論文の内容の要旨

Advanced Motion Control for Electric Vehicles Using Lateral Tire Force Sensors
（タイヤ横力センサを利用した電気自動車のモーションコントロール）

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The principal concern in motion control of electric vehicles is providing drivers with more enhanced safety by preventing risky driving situations. A close examination of accident data reveals that loss of the vehicle control is the main reason for most vehicle accidents. To help to prevent such accidents, vehicle motion control systems should be used, which require important information on vehicle state and tire-road conditions. Unfortunately, some critical parameters in vehicle motion control such as vehicle sideslip angle, roll angle, and tire-road friction coefficient are difficult to measure in a vehicle, due to both technical and economic reasons. Recently, automotive companies have looked at utilizing tire forces which are directly measured by lateral tire force sensors, e.g., multi-sensing hub (MSHub) unit invented by NSK Ltd. Since the vehicle motion is governed by tire forces generated by tire-road interaction, this tire force information can provide promising solutions for accurate state estimation and advanced motion control. In this thesis, several advanced methods for robustly estimating the vehicle state and controlling the vehicle motion are proposed based on lateral tire force sensors. These advanced methods include 1) novel algorithms for vehicle sideslip angle and roll angle estimation, 2) real-time algorithm to estimate tire-road condition, 3) advanced motion control algorithm based on vehicle sideslip angle estimation, 4) advanced motion control algorithm based on direct tire force control for vehicle safety enhancement.

Robust estimation of vehicle states such as vehicle sideslip angle and roll angle is a challenging issue in vehicle motion control applications like yaw stability control and roll stability control. In this thesis, novel methods for estimating vehicle sideslip angle and roll angle are proposed using lateral tire force sensors. For vehicle sideslip angle estimation, two estimation algorithms based on a recursive least square (RLS) approach and an extended Kalman filter (EKF) technique are designed, respectively. For roll angle estimation, Kalman filter (KF) is designed using available sensor measurements and physical roll dynamics model. The effectiveness of proposed estimation methods is verified through field tests on an experimental electric vehicle. Experimental results demonstrate that the proposed estimation

methods can accurately estimate the vehicle sideslip angle and roll angle.

The robust design of motion controllers for vehicle stability enhancement is challenging due to nonlinear characteristics in vehicle and tire models, e.g., varying tire cornering stiffness with respect to road condition and tire force saturation. In this thesis, the two motion control algorithms are designed based on lateral tire force sensor application; 1) a motion control algorithm, based on vehicle sideslip angle estimation, is designed using two-degree-of-freedom (2-DOF) control methodology for yaw rate and vehicle sideslip tracking control and an adaptive feed-forward control technique is applied for improving control performances, 2) a novel motion control algorithm based on direct tire force control is designed. In this control algorithm, the real-time estimation of a critical vehicle state, i.e., a vehicle sideslip angle, is not required anymore. A robust control approach is applied in the design of the controllers for improved robustness to uncertainties in the vehicle and tire models. Moreover, a disturbance observer (DOB) is utilized to compensate for changes in the dynamic tire model as well as for mechanical disturbances in the actuators. Both control algorithms are implemented on an experimental electric vehicle with in-wheel motors and those control performances, e.g., yaw rate, vehicle sideslip angle tracking, and lateral tire force tracking ability, are verified through field tests. It is shown that proposed control algorithms based on lateral tire force sensors can contribute to improvement of the vehicle stability.

This thesis proposes novel vehicle state estimation and motion control methods using lateral tire force sensors, and has discussed the practical application of lateral tire force sensors to motion control systems for future electric vehicles. Moreover, this thesis investigates important technologies for improving the motion control systems of electric vehicles not only based on theoretical approaches to vehicle, tire dynamics and estimation, and control design, but also implementation on experimental electric vehicles in real-time.