論文の内容の要旨

論文題目　Research on Advanced Motion Control for Electric Vehicles
(電気自動車の先進的運動制御技術に関する研究)

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This dissertation deals with integrated stability program (ISP) on electric vehicles (EVs). A novel vehicle motion control is achieved by utilizing electric motors' advantages. The proposed method is robust against both environmental disturbance and model error by applying state estimation and two-degree-of-freedom (2DOF) control.

Controllability is the most distinguishing feature of electric motors against internal combustion engines (ICEs). EVs' advantages are summarized as following four points; 1) motor torque response is 10-100 times faster than that of an internal combustion engine. This property enables high performance adhesion control, skid prevention and slip control, 2) motor torque can be measured easily by observing motor current. It can be used for road condition estimation, 3) since an electric motor is compact and inexpensive, it can be equipped in each wheel. This feature realizes high performance three dimensional vehicle motion control including rolling stability control (RSC) and yawing stability control (YSC), 4) there is no difference between acceleration and deceleration control. This actuator advantage enables high performance traction and braking control.

Recently, electronic stability control (ESC) has been installed on internal combustion engine vehicles (ICEVs). Especially in the United States, obligation of ESC installation has started since 2008. ESC is yaw moment control on a two dimensional surface and utilizes differential torque of traction force or braking force of right and left wheels.　However, as ICE is based on chemical explosion and braking force is based on PWM modulation, these forces cannot be known precisely; and they also contain dead time and time-delay. In case of all-in-wheel motor EVs, high performance vehicle motion control can be achieved utilizing the advantages mentioned above. On the other hand, EVs are relatively small and wheel width is narrow but height of the vehicle is maintained due to cabin space. So danger of rollover is comparability higher and drivability is different. Therefore, chassis technology should be established taking roll stability control (RSC) and yaw stability control (YSC) into consideration.

In addition to the actuator advantages, robust RSC is designed by utilizing robust state estimation method and 2-DOF control based on disturbance observer (DOB). As motor torque can be known precisely, unmeasurable vehicle and environmental state variables can be estimated by Kalman filter. Cornering stiffness adaptation algorithm contributes to the robust estimation against model error. 2-DOF control based on DOB, which fulfills tracking capability performance to reference value and disturbance suppression performance at the same time, achieves robust RSC. Besides, integrated stability control (ISP), which is a combination of RSC and YSC is proposed.

DOB compensates not only disturbance, but also error between actual model and nominal model of controller. It is called model nominalization. General control hierarchy of vehicle system consists of electric motor's current control, wheel slip/skid prevention control, vehicle motion control and vehicle network control such as platoon or autonomous control. If the minor controller is designed properly, it decreases load of upper controller design and stable and robust performance can be anticipated. The design methodology is a basic architecture for modern control system designs.

To verify the proposed method, three dimensional vehicle simulation software and experimental EV are developed. Simulation model is set to be the same as the experimental vehicle model. Implementation load decreased and analytical validation for experimental results became possible because of the simulation. The experimental vehicle has two in-wheel motors (ISPSM) on rear wheels. For experimental EV, time step for sampling and calculation of motor torque is 1ms to utilize motor's fast torque response. As cost limitation is very important for development of commercial cars, only local and inexpensive sensors such as accelerometers, gyro sensors, steering angle sensor and wheel velocity sensors are used instead of GPS and INS sensors.

Although vehicle driven by electric motors are gaining popularity these years, recognition of EVs was not enough when the author started to do this research. The situation has changed due to global warming and the global financial crisis in October of 2008. Electric driven vehicles are anticipated by society not only because of environmental reasons but also the creation of new business market. In addition, younger generations have less interest on cars in Japan. Some of the reasons are the change of consumer minds and products that lack individuality are sold in the market. Few would argue with the electrification of the transportation, the problem is after the technology and how to keep attracting consumers. The author confirms that active safety technology described in this thesis will be the next-generation technology.

This paper's content ranges from basic steps to vehicle motion control, the vehicle model definition, the model identification, the state estimation method and the robust vehicle motion control. In chapter 1, background and purpose of the research is described. Proposed ISP consists of state estimation system and vehicle motion control system, which are explained chapter 4 and 5. In chapter 2, research trends on vehicle motion control for IMEV are introduced. In chapter 3, vehicle dynamics which are tire dynamics, three dimensional vehicle dynamics taking into consideration on disturbance are explained. In chapter 4, state estimation method is proposed. Vehicle and environmental states which are not measured directly by actual sensors are estimated. In chapter 5, vehicle motion control, from tire control to robust ISP are proposed. Validity of the proposed methods is shown in chapter 6. In chapter 7, summary and future works are described.