

15th ADAMS USER CONFERENCE

ROM, 15. - 16. November 2000

Vehicle Dynamics Control for a 4 Wheel Steering Prototype Car



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RWTH
INSTITUT FÜR
KRAFTFAHRWESEN
AACHEN

Dipl.-Ing. Alfred Pruckner
Dipl.-Ing. Sven Fischer

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Overview

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- **Control Strategy**
- Development Method
- Side Slip Angle Observation
- Side Slip Angle Control
- Outlook

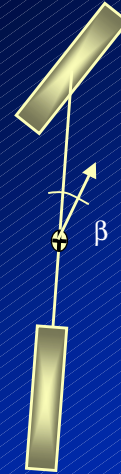
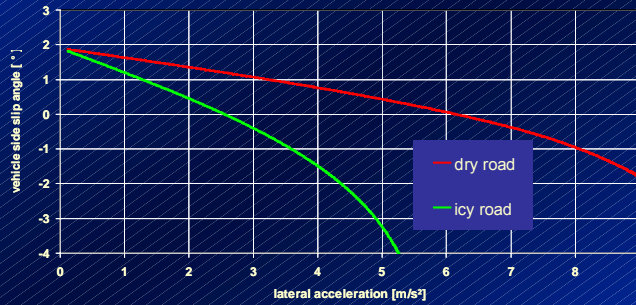
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4 Wheel Steering Control Strategy

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Vehicle Side Slip Angle β

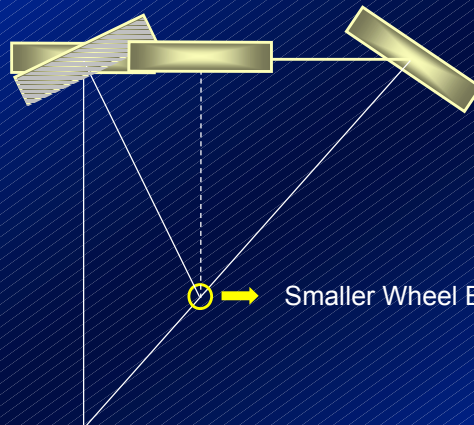
Steady State Cornering



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4 Wheel Steering Control Strategy

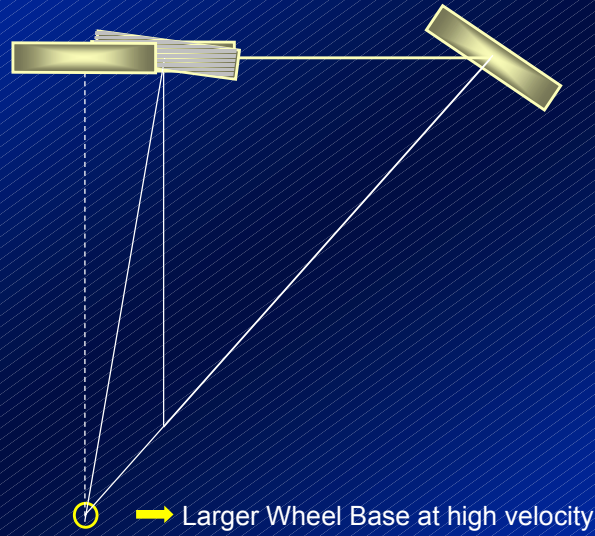
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4 Wheel Steering Control Strategy

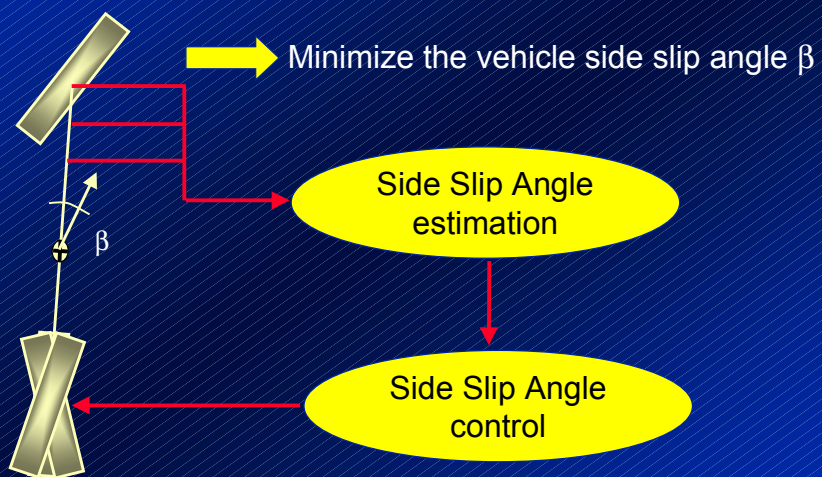
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4 Wheel Steering Control Strategy

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Overview

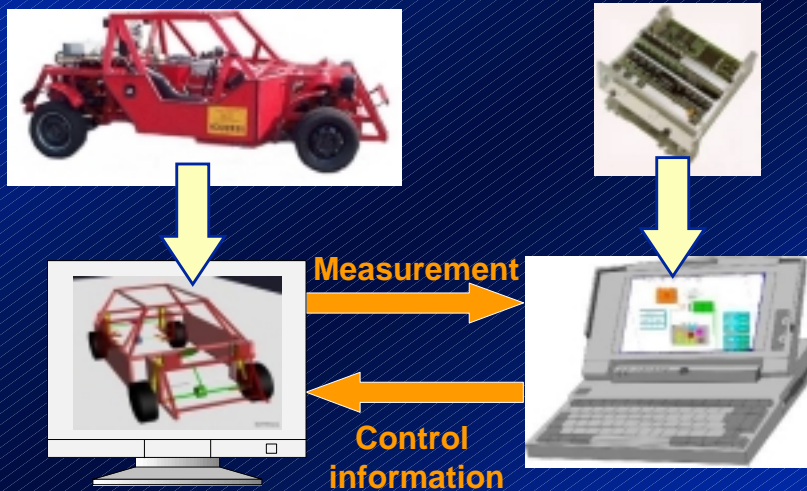
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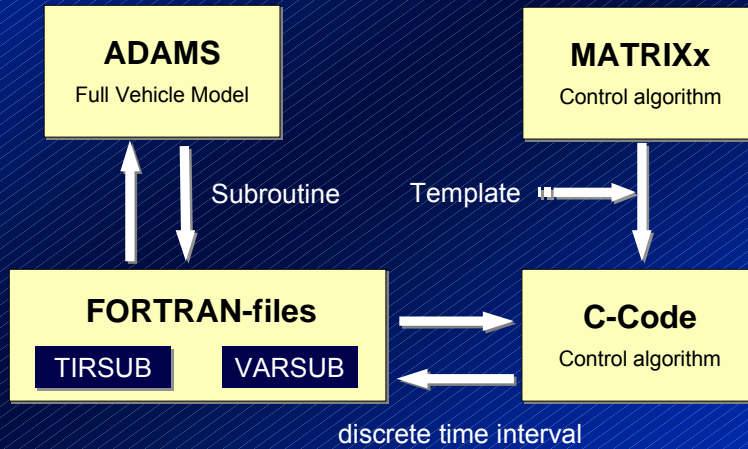
Virtual Prototyping

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Interface ADAMS und MATRIXx



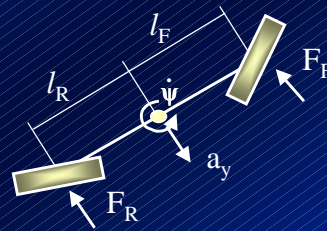
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Side Slip Angle Observation

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Linear Bicycle Model

- linear tire characteristics
- small angles
- centre of gravity on the street



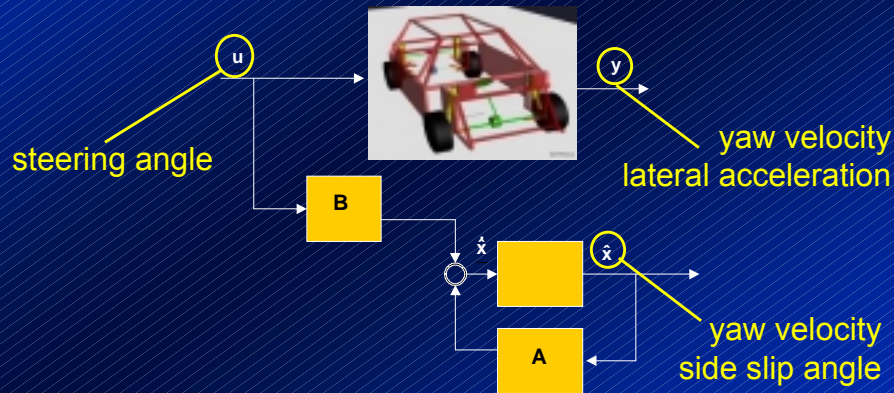
$$\begin{pmatrix} \dot{\beta} \\ \dot{\psi} \end{pmatrix} = \begin{pmatrix} \frac{-c_{sv} + c_{sh}}{m \cdot v} & -1 + \frac{l_v \cdot c_{sv} - l_h \cdot c_{sh}}{m \cdot v^2} \\ \frac{l_h \cdot c_{sh} - l_v \cdot c_{sv}}{J_z} & \frac{-l_v^2 \cdot c_{sv} - l_h^2 \cdot c_{sh}}{J_z \cdot v} \end{pmatrix} \cdot \begin{pmatrix} \beta \\ \psi \end{pmatrix} + \begin{pmatrix} \frac{c_{sv}}{l_v \cdot c_{sv}} & \frac{c_{sh}}{-l_h \cdot c_{sh}} \\ \frac{m \cdot v}{J_z} & \frac{m \cdot v}{J_z} \end{pmatrix} \cdot \begin{pmatrix} \delta_v \\ \delta_h \end{pmatrix}$$

$$\dot{\hat{x}} = A \cdot \hat{x} + B \cdot u$$

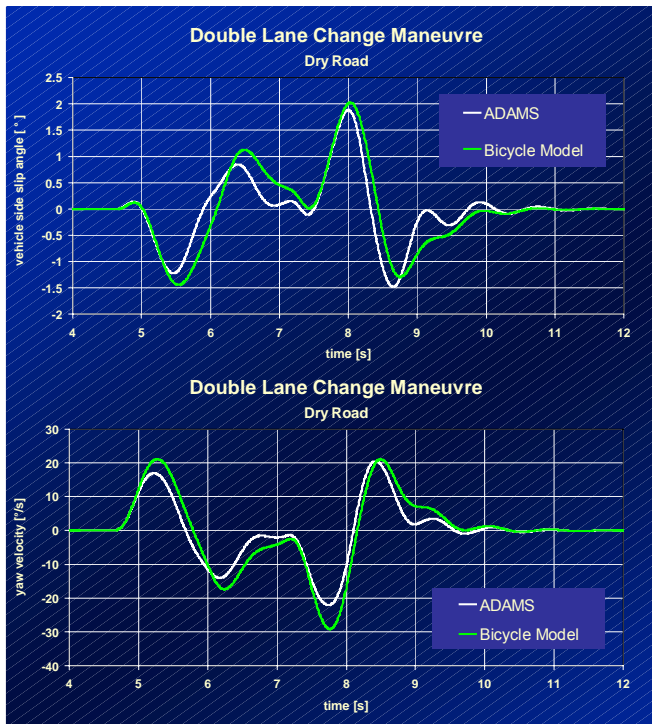
Side Slip Angle Observation

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Linear Bicycle Model



$$\dot{\hat{x}} = A \cdot \hat{x} + B \cdot u$$



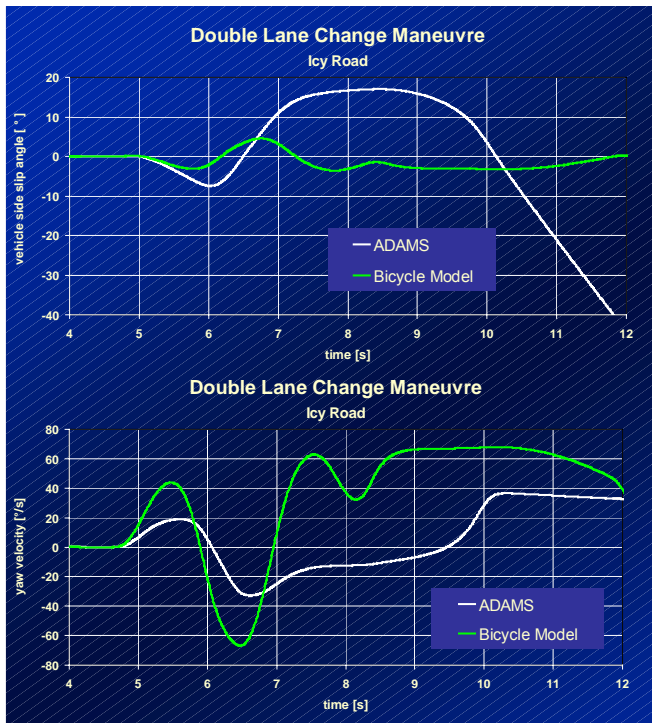
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**Side Slip Angle
Observation**

Dry Road

ADAMS

Bicycle Model



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**Side Slip Angle
Observation**

Icy Road

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Bicycle Model

Side Slip Angle Observation

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Linear Observer

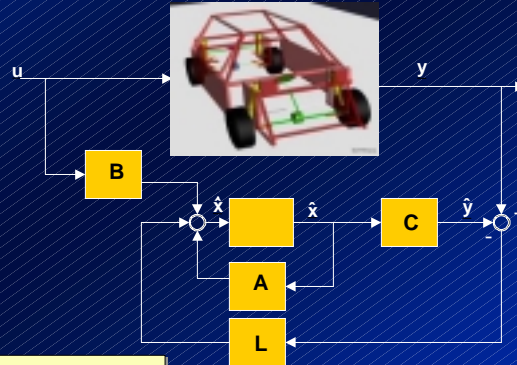
$$\dot{\underline{x}} = \underline{A}\underline{x} + \underline{B}\underline{u}$$

$$\dot{\hat{\underline{x}}} = \underline{A} \cdot \hat{\underline{x}} + \underline{B} \cdot \underline{u} + \underline{L}(\underline{y} - \hat{\underline{y}})$$

$$\dot{\tilde{\underline{x}}} = \dot{\underline{x}} - \dot{\hat{\underline{x}}} = \underline{A} \cdot \underline{x} + \underline{B} \cdot \underline{u} - [\underline{A} \cdot \hat{\underline{x}} + \underline{B} \cdot \underline{u} + \underline{L}(\underline{y} - \hat{\underline{y}})]$$

$$\dot{\tilde{\underline{x}}} = (\underline{A} - \underline{L}\underline{C})\tilde{\underline{x}}$$

$$\det(1 - (\underline{A} - \underline{L}\underline{C})) = \prod_{i=1}^n (1 - \lambda_i)$$



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Side Slip Angle Observation

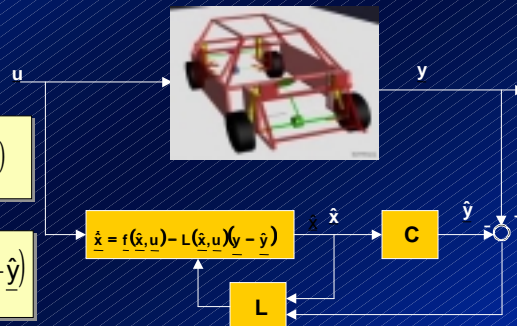
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Non-Linear Observer

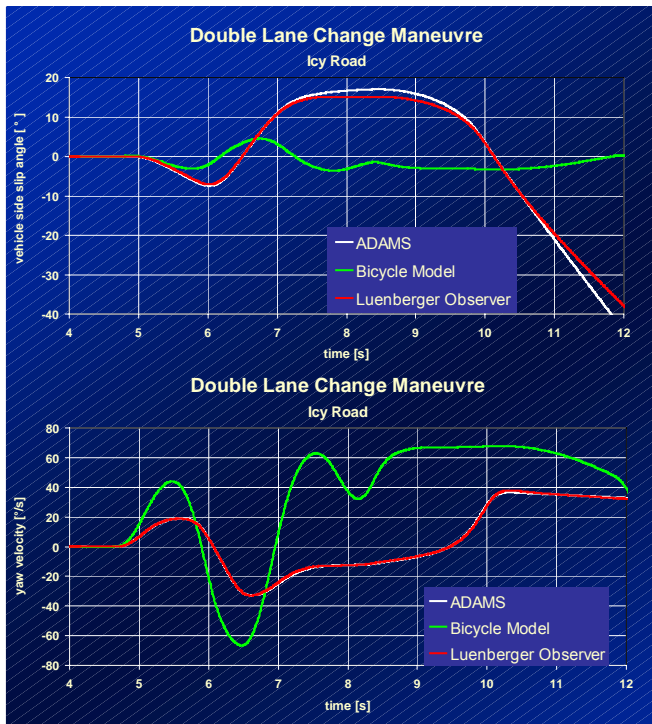
$$\dot{\underline{x}} = \underline{f}(\underline{x}, \underline{u}) \quad \dot{\hat{\underline{x}}} = \underline{f}(\hat{\underline{x}}, \underline{u}) + \frac{\partial \underline{f}}{\partial \underline{x}}(\hat{\underline{x}}, \underline{u}) \cdot (\underline{x} - \hat{\underline{x}})$$

$$\dot{\tilde{\underline{x}}} = \dot{\underline{x}} - \dot{\hat{\underline{x}}} = \frac{\partial \underline{f}}{\partial \underline{x}}(\hat{\underline{x}}, \underline{u}) \cdot (\underline{x} - \hat{\underline{x}}) - \underline{L}(\underline{y} - \hat{\underline{y}})$$

$$\underline{F}(\hat{\underline{x}}, \underline{u}) = \begin{pmatrix} \frac{\partial \beta}{\partial \beta} & \frac{\partial \beta}{\partial \psi} \\ \frac{\partial \psi}{\partial \beta} & \frac{\partial \psi}{\partial \psi} \end{pmatrix} \cdot \begin{pmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{pmatrix} \cdot \begin{pmatrix} 0 & 1 \\ \frac{\partial a_y}{\partial \beta} & \frac{\partial a_y}{\partial \psi} \end{pmatrix} = \begin{pmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{pmatrix}$$



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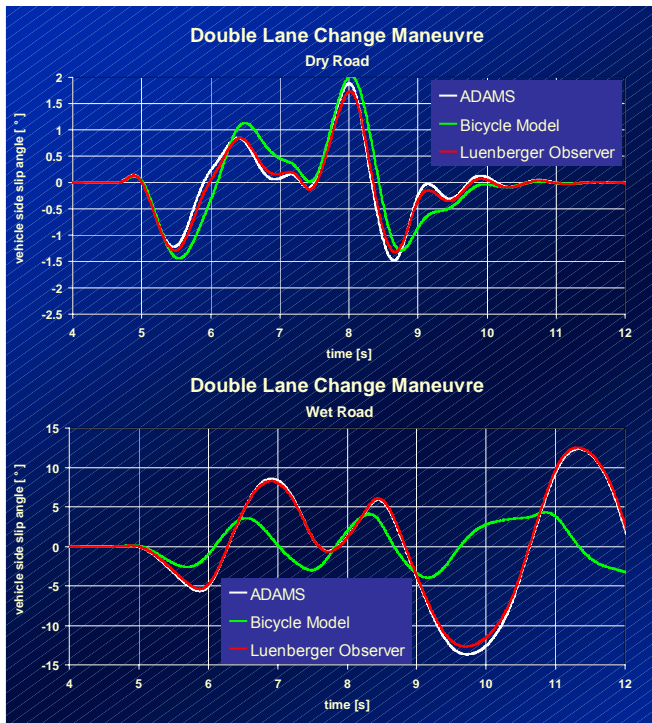
Side Slip Angle
Observation

Icy Road

ADAMS

Bicycle Model

Luenberger
Observer



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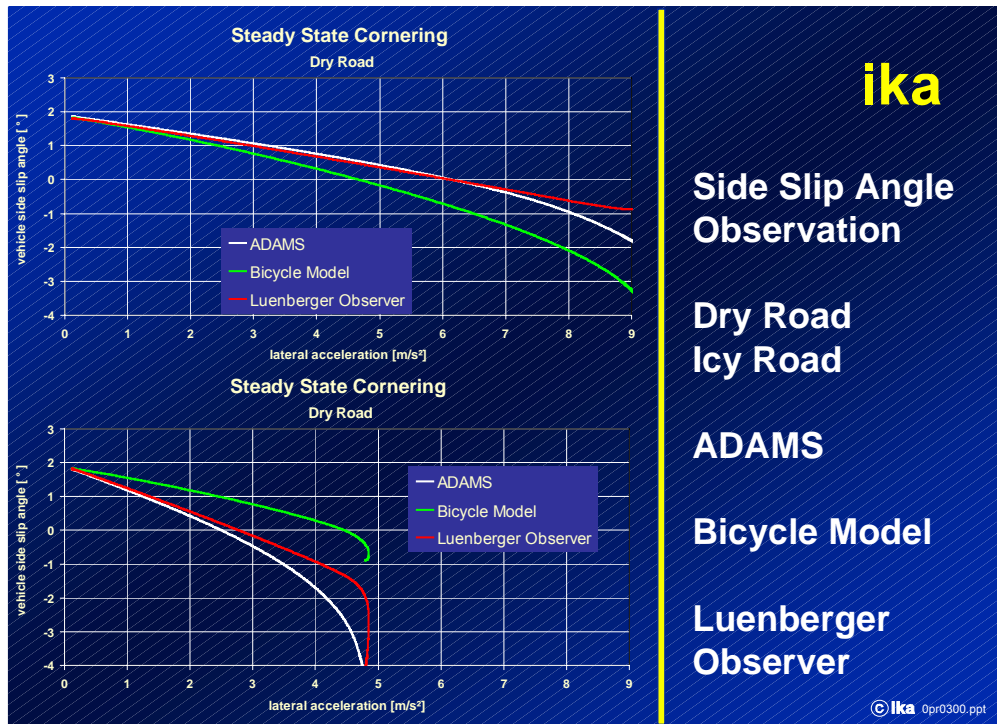
Side Slip Angle
Observation

Dry Road
Wet Road

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Bicycle Model

Luenberger
Observer



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Side Slip Angle Observation

**Dry Road
Icy Road**

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Bicycle Model

Luenberger Observer

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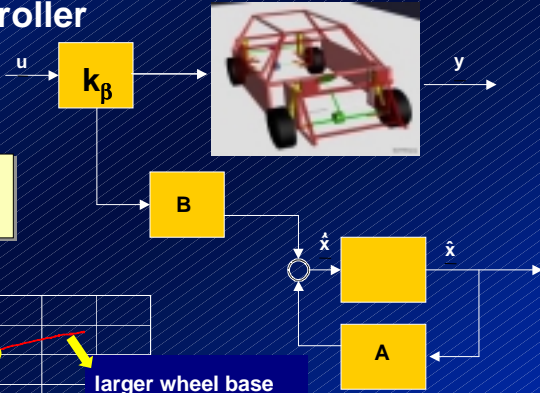
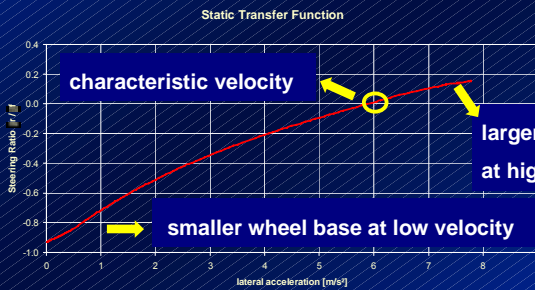
Side Slip Angle Control

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Bicycle Model Controller

$$\dot{\hat{x}} = A \cdot \hat{x} + B \cdot u$$

$$k_{\beta} = \frac{\delta_H}{\delta_V} = k_{\beta_stat} \cdot \frac{1 + i \cdot \omega \cdot T_D}{1 + i \cdot \omega \cdot T_1}$$



Side Slip Angle Control

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State Space Controller

$$\dot{x} = f(x, u)$$

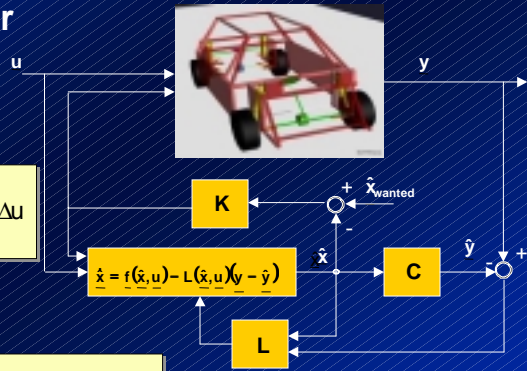
$$\Delta \dot{x} = \left(\frac{\partial f}{\partial x} \right) \cdot \Delta x + \left(\frac{\partial f}{\partial u} \right) \cdot \Delta u = A \cdot \Delta x + B \cdot \Delta u$$

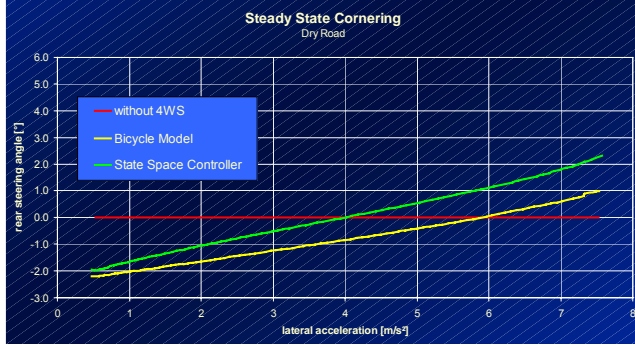
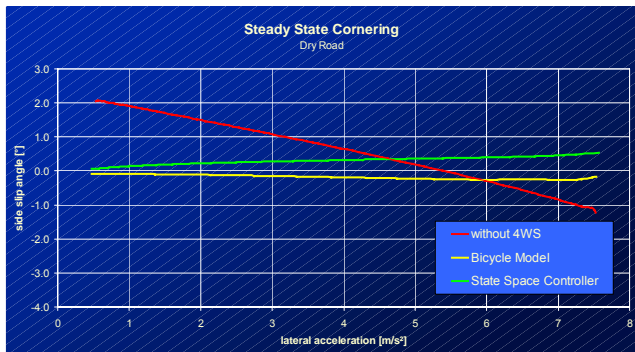
→ Ricatti Equation

$$P^*(k+1) = A^T(k) \cdot P_0(k) \cdot A(k) + Q$$

$$K^T(k+1) = P^*(k+1) \cdot B(k) \cdot [B^T(k) \cdot P^*(k+1) \cdot B(k) + R]^{-1}$$

$$P_0(k+1) = P^*(k+1) - K^T(k+1) \cdot B^T(k) \cdot P^*(k+1)$$





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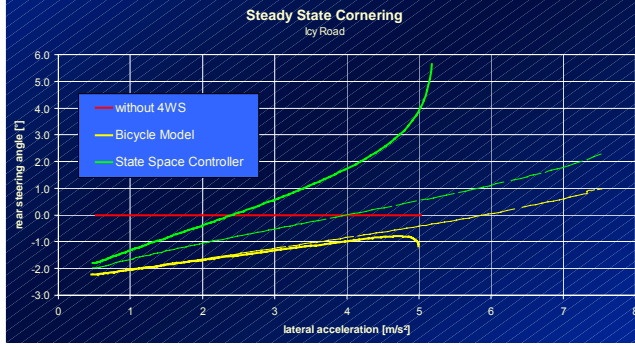
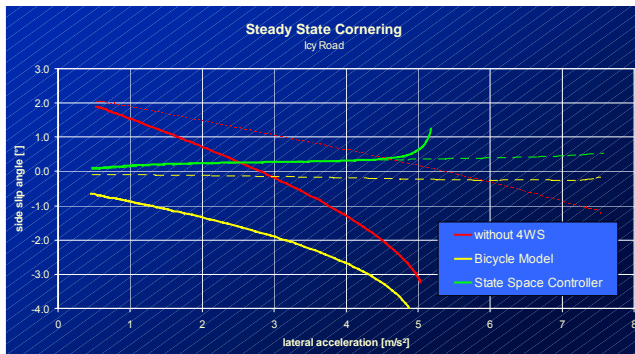
Side Slip Angle Control

Dry Road

Without 4WS

Bicycle Model Controller

State Space Controller



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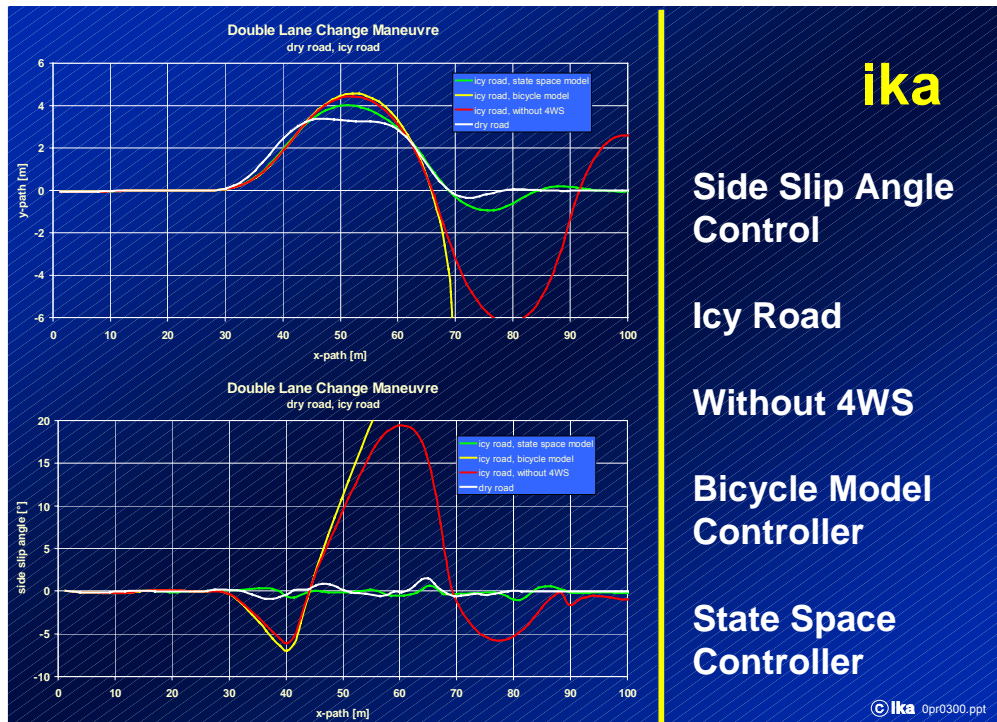
Side Slip Angle Control

Icy Road

Without 4WS

Bicycle Model Controller

State Space Controller



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- ika**
-
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Outlook

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Virtual Prototyping  Software Rapid Prototyping



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Vehicle Dynamics
Control for a
4 Wheel Steering
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