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Accident avoidance by active intervention for Intelligent Vehicles

Heavy Vehicle Dynamics Model & Path Control Algorithms

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Outline

- Introduction
- Use cases suitable for path control
- Heavy vehicle system dynamics in planar motion
- Path control algorithms
- Simulation results; rear-end collision avoidance
- Model verification; comparison with test data
- Summary

Introduction
interactIVe project overview

- Website: www.interactIVe-ip.eu
- Budget: EUR 30 Million
- EC funding: EUR 17 Million
- Duration: 42 months (January 2010 – June 2013)
- Coordinator: Aria Etemad, Ford Research & Advanced Engineering Europe
- 10 Countries: Czech Republic, Finland, France, Germany, Greece, Italy, Spain, Sweden, The Netherlands, The UK

European Commission
Information Society and Media

SEVENTH FRAMEWORK PROGRAMME

EUCAR
EUROPEAN COUNCIL FOR AUTOMOTIVE R&D

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Introduction
Partners and project structure

Sub-project 1: **Integrated project (IP) management**

Integrated advanced driver assistance systems (ADAS) for continuous support and emergency intervention

Sub-project 2: **Perception**
Specifications for sensor interfaces and fusion modules

Sub-project 3: **Information, warning and intervention (IWI) strategies**
Definition of use cases and requirements | Specifications for IWI strategies

Sub-project 4: **SECONDS**
Safety enhancement through continuous driver support

Sub-project 5: **INCA**
Integrated collision avoidance and vehicle path control

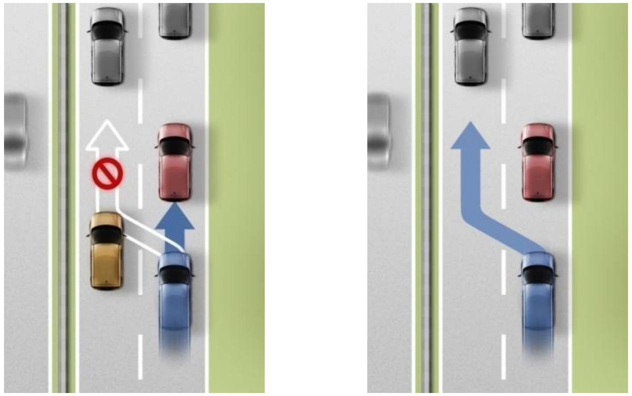
Sub-project 6: **EMIC**
Cost-efficient emergency intervention for collision mitigation

Seven demonstrator vehicles: six passenger cars and one truck

Sub-project 7: **Evaluation and legal aspects**
Test and evaluation framework for interactIVe applications | Analysis of legal aspects

Introduction
SP5: INCA

- Development of <u>in</u>tegrated <u>c</u>ollision <u>a</u>voidance and vehicle path control for passenger cars and commercial vehicles.
- “Vehicle path control” module dynamically evaluates a collision free trajectory in rapidly changing driving scenarios.
- 3 demonstrator vehicles:
  - Ford Focus
  - Volvo S60
  - Volvo FH13



- INCA coordinator: VOLVO
- INCA cooperators: CHALMERS, Ford, ICCS, VOLVO, DELPHI

Introduction
Current presentation

- Development of integrated collision avoidance and vehicle path control for commercial vehicles.
- 3 use cases are prioritized and the problem is narrowed down to path planning, actuators configuration, and control algorithm design.
- A robust path and speed controller should be developed to fulfil the requirements of all use cases.
- A simulation tool, that includes a heavy vehicle model, is needed to investigate performance and robustness of various actuator configurations, and the control algorithms.

Use cases suitable for path control

Definition and prioritization

- Use case: a description of specific sequence of interactions between the driver and truck to achieve a specific goal.
- Use cases are defined by name, accident type, and descriptive narrative.
- Use case prioritization is based on:
  - Accident statistics
  - Use case complexity
- Prioritized use cases are:
  - Rear-end collision avoidance (RECA)
    - Two lane road, single lane change
  - Run-off road prevention (RORP)
    - On a straight road
    - In a curve

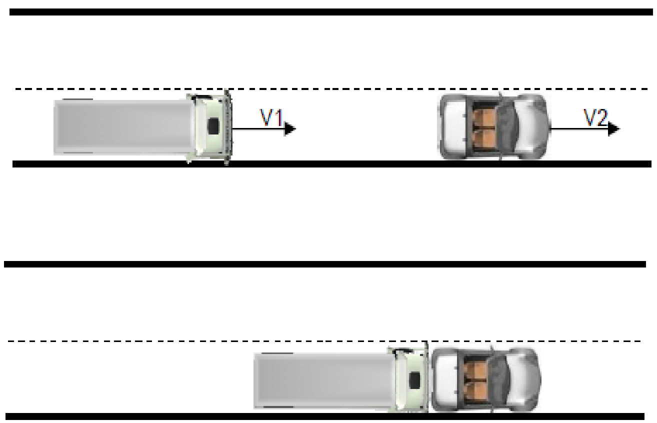
Use cases suitable for path control

Rear-end collision avoidance (RECA)

- **Use case name:** Rear-end collision avoidance (RECA)
- **Use case ID:** UC_01_504_v2

- **Use case description:**

  Prevents rear-end collisions
  by informing or warning the driver or
  by intervening by automatic braking
  and/or steering.



- **Reference**
  - **Level 1**

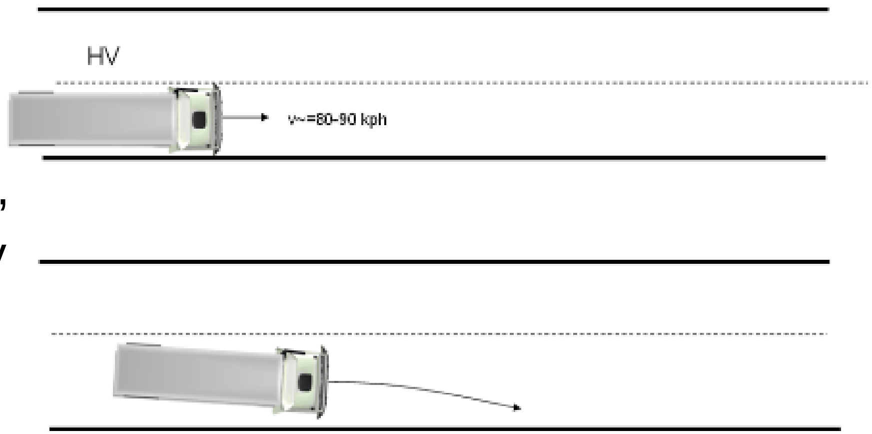
    TS_SP5_1 [Accident in queue (rear end)]
  - **Level 2**

    TS_SP5_1.1 [Rear end collision due to slowing vehicle in front]

Use cases suitable for path control
Run-off-road prevention on a straight road (RORP)

- **Use case name:** Run-off-road prevention on a straight road (RORP)
- **Use case ID:** UC_06_510_v2

- **Use case description:**
  Informs/warns the driver of an impending lane departure and, if needed, steers automatically to avoid road departure.



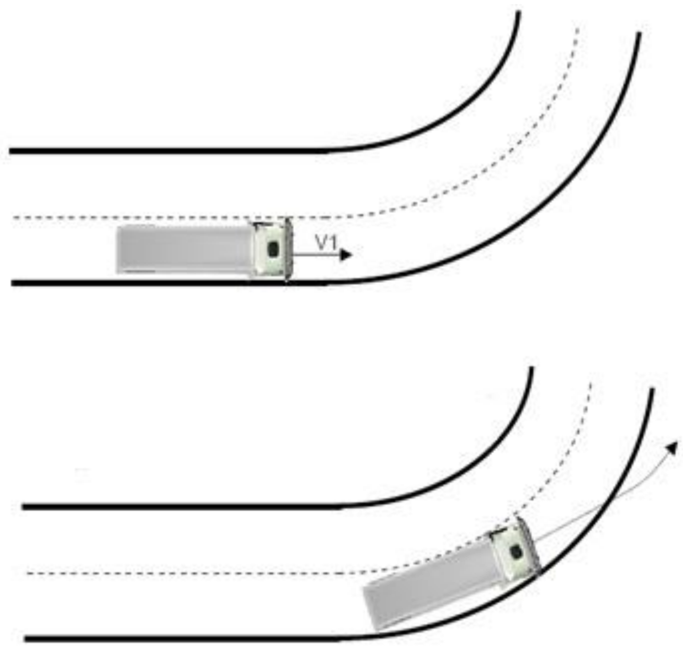
- **Reference:**
  - **Level 1**
    TS_SP5_2 [Single truck accident (run-off road)]
  - **Level 2**
    TS_SP5_2.1 [Running-off on a straight road]

Use cases suitable for path control

Run-off-road prevention in a curve (RORP)

- **Use case name:** Run-off-road prevention in a curve (RORP)
- **Use case ID:** UC_06_509_v2

- **Use case description:**
  Informs/warns the driver of an impending lane departure and, if needed, steers automatically to avoid road departure.

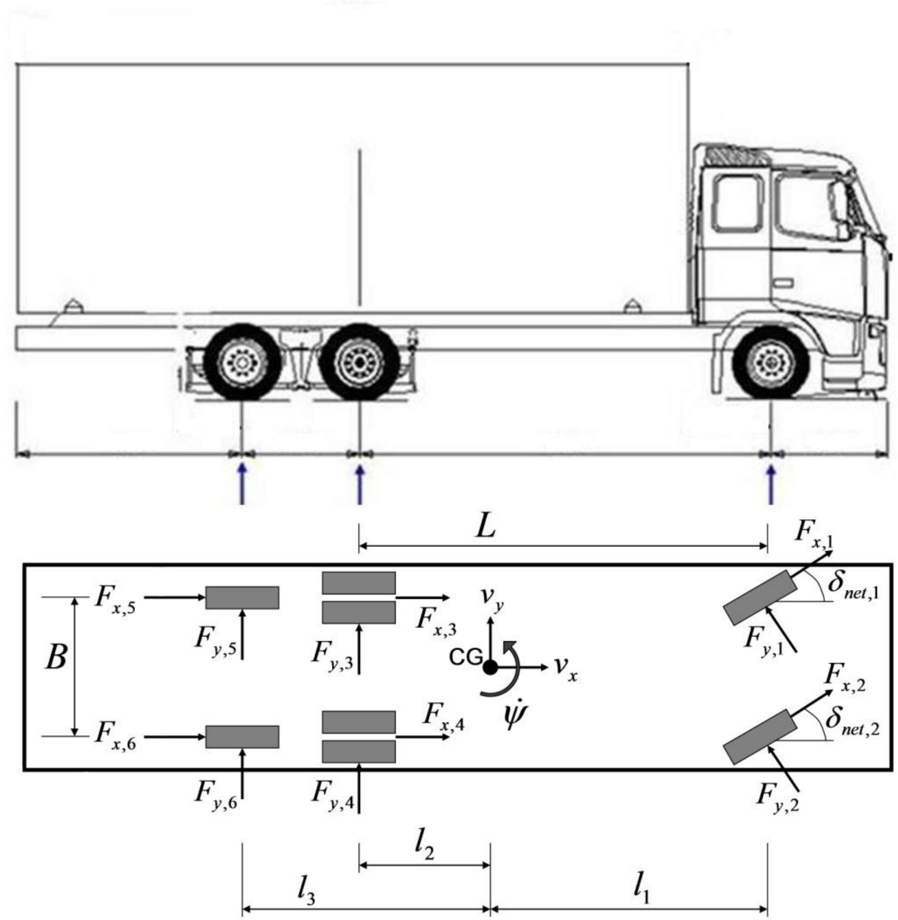


- **Reference:**
  - **Level 1**
    TS_SP5_2 [Single truck accident (run-off road)]
  - **Level 2**
    TS_SP5_2.2 [Running-off in a curve]

Heavy vehicle system dynamics in planar motion

The model

- A 4 DOF two-track model:
  - Longitudinal (X)
  - Lateral (Y)
  - Yaw (ψ)
  - Roll (ϕ)
- A nonlinear tyre model (Magic Tyre Formula):
  - Transient force build-up (relaxation length is considered)
  - Drop in adhesion coefficient for increased vertical load



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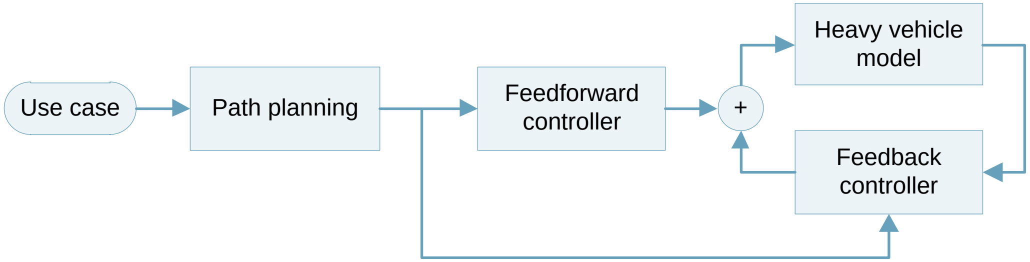
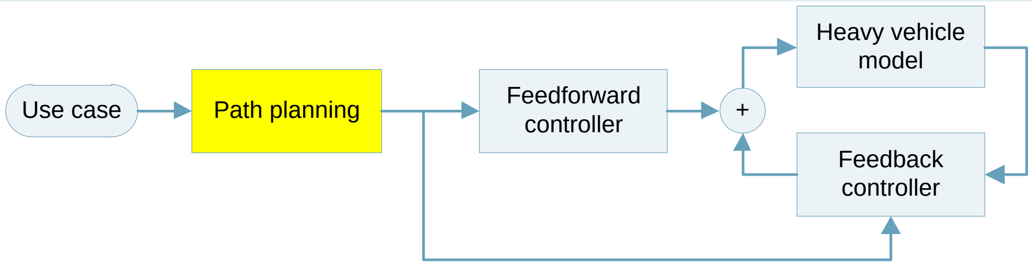
Path control algorithms

Overview

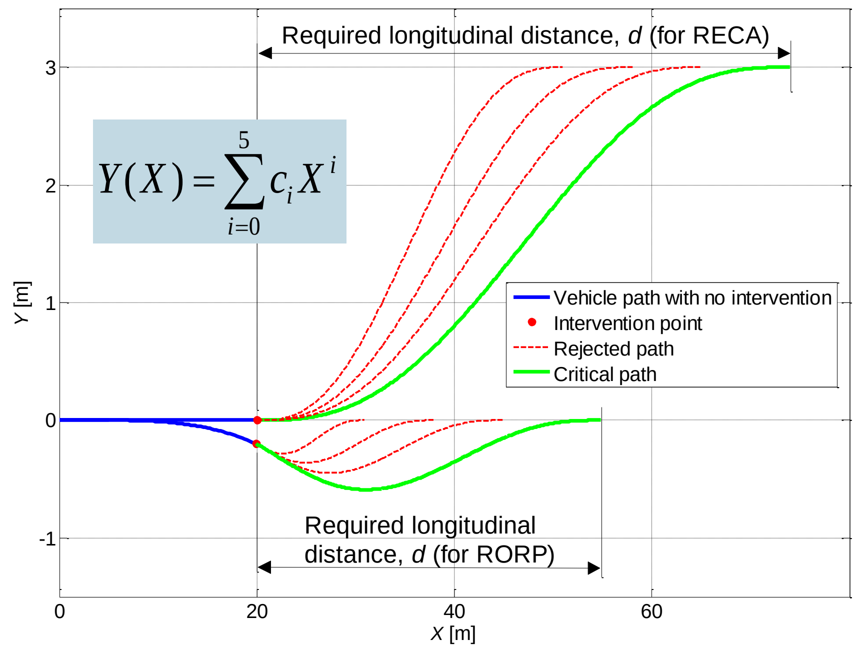
- Path planning block initiates the reference path that satisfies some criteria.
- Feedforward input is calculated based on the reference path.
- Feedback controller provides corrections to compensate for errors due to simplifications and uncertainties.
- General overview of the whole process:



Path control algorithms
Critical path



- Critical path: the shortest feasible escape path, that can be determined by iterative procedure:
  - Start with initial guess.
  - Checking criteria.
  - Increasing longitudinal distance if needed.
- Increasing longitudinal distance of the critical path is equivalent to adding safety margin to the manoeuvre.



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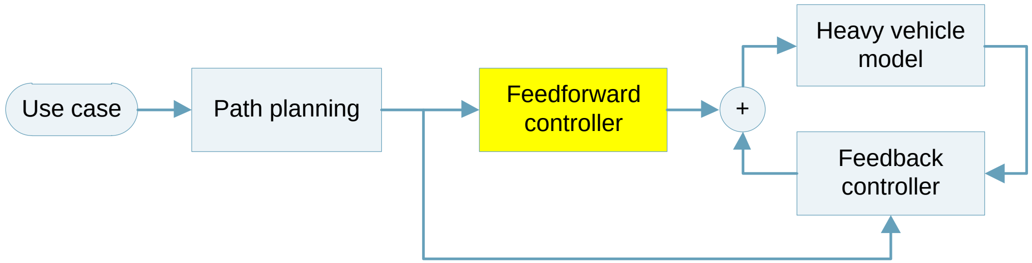
Path control algorithms
Feedforward control



- Feedforward control: steady state bicycle model is used to calculate steering inputs:

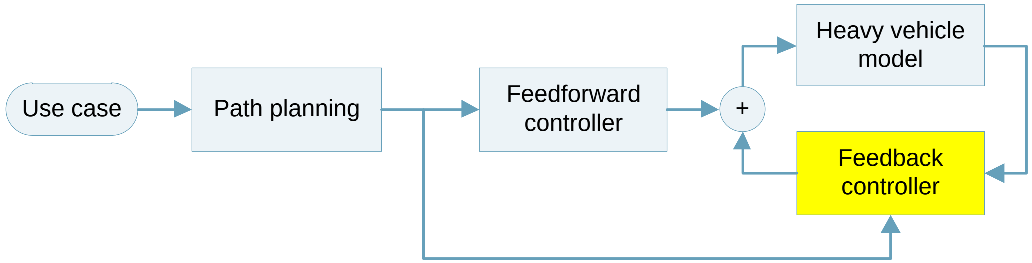
$$\delta_{FF} = \frac{l_e}{r} + K_{us}\frac{a_y}{g}$$

where:

$$l_e = l + \frac{\Delta^2}{l}\left(1 + \frac{C_{\alpha r}}{C_{\alpha f}}\right)$$

Path control algorithms

Feedback control



- Lateral position (Y) PID control:

$$\delta_{FB} = K_p (Y_{ref} - Y) + K_i \int (Y_{ref} - Y) d\tau + K_d (\dot{Y}_{ref} - \dot{Y})$$

- Yaw angle PD control:

$$\delta_{FB} = K_p (\psi_{ref} - \psi) + K_d (\dot{\psi}_{ref} - \dot{\psi})$$

$$\psi_{ref} = \tan^{-1}\left(\frac{dY_{ref}}{dX}\right) \qquad \dot{\psi}_{ref} = V \frac{d\psi}{dX} = V \frac{Y''}{1 + Y'^2}$$

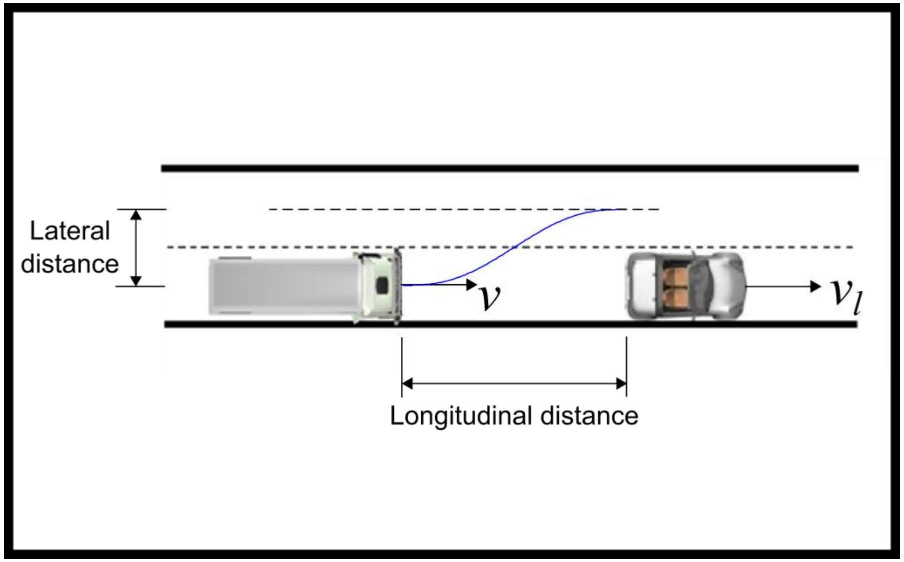
Simulation results

Rear-end collision avoidance (RECA)

Rear-end collision avoidance by steering: a single lane change manoeuvre.

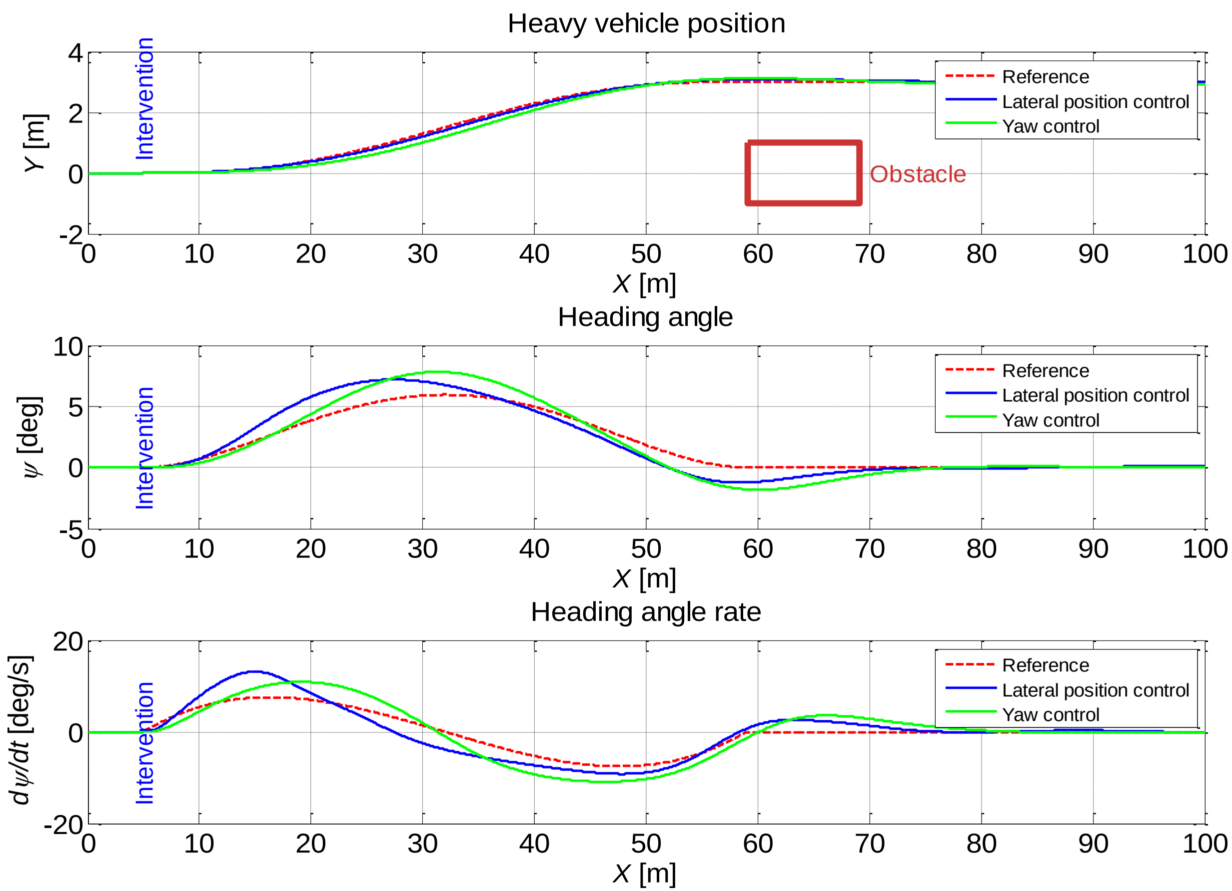
Parameter settings:

Parameters	**Values**
Friction, μ	0.65
Lateral distance	3 m
HV Initial Velocity, v	80 km/h
LV Initial Velocity, v_l	0 km/h
Longitudinal distance	56 m



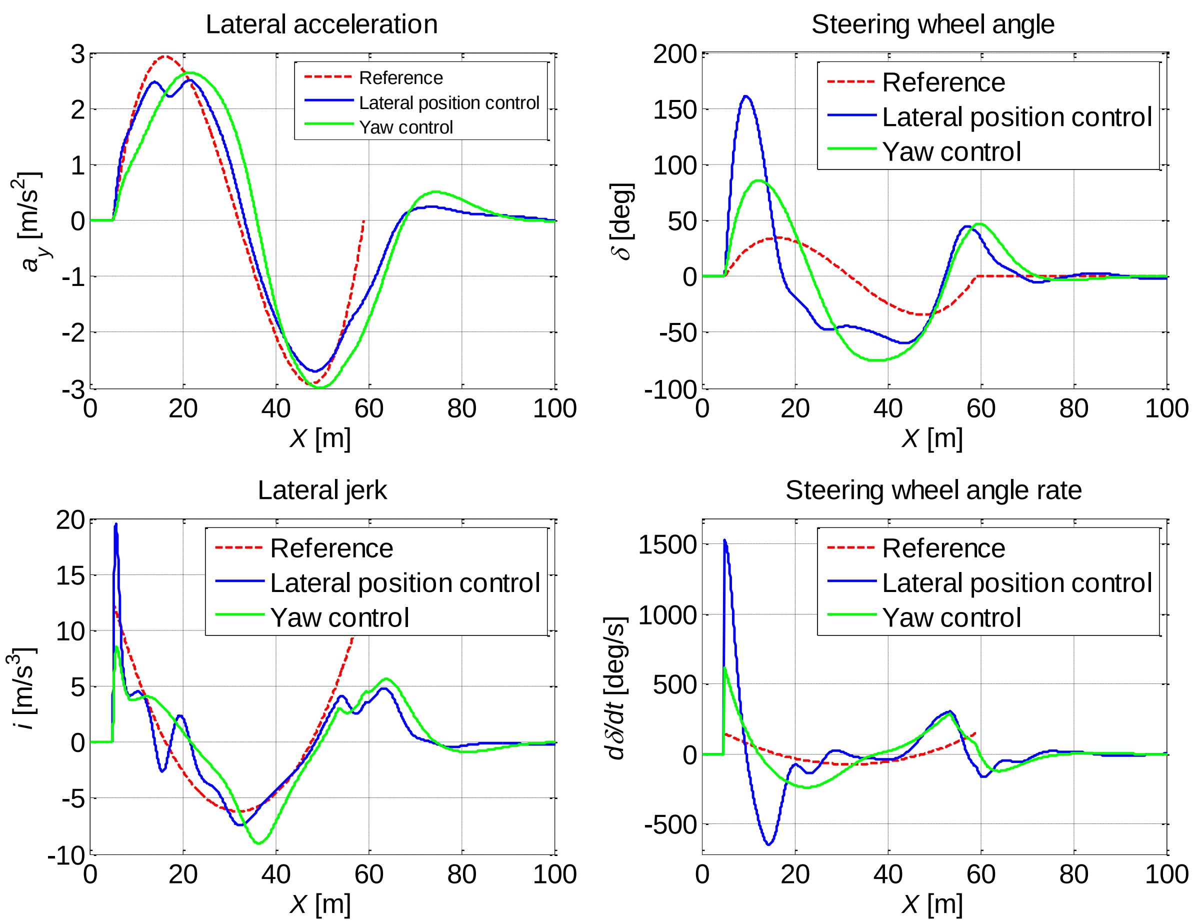
Simulation results

Rear-end collision avoidance (RECA)



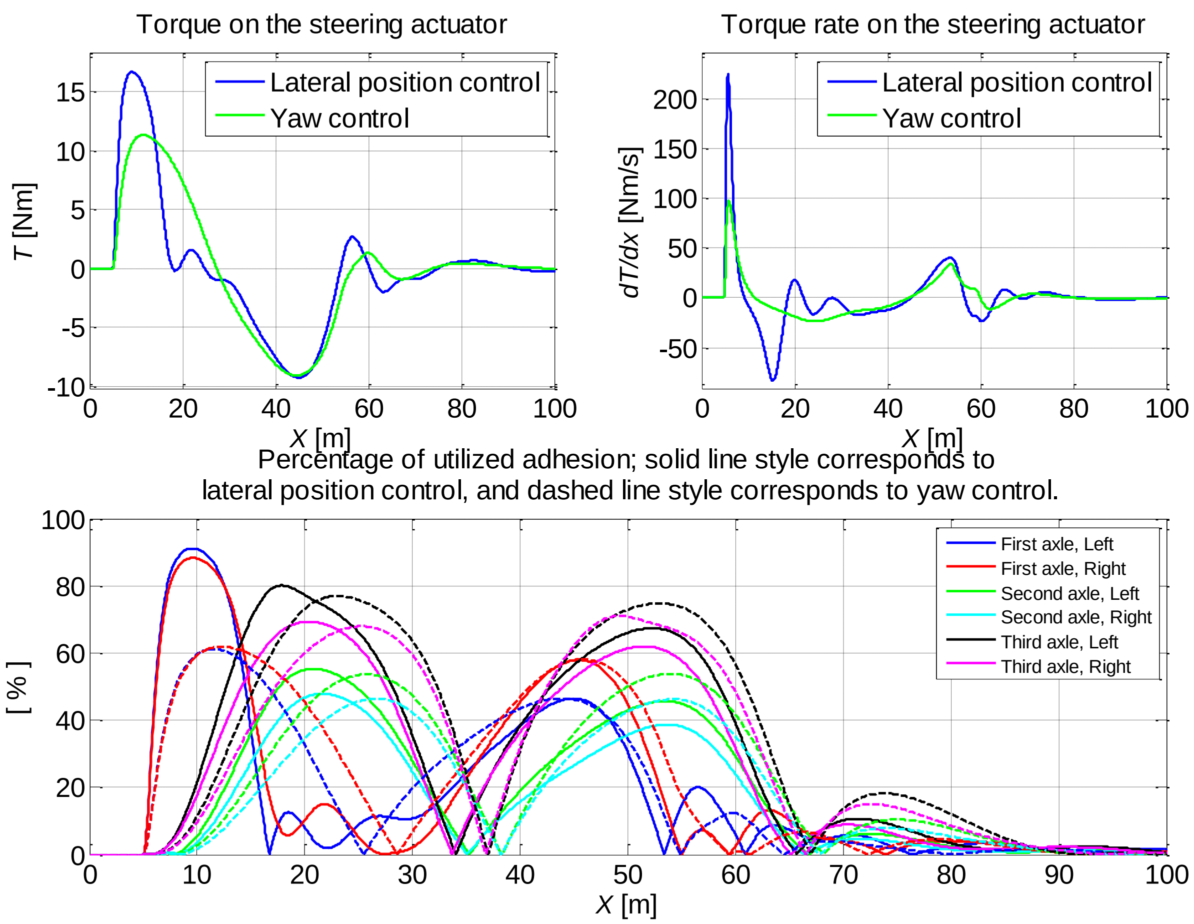
Simulation results

Rear-end collision avoidance (RECA)

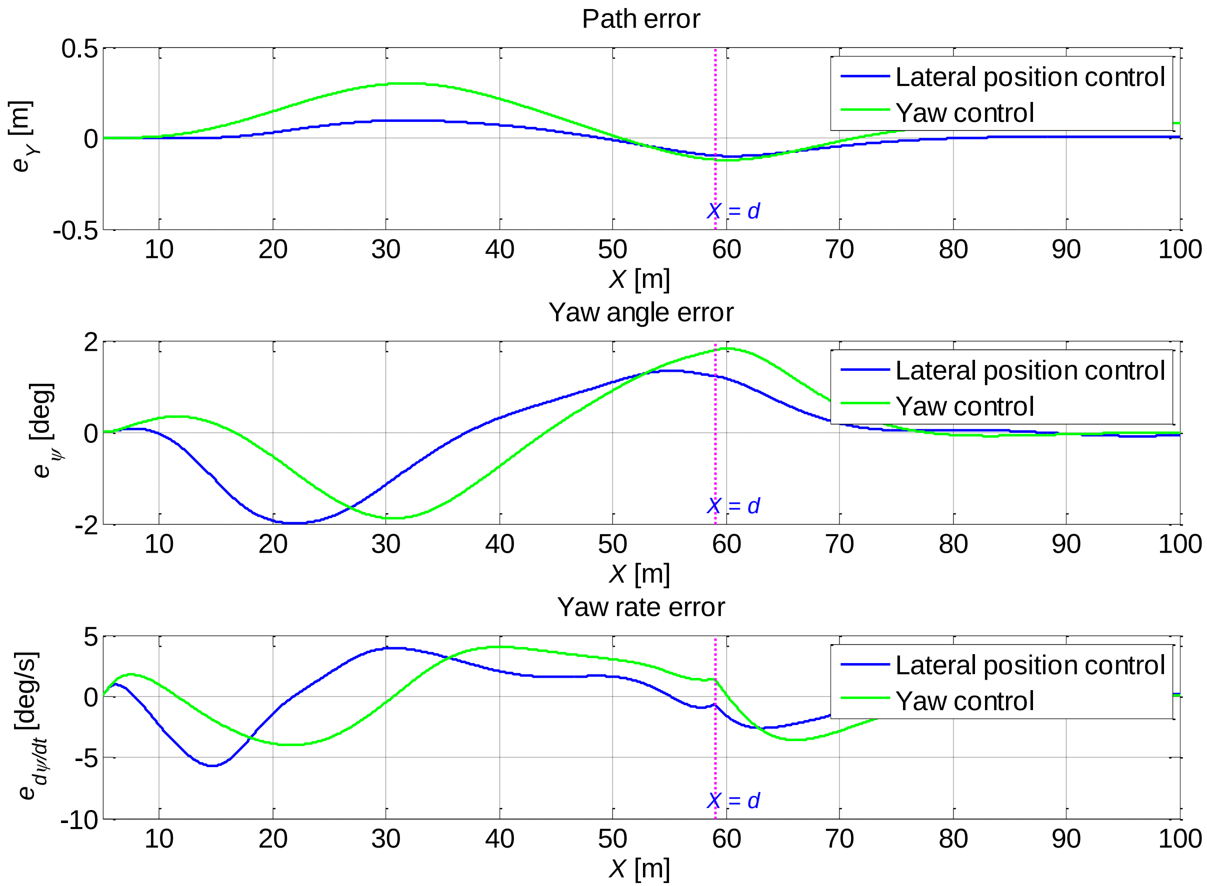


Simulation results

Rear-end collision avoidance (RECA)



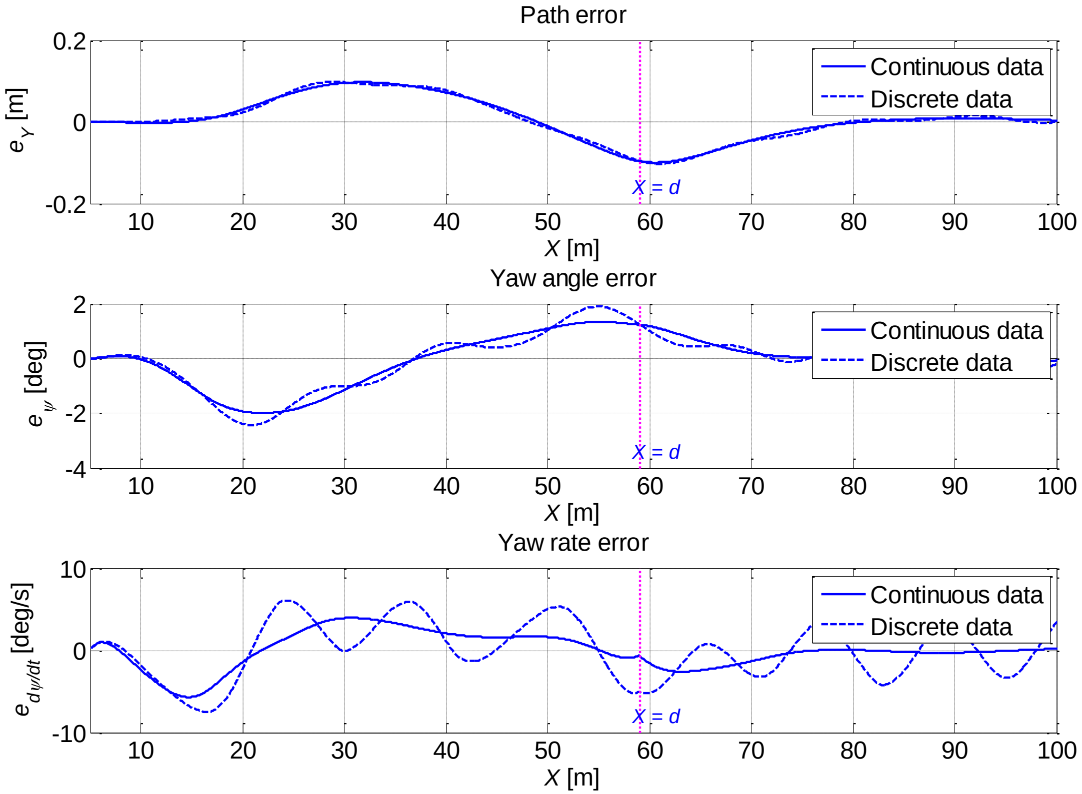
Simulation results
Rear-end collision avoidance (RECA)



Simulation results

Rear-end collision avoidance (RECA)

It is also tested with discrete input with update rate of 10 Hz; the controller demands new steering wheel angle every 0.1 second.

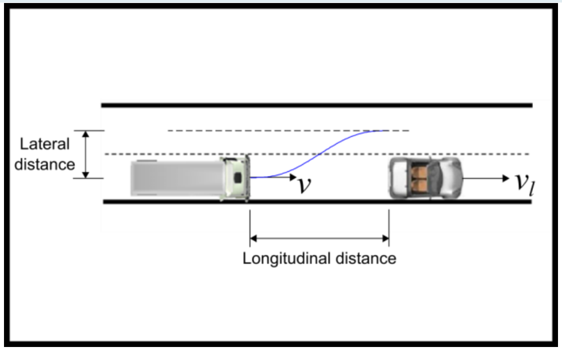


Model verification
Comparison with test data

- A series of tests were performed in the handling area of the Hällered Proving Ground.
- The steering input from test data is also used as input to the simulation in order to validate the simulation model.
- The results presented here also show a sample performance of the controller.

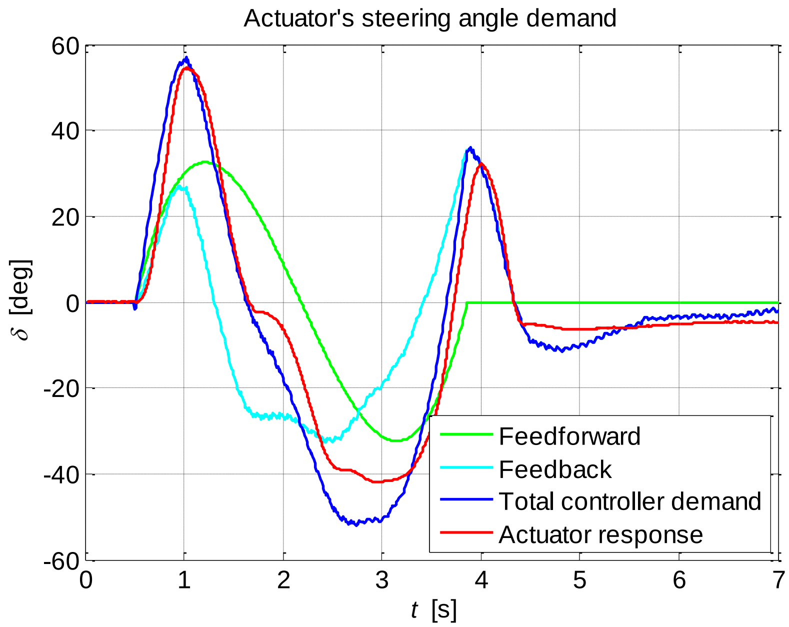
Model verification
Comparison with test data

A single lane change manoeuvre was performed with 50% safety margin for longitudinal distance.

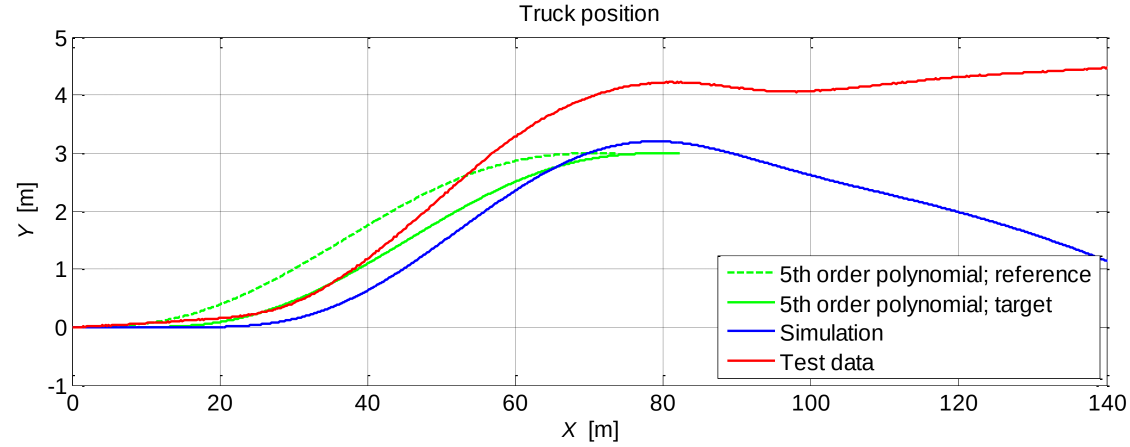


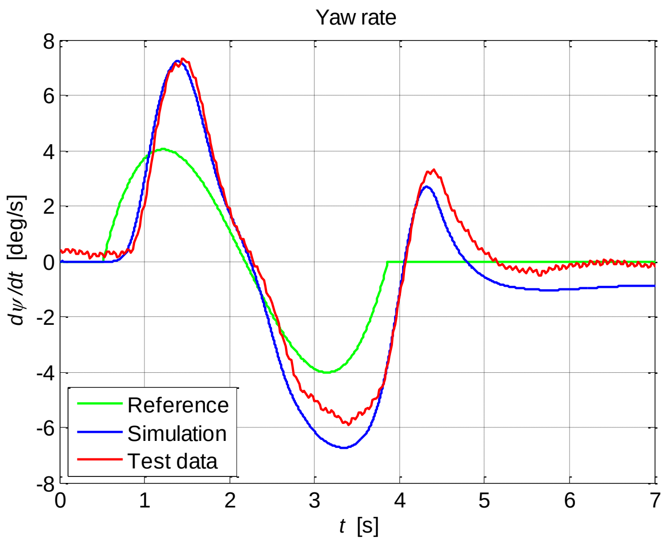
Parameter settings:

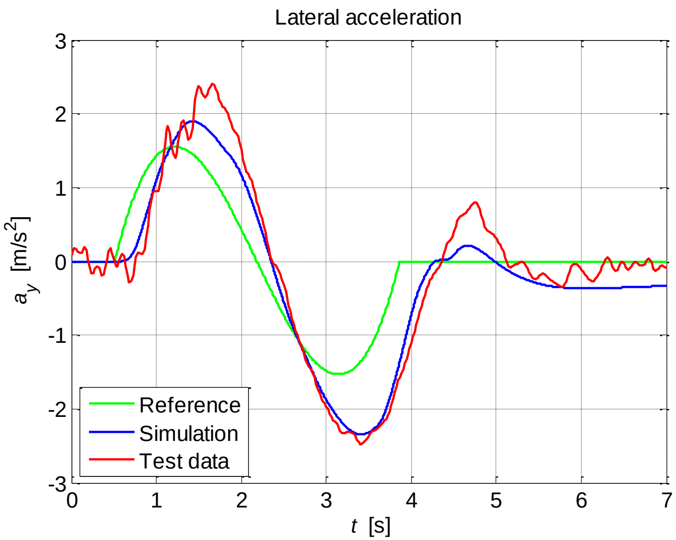
Parameters	Values
Lateral distance	3 m
HV Initial Velocity, *v*	80 km/h
LV Initial Velocity, v_l	0 km/h
Longitudinal distance	73.5 m



Model verification
Comparison with test data







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Thank you.

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