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Robust Torque Distribution Control with Energy Optimization for Four-Wheel Electric Vehicles

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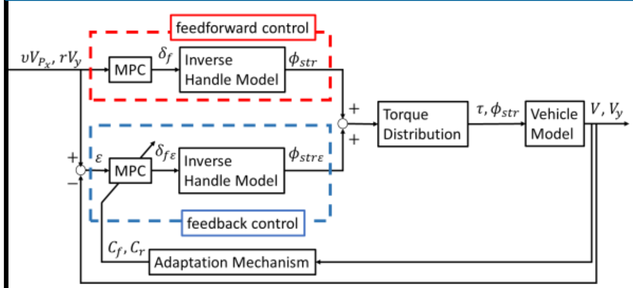
1. Introduction

Electric vehicles equipped with four in-wheel motors are attracting attention in automotive research due to their potential to improve driving control and energy efficiency.

One of the big advantages of this configuration is that the torque at each wheel can be controlled independently, which improves safety and path-following capabilities.

This research mainly addresses challenges in steering angle adjustment and motor tuning.

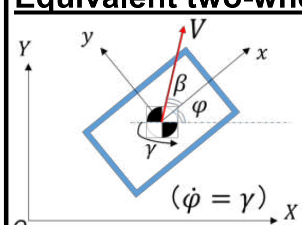
2. Control System Design



Using vehicle approximation model, reflect detailed vehicle parameters in feedback control.

3. Vehicle Model

Equivalent two-wheel model



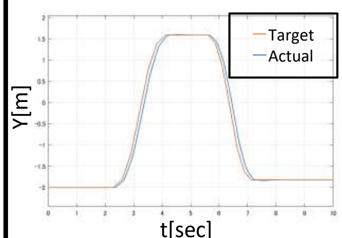
the vehicle speed V is constant and that only the front wheels are steerable.

$$\begin{bmatrix}\dot\beta\\ \dot\gamma\end{bmatrix}=\begin{bmatrix}-\frac{2(C_f+C_r)}{mV} & -\left(1+\frac{2(C_f l_f - C_r l_r)}{mV^2}\right)\\ -\frac{2(C_f l_f - C_r l_r)}{I} & -\frac{2(C_f {l_f}^2 + C_r {l_r}^2)}{IV}\end{bmatrix}\begin{bmatrix}\beta\\ \gamma\end{bmatrix}+\begin{bmatrix}\frac{C_f}{mV}\\ \frac{2C_f l_f}{I}\end{bmatrix}\delta_f$$

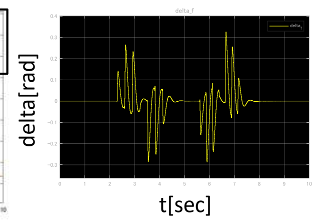
4. Control Method

4.1 Feedforward Control

・Set initial cornering power
・Make the approximate model travel the target route using MPC
・The actual front wheel steering angle at that time is used as feedforward control.



Time change in Y direction



Time change of front wheel actual steering angle

4.2 Feedback Control

$$C_f = \frac{mVl_r(\dot\beta+\gamma)+Il_f\dot\gamma}{2(l_f+l_r)\left(\delta_f-\left(\beta+\frac{l_f}{V}\gamma\right)\right)}$$

$$C_r = \frac{mVl_f(\dot\beta+\gamma)-Il_r\dot\gamma}{2(l_f+l_r)\left(-\left(\beta-\frac{l_f}{V}\gamma\right)\right)}$$

Estimating the cornering power in the equivalent two-wheel model from the observed β and γ.

Determine the optimal front wheel steering angle using MPC

4.3 Inverse Handle Model

$$A\beta + B\gamma + C\frac{d^2\delta}{dt^2} + D\frac{d\delta}{dt} + E\delta = \alpha$$

steering gear ratio has different values depending on whether the steering wheel angle is small or large.

Identifies the values from 10 seconds of data using the quasi-Newton method.

4.4 Torque Distribution

The torque control strategy was developed with several objectives in mind: maintaining a speed of 60 km/h, aligning with the slip angles from the model, reducing vibrations, and conserving energy.