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Design of an Autonomous Distributed Four-Wheel Independent Drive and Steering Control System Based on Broadcast Control

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The rapid advancement of vehicle electrification has brought about a fundamental transformation in vehicle architectures. The introduction of in-wheel motors and corner modules eliminates the need for mechanical couplings between wheels, such as drive shafts and tie rods, enabling the realization of high-degree-of-freedom vehicles known as four-wheel independent drive and steering (4WIDS) vehicles, in which the driving force and steering angle of each wheel can be controlled fully independently. While such vehicles offer enhanced motion performance and redundancy that are difficult to achieve with conventional architectures, they also introduce new challenges in control system design.

Integrated control for 4WIDS vehicles is fundamentally different from that for conventional vehicles equipped with electrically actuated components based on mechanical couplings, such as electronically controlled couplings, active differentials, and rear-wheel steering systems. Because there are no motion constraints between individual wheels, the degrees of freedom in determining driving forces and steering angles increase dramatically. As a result, directly extending conventional rule-based distribution methods leads to excessive rule complexity, accompanied by a significant increase in design and verification effort.

To address this issue, this study aims to move beyond rule-based approaches by applying broadcast control, a class of multi-agent control theory, to the design of driving force and steering angle distribution laws. In the proposed method, each wheel receives a common broadcasted control signal and autonomously changes its role according to the driving situation, thereby realizing a decentralized and autonomous distribution scheme. The control system adopts a hierarchical architecture as shown in Fig.1, in which the distribution layer is positioned between the high-level motion control and the low-level actuator control. Although the control objective is the integrated regulation of longitudinal and lateral vehicle dynamics, the use of a randomized controller inherent to broadcast control enables the achievement of control objectives without predefined distribution rules, while maintaining a simple and modular controller structure for longitudinal and lateral directions.

In the numerical simulations, braking maneuvers on a split-μ road surface were emulated. As shown in Figs. 2 and 3 (where “w ctrl” and “w/o ctrl” denote the cases with and without control, respectively), when the proposed control is applied, the driving force and steering angle are autonomously distributed to the wheels on the high-μ side. Owing to this distribution to the high-μ-side wheels, the stopping distance is reduced by more than 10 m compared with the case without control, while lateral displacement is suppressed to a comparable level.

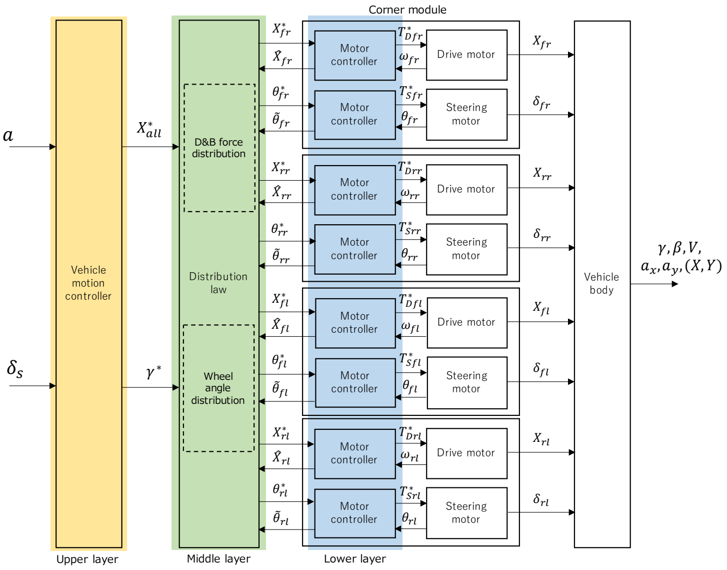

Fig.1 Layered structure of controllers

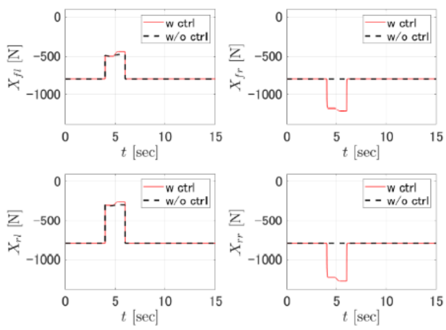

Fig.2 Driving force of each wheel

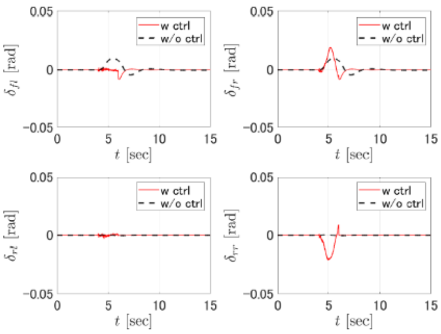

Fig.3 Wheel angle of each wheel