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Decoupling control of vehicle chassis system based on neural network inverse system

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ABSTRACT

Steering and suspension are two important subsystems affecting the handling stability and riding comfort of the chassis system. In order to avoid the interference and coupling of the control channels between active front steering (AFS) and active suspension subsystems (ASS), this paper presents a composite decoupling control method, which consists of a neural network inverse system and a robust controller. The neural network inverse system is composed of a static neural network with several integrators and state feedback of the original chassis system to approach the inverse system of the nonlinear systems. The existence of the inverse system for the chassis system is proved by the reversibility derivation of Interactor algorithm. The robust controller is based on the internal model control (IMC), which is designed to improve the robustness and anti-interference of the decoupled system by adding a pre-compensation controller to the pseudo linear system. The results of the simulation and vehicle test show that the proposed decoupling controller has excellent decoupling performance, which can transform the multivariable system into a number of single input and single output systems, and eliminate the mutual influence and interference. Furthermore, it has satisfactory tracking capability and robust performance, which can improve the comprehensive performance of the chassis system.

1. Introduction

With the continuous increasing requirements for the vehicle's handing stability, driving safety and ride comfort, more and more active control techniques have been applied in automobiles, such as the active front steering (AFS), anti-lock brake system (ABS), electronic stability program (ESP) and active suspension system (ASS). The introductions of these control methods can improve the flexibility of the integrated system effectively. However, because of the differences of control target and effective work area, it may cause the function overlaps of various controls and mutual interference, that is, the control coupling [1,2].

Taking the AFS and ASS as an example, the ASS can improve the vehicle's ride comfort by implementing the active control of vehicle vertical dynamics [3,4]. Furthermore, it can indirectly improve the handling stability of the vehicle by controlling the vertical load distribution on the wheel. Within the linear area of the tire, the AFS can superimpose an additional steering angle based on the input of the driver, which is used to optimize the response of the vehicle to the driver's input or to

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Nomenclature

u_x	longitudinal velocity, m/s^2
β	sideslip angle, rad
ω_r	yaw rate, rad/s
ϕ	roll angle, rad
$\dot{\beta}$	sideslip angle velocity, rad/s
$\dot{\omega}_r$	yaw acceleration, rad/s^2
$\dot{\phi}$	roll velocity, rad/s
$\ddot{\phi}$	roll acceleration, rad/s^2
m	vehicle mass, kg
m_2	suspended mass, kg
m_f	front non-suspended mass, kg
m_r	rear non-suspended mass, kg
a	distance from the front axle to the center of mass, m
b	distance from the rear axle to the center of mass, m
I_z	yaw moment of inertia, kg m^2
I_x	roll moment of inertia, kg m^2
I_r	product of inertia of roll and yaw motion, kg m^2
k_1	cornering stiffness of the front wheels, N/rad
k_2	cornering stiffness of the rear wheels, N/rad
K_ϕ	roll stiffness coefficient of suspension, N m/rad
D_ϕ	damping coefficient of suspension, N m s/rad
δ_f	front wheel angle, rad
T_ϕ	suspension roll moment, N m
G	gear ratio of the rack and pinion steering
α	gear ratio of planetary gear ring and sun wheel
θ_{sw}	steering wheel angle, rad
θ_{r2}	lower planetary gear ring angle, rad
r_d	ideal yaw rate, rad/s
K	stability factor
θ_d	ideal roll angle, rad
δ_f^*	ideal front wheel angle, rad
i	ideal angle transmission ratio of the steering system
G_δ^r	yaw rate gain of the vehicle
K_u	understeer coefficient

improve the handling stability under emergency conditions [5,6]. However, the two control systems are always control a single performance index of the vehicle, and rarely consider the interaction between different subsystems. In fact, when the car is turning, the change of the front wheel angle will cause the lateral force to change and bring about the lateral movement. The roll moment may cause the redistribution of the vertical load, and affect the cornering characteristics of tire. These will change the steady state response of the vehicle. Therefore, the AFS and ASS all have influences on the handling stability and ride comfort of the vehicle. If the two subsystems are simply used together, the interference may reduce the overall performance of the vehicle [7–9].

Therefore, how to avoid the conflict and interference between subsystems and achieve the best comprehensive performance by appropriate control method has become the key problem of the chassis dynamic control [10–12]. Nowadays, in the studies of the decoupling control of chassis integrated system, Skarpetis et al. [13] used the decoupling control method of the static state feedback control and the static compensator to realize the independent control of the steering angle and sideslip angle of the vehicle, based on the four-wheel-steering (4WS) vehicles. Chen et al. [14] reconstructed the nonlinear model of the vehicle with three degree of freedom by quasi-linearised method. Then, the decoupling of the three degree of freedom nonlinear system is realized by decoupling control method. Hwang et al. [2] designed the decoupling compensator of vehicle system by the characteristic trajectory method, and obtained the equivalent single variable system by decoupling. Marino et al. [15] presented the proportional-integral (PI) active front steering control and the PI active rear steering control. The lateral velocity and yaw rate dynamics are decoupled by providing yaw rate error and an additional feedforward signal to the side slip angle. Marino et al. used [16] output feedback to decouple the yaw and lateral dynamics, and eliminated the coupling between yaw and lateral dynamics.

Throughout the published literatures, it can be seen that there are little researches on the decoupling control of the integrated system based on AFS and ASS. In fact, in the design of the integrated control system, if the multivariable system with coupling channels can be decoupled, and transformed into a number of single input and single output system, it will realize