REAL-TIME MULTIDIMENSIONAL VEHICLE DYNAMIC STABILITY DOMAIN CALCULATION AND ITS APPLICATION IN INTELLIGENT VEHICLES

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Introduction

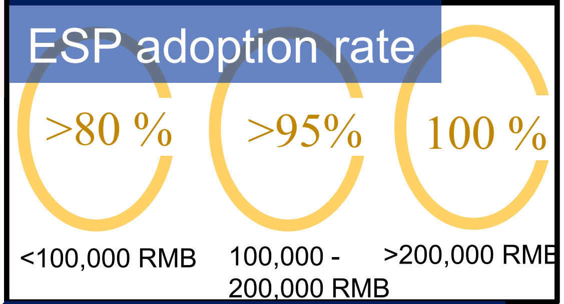
1.Introduction

■ Stable driving is critical for safe path tracking in complex scenarios

- **high-precision control systems** and **intelligent chassis** will become key indicators for the next generation of smart vehicles.

- **The stability controller** is one of **the most common active safety control technologies** in modern vehicles.

- The future will focus on exploring **the vehicle's maximum safety performance** and improving **path tracking accuracy in extreme scenarios**.



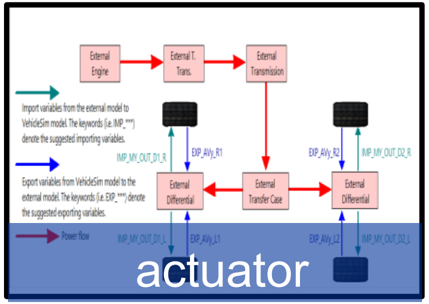
Vehicle stability is fundamental to the safe operation of intelligent vehicles

1.Introduction

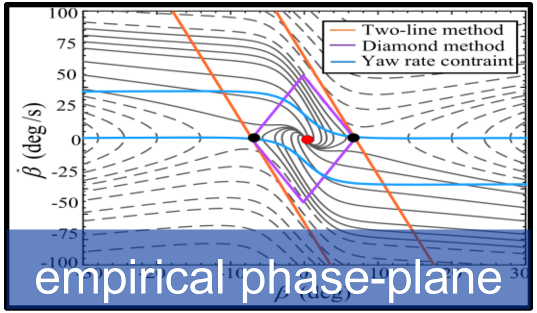
Unclear stability domain under multidimensional input

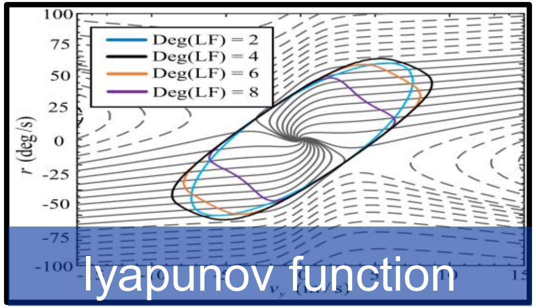
Multidimensional Input

Vehicle Dynamic



Stability Domain



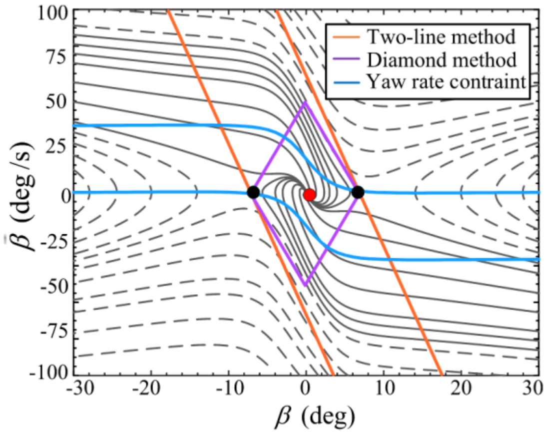


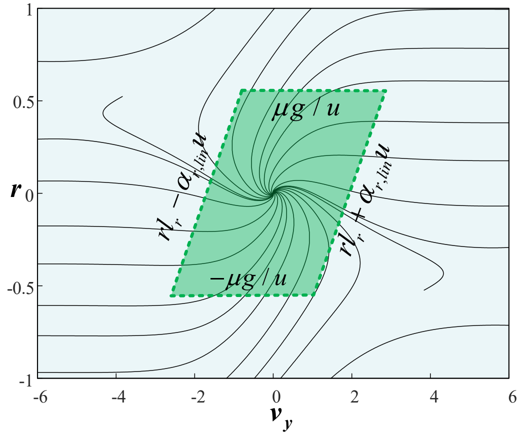
The real stability domain is difficult to parameterize accurately

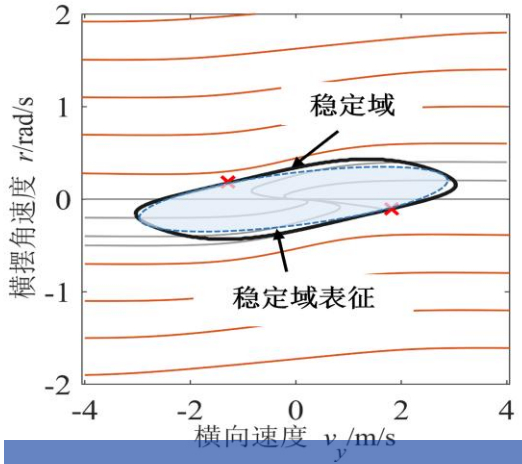
1.Introduction

■ Challenge for real-time stability-domain estimation

Portrait Phase Method	Dynamics Constraint	Graphical Fitting







Lack of detailed analysis

overly conservative for its linear assumption

Highly irregular for complex conditions

Real-time estimation is essential for effective vehicle stability control

2

Methodology

2.1 Technical Route

Structure of Article

Stability Domain Calculation

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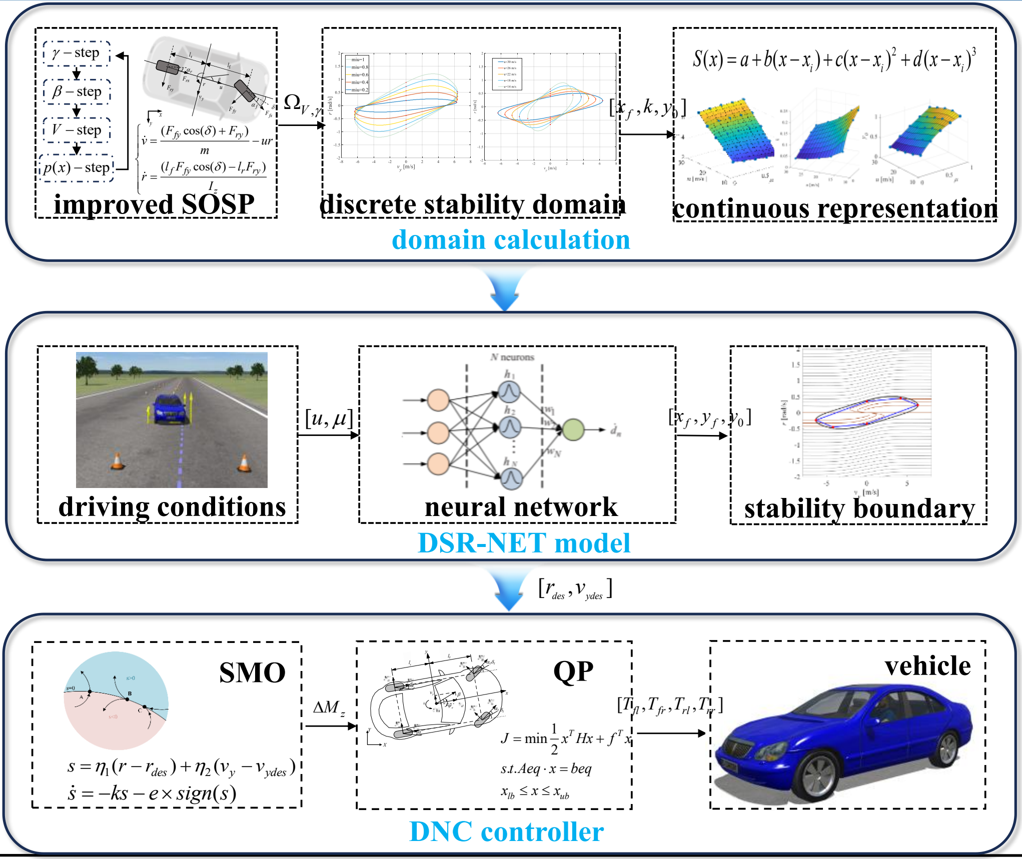
Real-Time Representation

↓

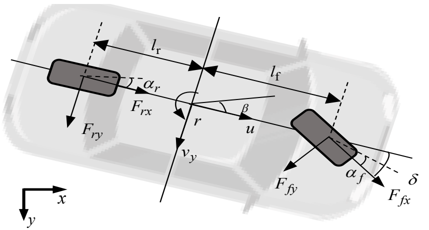
Stability Controller



2.2 Dynamics Model

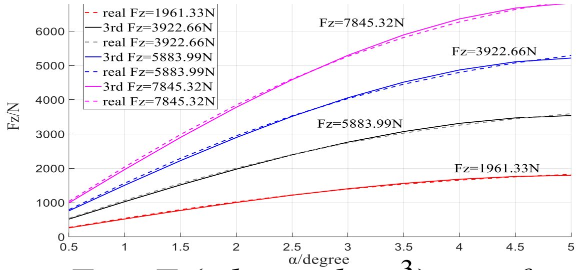
Dynamic model and SOSP

Vehicle Dynamic Model



$$\begin{cases} m(\dot{v}_y + ur) = F_{fy}\cos\delta + F_{ry} \\ I_z\dot{r} = l_f F_{fy}\cos\delta - l_r F_{ry} \end{cases}$$

Cubic Polynomial Tire Model



$$F_y = F_z(-k_1\alpha_i + k_2\alpha_i^3) \quad i = f, r$$

Nonlinear System Model of SOSP

$$\begin{cases} \dot{v} = \dfrac{(F_{fy}\cos(\delta) + F_{ry})}{m} - ur \\ \dot{r} = \dfrac{(l_f F_{fy}\cos(\delta) - l_r F_{ry})}{I_z} \end{cases}$$

$$F_y = F_z(-k_1\alpha_i + k_2\alpha_i^3) \quad i = f, r$$

Sum of Squares Programming

$\gamma - step$: find the $V(x)$ that maximizes the value γ

$\beta - step$: find the $p(x)$ that maximizes the value β

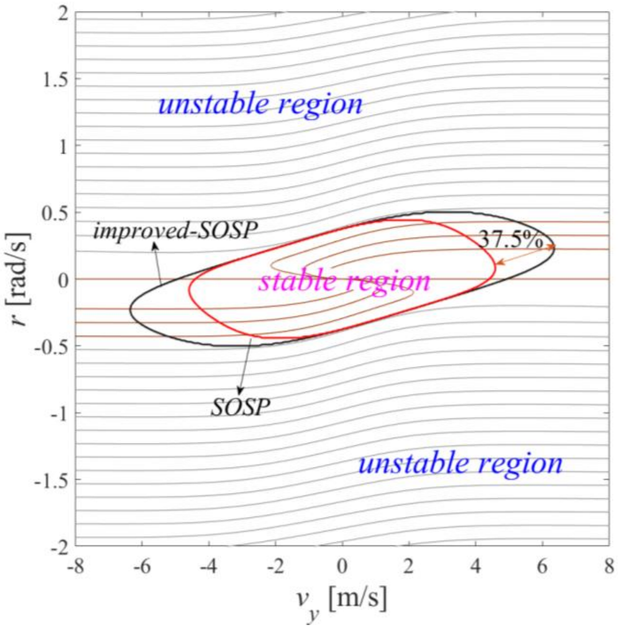
$V - step$: ensuring $V(x) > 0$ and $\nabla V(x) f > 0$.

$p - step$: $p(x)$for next iteration = $V(x)$

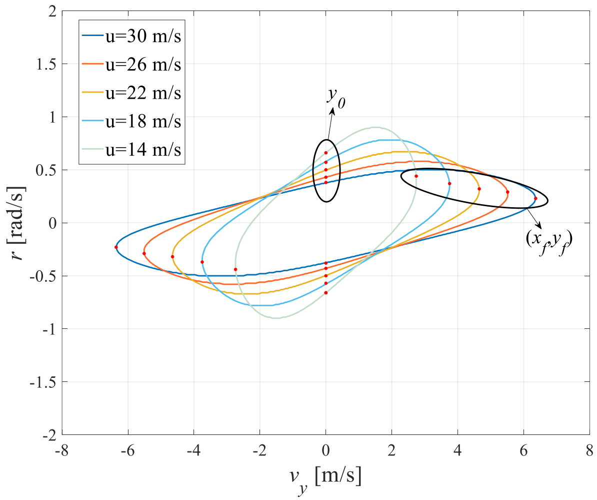
2.2 SOSP estimation

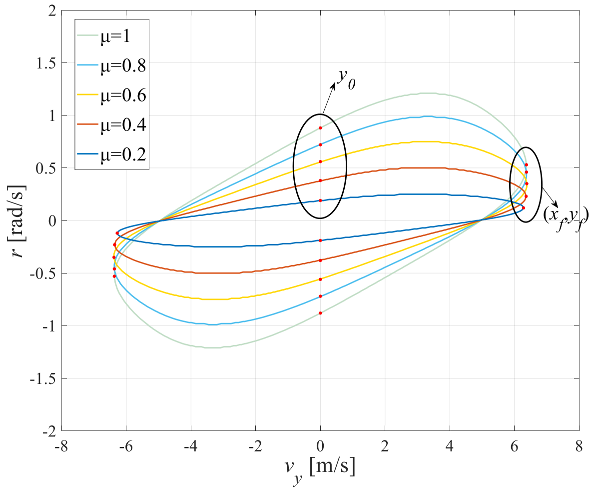
■ SOSP based stability-domain estimation

Improved-SOSP Estimation



Variation Patterns at Different Speeds/Coefficients

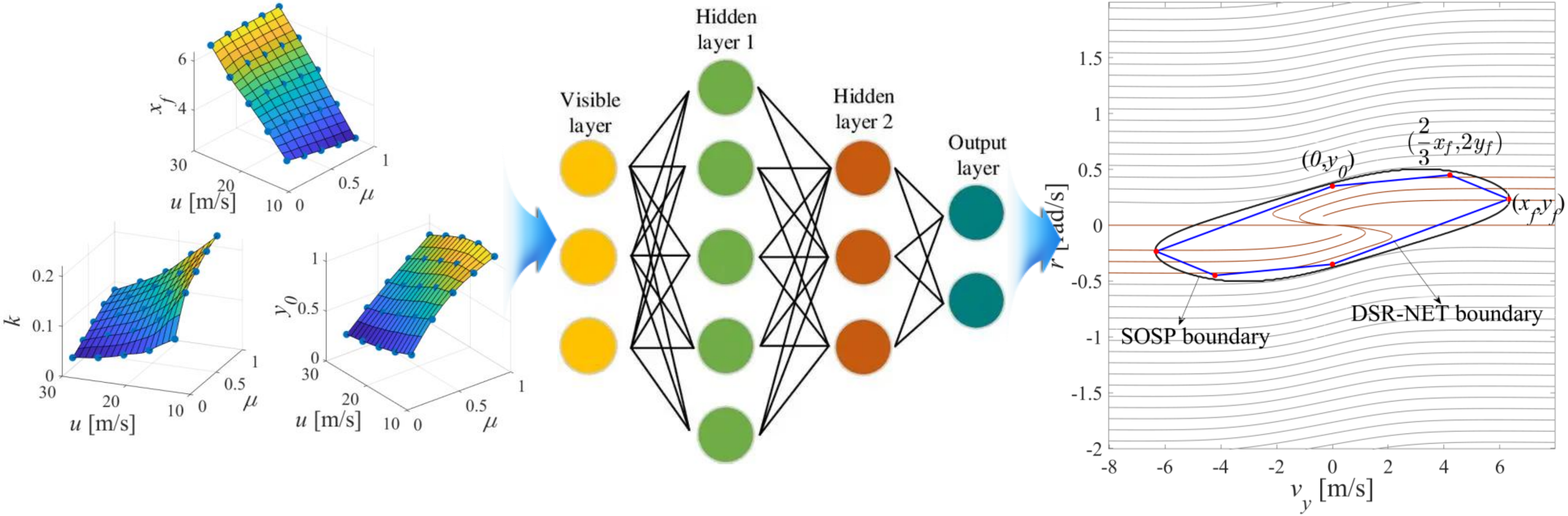




2.3 Real-time Vehicle Stability-domain Representation

■ Neural Network-based Representation Method

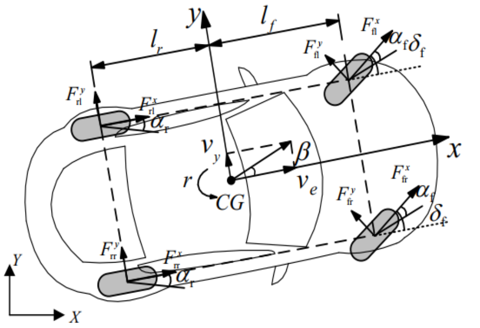
Interpolation Function **Feedforward Neural Network** **Boundary Fitting Method**



2.4 Design of A Path Tracking Controller

DSR-NET Stability Controller Design (DNC)

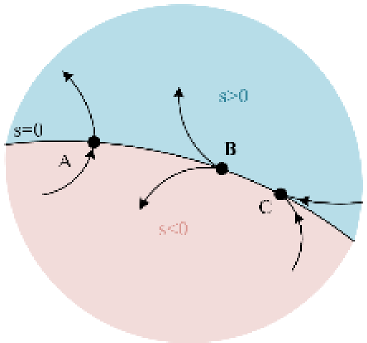
the control model



$$\begin{cases} m(\dot{v}_y + ur) = F_{fy}\cos\delta + F_{ry} \\ I_z\dot{r} = l_f F_{fy}\cos\delta - l_r F_{ry} + \Delta M_z \end{cases}$$

$$\Delta M_z = (F_{xfr} + F_{xrr} - F_{xfl} - F_{xrl})\frac{B}{2}$$

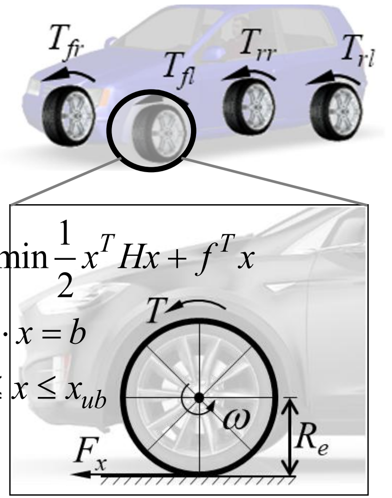
the SMO design



$$s = \eta_1(r - r_{des}) + \eta_2(v_y - v_{ydes})$$

$$\dot{s} = -ks - e \times sign(s)$$

the optimal torques



$$J = \min \frac{1}{2}x^T Hx + f^T x$$

$$s.t. A \cdot x = b$$

$$x_{lb} \le x \le x_{ub}$$

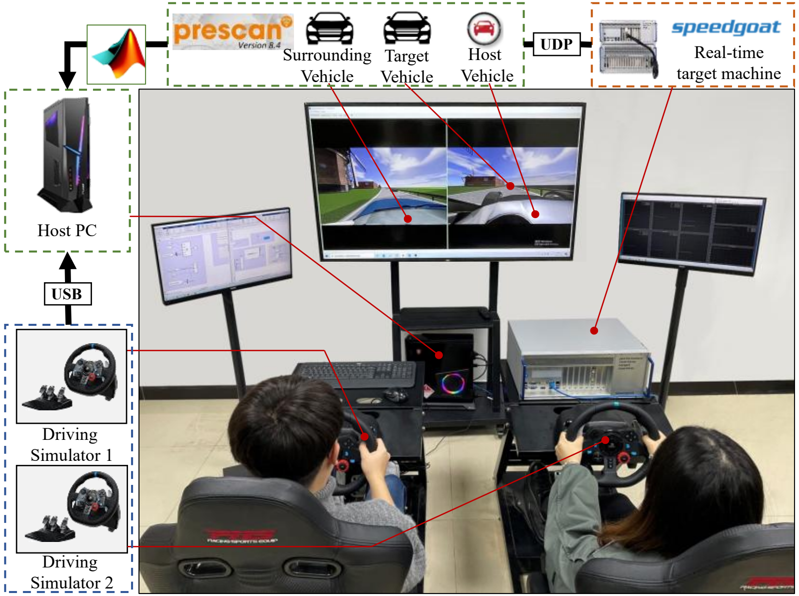
$$J_w\dot{\omega}_{ij} = T_{ij} - F_{ij}^x R_e$$

3

Experiment Test

3.1 Test Platform

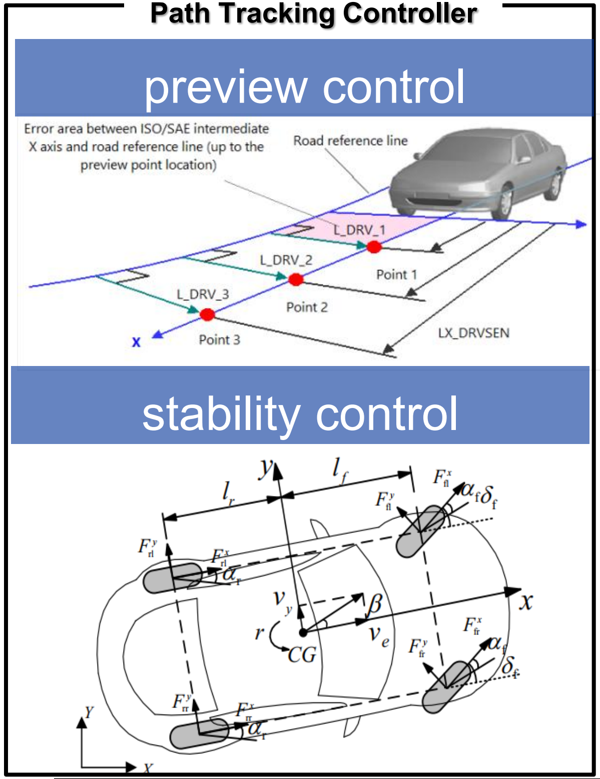
HiL System Platform

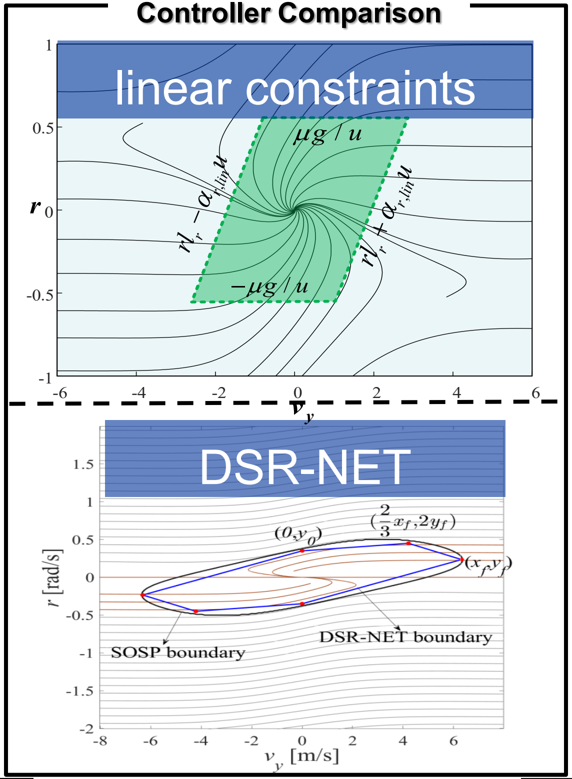


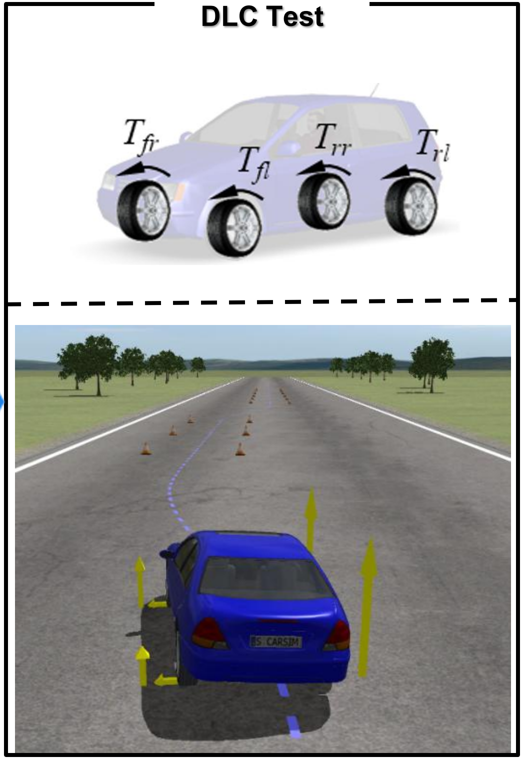
hardware	Driving simulator, Speedgoat real-time target machine, Host machine, displayer
software	Matlab/Simulink, Carsim, Prescan, Logitech driver
controller	Driving simulator, Speedgoat real-time target machine
comm	UDP (Speedgoat-Host machine), Serial port (Driving simulator-Host machine)

3.2 Test Scene

Linear controller (LC) VS DSR-NET controller (DNC)



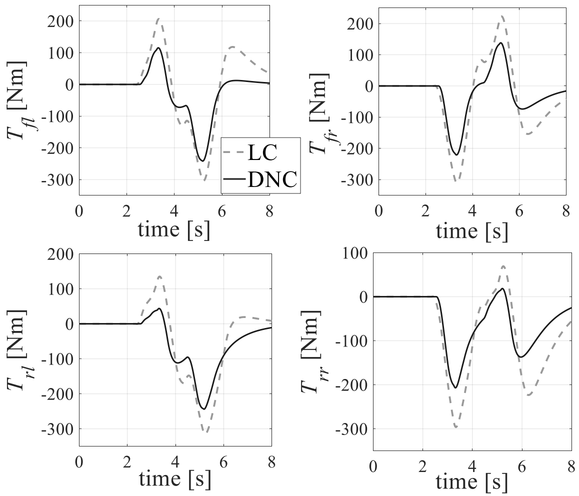




3.3 Validation Results

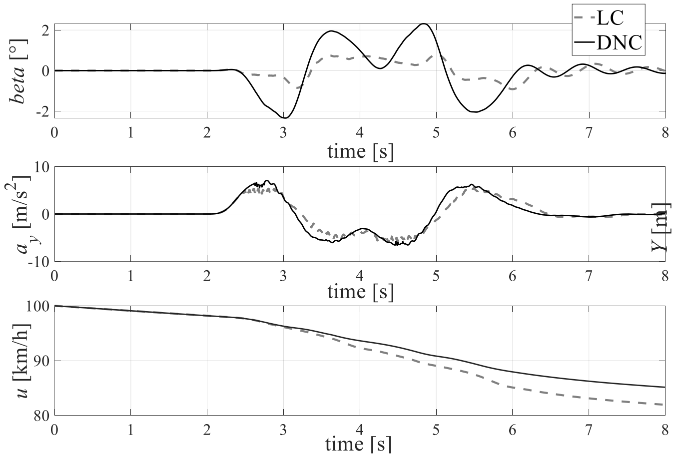
Results under DLC (100km/h, u=0.6)

Optimal Wheel Torques



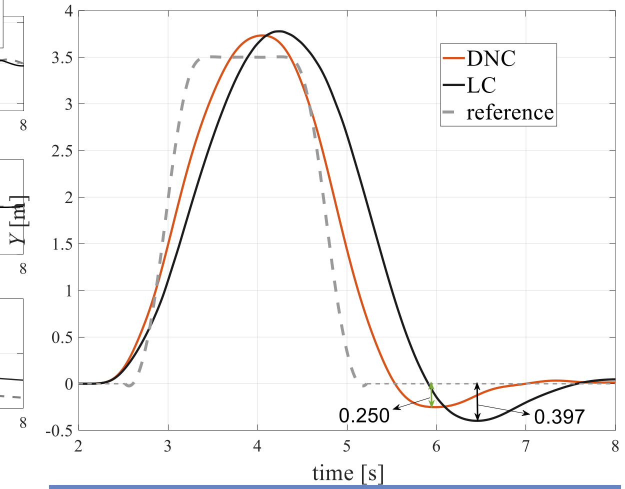
DNC **intervenes less** and **optimize smaller torques**

States Responses



DNC has **a better motility**

Path Tracking Error



DNC achieves **smaller tracking errors**

4

Conclusion

4. Conclusion

➢ Conclusion

1）By adding an iterative shape-function to the traditional SOSP, **the estimated stability-domain is developed.**

2）An FNN-based model maps between driving factors and stability boundaries to achieve **a continuous stability-domain description**.

3）A HiL platform is built to show that the DNC halves peak tracking error due to a **reasonable stability threshold for vehicle motion**.

➢ Outlook

Future work will aim to demonstrate the practical value of the DNC **through full-vehicle tests**, **integrate advanced path-tracking control method**, and apply **machine-learning methods to capture the characteristics of the extended stability domain under varying control inputs**.

Thanks

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