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Integrated Control of Three-Axle Vehicles to Improve the Lateral Dynamics on Slippery Road

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Abstract
To improve the handling and directional stability of three-axle heavy vehicles, this paper suggests a control strategy that combines direct yaw moment control (DYC) and active front steering (AFS). The control system's structure is divided into three main layers. Based on an online adjustable index, a fuzzy controller acting as a supervised system decides the cooperation of DYC and AFS in the upper layer. In the intermediate layer, the DYC system controller uses a sliding mode controller to calculate the corrective body moment. The AFS system uses a fuzzy controller to generate the corrective steering angle necessary to achieve the three-axle vehicle motion objective. The algorithm for distributing braking force and the slip ratio control (SRC) system comprises the lower layer. The anti-lock braking system (ABS) in the SRC system is built to produce the necessary braking forces at low slip ratios while preventing the wheels from locking up at high slip ratios. Consideration has been given to a heavy, three-axle, 9-DOF nonlinear vehicle with uncertain dynamics. Trucksim software and simulation tests have validated the model. The proposed control system's satisfactory performance is shown through various maneuvers.

Keywords Three-axle vehicle · Active safety · Integrated control · Sliding mode control · Fuzzy control

1 Introduction

The enhancement of vehicle safety has become a crucial factor in the manufacturing of new vehicles. active front steering (AFS), direct yaw moment control (DYC), and anti-lock braking systems (ABS) are a few of the active safety technologies that have been developed and put into use for cars. Since heavy and multi-axle vehicles handle a significant portion of road transportation. As a result, study on these types of vehicles is more engaging for researchers and they have employed different control systems to achieve control objectives. Lateral instability is a prevalent concern among heavy-duty trucks when traversing slippery roads, which may lead to catastrophic accidents and substantial financial losses. Active front steering corrects the driver's steering command as a steering support device. Saturation of lateral tire forces limits this strategy (Li et al., 2008; Shibahata et al., 1993). The DYC system compensates for AFS's limitation in the tire's nonlinear zone. Differential barking regulates lateral vehicle motion and this system causes the corrective yaw moment diminishes ride comfort and slows the vehicle (Nagai et al., 1997; Zheng et al., 2006). Integrating and coordinating these systems is a realistic and efficient strategy to maximize their capacities without sacrificing vehicle stability. Thus, passenger car researchers have studied system coordination and integration.

Accordingly, various control systems have been proposed for this. Zhang and Li (2018) suggested a hierarchical vehicle chassis control approach to coordinate AFS and DYC systems, improving vehicle handling and stability. Yim et al. (2015) proposed a sliding mode control system based on a bicycle model to generate the vehicle corrective yaw moment to enhance vehicle stability and handling and an adaptive optimum yaw moment distribution structure of DYC and AFS systems based on the phase plane analysis. Zhang et al. (2017) proposed AFS and DYC main-servo loop integrated vehicle chassis control. The main loop estimated and allocated generalized force to improve vehicle handling and stability. Sequential quadratic programming and an optimal robust controller are used in this system. Fu and Li (2017) developed an approximation dynamic programming-based

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