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A Hierarchical Motion Control Framework for Constrained EVs with Four In-Wheel Motors

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***Abstract*— Ensuring motion comfort and optimizing economy performance are pivotal benchmarks for vehicle chassis dynamics control, presenting considerable challenges for automotive engineers. This paper introduces a hierarchical comfort constraints control framework to enhance the body motion control and energy efficiency of Electric Vehicles (EVs) equipped with four In-Wheel Motors (IWM). Given the stringent constraints on vehicle body motion states for optimal passenger comfort, a dynamic comfort filter is employed, which can dynamically adjust tracking reference signals, and strike a balance between comfort constraints and velocity tracking performance. Once these signals are recalibrated, an adaptive gain-scheduling PID controller is designed to improve the velocity tracking performance, even in the face of uncertain road conditions and vehicle dynamics parameters—and this without necessitating a detailed vehicle dynamics model. Further, in acknowledgment of the EV's over-actuated nature, the overall driving torque is divided into four distinct wheel driving torques. This division is based on optimizing tracking performance, energy consumption, and wheel vertical loading. MATLAB-Simulink simulation results are conducted to validate the effectiveness of our proposed method, demonstrating its capability in addressing high-performance constraints tracking issues for EVs.**

I. Introduction

In recent years, it witnessed a large volume of processes in the development of electric vehicles (EVs), such as the application in vehicle-to-grid technology, autonomous driving, battery management systems, and human-machine interaction [1], [2]. Among these applications, a basic problem is vehicle dynamic control, which calculates four-wheel commands to govern the EV to reach the desired motion states while satisfying soft-state and hard-actuator constraints simultaneously. Based on the different types of suspensions, vehicle dynamic control approaches can be categorized into two distinct types: active and passive suspensions [3].

The dynamic control of active suspensions in EVs has been studied much because the active suspensions contain additional control inputs, which thus can reduce the oscillation of the suspensions directly, such as optimal strategy and robust control methods [4]. Another avenue of research delves into the dynamic control of passive suspensions, which actually designs four-in-wheel torques to implicitly control the suspension system. However, due to the lack of control input for suspensions, this kind of approach will pose more challenges in satisfying the constraints of the vehicle's state. Therefore, the constrained EVs with passive suspensions still remain an open problem.

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To this end, we propose a hierarchical comfort constraints control framework to enhance the body motion control and energy efficiency of EVs equipped with four IWMs. For more details refer to Section II.

II. Methodology and Framework

As shown in Fig. 1, the proposed framework consists of two modules: (1) the higher-level dynamic filter, and (2) the lower-level optimal torque distribution module. In module (1), a dynamic comfort filter is employed, which can dynamically adjust tracking reference signals. Once these signals are recalibrated, an adaptive gain-scheduling PID controller is designed to improve the velocity tracking performance. Moreover, in acknowledgment of the lower-level module (2), the requested overall driving torque is divided into four distinct wheel driving torques. This division is based on optimizing driving comfort, and energy consumption while satisfying the state constraints.

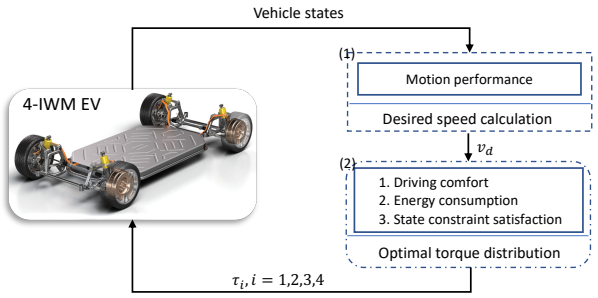

Fig. 1. The proposed hierarchical control framework for 4-IWM EV.

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