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Decoupling and robust control of velocity-varying four-wheel steering vehicles with uncertainties via solving Attenuating Diagonal Decoupling problem

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Abstract

This paper is devoted to solve the combined problem of input–output decoupling and robust control of the four-wheel steering vehicles. A more practical three-degree-of-freedom systems covering longitudinal, lateral and yaw motions are used to improve the safety and steerability while uncertainties and external disturbances are considered. A novel decoupling conception Attenuating Diagonal Decoupling and a new index Coupling Attenuation Index are introduced and the system is divided up into two systems with a special structure. The first system is caused by uncertainties and disturbances and the second system is a certain system coupling with the first one. A control scheme composed of a coupling attention controller and a decoupling controller are explored. The influences of the uncertainties and disturbances on the output are attenuated under the coupling index by the coupling attention controller designed for the first system while the input–output decoupling is achieved by employing the decoupling controller designed for the second system. Furthermore, we prove in theory that the input–output decoupling and robust control are both established for the closed-loop system of the control scheme and the primordial vehicle system. Besides these works, a switching law is introduced such that the above excellent performances are realizable in four-wheel steering vehicles with conventional steering interfaces. Simulations show that even with a large velocity varying range, the decoupling and robust performances are guaranteed simultaneously, i.e. the handling stability and steerability are improved.

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1. Introduction

Handling stability and steerability are two main goals of the vehicle control. As shown by Brennan [1] and Zhang and Wang [2], the dynamics is very dependent on its varying velocity. Recently, Horiuchi et al., using constrained bifurcation and continuation method, find that the size of the stability region shrinks with increases in the longitudinal deceleration and front-steer angles [3]. Thus, the longitudinal dynamics should be considered to get more perfect performances. Moreover, according to the work of Yin et al. [4], model uncertainties and external disturbances may be existing in practical steering process. Hence, the robust control should be considered to get more excellent stability for 4WS vehicles. From Jia [5] and Marino and Scalzi [6], input–output decoupling control can improve steerability effectively. Thus, the combined problem of input–output decoupling and robust control for three-degree-of-freedom (3DOF) models of four-wheel steering (4WS) vehicles is very valuable to be studied to get more perfect handling stability and steerability simultaneously.

There are some attractive results of the input–output decoupling control for 4WS vehicles, such as [5–14]. Taking front and rear steering angles and the longitudinal acceleration/braking force as control inputs, the longitudinal velocity, lateral velocity and yaw rate are decoupled for the quasi-linear system with varying velocity [5]. Taking steering angles as control inputs, lateral velocity and yaw rate are decoupled with disturbance rejection performance at a constant longitudinal speed [6–9]. Based on [5], decoupling of a nonlinear model under varying velocity is presented in [10] and a method to optimize results of [5–7] is derived in [11] to improve the vehicle performances further. And in [12,13], the nonlinear decoupling control is studied by selecting the virtual control inputs for the quasi-linearized model of [5].

The above decoupling methods are all effective to solve the decoupling control problems with the presented hypotheses in the corresponding paper. However, the longitudinal dynamics is ignored in [6–11] while the input–output decoupling control problem for the 3DOF models is solved in [12,13] without considering the model uncertainties. And [5] considers model uncertainties and designs a robust controller with decoupling performance for the 3DOF dynamics by employing the quasi-linear method to approximate the vehicle model. Recently, the decoupling control of varying-velocity 4WS vehicles with model uncertainties and external disturbances is explored and input–output triangular decoupling is obtained in [14]. The triangular decoupling results in [5,14] are obtained by two steps: the first step is decoupling longitudinal motion from lateral and yaw motions and the second step is decoupling the lateral motion from yaw motion.

Different from the above mentioned works, the combined problem of diagonal decoupling and robust control for the 3DOF model with uncertainties and disturbances of 4WS vehicles is solved without the first step in this paper. The main differences and contributions are as follows:

1. The primordial vehicle system is transformed into a more practical nonlinear system with uncertainties and disturbances, and then divided up into two coupling systems: the first one is caused by uncertainties and disturbances, and the second one is a certain system coupling with the first one.
2. Two novel conceptions Attenuating Diagonal Decoupling (ADD) and Coupling Attenuation Index (CAI) are invented and a new control scheme is established to solve the combined problem of diagonal decoupling and robust control for the uncertain nonlinear systems with external disturbances.