Comparing the Performance of Active and Passive Suspension Systems for a ¼ Vehicle using MATLAB/Simulation

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https://doi.org/10.31972/iceti2024.009

Abstract

We sincerely believe that the suspension system significantly guarantees comfort and driving safety in various scenarios and road conditions since it only connects the vehicle to the occasionally uneven road. Thus, the performance of two distinct suspension systems, passive (PSS) and active (ASS), was the main focus of this investigation. The MATLAB/Simulink environment models and simulates a representative vehicle in a two-degree-of-freedom system. By utilizing software modeling and simulation, it is possible to understand how the two systems behave under identical conditions and parameters by analyzing the differential motion equations that describe them. Numerical and graphical findings comparing the two systems demonstrated that the ASSs with controllers perform better than the traditional systems in terms of suspension system adjustment and response time (rising time, overshoot, settling time, and steady-state error). It also reduces roll and pitch movements, dissipates vertical oscillations, and reduces dissipation, which was the research's main objective.

Keywords: Feedback controller, Modeling, Quarter car, Simulation, Suspension systems.

1. Introduction

The suspension system's functions include maintaining the traction force between the tires and the pavement, supporting the weight of the vehicle, and shielding the body from road disturbances. Enhancing ride comfort, handling traction on the road, and stability of cars are the goals of the suspension system. Three types of suspension systems exist: passive, semi-active, and active. We refer to the more expensive, completely active suspension system as a semi-active one since it balances the passive and fully active systems. Semi-active systems can significantly improve ride quality compared to active systems because they use substantially less power, and are simpler, more reliable, and less complex (Bhise *et al.*, 2016). To learn more about how these systems behave and function, consider the following models:

On one of the quarter vehicle model's four wheels, one suspension center is examined. (Qasim and Mashhadany, 2024) The half-vehicle model examines two suspension centers on two wheels, while the whole-vehicle model studies all four suspension centers on each wheel. This study uses the quarter-vehicle model to model and simulate each of the ASS and PSS. Due to space limits, only the displacement of the sprung mass and the difference between the sprung and unsprung mass are provided in this study.

2. Passive Suspension System Modeling and Simulation

Passive means that the suspension system cannot receive energy from the suspension elements. The PSS restricts motion by limiting the body's and the wheel's relative velocities to a rate that provides the necessary ride comfort. This is accomplished by utilizing a dampening element, such as a hydraulic shock absorber, positioned between the vehicle's body and wheels. The damper's desired qualities are the ideal tire-road contact force and reduced vertical body acceleration (Bhise *et al.*, 2016). To create block diagrams that are reflective of the model in Simulink, we must first acquire the differential equations that describe the model that we have selected (¼ of the vehicle). PSS is the term for traditional suspension, which consists of dampers and springs. Its control system is open-loop. Its only objective is to satisfy a certain need (Alzughaibi, Xue, and Grosvenor, 2019).

2.1. Vehicle Suspension System Mathematical Modeling

Each type of vehicle can have a model made by combining the sample values of the masses (m), the stiffness coefficients (k), and the coefficients of the damping components (c). The vehicle's model schematic for ¼ is displayed in Figure 1.

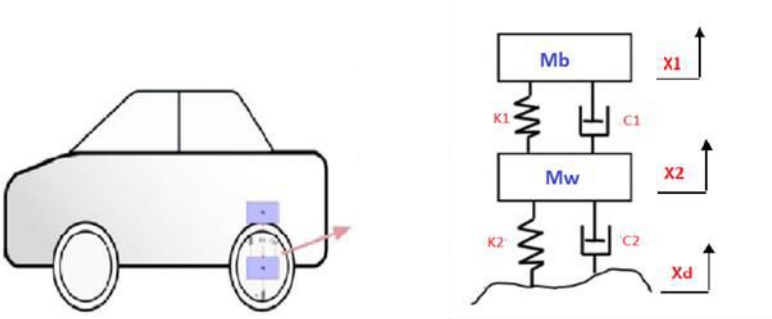

Figure 1: (a) Schematic passive suspension system quarter car. (**b)** Passive suspension system quarter car.

The equations of motion for each of the masses will be generated by consulting Newton's Second Law, upon which the mathematical model of this PSS is built.

Fundamental procedures form the foundation of the mathematical model's development:

1. The directions of (x1, x2)'s coordinates are defined. When the system is in static equilibrium, let x1 = 0, x2 = 0.
2. The mathematical model of the system is represented by second-order differential equations, which we represent based on Newton's laws. By examining the reciprocal effects of the input and output forces on the inertia components of our system, the following equations are obtained:

$$M_b \ddot{x}_1 = -k_1(x_1 - x_2) - C_1(\dot{x}_1 - \dot{x}_2)$$
(1)

$$M_w \ddot{x}_2 = -C_2(\dot{x}_2 - \dot{x}_d) - k_2(x_2 - x_d) + C_1(\dot{x}_2 - \dot{x}_1) + k_1(x_2 - x_1)$$
(2)

2.2. System Parameters and Conditions

The following setup parameters and conditions were used for dynamic modeling. The parameters of a standard passenger car utilized in the MATLAB/Simulink simulated analysis are provided in Table 1 (Wu *et al.*, 2023) .

Table 1. Simulation parameter PSS for a 1/4 vehicle (Bhise *et al.*, 2016).

Parameters	**Symbol**	**Values**	**Units**
Body mass	M_b	241.5	Kg
Wheel mass	M_w	41.5	Kg
Stiffness of the first spring	K_1	6000	N /m
Stiffness of the second spring	K_2	14000	N /m
The damping factor of the first damper	C_1	1000	N.s /m
The damping factor of the second damper	C_2	1500	N.s /m

2.3. MATLAB/Simulink Modeling and Simulation

The modeling is done in the Simulink workspace, where individual blocks that meet the needs of the system under investigation are chosen from the library. These blocks are then connected to build a functioning and representative whole of the system. Put differently, Simulink is a platform that makes it easier to model, simulate, and analyze dynamic systems and their behavior graphically in the frequency and time domains, as seen in Figure 2.

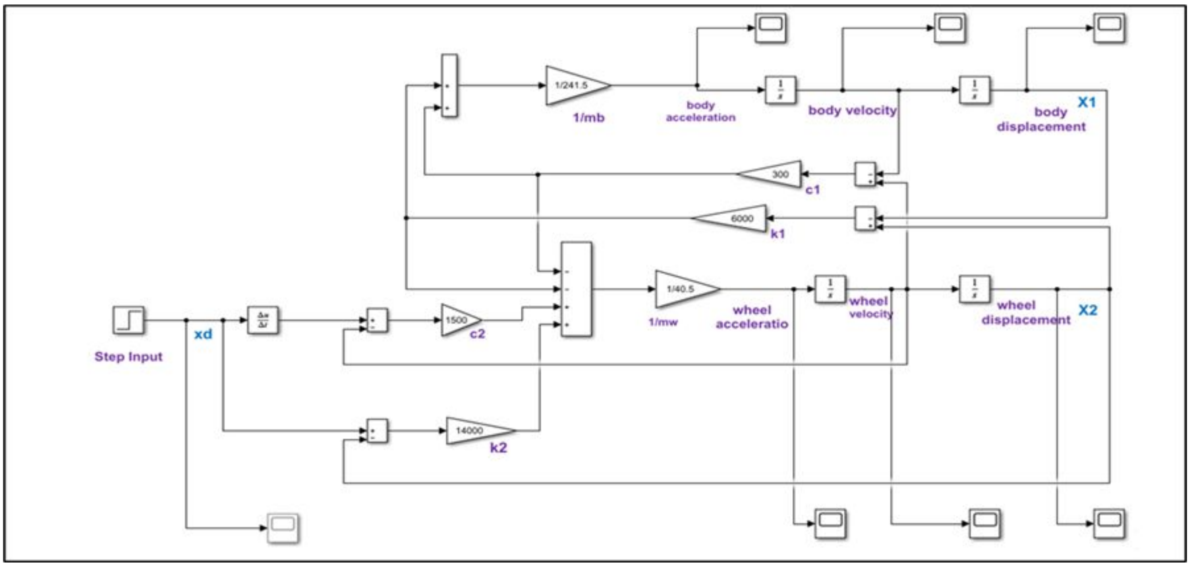

Figure 2. Simulink environment-developed passive ¼ car suspension model.

.3Active Suspension System Modeling and Simulation

ASS is made to meet specific needs. Suspension systems should normally be able to improve the two most important functions: disturbance shocking up (also called passenger comfort) and vehicle handling (also called disturbance transfer to the road) (Jibril and Tadese, 2020). A closed-loop control system and a force actuator are used in ASS to restore suspension performance. A force actuator is a mechanical component located inside the system that a controller manages (Moghadam-Fard and Samadi, 2015). The controller can modify the system's energy output by utilizing input-provided sensors. Road data will be gathered by sensors. Profile, directed at the controller. As a result, when an active component of the suspension system meets both requirements, the system's efficiency is increased (Jibril and Tadese, 2020a).

3.1 The Active Suspension System's Mathematical Model

After adding the forces operating on the body and suspension masses, positions and velocities will be obtained from the two-time integration of the accelerations of each mass. For each mass, Newton's law will be used (Aljarbouh and Fayaz, 2020). The system contains two masses, two springs, one damper, and one actuator in the system. The first mass is the body mass, Mb (kg), and the second mass are the wheel mass, Mw (kg). These two masses are connected by a hydraulic actuator with force Fa (N), a damper with damping coefficient C1 (N.s/m), a spring with stiffness factor K1 (N/m), and a tire with stiffness factor K2 (N/m) and damping coefficient C2 (N.s/m). as Arrangement in Figure 3 (a) ASS quarter car model and Figure 3 (b) represented Free body diagram ASS model (Xue, et al., 2019).

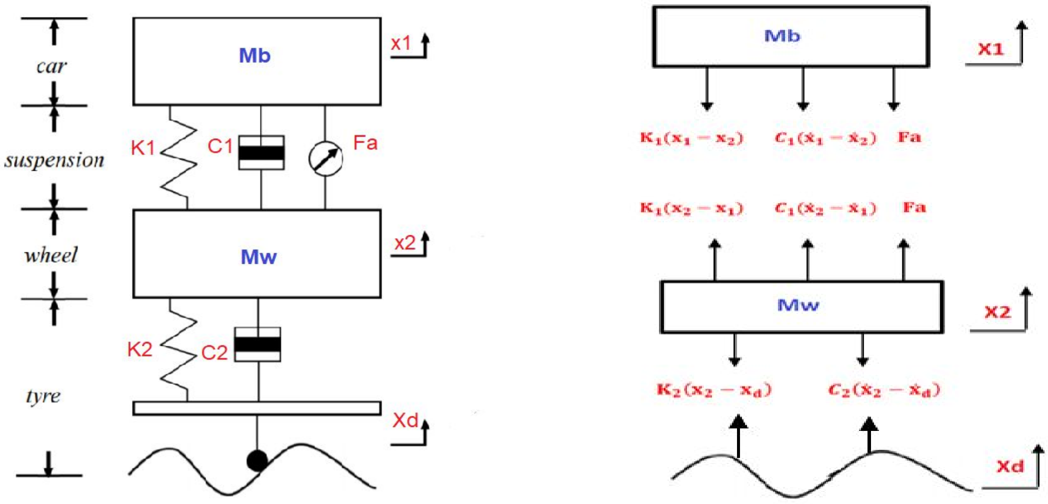

Figure 3. (a) ASS model (Han, et al., 2022). (b) Free body diagram ASS.

For this system, the equations of motion (EOM) must be computed by identifying the free body diagram for each mass. The diagrams should depict the forces operating on each of the two masses in the system using the notion and Newton's second rule of motion; two equations of motion will result. **Figure 3 (b)** describes the free body diagram for the M_b and the control force exerted by the active element applied between the body and the wheel of the active suspension system, spring force, and damping force (Abut Tayfun, *et al.*, 2023). The system's status variables include the displacement x_1 (m) and x_2 (m) and velocity $\dot{x}_1$(m/s) and $\dot{x}_2$(m/s) of the body and wheel masses respectively, The road's vertical displacement X_d (m) is devoted to the road disturbance, (Han, *et al.*, 2022).The equation of motion is associated to the body mass M_b is given by: (Kumar, *et al.*, 2022) (Basargan, *et al.*, 2023) (Abut and Salkim, 2023)**.**

The equation of motion is associated with the wheel mass M_w is given by:

$$\boldsymbol{M_w \ddot{x}_2 = K_1(x_2 - x_1) + C_1(\dot{x}_2 - \dot{x}_1) - K_2(x_2 - x_d) - C_2(\dot{x}_2 - \dot{x}_d) - Fa} \quad \mathbf{(5)}$$

$$\ddot{x}_2 = \frac{1}{M_w}\left(K_1(x_2 - x_1) + C_1(\dot{x}_2 - \dot{x}_1) - K_2(x_2 - x_d) - C_2(\dot{x}_2 - \dot{x}_d) - Fa\right) \quad \textbf{(6)}$$

3.2 Modelling Active Suspension System in MAT LAB Simulink

The code, as made known in **Figure 4**, is developed in MATLAB/Simulink environment by using Equations (5 and 6) to establish the system's reaction (Ghoniem, Awad and Mokhiamar, 2020).

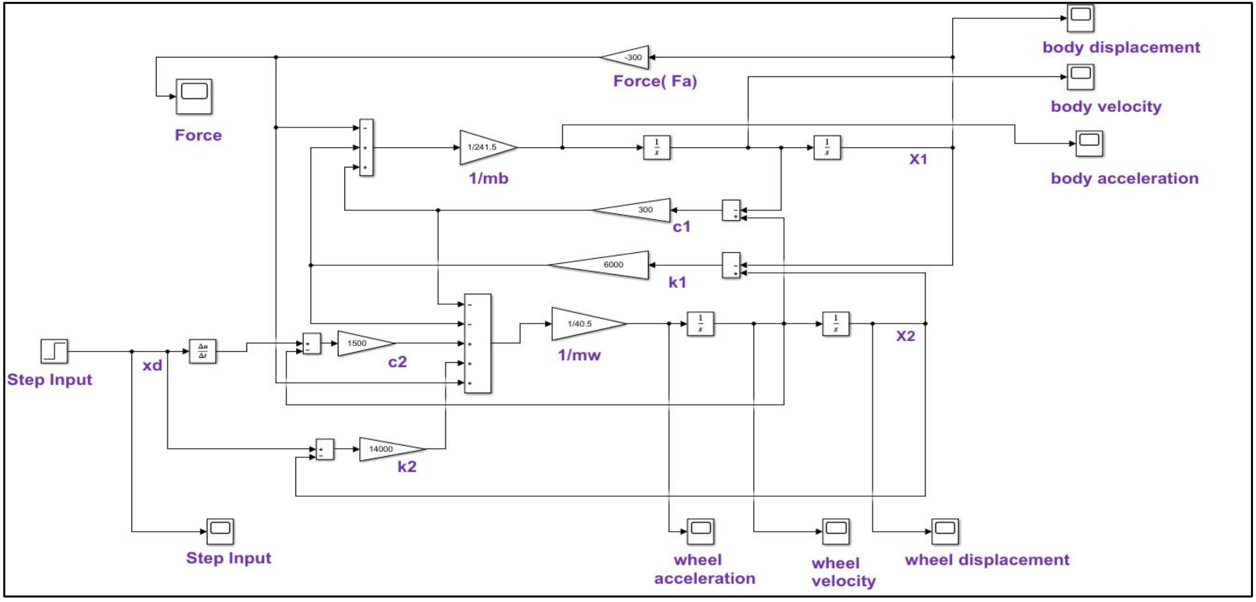

Figure 4. Simulink model for the ASS.

4. Results and Discussions

In this part of the paper, the quarter-car model in MATLAB/Simulink has been used to simulate the vehicle's ASS Figure 4 expressions of the code for a quarter-car model. We present a step input along with the outcomes for each system PSS and ASS.

4.1 Road Disturbance (Profile)

The primary cause of vibrations experienced by drivers of automobiles is road disturbances; these vibrations flow through the body of the vehicle and eventually reach the driver and passengers. Road disturbances must be replicated to examine the suspension system and lessen vibrations (Yu, Evangelou and Dini, 2024). Tests were done on one of the forms of traffic disturbances.

- The step input road profile can be obtained through MATLAB/Simulink's step tool. Figure 5 Initial value = 0 m, final value = 0.1 m, step time = 1 t.

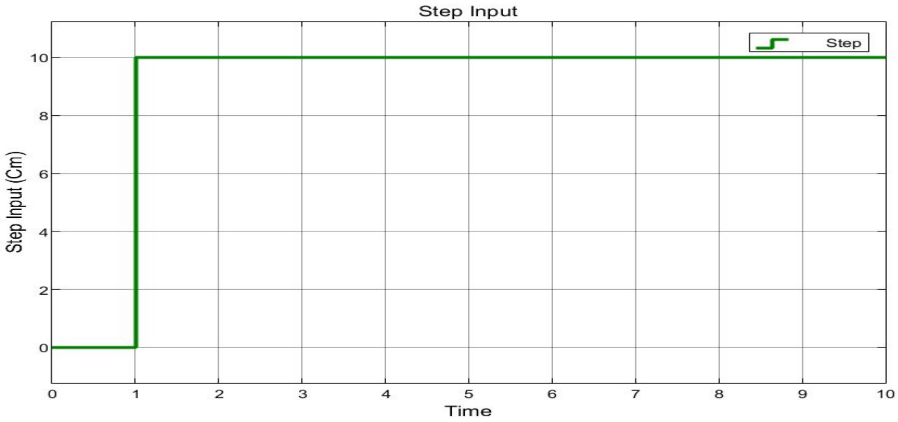

Figure 5. Simulink of road disturbance (step input).

After simulating the Step input for 10 seconds, the following results were discovered:

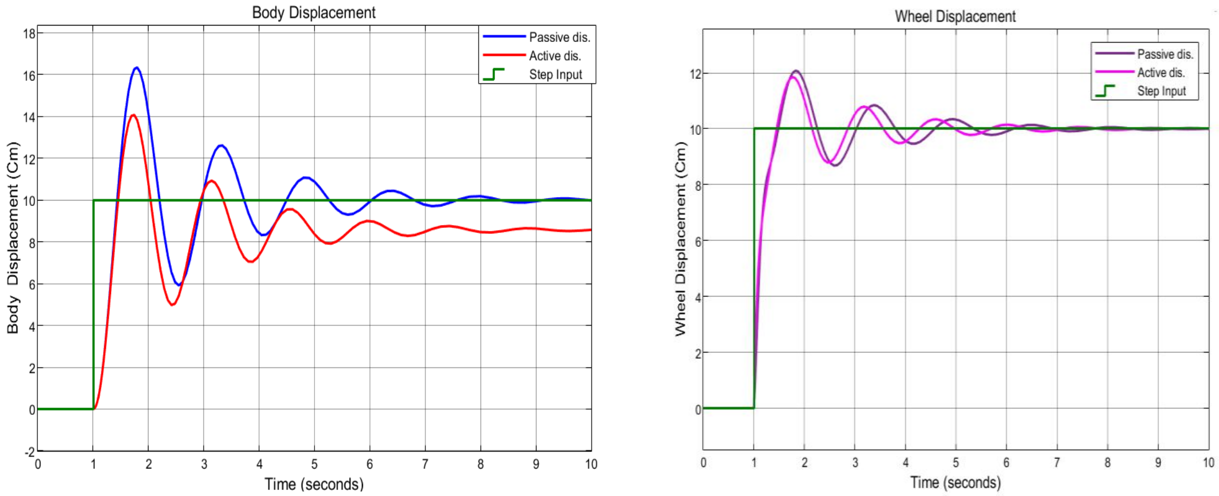

Figure 6. Sprung and unsprung masses displacement for ASS and PSS.

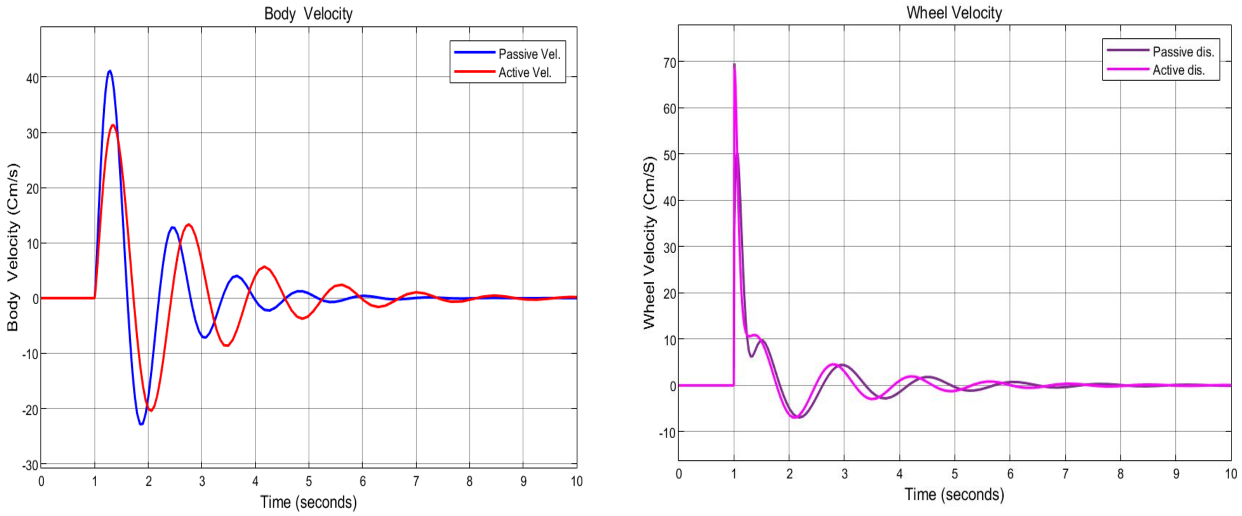

Figure 7. Sprung and Unsprung masses Velocity for ASS and PSS.

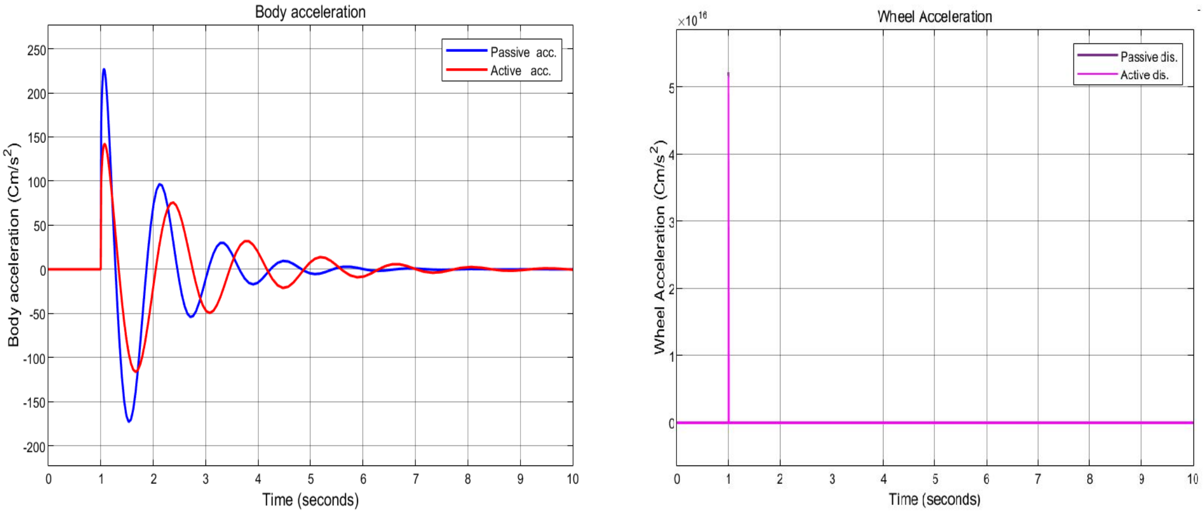

Figure 8. Sprung mass and Unsprung masses Acceleration for ASS and PSS.

Automobiles having anti-roll bars (ASSs) are better suited to cushion initial hits when they occur. The step-input road disturbance is used to demonstrate this, as seen in Figure 6, and the simulated displacement of the wheel and body is compared to the PSS.

1. The results indicate that the ASS is superior to the PSS in suppressing oscillations by 51.162%.

2. The ASS is 18 % faster at eliminating oscillations compared to the PSS, as shown in the Table. 2

Table 2. The distinction between the body mass and the wheel mass displacement-step input function.

Type of suspension systems	Passive	active	Passive - Active improvement (%)
The differences in mass displacement between sprung and unsprung	4.3 Cm	2.1 Cm	51.162 %.
Stabilizing time	10 S	8.2 S	18 %

3. The vertical velocity of the wheel fluctuates proportionally to variations in the road surface it encounters. This causes variations in wheel speed, as seen in Figure 7.
4. Higher wheel acceleration occurs on rougher roads because of the abrupt changes in wheel displacement and velocity brought on by these disturbances, as seen in Figure 8.

   Similar displacement patterns can be observed by comparing the simulated acceleration and velocity responses of a car with the ASS and PSS to various road disturbance inputs.

5. Conclusion

Comparing the ASS of a passenger car to a PSS, the controller design technique developed for the system allows the ASS to outperform the PSS in achieving design objectives. A two-degree-of-freedom automobile model has been utilized for the mathematical modelling of both PSS and ASS systems.

1. Based on the simulation results, an ASS's superior ride quality over a traditional PSS is its main advantage. depending on several factors like driving technique, car speed, and road conditions. By offering a softer ride, this option improves comfort on straight highways.
2. ASS has several key benefits over PSS, such as almost complete system oscillation elimination, a decrease in oscillatory phenomenon magnitude, and a shorter disruptive duration.

Ultimately, the simulation results demonstrate the superior performance of the ASS.

Nomenclature

Symbol	Description	Symbol	Description
M_b	Mass of body (Kg)	x_2	Vertical Wheel displacement(m)
M_w	Mass of wheel (Kg)	x_d	Road profile displacement(m)
$\ddot{x}_1$	Acceleration of body mass(m/s^2)	C_1	Coefficient of suspension damping (N.s/m)
$\ddot{x}_2$	Acceleration of wheel mass (m/s^2)	C_2	Coefficient of tire damping (N.s/m)
$\dot{x}_1$	The velocity of body mass (m/s)	k_1	Coefficient of suspension spring (N/m)
$\dot{x}_2$	The velocity of wheel mass (m/s)	k_2	Coefficient of tyre spring (N/m)
x_1	Vertical Body displacement (m)		

Acknowledgments

The author would like to thank all of the members of the Mechanical Engineering Department at the University of Baghdad's College of Engineering for their great assistance and direction.

Declaration of competing interest

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