Control of Vehicle with a Large Sideslip Angle

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DREEMS

Dependable-and-**R**obust-in-**E**xtreme-**E**nvironment-vehicle **M**aneuver **S**ystem

Sideslip Motion During Automotive Race

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Skilled drivers utilize sideslip motion to drive a car fast [2] in automotive races such as rally races.

e.g., Drift

Drifting rally car [3]

If we could control a vehicle with a large sideslip angle, fast and safe driving, like a rally driver could be realized.

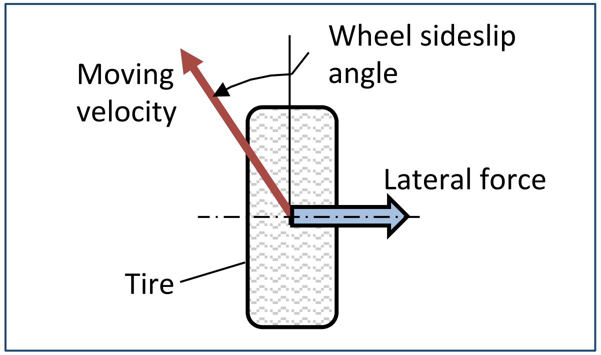
[2] M. Croft-White, “Measurement and analysis of rally car dynamics at high attitude angles,” Ph.D. dissertation, Cranfield Univ., Cranfield, UK, May 2006.
[3] TRD rally challenge http://trdrallychallenge.jp/

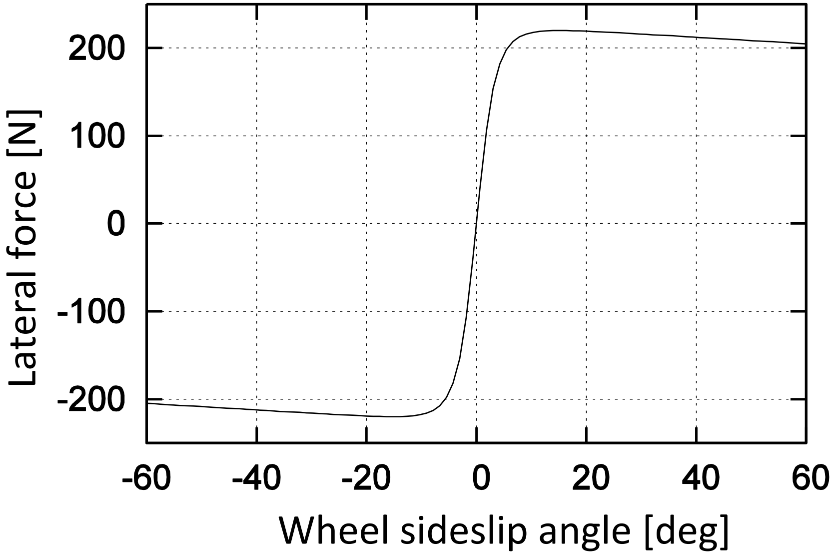
Nonlinear Tire Friction Property

During a large sideslip motion, nonlinearity of tire-road friction property could not be negligible.

Nonlinear tire model

- Depends on environment-related properties
  - road surface condition
  - temperature





Typical friction property between tire and road

Goal of Project DREEMS

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To develop a control system for a vehicle with a large sideslip angle using a steer angle of front wheels and driving forces of four independently-driven wheels.

- A motion control system is designed based on a planar vehicle dynamics.
- The resultant control system does not require the nonlinear tire model.
- A steady-state cornering experiment is executed to illustrate the effectiveness of the proposed scheme.

Vehicle Model

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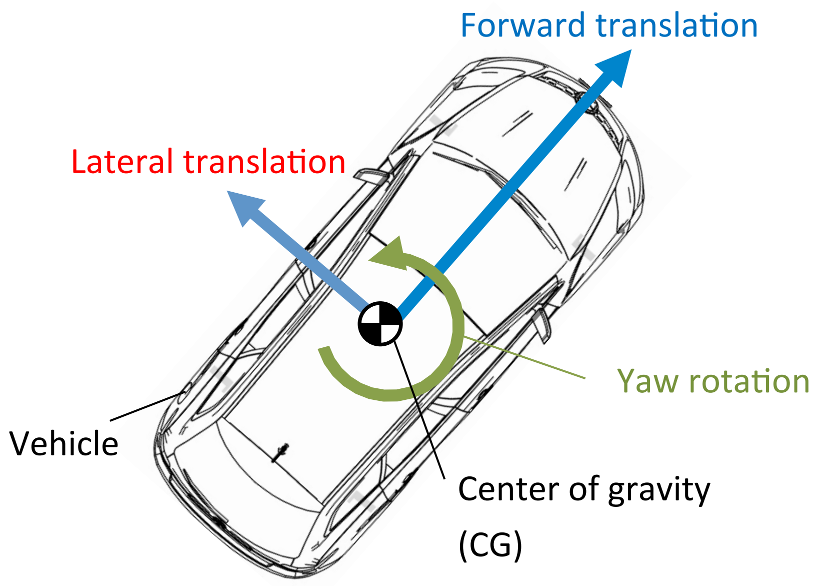
Assuming that roll and pitch rotations are negligible, we consider to control the following three motions;

- Forward translational motion
- Lateral translational motion
- Yaw rotation,

by using driving forces of four wheels and the steer angle of front wheels as control inputs.



Vehicle moving on horizontal plane

Controller Design

- Forward translational motion
  - Driving forces could be considered dominant force.

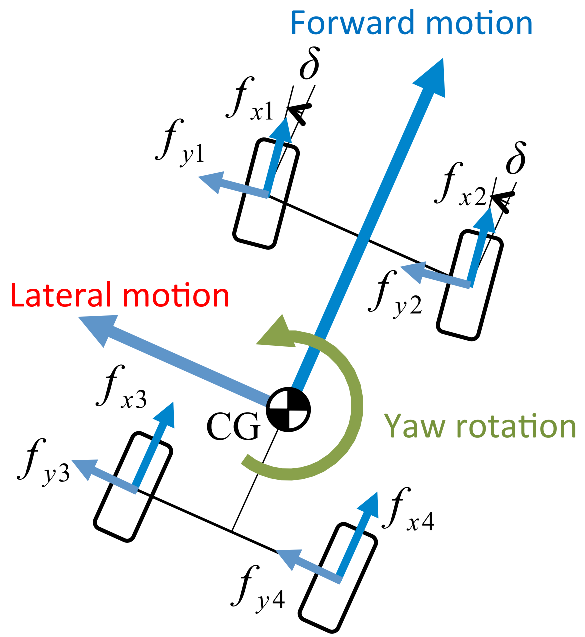
  ➡ Controlled using Driving forces

- Lateral translational motion
  - Lateral forces could be considered dominant force.

  ➡ Controlled using Lateral forces

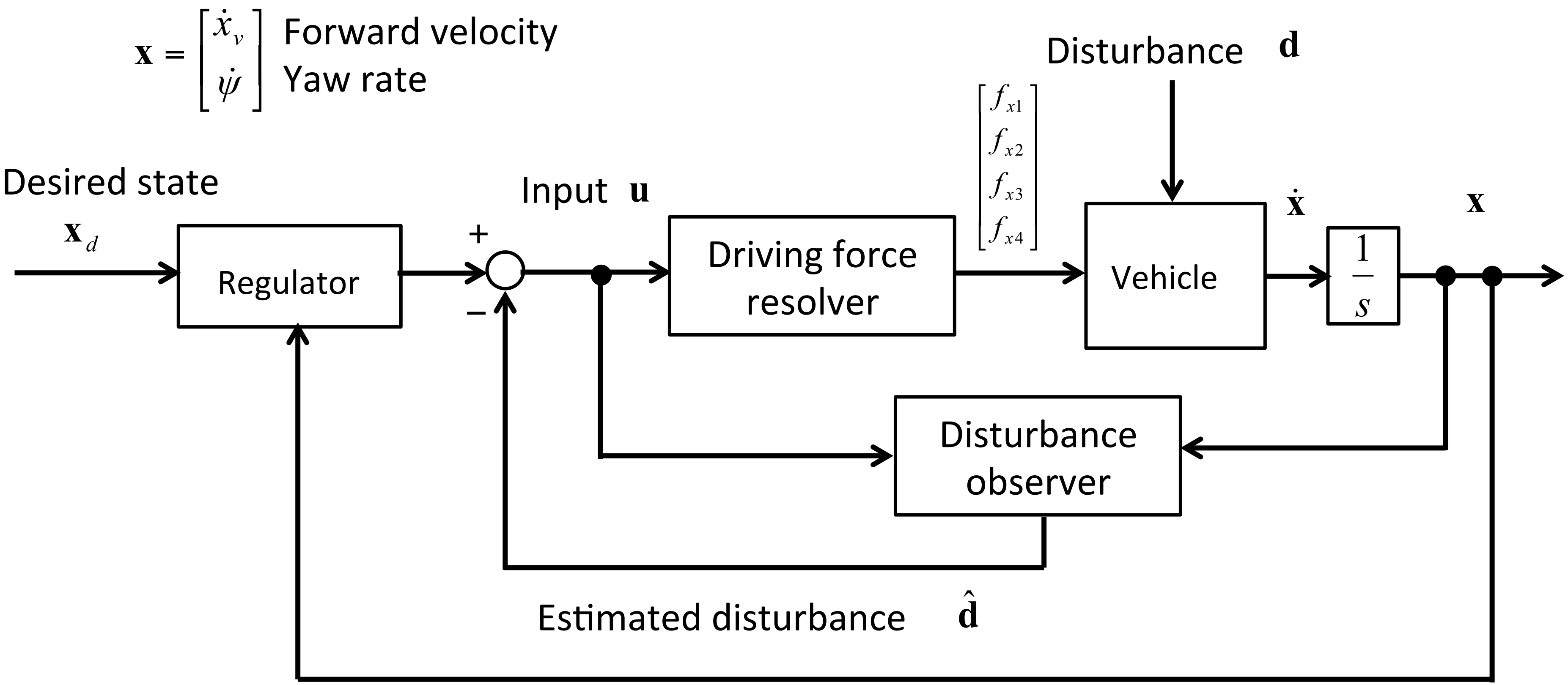
- Yaw rotation
  - Motion are affected by driving forces and lateral forces.

  ➡ Controlled using Driving forces



- Redundancy
- Easy to observe
- Generated actively

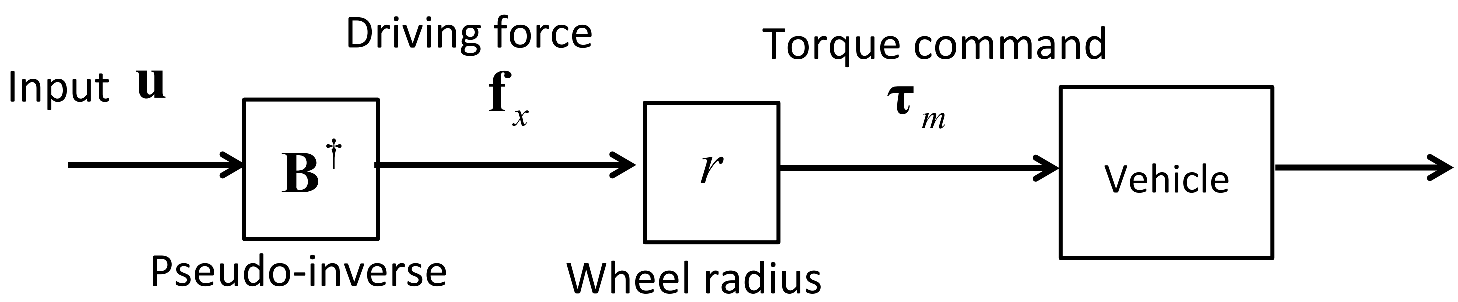
Controller for Forward Translational Motion & Yaw Rotation



Block diagram of the control system for forward translational motion and yaw rotation

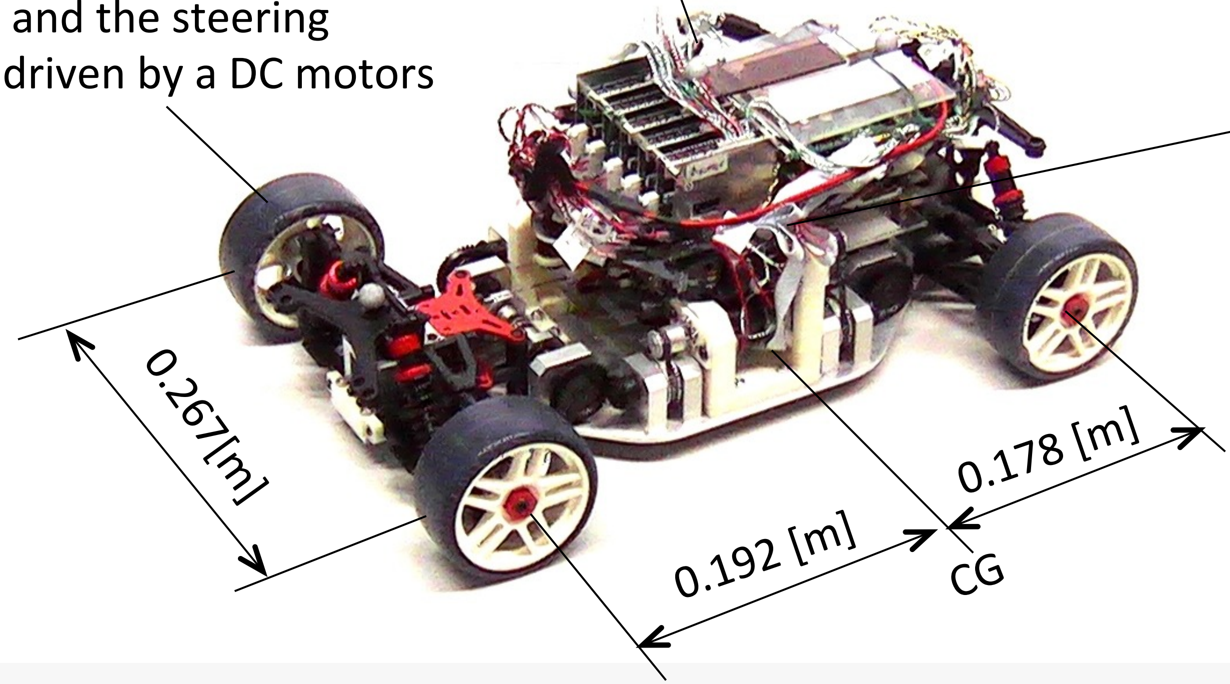
Controller for Forward Translational Motion & Yaw Rotation

- We utilize the pseudo-inverse method for deriving the driving forces.



Block diagram of part of driving force resolver

Experimental System



Vehicle mass :	5.77 [kg]
Yaw moment of inertia :	0.1043 [kgm^2]
Wheel diameter :	0.097 [m]
Wheel polar moment of inertia :	0.156x10^{-3} [kgm^2]
Control frequency :	1 [kHz]
Controller gain :	$\begin{bmatrix} k_{Vx} & k_{V\psi} & k_{V\beta} \end{bmatrix}^T = \begin{bmatrix} 10 & 30 & 10 \end{bmatrix}^T$
Cornering stiffness :	$C_1 + C_2 =$ 40 [N/rad]

Experimental System

- Forward velocity
- Lateral velocity
  (Sideslip angle)

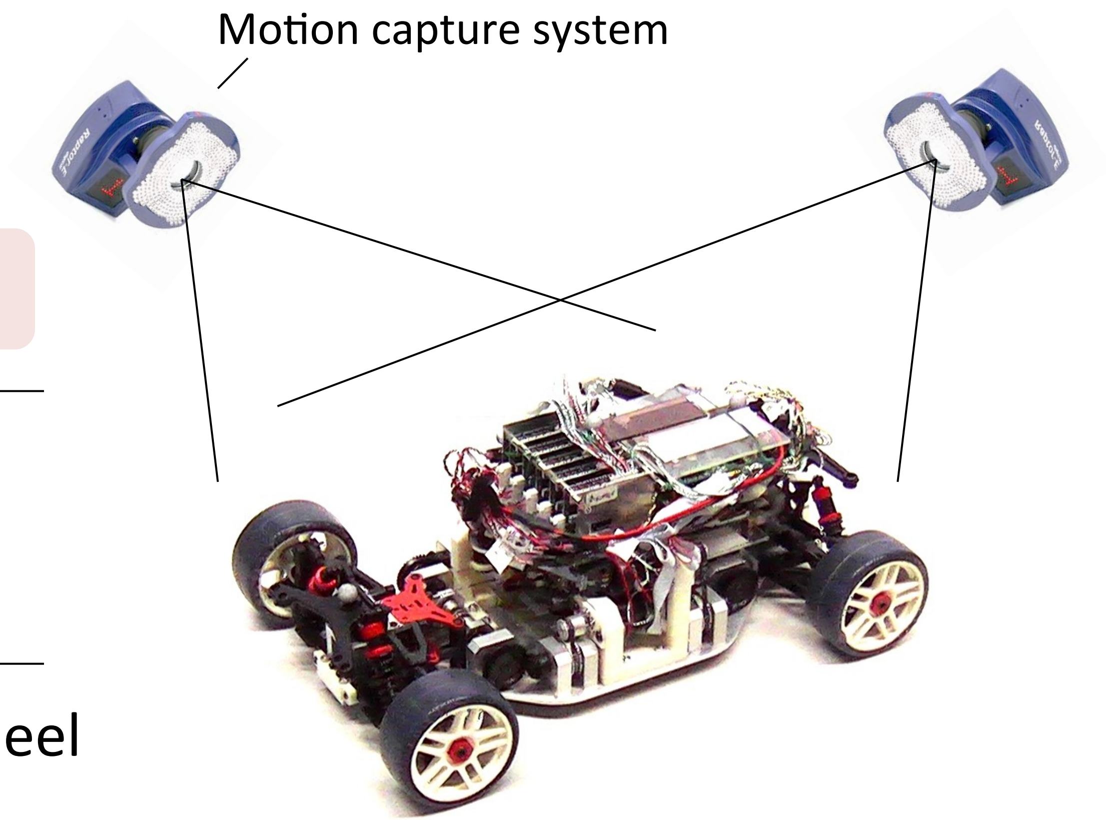
⇨ Motion capture system

- Yaw rate

⇨ Gyroscope

- Angular velocity of each wheel
- Steer angle

⇨ Rotary encoder



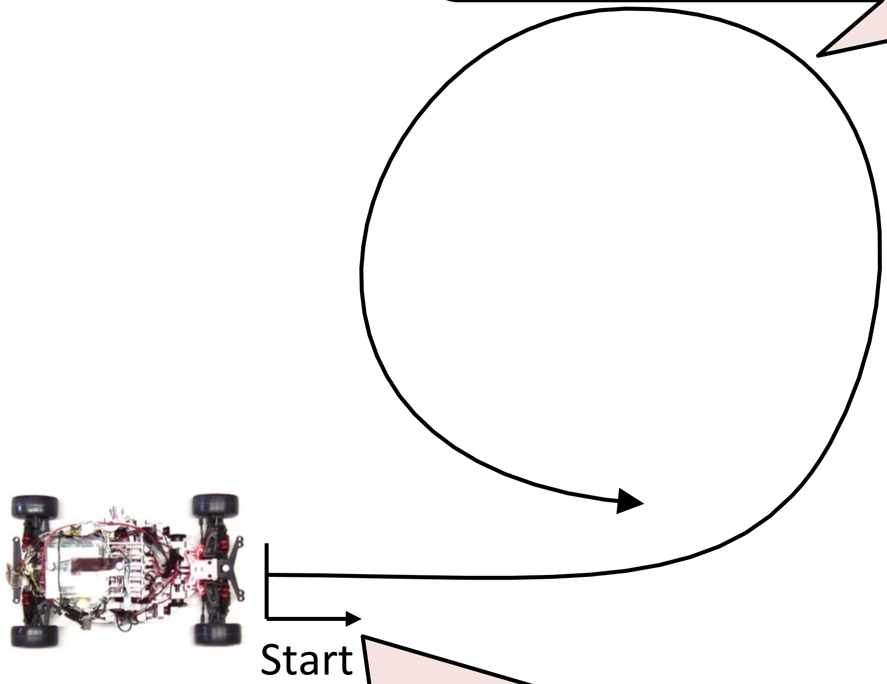
Experiments

Steady-state cornering experiment

Stopped state

⇩

Desired state



4 seconds after start
Increase the desired value of sideslip angle

Shortly after start
Increase the desired value of forward velocity & yaw rate

Experimental Results

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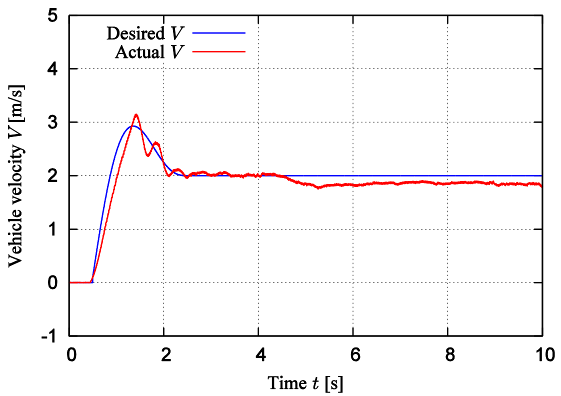
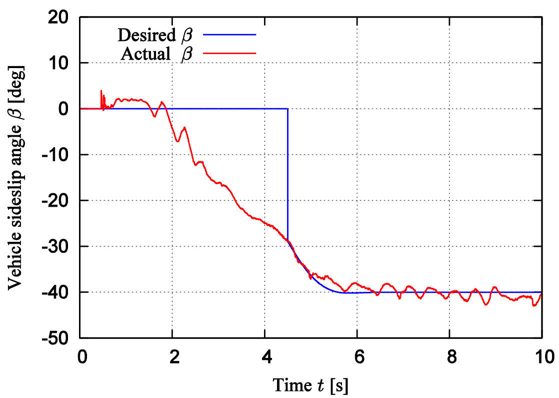
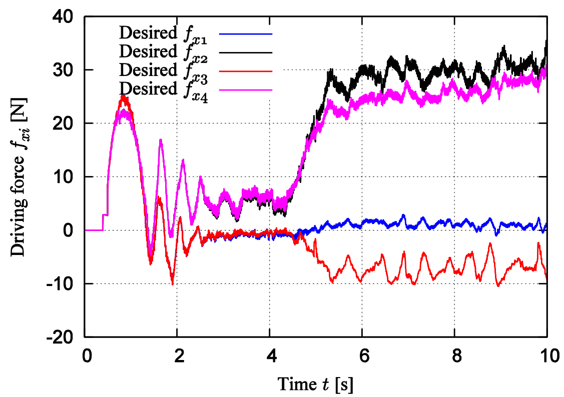
Controller 2 Sideslip angle β = -40deg



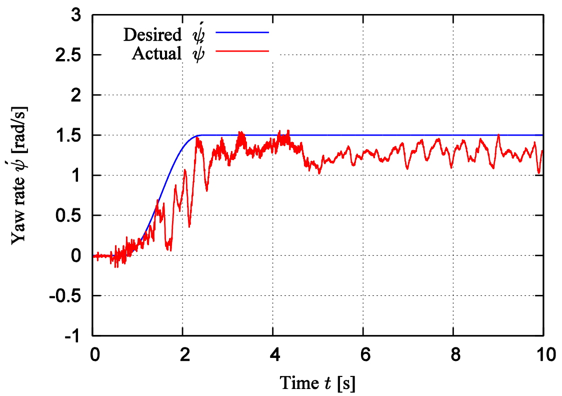
Vehicle velocity



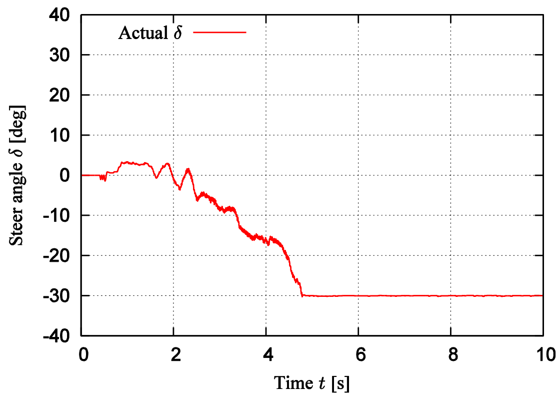
Sideslip angle



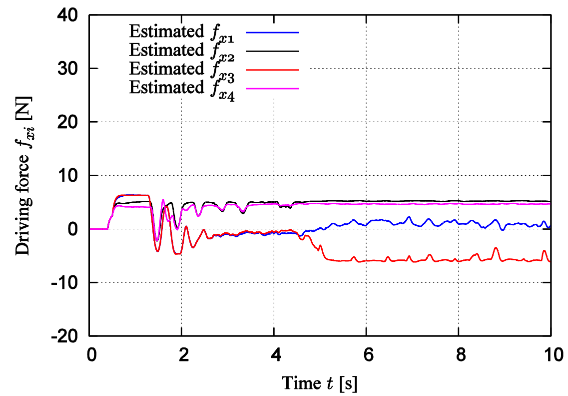
Desired longitudinal force



Yaw rate



Steer angle



Estimated longitudinal force

Conclusion

- We proposed a motion control system of an electric vehicle with a large sideslip angle using driving forces of four independently-driven wheels and the steer angle of front wheels.
- Proposed control system is separated into two controllers.
  - Forward translational motion & yaw rotation controller using redundant driving force inputs.
  - Lateral translational motion controller using steer angle as an input.
- Steady-state cornering experiment is executed.
- The experimental result shows that the proposed method can control the large sideslip motion of the vehicle.