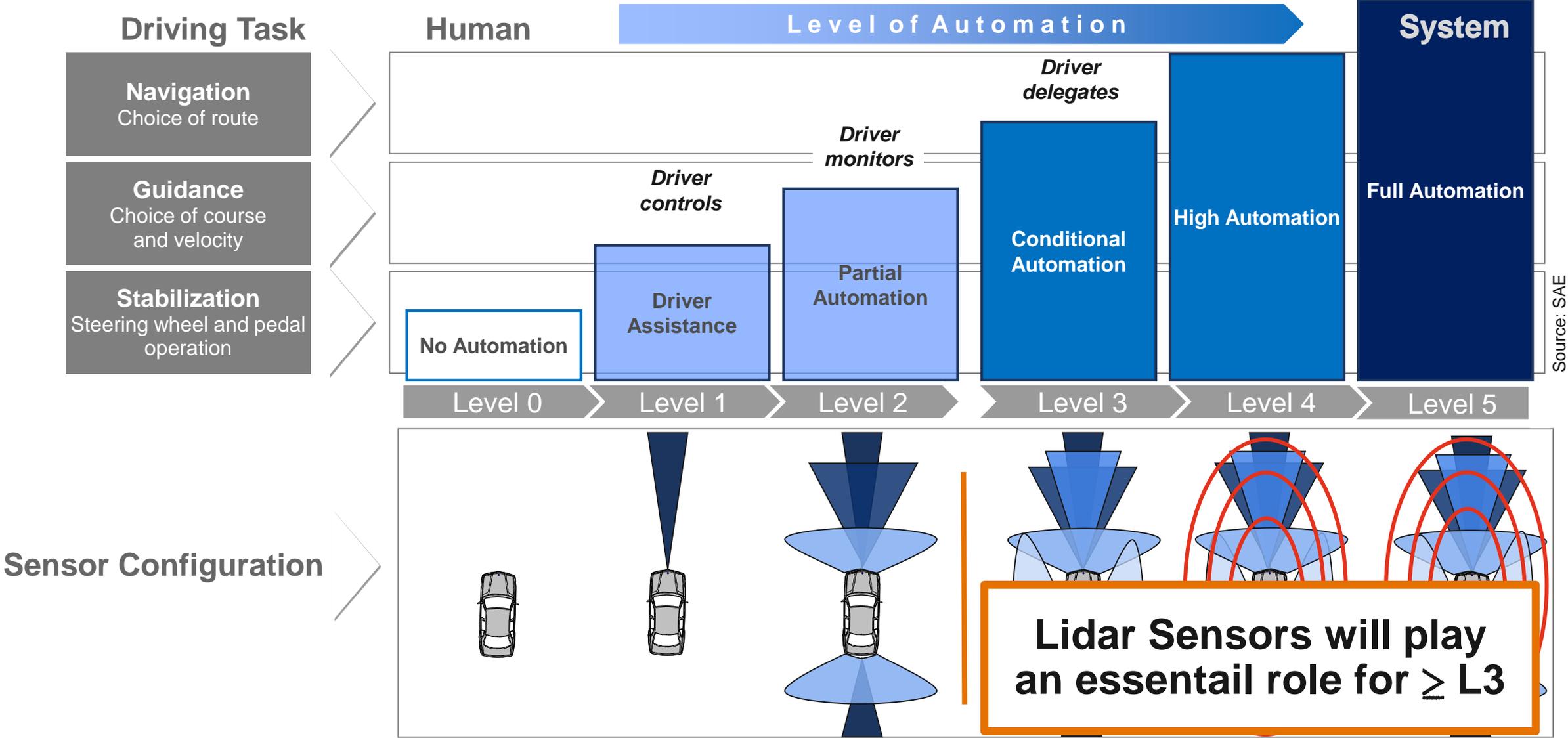# Lidar Test Methods for Automated Driving – Past, Present and Future
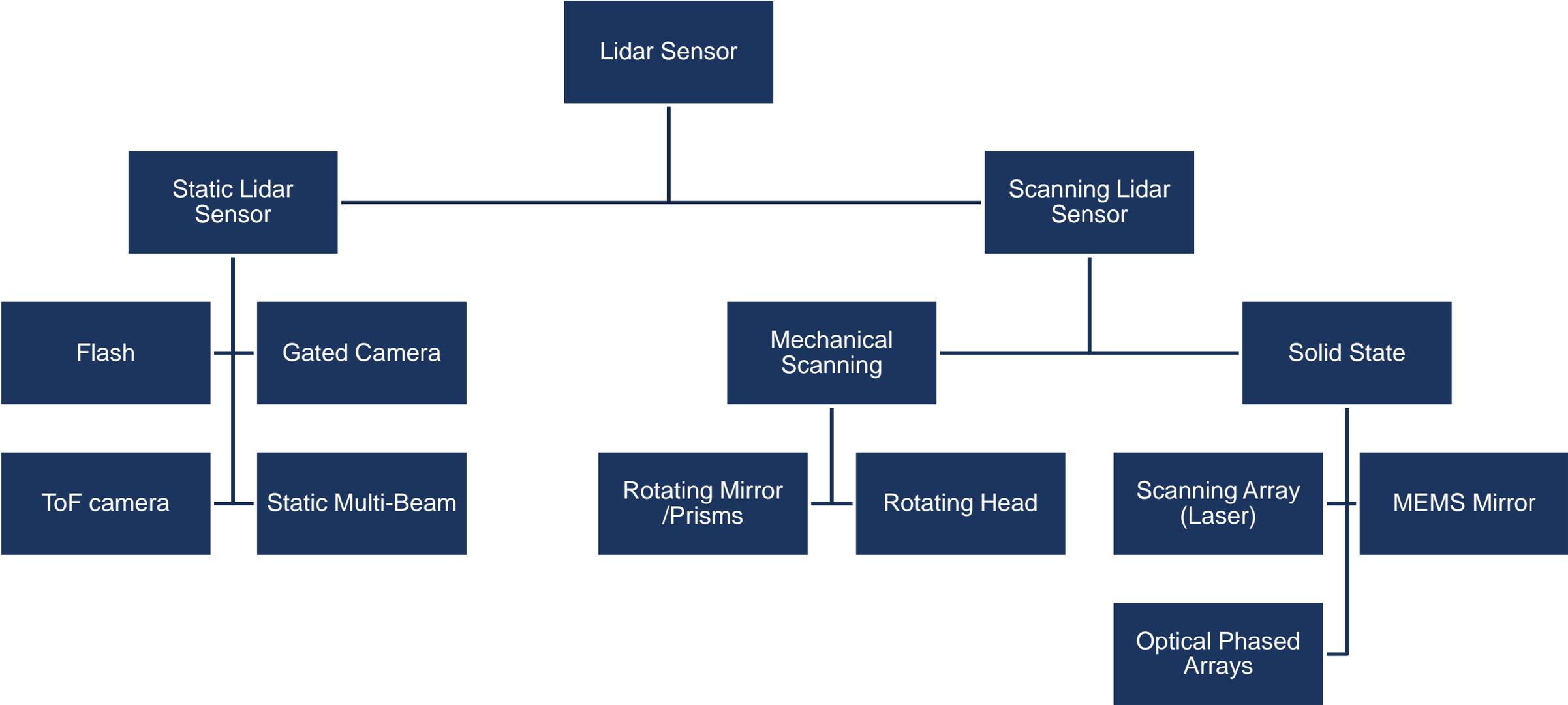
Dr. Adrian Zlocki
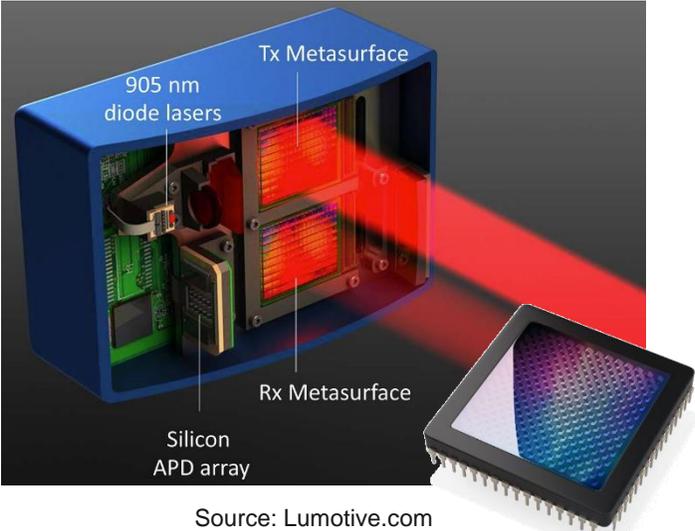
Sensor Configurations in different Automation Levels

fka

Driving Task

Navigation
Choice of route

Guidance
Choice of course and velocity

Stabilization
Steering wheel and pedal operation

Human

Level of Automation

System

Driver delegates

Driver monitors

Driver controls

High Automation

Full Automation

Conditional Automation

Partial Automation

Driver Assistance

No Automation

Source: SAE

Level 0 > Level 1 > Level 2 > Level 3 > Level 4 > Level 5

Sensor Configuration

Lidar Sensors will play an essentail role for ≥ L3

Lidar Sensor Classification

Examples for Automotive Lidar Sensors

rotating mirror 750rpm

heated front screen

receiver unit

laser diode

connector to FlexRay bus

scan angle 145°

Tx Metasurface

905 nm diode lasers

Rx Metasurface

Silicon APD array

Source: Lumotive.com

Evaluation Methodologies

Methods

DRIVER VEHICLE ENVIRONMENT

Field Operational Test

+ trajectory & interaction 1:1 perceptible
- reproducibility limited
- relevant situations occur rarely
- extensive effort

REAL

Controlled Field

+ trajectory & HMI quite well perceptible
o reproducibility
- situation space limited
- high effort

Dynamic Driving Simulator

+ trajectory & HMI well perceptible
+ reproducibility
+ critical situations possible
o medium effort

Increase of validity

Simulation

- trajectory bad perceptible
o interaction limited perceptible
+ reproducibility
+ low effort

VIRTUAL

Determination of Test Level

Tools for physical Testing

» **Different test tools are available for automation level 1 and 2 systems and for active safety systems**

» **Scenario based test tools are designed sensor independent**

» **Design of test tools according to physical principle of sensor under test**

» **This results in different characteristics of targets**

- Optical characteristics
- Reflectivity (e.g. leg movement in pedestrian dummies for radar Micro-Doppler detection)
- Heat systems for IR-sensors
- Crash ability (scenario dependent)
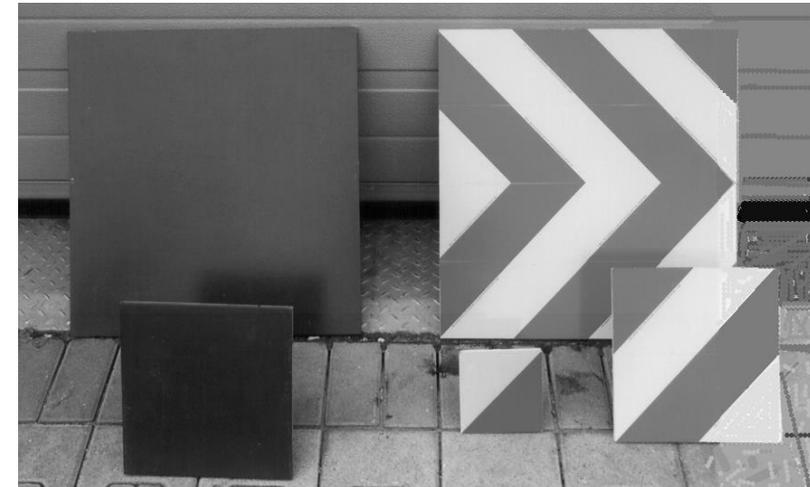- Etc.

Examples for stationary and dynamic tests

Specific Lidar Sensor Targets

Real target vehicles

Vehicle class	Target vehicle	Vehicle
F1	truck with trailer	MAN F 90
F2	transporter	MB Sprinter
F3	passenger car	BMW 3 series
F4	motorcycle	Honda VFR 850
F5	truck	MAN F 90
F6	light truck	MB 1317

Artificial targets

| Triple reflector	Radar diameter [m^2]	Type of vehicle
R_1	10.000	truck
R_2	1.000	transporter
R_3	60	passenger vehicle
R_4	6	motor cycle
R_5	1	pedestrian

» **Same targets used since 1997, therefore measurements comparable**

» **The first public demonstration of distance sensors within automotive applications is dated back to the PROMETHEUS project (1986-1994)**

» **Test methodology for reproducible and reliable tests are developed by a consortium (several OEMs and suppliers) under the lead of ika/fka in 1996**

» **ika/fka sensor test catalogue for front facing sensors available since 1999**

» **Initial ADAS function: ACC and ACC relevant scenarios**

Lucas Automotive GmbH

Forschungsgesellschaft Kraftfahrwesen Aachen mbH

Thomson-CSF Radars & Contre-Messures

A.D.C GmbH

Adam Opel AG
Bayerische Motorenwerke AG
Daimler-Benz AG
Daimler-Benz Aerospace AG
Hella KG Hueck & Co
ITT Automotive Europe GmbH
MAN Nutzfahrzeuge AG
Robert Bosch GmbH
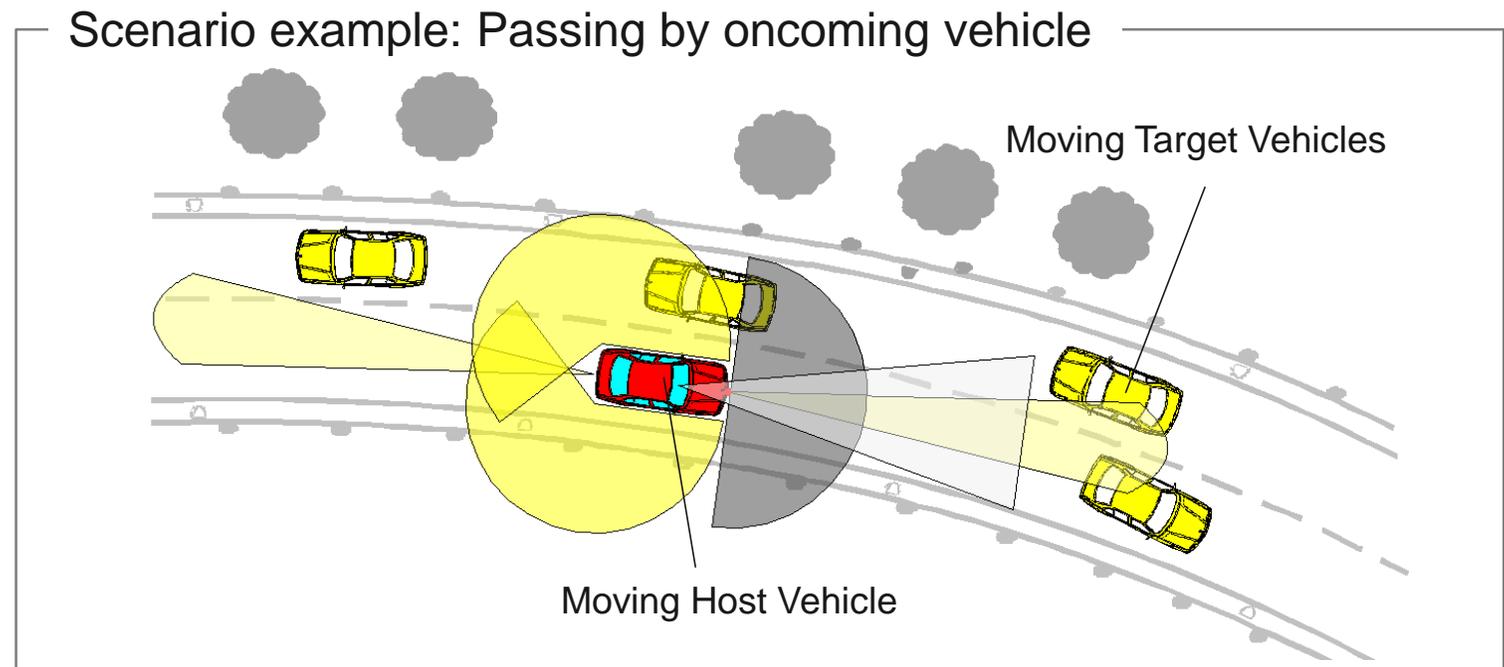Siemens AG
Volkswagen AG

Stationary Test Scenarios
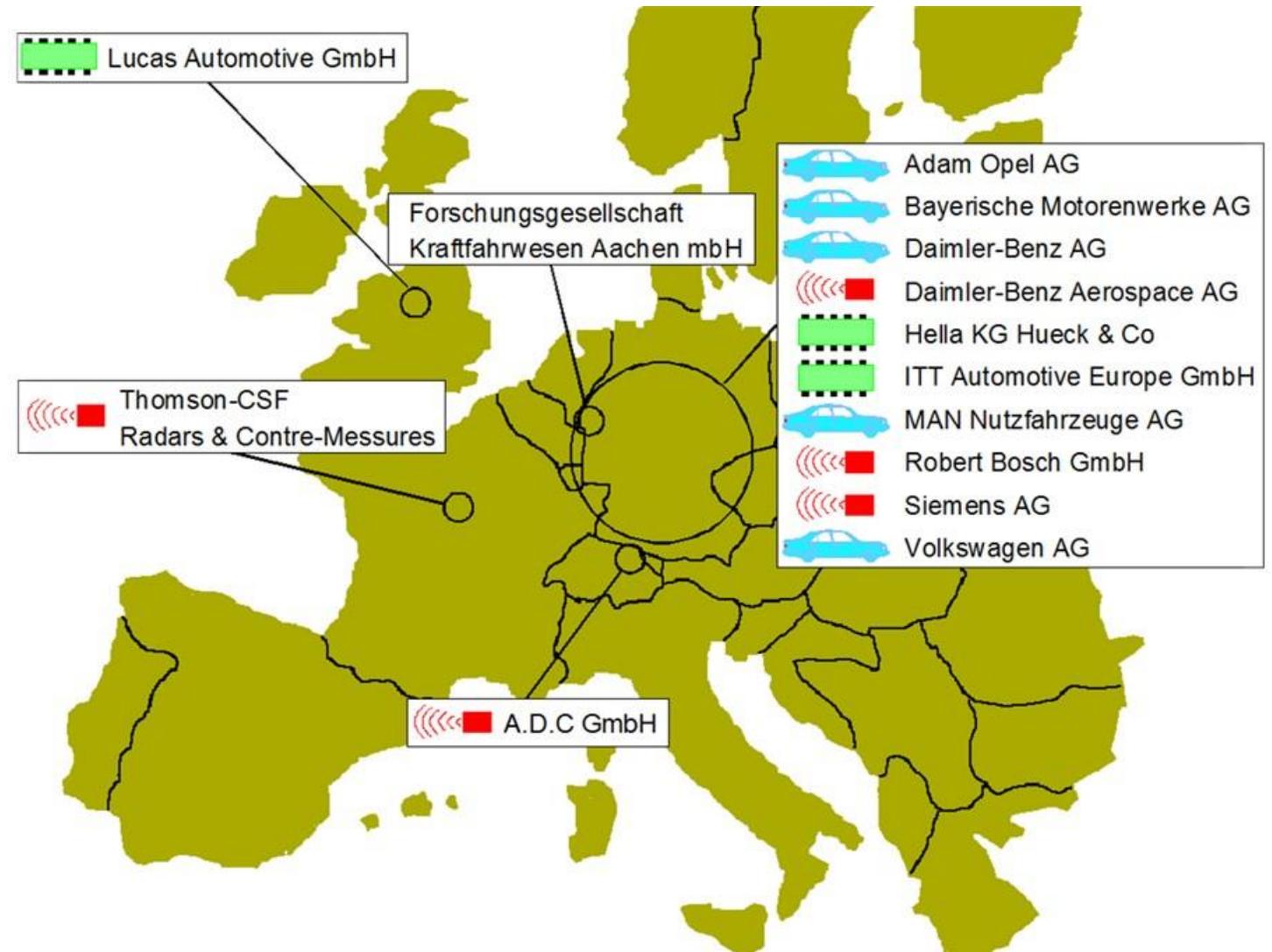
» The basic tests aims to determine the sensor characteristics such as range, detection field, reaction time etc.

» Those almost static tests are conducted by means of artificial and real target vehicles.

» The tests can be divided:
   ▪ Maximum and minimum range
   ▪ Clarity in case of overshoot
   ▪ Field of location
   ▪ Black holes
   ▪ Dynamic
   ▪ Reaction time

Scenario example: Field of location with artificial target

Stationary Host Vehicle   Stationary Artificial Target
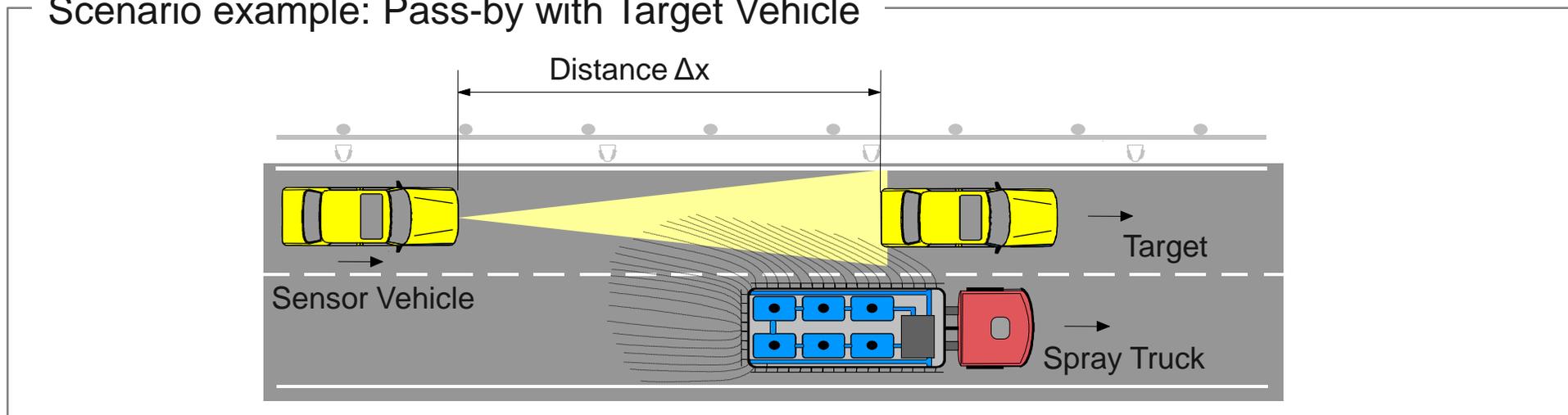
Driving Tests in Dynamic Test Scenarios
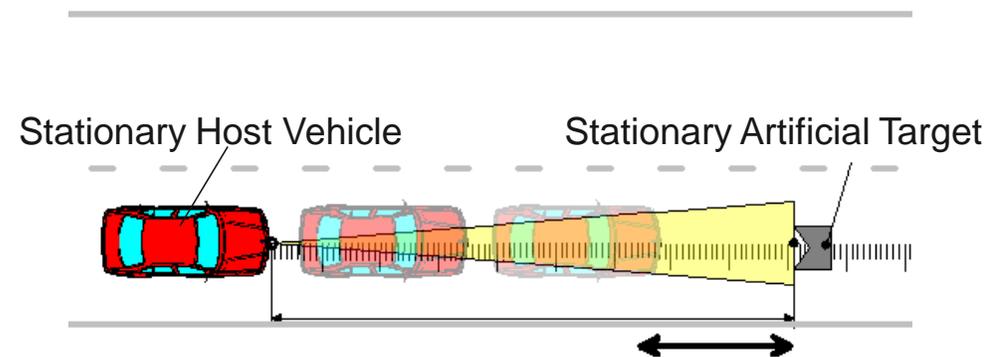
» The sensor characteristics under realistic road and environmental conditions are tested within the driving tests

» The tests are conducted in open traffic, considering different curvatures and traffic situations (e.g. passing by vehicle, cut-in/ cut-out etc.)

» Each scenario is tested under specified conditions and is reproducible, due to standardized target vehicles and test tracks

Scenario example: Passing by oncoming vehicle

Moving Target Vehicles

Moving Host Vehicle

Tools for physical Testing - Example Spray Truck

» Test possibilities
  - Reproducible artificial spray cloud
  - Different nozzle configuration for variation of spray density
» Technical data
  - 6 water tanks with an overall capacity of 6000 l
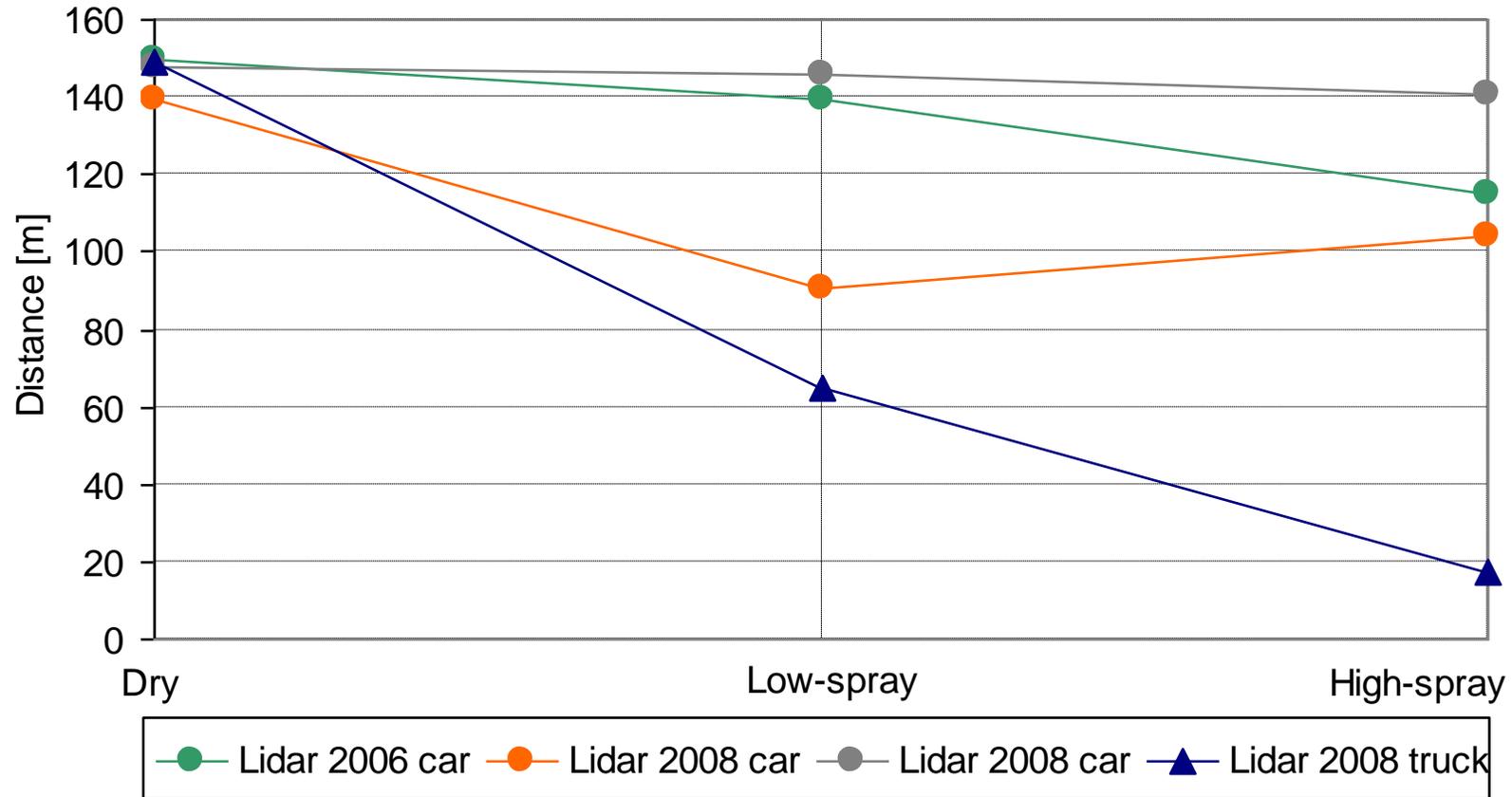 - Pump delivery volume: 600 l/min at 6 bar

Scenario example: Pass-by with Target Vehicle

Distance Δx

Target

Sensor Vehicle

Spray Truck

Examples from Testing - Lidar Sensors Spray Tests

» **Scenario: Approaching Spray Truck at 80/120 km/h**

» **Detection range for lidar sensors depend on weather conditions**
» **Improvement in tracking algorithm provides good results for new lidar sensors**
» **Mounting position needs to be taken into account in algorithm development**

Virtual Lidar Sensor Tests for Automated Driving

» **Modelling of sensor requires modelling of the environment (including all characteristics)**

» **3D environment models for camera sensors are well developed**

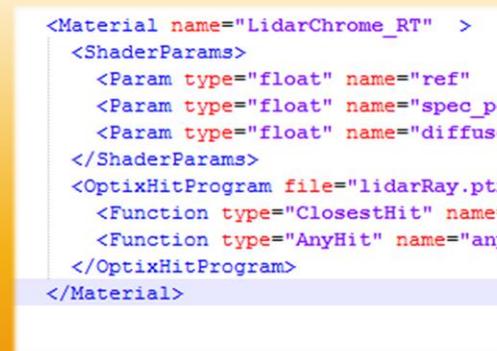» **Modelling radar and lidar sensors are currently in focus for virtual sensor tests**

3D Environment Model
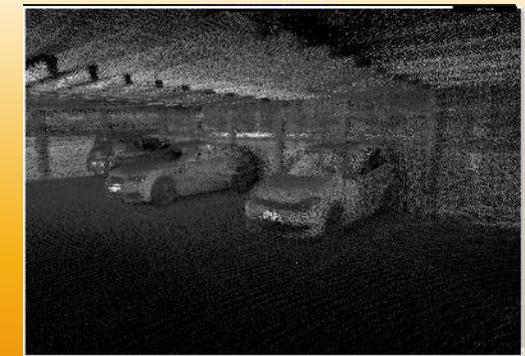
fka LIDAR Sensor Plugin
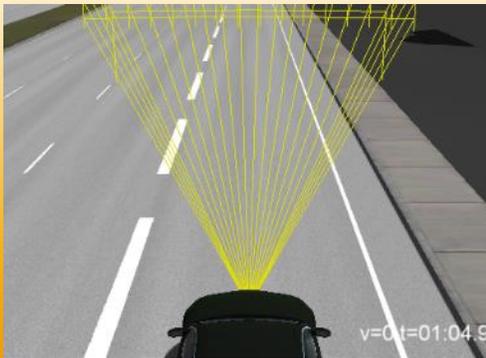
Beam Generation
According to sensor specifications
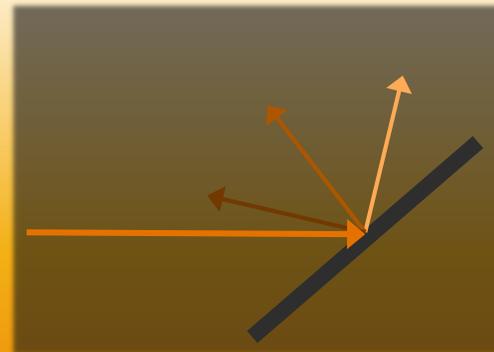
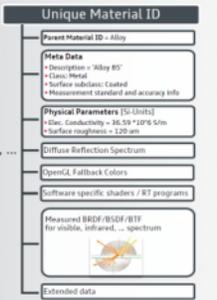**Ray-Surface Interaction Model (BRDF)**
Fully programmable

Material Database
Free choice of parameters to match real-world test results

Post Processing & Point Cloud Generation

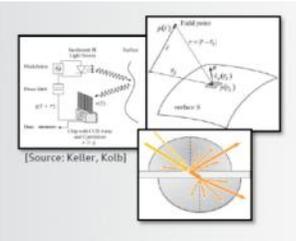# Lidar Sensor Modelling for Sensor Simulation

Advanced Materials

Extended material and light source description

- covering also non-visible light spectrum
- meta data for material/emitter classification
- storage of physical properties in form of scalars and textures

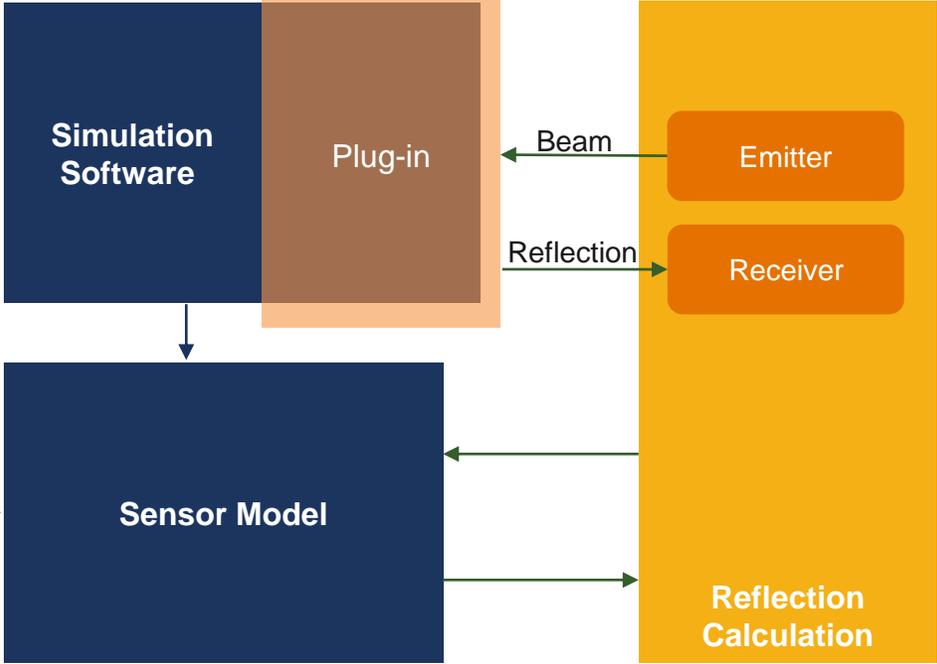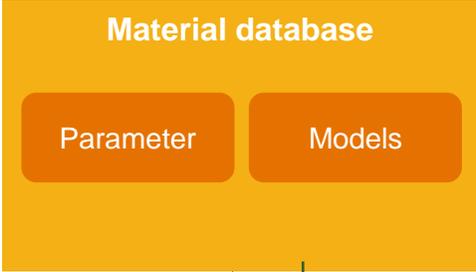**Literature** · **Validation** · **Testing**

Sensor Model

Physics-oriented modeling of

- sensor data acquisition
- related systematic & stochastic distortion effects
- material, surface and emitter properties

Material database

Parameter | Models

Simulation Software

Plug-in

Beam — Emitter

Reflection — Receiver

Sensor Model

Reflection Calculation

Functional based vs. Scenario based

» **Functional based test cases are derived from functions at the beginning of the development process**
- Strong focus on use cases (Quadrant I)
- True Negative (Quadrant IV) can be analysed
- Difficult to examine false negatives (Quadrant III)
- Impossible to identify false positives (Quadrant II)

» **Currently scenario based approaches are in focus**
- Independent of function
- Can be defined by third party

» **Need of methodology for false positive detection**
- **Data based scenarios**
- Can be collected and stored in data bases

	Condition Present	Condition Absent
Positive Results	**I** True Positive	**II** False Positive
Negative Results	**III** False Negative (Missed)	**IV** True Negative

fka's PEGASUS Database for Scenario based Testing

fka

Data with traffic events	(Logical) scenario	(Logical) scenario with parameter distributions
		Concrete scenario

Input Data

Source FOT

Source Test drives

Source xy

Source Accident data

1. Integration by database mechanics

3. Generation of complete scenario space

2. Storage in database

4. Output generation & test concept

Usage testing ground

Usage driving simulator

Usage simulation

Data Sources Possibilities for Senario Extraction

How to measure?		Scenario Description	Scenario Relevance	Scenario Reference
	Real Traffic Data (uninfluenced driving)	Is Scenario Description complete?	Frequency of scenarios for current traffic?	Human performance in scenario?
	FOT/Pilots with active AD function	Complete (depending on sensor setup)	Frequency of scenarios with HAD/ADAS-function	-
	NDS without AD function (Measurement vehicles)	Complete (depending on sensor setup)	Frequency of scenarios with human driver, but influenced driving	Good to identify human performance
	Proving ground (test track)	(forms the basis for the test)	-	Identification of human performance
	Simulation	Identification of physical boundaries of the scenarios	-	Theoretical performance
	Accident data	Limited, since ex post	Limited, only with statistical population	Examples for negative human performance
	Driving simulator	-	-	Identification of human performance

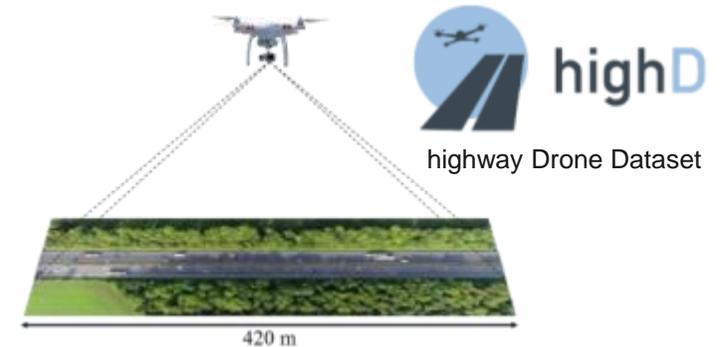# HighD – The Highway Drone Dataset

Method

Road user trajectories extracted from aerial videos captured by UAV using Deep Learning

Advantages:

- All road users are detected and tracked
- Completely naturalistic, uninfluenced driving behavior
- No or little occlusion due to "bird`s eye" perspective
- Very accurate with 4K camera and our algorithms
- High efficiency regarding cost and effort
- Recordings unbound to any location

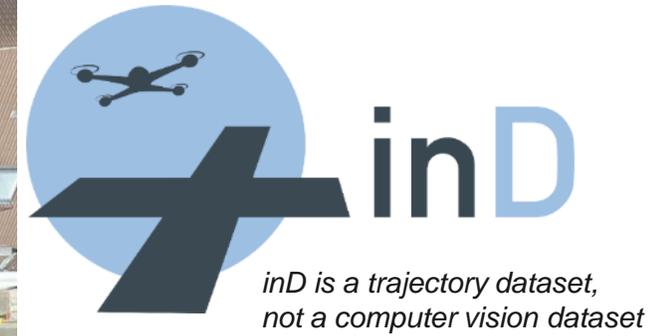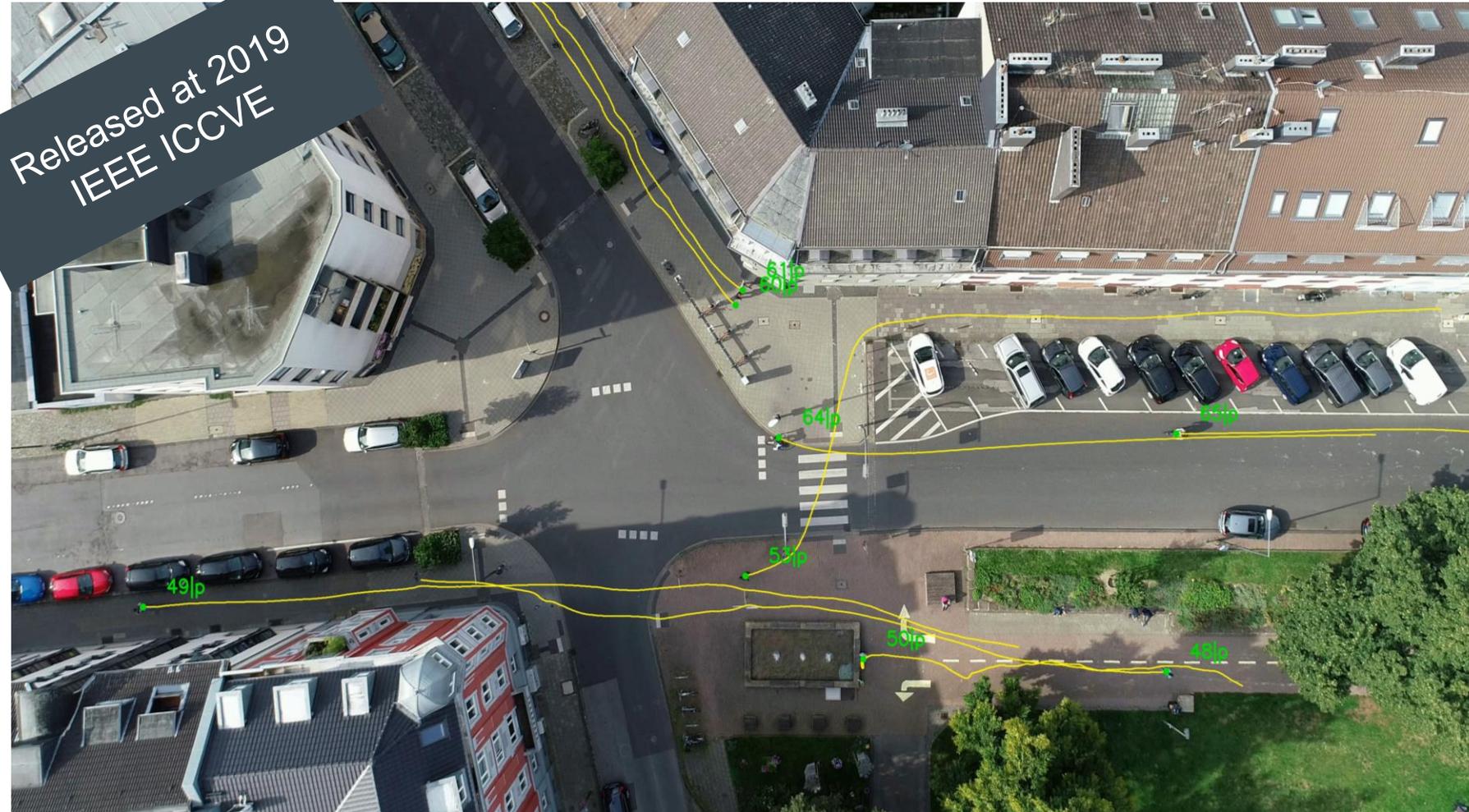→ Creation of a large-scale naturalistic trajectory dataset

highway Drone Dataset

420 m

highD Dataset (free for non-commercial use) [1]

- 6 locations
- Number of vehicles: 110 000
- Driven distance: 45 000 km
- Pixel-level accuracy = 0.1-0.2 m

[1] Krajewski et al. 2018: The highD Dataset: A Drone Dataset of Naturalistic Vehicle Trajectories on German Highways for Validation of Highly Automated Driving Systems

inD - The intersection drone Dataset

Released at 2019
IEEE ICCVE

inD is a trajectory dataset,
not a computer vision dataset

Dataset at a Glance

- **Highly interactive intersections**
- **All road user types:**
  car, truck, bus, pedestrian,
  bicycle, motorcycle
- **4 measurement locations**
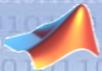- **Pixel-level accuracy** (~0.1m)

Upload Process for Data into the Database

✓ Signals according to JSON definitions
✓ Minimum requirements on dataset
✓ Format: Mat or HDF5

Dataset → Converted **dataset** → Database

Converting to JSON signal definition   Database Upload

Testing of a Concrete Scenario in Simulation

- The selected concrete scenario can be reproduced in the simulation. A HAD-function integrated in the simulation can be tested.

- Here: "Slower turn into path challenger" (see screen 1)

Testing of a Concrete Scenario on the Test Track

- The selected concrete scenario can be reproduced on the test track. A HAD-function integrated in VUT can be tested.

- Here: "Slower turn into path challenger" (see screen 1)

» **Automated driving functions of level 3 or higher require Lidar as additional sensor technology**

» **Increasing number of suppliers/start-ups offer solutions based on various technologies**
  - Specifications contain different performance measures etc.
  - Performance measures are determined under varying test conditions

» **OEMs and Tier 1s have huge efforts in order to select suitable Lidar sensors that meet requirements**

» **Fka is preparing a harmonized test procedure for Lidar sensors, in order to provide a**
  - sound,
  - transparent,
  - comparable and
  - independent

  evaluation of sensor performance.

» **Test procedure will provide function-independent performance metrics, test conditions and evaluation criteria**

Thank you for your attention!

fka GmbH
Steinbachstr. 7
52074 Aachen
Germany

phone   +49 241 8861 0
e-mail   Adrian.zlocki@fka.de
web   www.fka.de

Dr. Adrian Zlocki

fka

CREATING IDEAS &
DRIVING INNOVATIONS