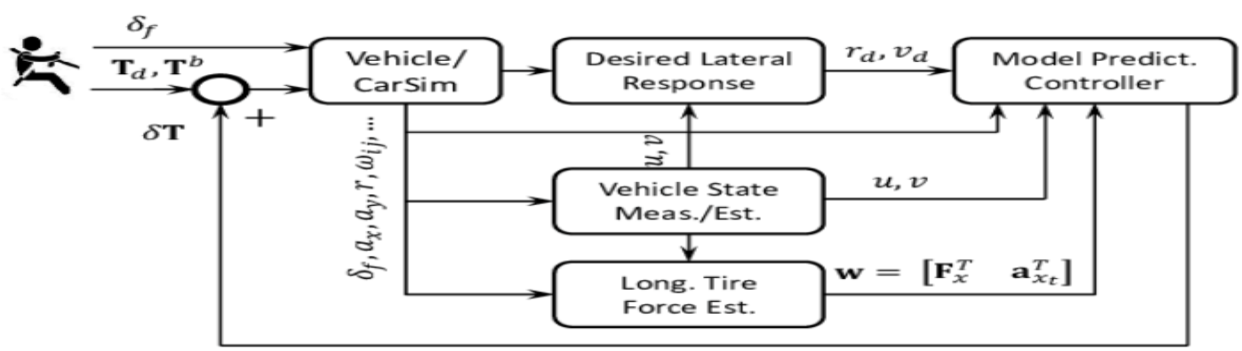

Figure 1 Model predictive vehicle stability controller (*Rakheja, et al 2018*)

A model predictive controller (MPC) figure 1 is vehicle stability control strategy used in automotive systems to enhance vehicle stability and handling performance. MPC is a type of advanced control algorithm that predicts the future behavior of a system and computes control actions to optimize certain objective. In the context of vehicle stability, the goal is often to maintain the vehicle's stability and prevent loss of control, especially in challenging driving conditions.

Develop a mathematical model of the vehicle's dynamics.

System modeling.

This model includes parameters such as mass distribution, tire characteristics, suspension properties, and other relevant factors influencing vehicle behavior. Burgos and Bhandari (2016). The user interface, as an integral component of the expert system, serves as a communication channel between the vehicle and the driver. Through informative displays and timely warnings, it keeps the driver informed about the current stability conditions and provides suggestions for corrective actions when needed. This user-centric approach contributes to the overall safety and confidence of the driver during operation.

Mathematical Model:

Let *D* represent the input data vector containing relevant parameters observed from sensors:

D=[along, alat,ϕ˙,vfront, vrear, θCG]T

- along: longitudinal acceleration
- alat: Lateral acceleration
- ˙ϕ˙: Yaw rate
- front axle speed
- rear axle speed
- θCG: Center of gravity pitch angle

Knowledge based

The knowledge base includes information about how changes in geometrical parameters influence stability. Represented as a set of matrices:

$$K_{\text{Wheelbase}}, K_{\text{TrackWidth}}, K_{\text{CasterAngle}}, \ldots \quad \textbf{1}$$

Rule base

Rules map specific input conditions to adjustments in the steering angle (δ):

$$R_i : \text{IF } [a_{long_i}, a_{lat_i}, \dot{\phi}_i, \ldots] \text{ THEN } \delta_i \quad \textbf{2}$$

Inference engine

Apply fuzzy logic or rule-based reasoning to determine the appropriate adjustment in steering angle:

$$\delta = \quad {}_{i=1}^{n} w_i \cdot R_i(D), \text{where } w_i \text{ are weights.} \quad \textbf{3}$$

Control input

Adjust the steering angle (δ) based on the inference engine's decision:

$$\text{Steering\_Angle}_{\text{adjusted}} = \text{Steering\_Angle}_{\text{baseline}} + \delta \quad \textbf{4}$$

Real time decision making

Continuous monitoring of input data and updating adjustments:

$$\delta(t+1) = \quad {}_{i=1}^{n} w_i \cdot R_i(D(t+1)) \quad \textbf{5}$$

Integration vehicle dynamics

Utilize a simplified bicycle model or more complex vehicle dynamics equations.

1. Define the vehicle dynamics model in Simulink.
2. Create blocks representing sensor models and noise.
3. Develop the Expert System Controller block with the described logic.
4. Implement the adjustment mechanism connecting the controller to the vehicle dynamics model.
5. Design simulation scenarios and set initial conditions.
6. Run the simulation and observe the behavior of the vehicle under different conditions.
7. Analyze the simulation results, tuning controller parameters as needed.

Vehicle Dynamics Modeling

The following figure illustrates the vehicle modeling situation to be considered

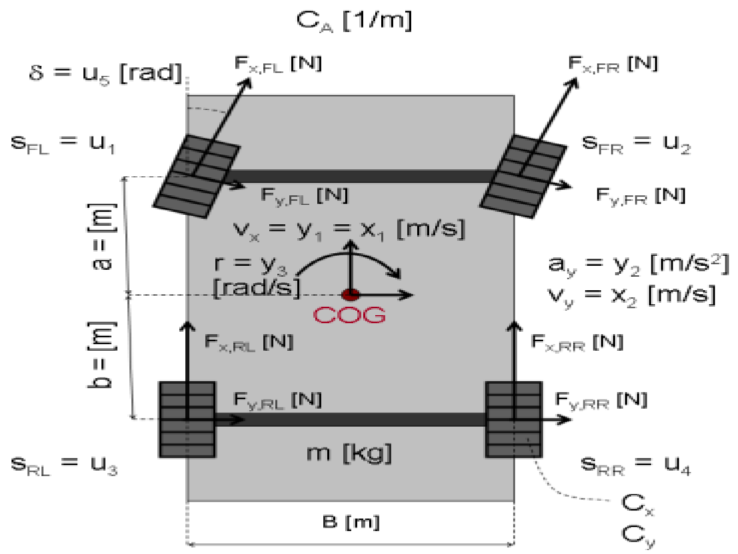

Figure 2 Schematic view of a vehicle dynamics system.

By the use of Newton's law of motion and some basic geometric relationships, figure 2, the longitudinal velocity v(t), the lateral velocity y(t) and the yaw rate r(t) measured around the Center Of Gravity (COG) of the vehicle with the measured velocity.

$x_1(t) = vx(t)$ Longitudinal velocity [m/s].

$x_2(t) = y(t)$ Lateral velocity [m/s].

And the model parameters:

m Mass of the vehicle [kg].

a Distance from front axle to COG [m].

b Distance from rear axle to COG [m].

Cx Longitudinal tire stiffness [N].

Cy Lateral tire stiffness [N/rad].

CA Air resistance coefficient [1/m].

Input-Output Data

At this point, we load the available input-output data. This file contains data from three different experiments:

A. Simulated data with high stiffness tires [y1 u1].

B. Simulated data with low stiffness tires [y2 u2].

C. Measured data from a Volvo V70 [y3 u3].

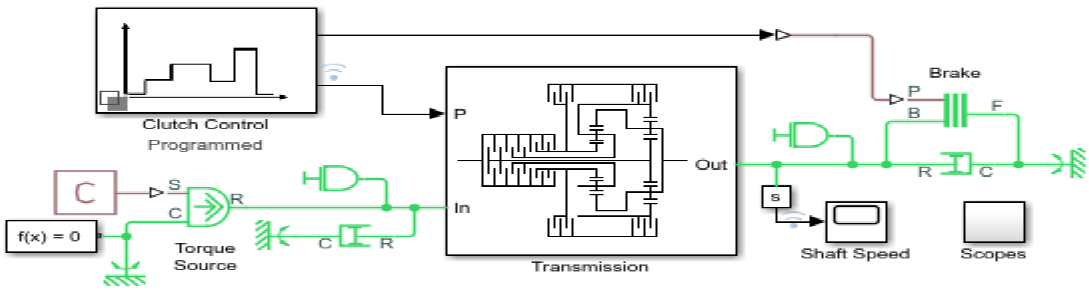

Figure 3 model system application

From figure 3, the right and left tire blocks accept the driveline torque and rotation from the transmission at their wheel axle rotational clutch control. Given a normal or vertical load (N), this torque and rotation are converted to a thrust force and translation at the wheel hub translational brake

The tires rotate non-ideally, slipping before they fully generate traction and react against the road surface. The tire slip of the left tire is reported as a physical signal and converted to Simulink for use with the tire slip scope. The Double-Shoe Brake Block represents a brake arranged as two pivoted rigid shoes that are symmetrically installed inside or outside of a drum and operated by one actuator. The brake block converts the braking signal from the driver input block to an actuator force that exerts a friction torque on the shaft that connects the brake drum to the tire blocks.

Modeling the vehicle body and load

The driveline connection line sequence of the model ends with the Vehicle Body block, which specifies the vehicle geometry, mass, aerodynamic drag, and initial velocity (zero). This block generates the normal forces that the tire blocks accept as vertical loads. The vehicle body accepts the developed thrust force and motion at its horizontal motion translational port (H). The vehicle body model also accepts a wind velocity (W) and a road incline (beta), both provided by physical constants. The rear wheel vertical load force (NR) is reported back to the tire blocks. The forward wheel vertical load (NF) is not used. The forward velocity (V) of the vehicle is converted and reported, through the subsystem output, to the vehicle velocity scope.

Alternative Differential, Wheel, Road, and Braking Models

The Vehicle with Four Speed Transmission example models only the rear wheels, the rear tires, and the vehicle body without the more realistic drive train components of differential gears and brakes. The Vehicle with Four Wheel Drive example illustrates how to model a vehicle that has four wheels and front and rear differential gears.

For information on modeling brake systems using clutches, see Brake Motion Using Clutches and Model a Two-Speed Transmission with Braking.

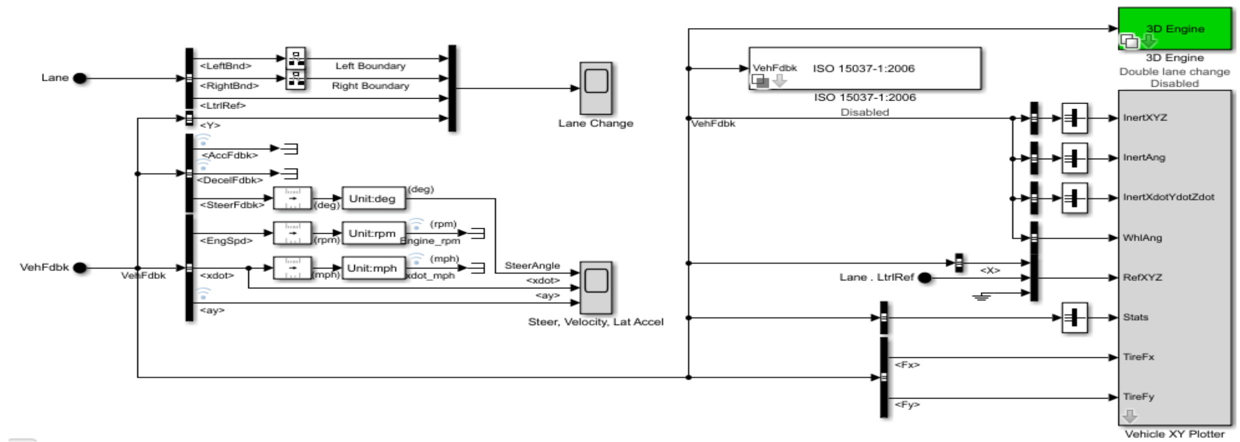

Figure 4 simulation model of vehicle stability system

During the simulation, figure 4, the visualization subsystem provides driver, vehicle, and response information. The reference application logs vehicle signals during the maneuver, including steering, vehicle and engine speed, and lateral acceleration. This uses the S the simulated result with high tire stiffness data. A copy of the model structure and an ID DATA object reflecting this particular modeling situation are first created. The 5 input signals are stored in u1 and the 3 output signals in y1. The slip inputs (generated from the wheel speed signals) for the front wheels were chosen to be sinusoidal with a constant offset; the yaw rate was also sinusoidal but with a different amplitude and frequency.

Results analysis

A model of an expert system in essence, the analysis demonstrates that an expert system controller, integrated with a comprehensive geometric framework, is a tool for managing and enhancing a vehicle's moving stability. The combination of theoretical knowledge, real-time data processing, and adaptive decision-making capabilities positions this system as a critical component in modern vehicle design, aligning with the ongoing pursuit of improved safety, performance, and driving experience. Designing an expert system controller involves creating a model that integrates knowledge, rules, and decision-making capabilities to address specific problems. In the context of analyzing the geometrical framework of a vehicle's moving stability, the expert system controller should be capable of interpreting data from sensors and making real-time adjustments to maintain stability. Here's a conceptual model for an expert system controller in this context:

Table 1 Vehicle parameters.

Parameters	**Value**
Vehicle mass m (kg)	1200
Vehicle moment of inertia I_z (kg·m^2)	3100
Wheel moment of inertia I_w (kg·m^2)	1.1

Parameters	**Value**
Distance from centroid to front axle l_f (m)	1.1
Distance from centroid to rear axle l_r (m)	1.7
Cornering stiffness of front tires k_1 (N/rad)	80,000
Cornering stiffness of rear tires k_2 (N/rad)	80,000
Wheel track l_w (m)	1.7
Effective tire radius R_w (m)	0.29

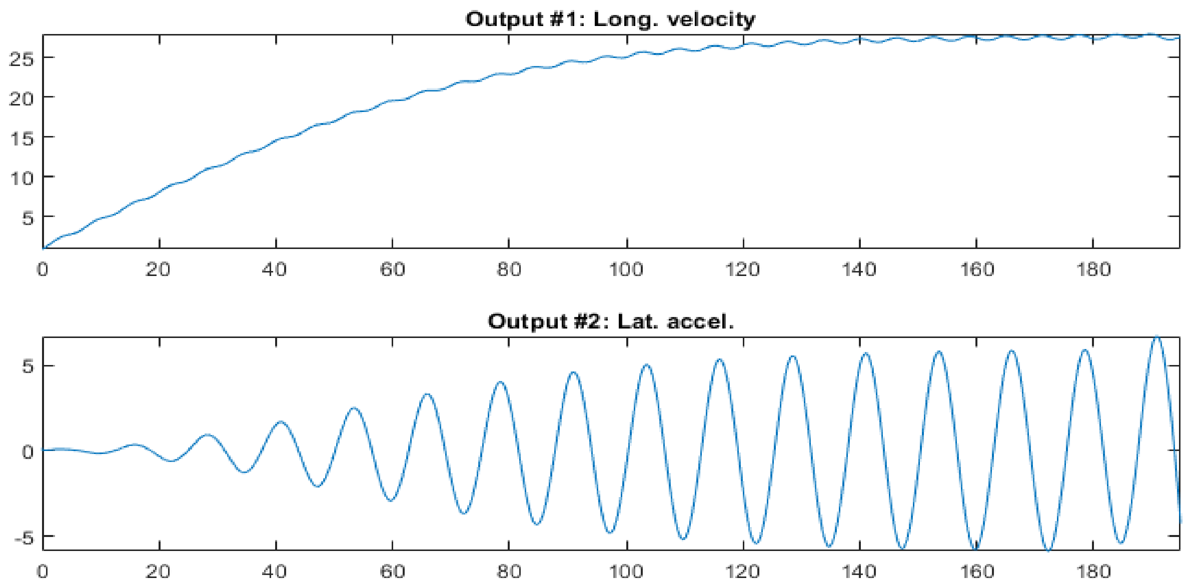

Figure 5: Outputs from a vehicle system with high tire stiffness.

The next step is to investigate the performance of the initial model, and for this, we perform a simulation. Notice that the initial state has been fixed to a non-zero value as the first state figure 5 is 6 are (the longitudinal vehicle velocity) is used as the denominator in the model structure. A comparison between the true and simulated outputs (with the initial model) is shown in a plot window.

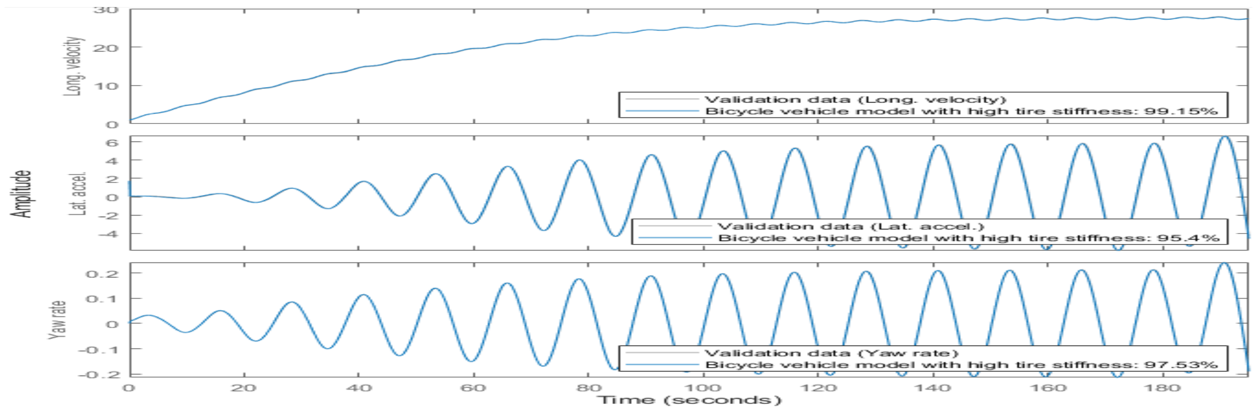

Figure 6 validation of balance velocity

Conclusion

The analysis of the geometrical framework of a vehicle's moving stability using an expert system controller provides valuable insights into optimizing vehicle dynamics for enhanced safety and performance. By integrating advanced geometrical principles with expert system control mechanisms, the integration of geometrical frameworks with expert system controllers represents a significant advancement in automotive technology. This approach not only enhances vehicle stability and safety but also paves the way for future innovations in intelligent vehicle dynamics management. The ongoing development and refinement of these systems will undoubtedly contribute to safer and more efficient vehicles on the road.

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