

Using AI to control the car's active suspension system

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Received: 12/3/2024; Accepted: 16/3/2024; Published: 28/3/2024

Abstract. *This paper presents the Physics-Guided Deep Reinforcement Learning (DRL) for adjusting an active suspension system's variable kinematics and compliance properties for a quarter-car model in real-time. The proposed model was trained on stochastic road profiles according to ISO 8608 standards to optimize the actuator's control policy. The forces generated from the actuator for stiffness and damping control are bound within specific ranges to maintain the system's physical consistency. According to qualitative results on simulations, the vehicle body reacts smoothly to various novel real-world road conditions, having a much lower degree of oscillation. These observations mean a higher level of passenger comfort and better vehicle stability. Quantitatively, DRL outperforms passive systems in reducing the average vehicle body velocity and acceleration by 43.58% and 17.22%, respectively, minimizing the vertical movement impacts on the passengers.*

Keywords: *Deep Reinforcement Learning, Active Suspension System, Vehicle*

1. Introduction

In the area of controlled systems, there are three major categories of suspension systems: passive, semi-active, and active suspension systems. The passive suspension system has fixed spring and shock absorber. However, since the road environment constantly changes and is unpredictable, using passive suspension system is unable to maintain the best vehicle operation experience. Given that the passive suspension system has fixed dampers and does not allow external control, it fails to handle the possible road disturbance or fully absorb vibrations. [1] Therefore, active and semi-active suspension systems with adjustable operational parameters were introduced to overcome the weaknesses of passive suspension systems. They allow built-in electronic control units to manipulate multiple parameters such as damping rates [2] and additional forces on spring [3] based on different road situations in real-time.

The traditional controllers including proportional–integral–derivative (PID), linear parameter varying (LPV), and Linear–quadratic–Gaussian (LQG) [4] have been the common and conventional control methods. Nonetheless, the above algorithms are all linear controllers while active suspension system in real practice has non-linear and complex characteristics [5]. Deep reinforcement learning (DRL), as one of the new machine learning research fields, focuses on learning optimal actions in a sequential decision-making process. Controllers based on the reinforcement learning model enable

learning from the interaction with the environment to adapt the best suspension system parameters under certain road conditions leading to improved vehicle overall performance. Compared to normal neural network [6], DRL does not require any human-labeled or controller-generated samples for training and can generate large amounts of training data solely by physics simulation, which inspires many existing works on DRL-based controllers. On the other hand, Xi Wang et al. adopted the deep Q Network (DQN) [7] technique to the quarter suspension system and achieved higher driving comfort with respect to Skyhook Damper Control (SDG). Nonetheless, these previous research topics relating to DRL are limited to experimenting on non-standard roads, which could introduce unrealistic high/low vibrations caused by bumps. Most simulation results of these studies show a promising new generation of control strategies. Still, some results show that the system response is quite fast according to random rough roads, which cause psychological discomfort for passengers. In contrast, others have smoother system responses, yet the delay is too significant, causing inconsistency in dynamic control. Besides, the DRL model would interact with the vehicle by adjusting the active control force.

This research focuses on applying DRL on the quarter suspension system by interacting with existing components in actual engineering while considering road conditions satisfying International Organization for Standardization (ISO) standards.

The controller is also tested on speed bumps of 0.09m height to simulate one of the strong common vibrations vehicles may experience.

2. Vehicle suspension and road excitation model

In the context of the quarter car model, the term “sprung mass” is known as the vehicle’s body or chassis, which accounts for approximately a quarter of the total weight of

the whole vehicle structure. The suspension system serves as an intermediary component linking the wheel and the body of the car, and its composition varies depending on the specific type of suspension system employed, which may include passive, semi-active, or active suspension systems. The unsprung mass encompasses the combined weight of all components positioned geometrically below the suspension system, including the axle, wheel, and other relevant elements. Within this context, the term “wheel” refers to the tire, including its inherent properties of springiness and damping properties.

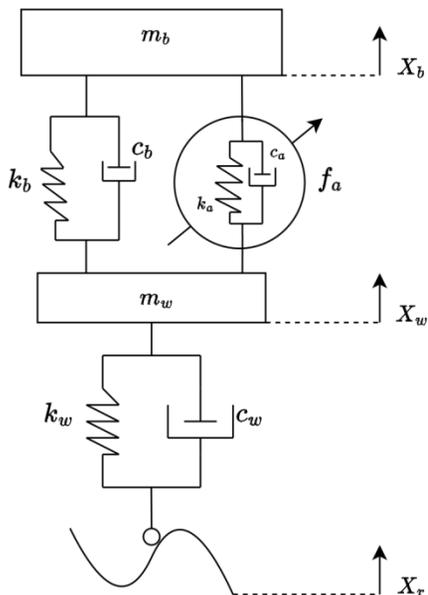


Fig 2.1. Quarter vehicle model with active suspension

According to the quarter car model in Fig 2.1, the dynamic equations of the system which satisfy Newton’s second law can be provided by the following equations:

$$\begin{cases} m_b \ddot{x}_b = -k_b(x_b - x_w) - c_b(\dot{x}_b - \dot{x}_w) + f_a \\ m_w \ddot{x}_w = k_b(x_b - x_w) + c_b(\dot{x}_b - \dot{x}_w) - k_w(x_w - x_r) - c_w(\dot{x}_w - \dot{x}_r) \end{cases} \quad (1)$$

3. Deep deterministic policy gradient (ddpg) for active suspension control

In this paper, we employ the Deep Deterministic Policy Gradient (DDPG) algorithm [10] to obtain optimal dynamic control policy for the active suspension system. Briefly Explain DDPG. After extensive experiments, the optimal network architecture and optimal set of hyper-parameters were selected.

The input state space of the Policy Network at time step t is defined as:

$$(X_\mu)_t = [(\dot{x}_b)_t (\dot{x}_w)_t (\dot{x}_r)_t (\dot{x}_b)_{t-1} (\dot{x}_w)_{t-1} (\dot{x}_r)_{t-1}]^T \quad (2)$$

Multiple existing works on DRL-based Semi-active suspension system used $X_\mu = [x_b \ x_w \ \dot{x}_b \ \dot{x}_w]^T$ as the input state space (cite).

In our work, we remove x_b and x_w because this removal helps speed up the optimization convergence while empirically increasing the performance of the agent on novel road profiles. Additionally, we introduce information from past time step $(\dot{x}_b)_{t-1}, (\dot{x}_w)_{t-1}, (\dot{x}_r)_{t-1}$ to the state space for potential temporal dependency. The output of the Policy Network at each time step t is:

$$(y_\mu)_t = [(k_b)_t (c_b)_t]^T \quad (3)$$

The primary purpose of the active suspension system is to minimize the movement impacts on passengers. To achieve this purpose, we need to minimize vertical body displacement \dot{x}_b and vertical body acceleration \ddot{x}_b . Empirically, we find that using only \dot{x}_b in the reward function yields better results in terms of both $|\dot{x}_b|$ and $|\ddot{x}_b|$ minimizations than any other combinations with \ddot{x}_b or other variables. In our study, the immediate reward function is

$$r_t = -0.1|\dot{x}_b|_t \quad (4)$$

4. Results and analysis

When the vehicle crosses through the speed bump, the amplitude and frequency of the body vehicle displacement and acceleration, shown in Fig 2.2 are much smaller than the passive system and stable during travel, which means the proposed suspension system demonstrates that the ride comfort and road-holding are improved, and eliminated the resonance of the wheel vibration to the body vibration. It shows that the system worked robustly with disturbances and uncertainties from the road.

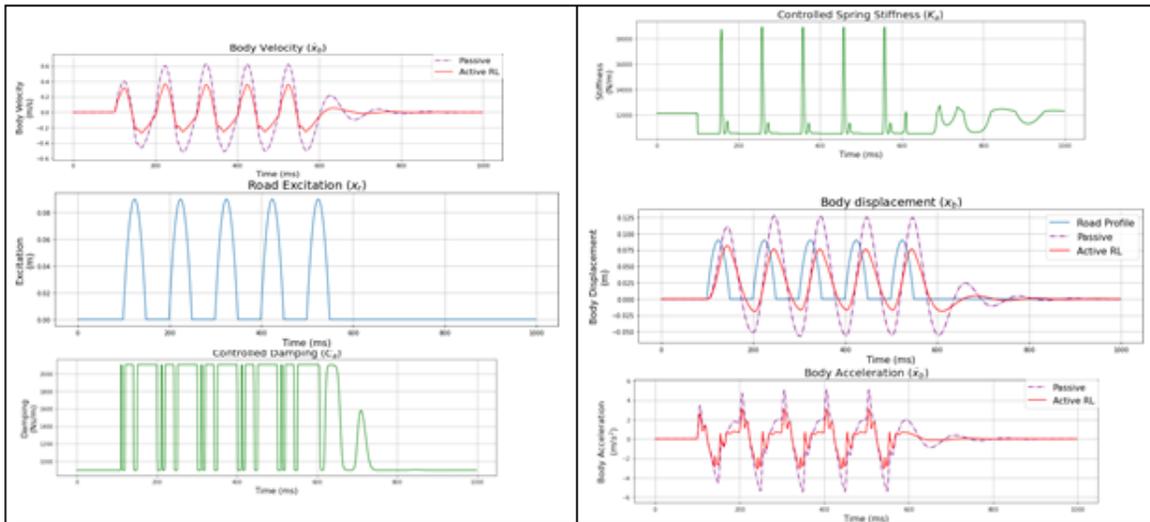


Fig 2.2. Multiple speed humps road: comparative performance of DRL-based Active Controller against Passive Suspension.

5. Conclusions

Simulation results demonstrate that the proposed approach outperforms passive suspension systems in terms of vehicle ride comfort and road-holding. Vehicle body displacement and vertical acceleration reflect the dynamic response of the vehicle’s suspension system to road disturbances. They provide insights into the level of comfort experienced by the passengers and the effectiveness of the suspension system in minimizing vibrations and maintaining stability. Qualitatively, compared to the Passive system, the DDPG-based controller has significantly lower vehicle body vibrations and oscillations. In future studies, we aim to further extend and investigate the applicability of our framework to half and full-vehicle suspension systems. These systems are more complex than the Quarter Car model due to the non-linear interactions between the wheels, introducing additional state variables and controllable coefficients. This poses a higher level of challenge for Deep Reinforcement Learning optimization and convergence, but it is a necessary milestone toward real-world deployment on commercial vehicles.

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