

TNO Automotive
Advanced Chassis & Transport Systems

Development of Advanced Driver Assistance (ADA) systems using Hardware-In-the-Loop technology

TNO | Knowledge for business

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Development of ADA systems using HIL technology - VD Expo 2006 May 2006

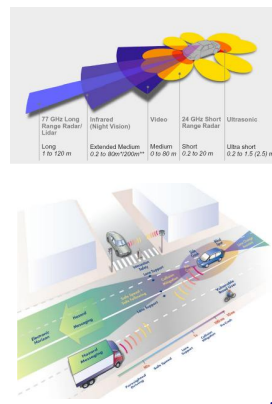
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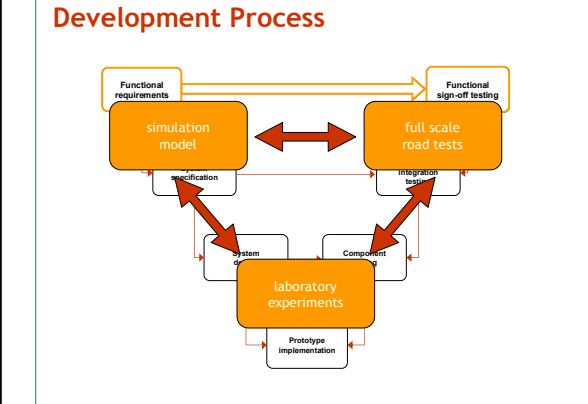
Introduction

- Advanced Driver Assistance**
 - vehicle + environmental sensor(s)
 - assistance functionality, e.g.:
 - Advanced Cruise Control (ACC)
 - Forward Collision Warning
 - Collision Mitigation
 - Collision Avoidance
 - etc...
- Developments in Advanced Driver Assistance**
 - (slowly) increasing presence in passenger cars and trucks
 - comfort → safety
 - ⇒ efficient development process increasingly important



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Development Process




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Development process

Major challenges

- In general, testing is:**
 - Costly
 - Unsafe
 - Time consuming
 - Inaccurate
 - Not reproducible
- Difficult to analyze performance of individual sensors, controllers and actuators**




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VeHIL

Basic concept

- Relative motion: motion of other road users with respect to the test vehicle (Vehicle Under Test – VUT)**




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VeHIL Basic concept

- Relative vs. absolute vehicle motions

On the highway



At the VEHIL test facility

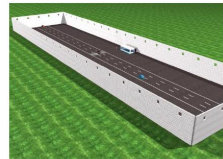


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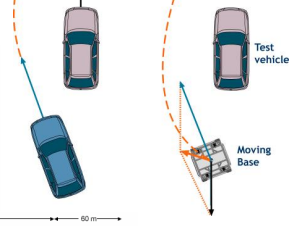
VeHIL Basic concept

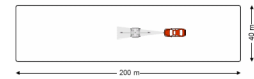
- Relative vs. absolute vehicle motions

Real world




VEHIL






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VeHIL Hardware in the Loop concept




Vehicle Under Test (equipped with ADAS)



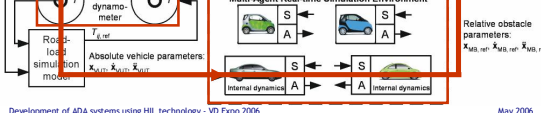
Sensor



Moving Base with dummy (representing other traffic participant)



Closed loop



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VeHIL Summary

- World-wide unique test lab for calibration and verification of IVS
 - Accurate & reproducible
 - Efficient & flexible
 - Safe for man & material
 - Benchmarking & calibration of sensor systems
 - Controlled environment for rapid prototyping of
 - Sensor data fusion algorithms
 - Vehicle control/decision algorithms
- Unique features
 - Closed-loop interaction between Vehicle under Test and other traffic
 - Comparison of sensor output with 'ground truth' data
 - Only safe solution for testing of safety-critical traffic scenarios enabled by use of highly manoeuvrable Moving Bases

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Case: Stop&Go ACC development

- Project objective
 - Integrate any forward looking sensor in any vehicle to illustrate and further explore its as the basis for Advanced Driver Assistance systems.
- Flexibility on
 - Forward looking sensor (FLS)
 - Vehicle (Sedan, SUV, Truck, Automatic gearbox, CVT)

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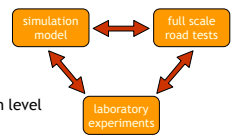
Case: Stop&Go ACC development Approach (1)

simulation model

↔

full scale road tests

- Step 1: basic control design
 - mathematical modeling
 - basic controller design on a simulation level
- Step 2: vehicle implementation
 - computer system + controller software
 - interfacing brake/throttle
 - interfacing FLS, vehicle
 - Human-Machine Interface
- Step 3: ACC and Stop & Go controller HIL testing
 - vehicle 'in the loop'
 - FLS not included yet



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Case: Stop&Go ACC development
Approach (2)

- Step 4: full system HIL testing
 - VEHIL: Vehicle Hardware In the Loop
- Step 5: road tests
 - Fine tuning to various traffic situations & driver expectations

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Case: Stop&Go ACC development
Step 1: Basic Control Design

- Modelling
 - very limited because real challenge is at (very) low speeds up to full stop, which is tough to accurately simulate
- Control Design

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Case: Stop&Go ACC development
Step 1: Basic Control Design

- Control design
 - acceleration control: open loop 'allocation' of a_{ref} to throttle & brakes
 - ACC and Stop & Go control: PD-controller + feedforward

$$a_{ref} = K_h(h_{ref} - h) + K_v(v_1 - v_2) + a_{refFF}$$

with $K_h = f_h(h, v_1, v_2)$
 $K_v = f_v(h, v_1, v_2)$

- "maintain headway, without high velocity difference"
- Conflicting requirements
 - Safety: limited velocity difference/ desired headway (as a function of velocity)
 - Comfort and fuel economy: smooth reaction

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Case: Stop&Go ACC development
Step 2: Vehicle implementation

- Throttle and brake interface
 - Throttle-by-Wire widely used and generally easy to interfere
 - Brake interfacing either by accessing factory brake system or by implementing Electro Hydraulic Brake-by-Wire (EHB)
- HMI
 - Driver input
 - same lever, same functionality
 - Driver feedback
 - same display
 - additional 'MIO detected' indicators (2 LED's)

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Case: Stop&Go ACC development
Step 3: ACC/S&G controller HIL testing

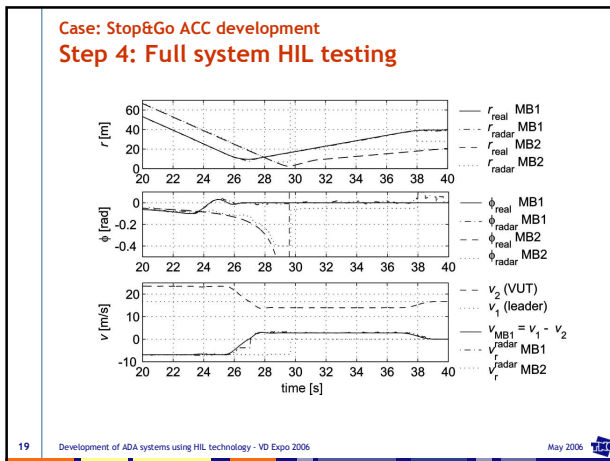
- Vehicle on VeHIL chassis dynamometer
 - Simulation of vehicle ahead
 - Controller tuning, FLS-independent
- Specifications
 - Track width 1.2 - 2.5 m
 - Wheel base 0.8 - 4.0 m
 - Independent drum drive
 - Total peak power 832 kW
 - Maximum force 24000 N
 - Response time < 10 ms
 - Drum diameter 1592 mm
 - Maximum speed 250 km/h
 - Cars 800 - 3500 kg
 - full dynamic range, 10 m/s²
 - Commercial vehicles ≤ 12000 kg
 - reduced dynamics

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Case: Stop&Go ACC development
Step 4: Full system HIL testing

- Truck in VEHIL
 - evaluation of full system: Vehicle, ACC/S&G controller, FLS
 - other traffic simulated by wheeled mobile robots
 - Scenario's from experience, sensor expectations and (!) iterations with step 5

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- Case: Stop&Go ACC development**
Step 5: Road tests
- Explicitly distinguish traffic situations
 - accelerate at green traffic light ↔ accelerate in traffic jam
 - approach slow vehicles with small headway ↔ with (very large) headway
 - straight line following ↔ in-corner following
 - ...
 - and tune controller to these situations
 - Take driver expectations into account
 - The result ... let's drive!
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Conclusions

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