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Single-parameter skidding detection and control specified for electric vehicles

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Abstract

This paper discusses a unique skidding detection and control strategy specified for electric vehicles. The anti-skid control is an exact example to explain that electric drive motors can be utilized not only for propulsion, but also as sensors and actuators in electric vehicles. This unique advantage of electric motors enables a simplified but effective anti-skid control strategy. The basic idea is to monitor and regulate a newly defined single parameter, R_{at}, the ratio of wheel equivalent linear acceleration to drive motor torque. The wheel slip level in longitudinal direction is proved to correlate to the value of R_{at}. A fuzzy-logic-based controller is then designed to regulate the variation range of R_{at}. Both simulation and experimental results validate the effectiveness of the proposed vehicle skidding detection and control. It is shown that by simultaneously using electric motors as drivers, actuators and sensors, the electric vehicles could achieve high-performance motion control with a flexible and simplified control configuration.

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1. Introduction

It is now widely recognized that vehicle electrification provides a viable solution to alleviate the emission and oil shortage problems brought by today's millions of internal combustion engine vehicles (ICEVs). Naturally most effort has been devoted to the environment and energy aspects of electric vehicles (EVs including the hybrid electric vehicles). And the widespread use of EVs is considered to largely rely on the development of long-term energy storage devices at competitive cost [1]. Meanwhile, the significance of vehicle electrification could be far beyond replacing engines and oil tanks with electric motors and batteries.

For example, the motion of EVs is produced by wheels either driven or partly driven by electric motors. Unlike conventional ICEVs, EVs are actually typical mechatronic systems. They have a configuration similar to many existing mechatronic systems such as hard disks, robots, and machine tools. Motion control is one of the most important mechatronic technologies that provides quick response and high accuracy [7]. By making best use of the capability of accurate and fast motion control, future EVs would not only be clean, but also be able to achieve a higher level of safety, maneuverability and riding comfort [2–4]. Especially, four-wheel-independent-drive using in-wheel motors can enable advanced vehicle dynamics [3,5,6].

From the viewpoint of motion control, the unique advantages of electric motors over internal combustion engines and hydraulic braking systems could be summarized as follows:

(1) Far less complex dynamic model: Approximation by a first-order system is usually sufficient for motion controller design.
(2) Fast torque response in milliseconds: Time response is 10–100 times faster than that of engines.
(3) Easiness in obtaining accurate torque feedback: Generated torque is proportional with motor current, and thus easy to calculate.
(4) Capability of generating both traction and braking forces: Electric motors can assist the existing hydraulic systems for a faster and more accurate braking control.
(5) Easiness in implementing distributed in-wheel-motor systems: Independent torque control of each wheel enables advanced vehicle dynamics.

Compared to the engines, the electric motors have a fast and accurate response and relatively simple dynamics. Consequently, the fundamental difference between them is that the electric motors can be used not only for mobile propulsion, but also as actuators and sensors. As a simple example shown in Fig. 1, for a motor with an inertia J_m, theoretically the disturbance torque T_d (actually the vehicle traction/braking force here) can be estimated using its reverse dynamic model J_ms, torque and angular velocity feedback signals, T_m and ω_m. Because the electric motors may replace most of motion control actuators in conventional vehicles, high performance control of EV motion could be possible with a flexible and simplified configuration. One of those typical applications is the anti-skid control, in which the fast and accurate control and sensing capability of the electric motors could improve the performance. For conventional vehicles, the lack of accurate engine model and the hydraulic time delay of actuators make it complicated to perform quick and accurate control actions.

In this paper, a unique anti-skid control for electric vehicles is proposed based on monitoring and regulating a single parameter R_{at}, the ratio of wheel equivalent linear acceleration to drive