This presentation is based on the following paper, presented at 2014 IEEE/ASME International Conference on Advanced and Intelligent Mechatronics:
H. Nakano, K. Okayama, J. Kinugawa, and K. Kosuge, Control of an Electric Vehicle with a Large Sideslip Angle Using Driving Forces of Four Independently-Driven Wheels and Steer Angle of Front Wheels.

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Dynamic Motion Control of a Vehicle with a Large Sideslip Angle

Kazuhiro Kosuge
Bioengineering and Robotics
Graduate School of Engineering
Tohoku University
Sendai 980-8579
JAPAN

DREEMS

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

Vehicle Motion Control System

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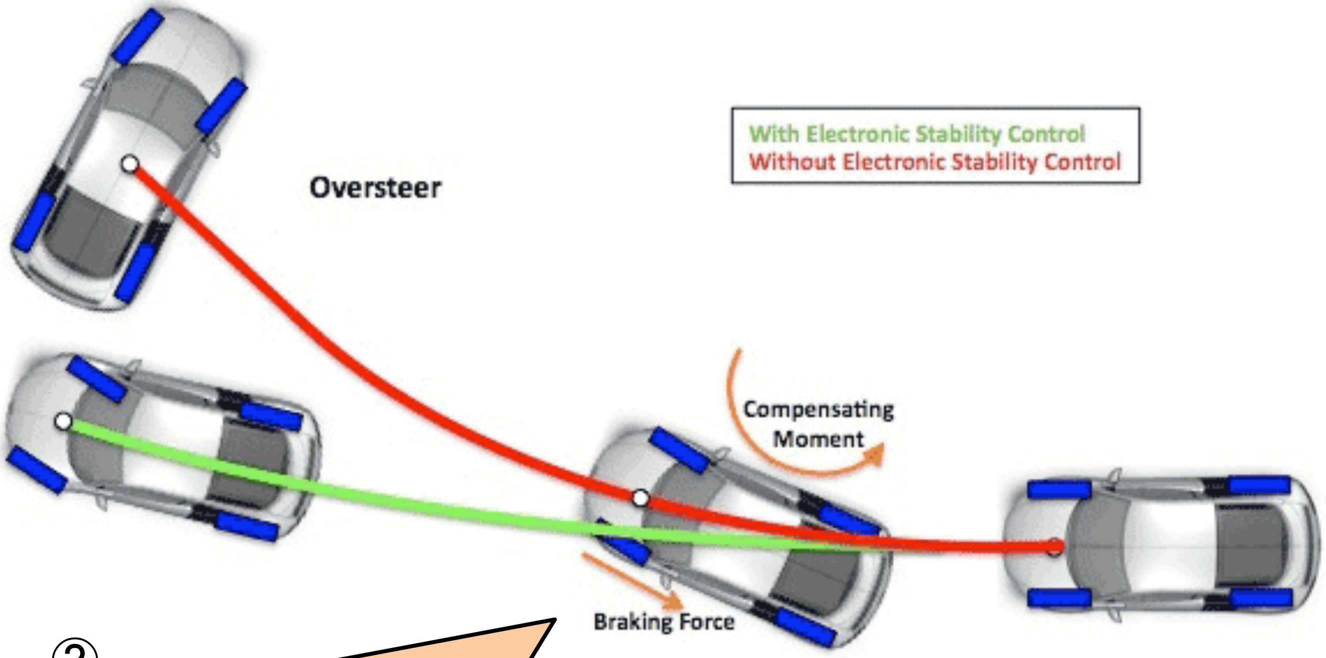
Electric Stability Control System (ESC)

Actual motion

① Detect differences

Intended motion



② Braking each wheel and reducing engine output to reduce unintended slip

Figure [1]

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[1] Electronic Stability Control System / THE CLEMSON UNIVERSITY VEHICULAR ELECTRONICS LABORATORY http://www.cvel.clemson.edu/auto/systems/stability_control.html

Sideslip Motion During Automotive Races

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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]

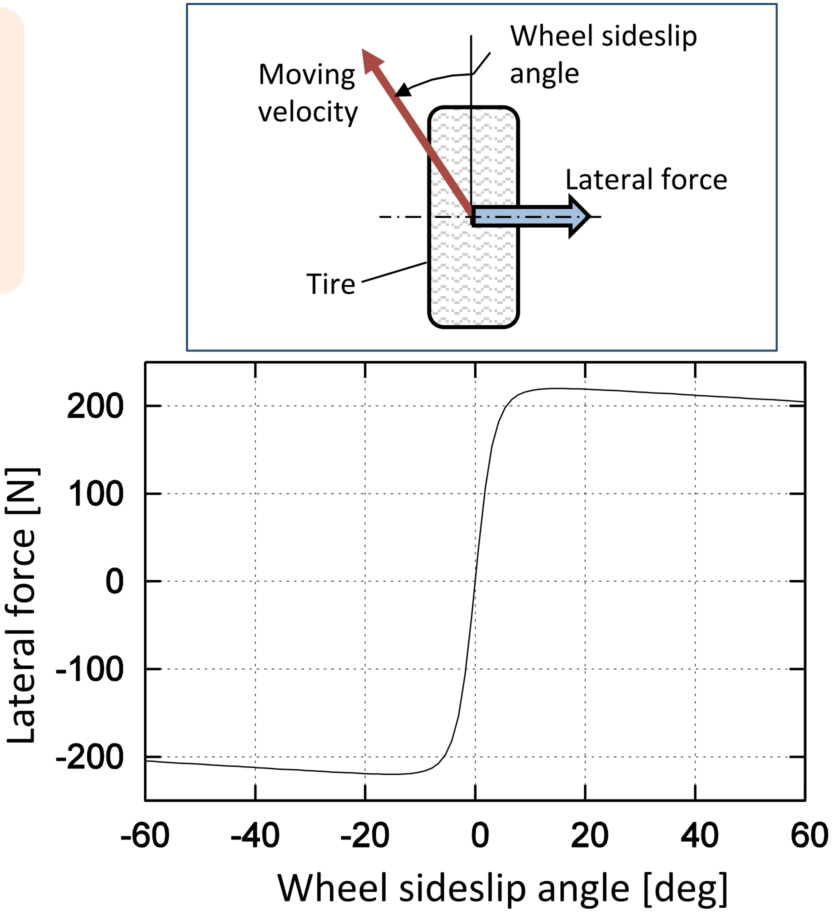
If we could control a vehicle with a large sideslip angle, fast and safe driving, like a rally driver could be realized.

[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.



Typical friction property between tire and road

Nonlinear tire model

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

Goal

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.

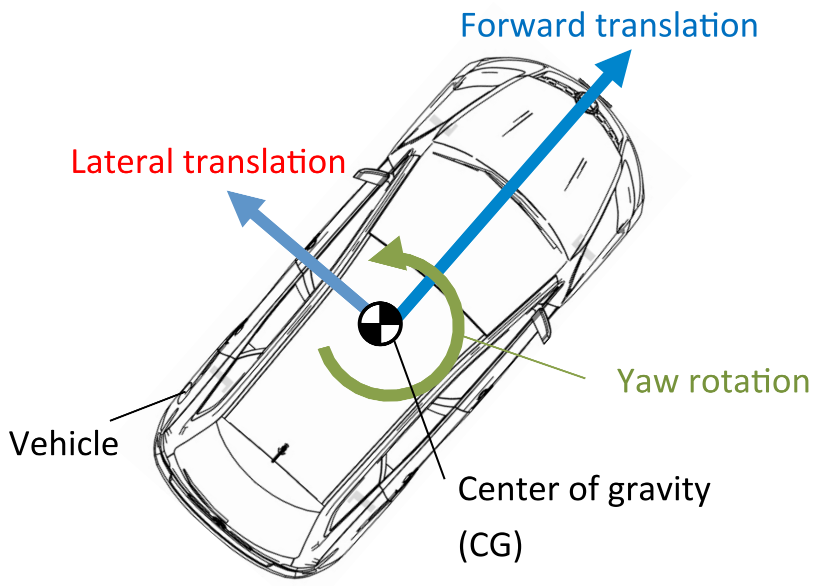
- A motion control system is designed based on a planar vehicle dynamics.
- The resultant control system does not require the nonlinear tire model.
- A steady-state cornering experiment is executed to illustrate the effectiveness of the proposed scheme.

Vehicle Model

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

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

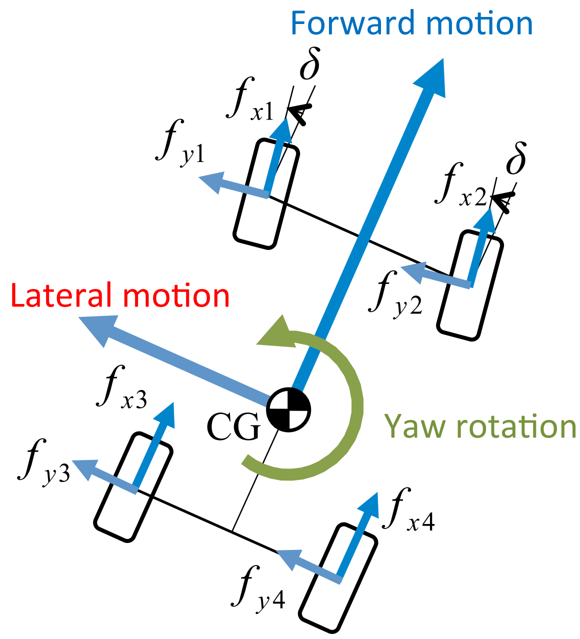
  ➡ Controlled using Driving forces

- 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

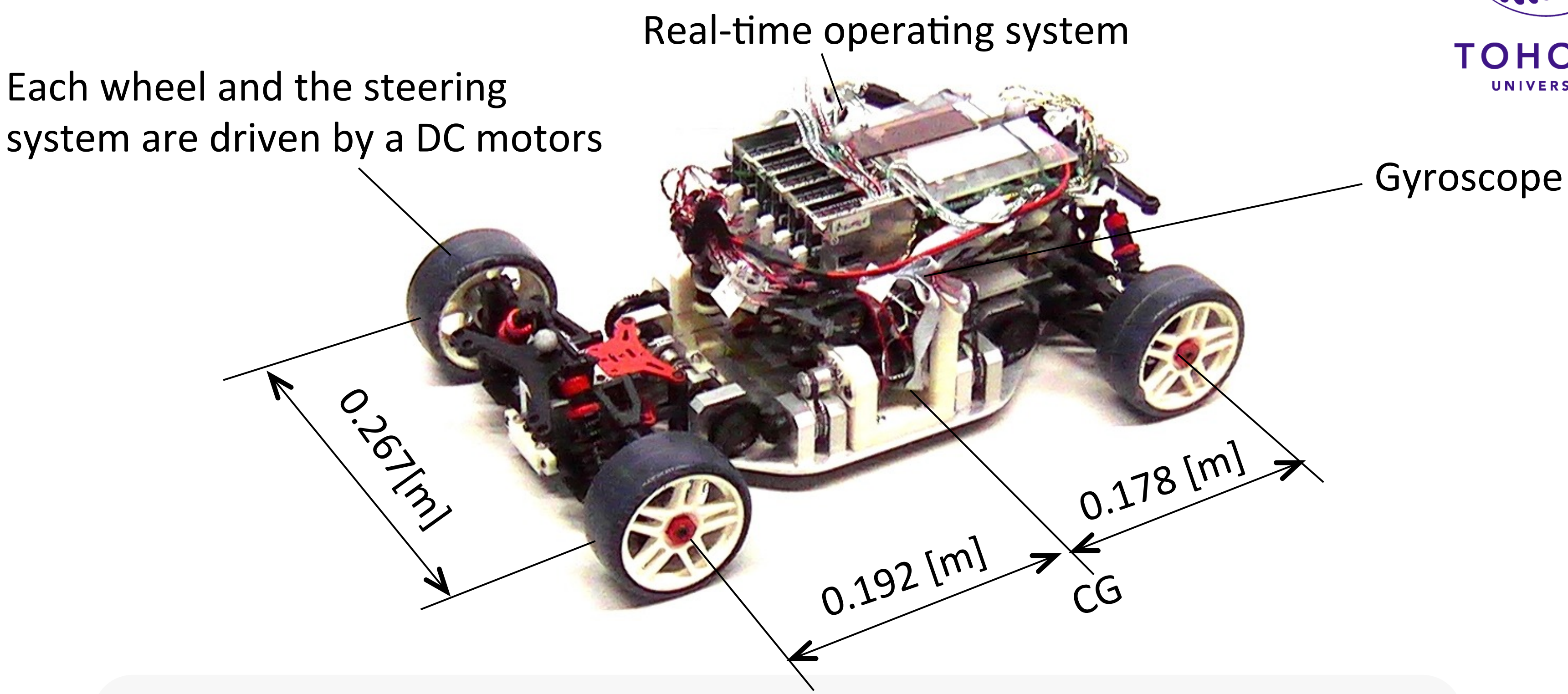
Controller Design

Controller is designed in two steps.

- Controller for the forward translational motion & yaw rotation using driving forces as control inputs

- Controller for the lateral translational motion using the front-wheel steer angle as a control input

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]

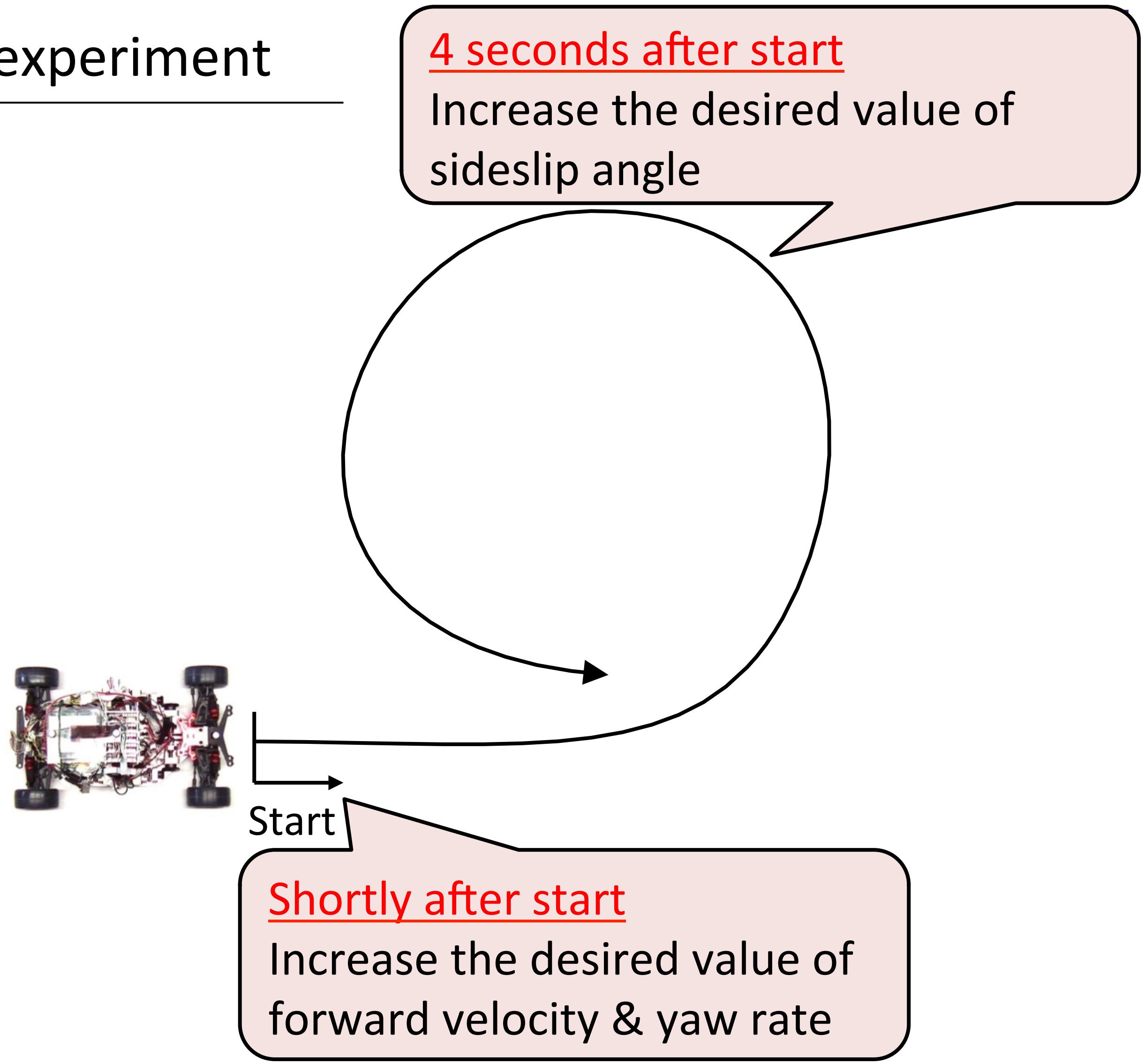
Experiments

Steady-state cornering experiment

Stopped state

⇩

Desired state



Experimental Results

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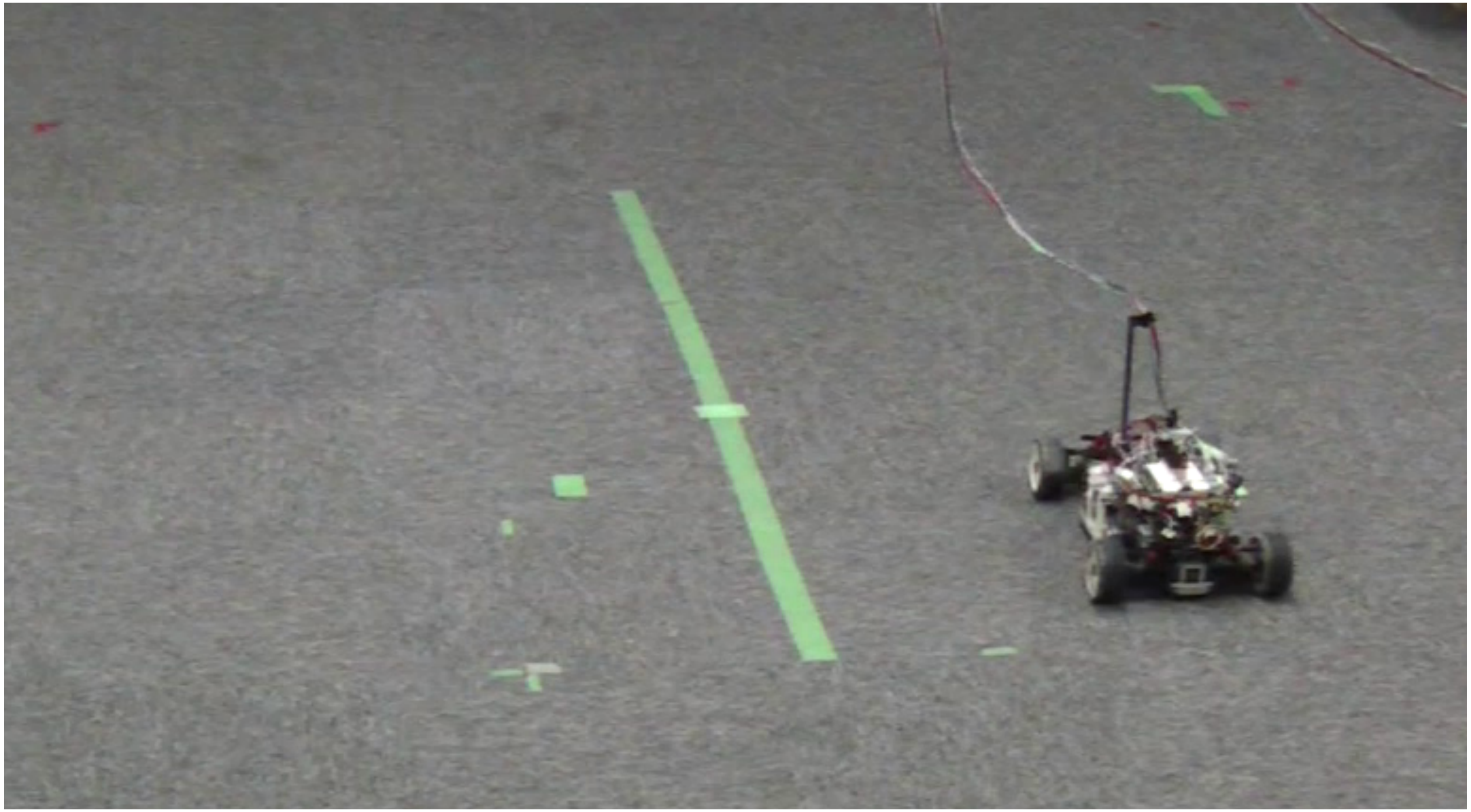
Controller 1 Sideslip angle $\beta = -20\mathrm{deg}$



Experimental Result

Experimental Results

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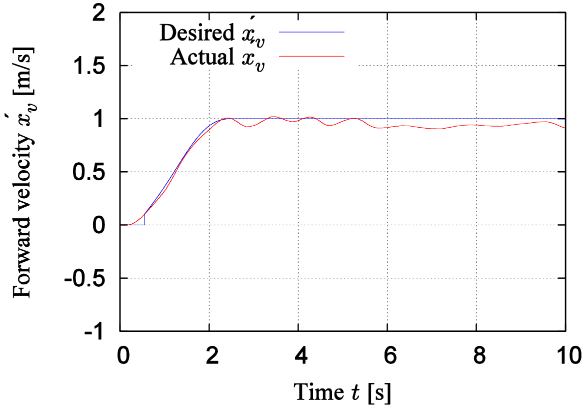
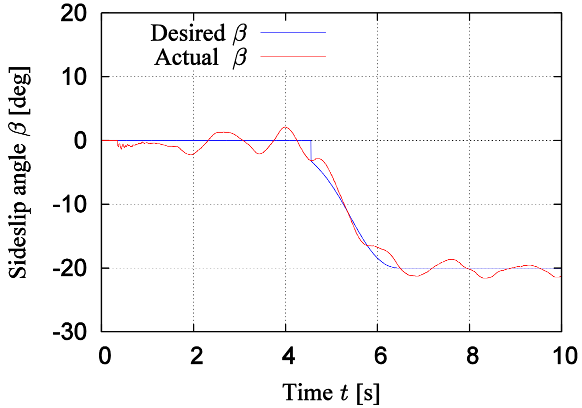
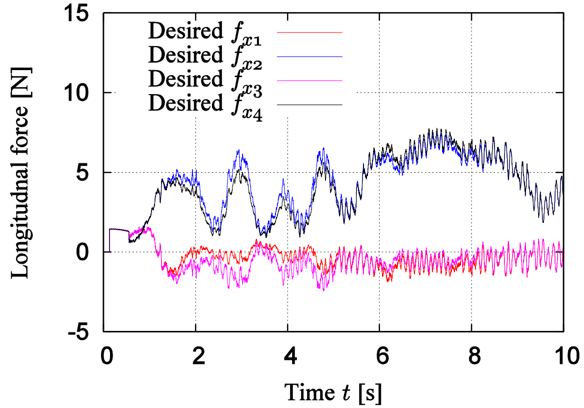


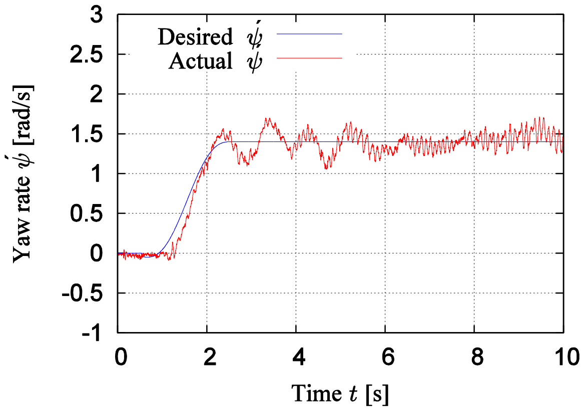
Forward velocity



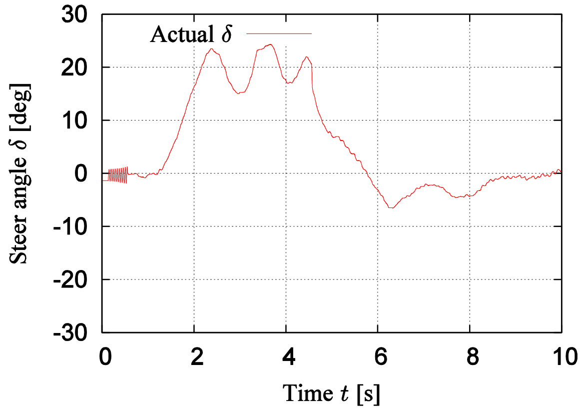
Sideslip angle



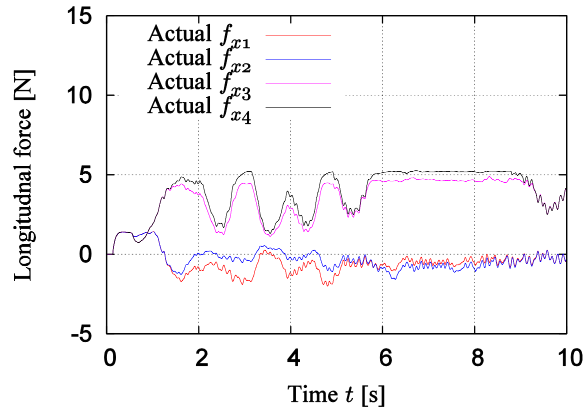
Desired longitudinal force



Yaw rate



Steer angle



Estimated longitudinal force

Conclusions

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- We proposed a motion control system of a 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 experiments were carried out and the experimental results illustrated that the proposed controllers could control the large sideslip motion of the vehicle.