Hochschule Kempten
University of Applied Sciences

A drive. livinglab

Vehicle Technology SS 23
Lecture 3

# FT30 – Advanced Driver Assistance Systems

## ADAS/AD for Lateral Guidance

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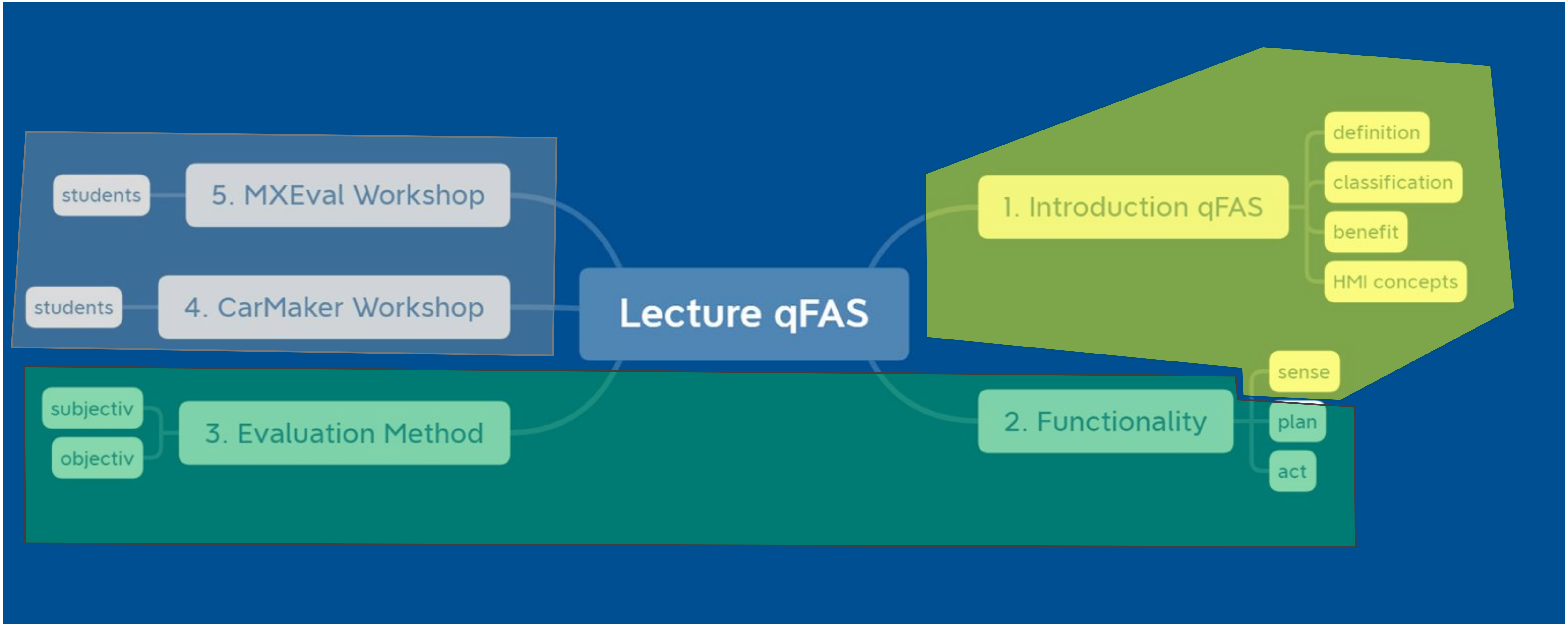
IFM Institut für Fahrerassistenz und vernetzte Mobilität

# Agenda

| Time | Content |
|---|---|
| 8:30 – 8:45 Uhr | Start |
| 8:45 - 10:00 Uhr | Introduction + Sense |
| 10:00 - 10:30 Uhr | Break |
| 10:30 – 12:00 Uhr | Plan + Act + Evaluation |
| 12:00 – 13:00 Uhr | Break |
| 13:00 – 15:00 Uhr | CarMaker & MXeval Workshop |

# Agenda


Lecture qFAS
1. Introduction qFAS
definition
classification
benefit
HMI concepts
2. Functionality
sense
plan
act
3. Evaluation Method
subjectiv
objectiv
4. CarMaker Workshop
students
5. MXEval Workshop
students

# What is lateral guidance?

- The vehicle follows the course through a lateral intervention
- A camera detects the boundary lines and determines via the control variable, the strength of the intervention

- The driver must remain active all the time

→ Level 2/3

# Explanation LKAS

# Lane Change Warning

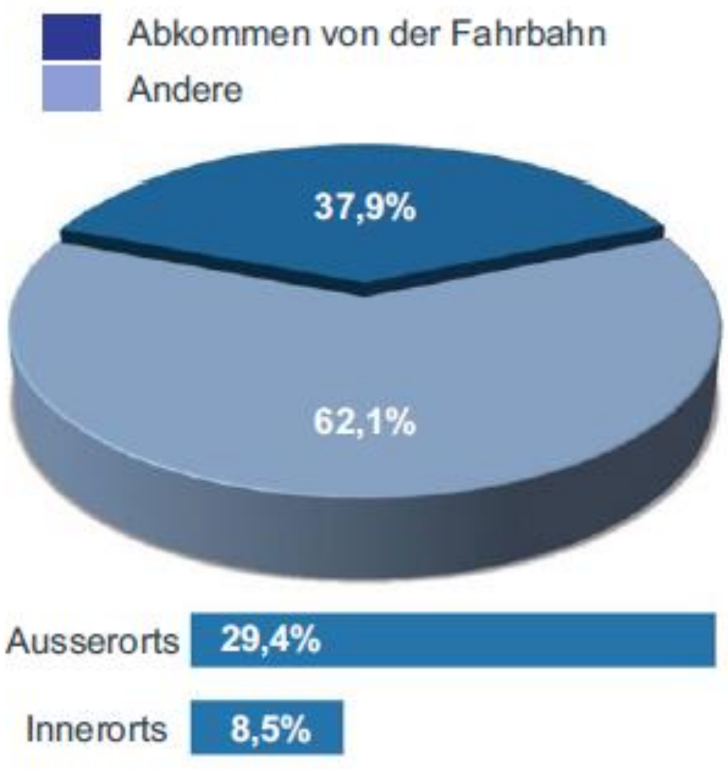
HOW-TO BMW.

HOW TO CHANGE THE SETTINGS FOR LANE CHANGE WARNING.

BMW 330e Sedan: Fuel consumption in l/100 km (combined): 1.9-1.6 l/100 km; electric power consumption in kWh/100 km (combined): 15.4-14.8 kWh/100 km, $CO_2$ emissions in g/km (combined): 43 - 37 g/km.

# Motivation

## Reduction of accidents



GIDAS, Datenbankabzug 12/2012, Pkw-Insassen mit Verletzungsschwere MAIS2+ in erster Kollision

## Step towards autonomous driving

Sicherheitspotential (ADAC):

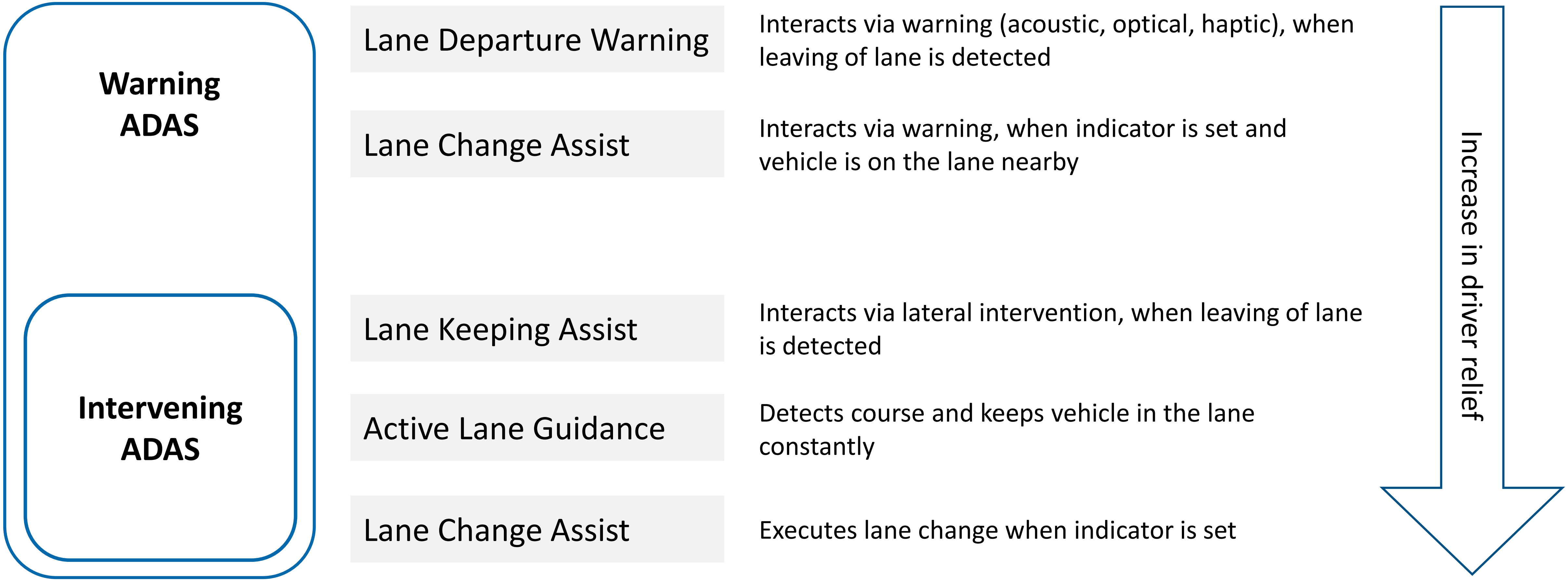
### Spurhalteassistent:

Schätzungen zufolge führt eine Einführung zu bis zu 3500 weniger Toten und 17.000 weniger Schwerverletzten (Visvikis C, Smith TL, PitcherM. und Smith R. (2008). Studie zu Spurhaltewarnsystemen und Spurwechselassistenten: Abschlussbericht. PPR374. TRL Limited, Crowthorne, UK)

### Spurwechselassistent:

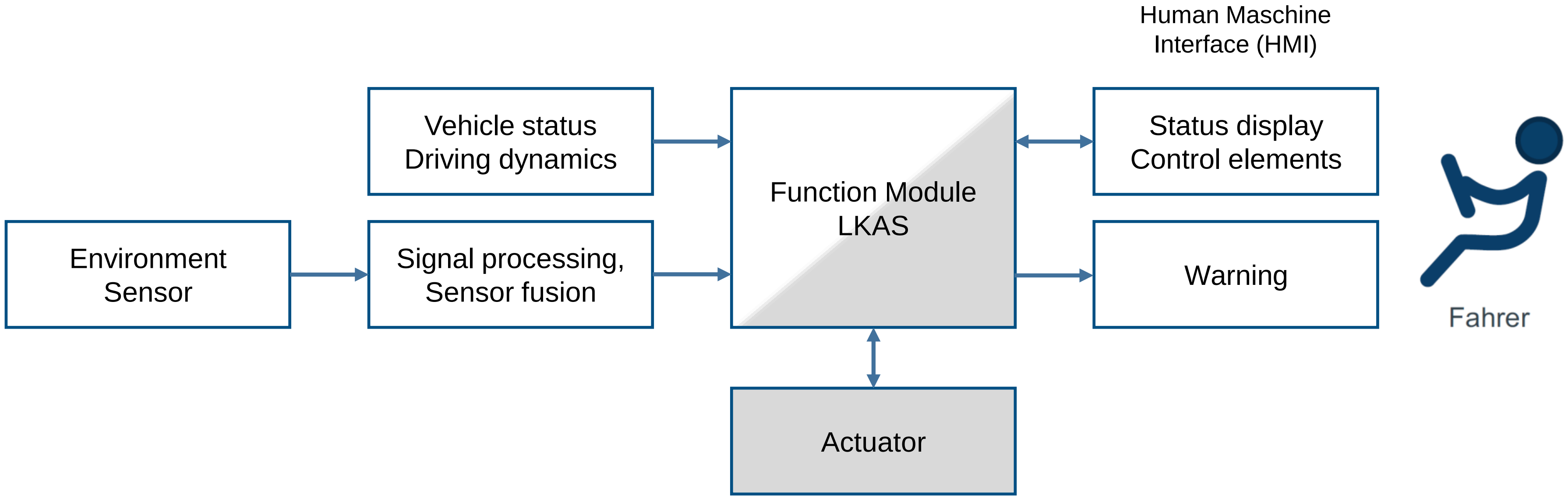
26% weniger Unfälle beim Spurwechsel (Insurance Institute for Highway Safety, Crash Avoidance Potential of Five Vehicle Technologies, IIHS 2008)

# Classification



| | |
|---|---|
| Lane Departure Warning | Interacts via warning (acoustic, optical, haptic), when leaving of lane is detected |
| Lane Change Assist | Interacts via warning, when indicator is set and vehicle is on the lane nearby |
| Lane Keeping Assist | Interacts via lateral intervention, when leaving of lane is detected |
| Active Lane Guidance | Detects course and keeps vehicle in the lane constantly |
| Lane Change Assist | Executes lane change when indicator is set |

# Procedure of lateral guidance



Human Maschine Interface (HMI)

Vehicle status
Driving dynamics

Environment Sensor

Signal processing, Sensor fusion

Function Module LKAS

Status display
Control elements

Warning

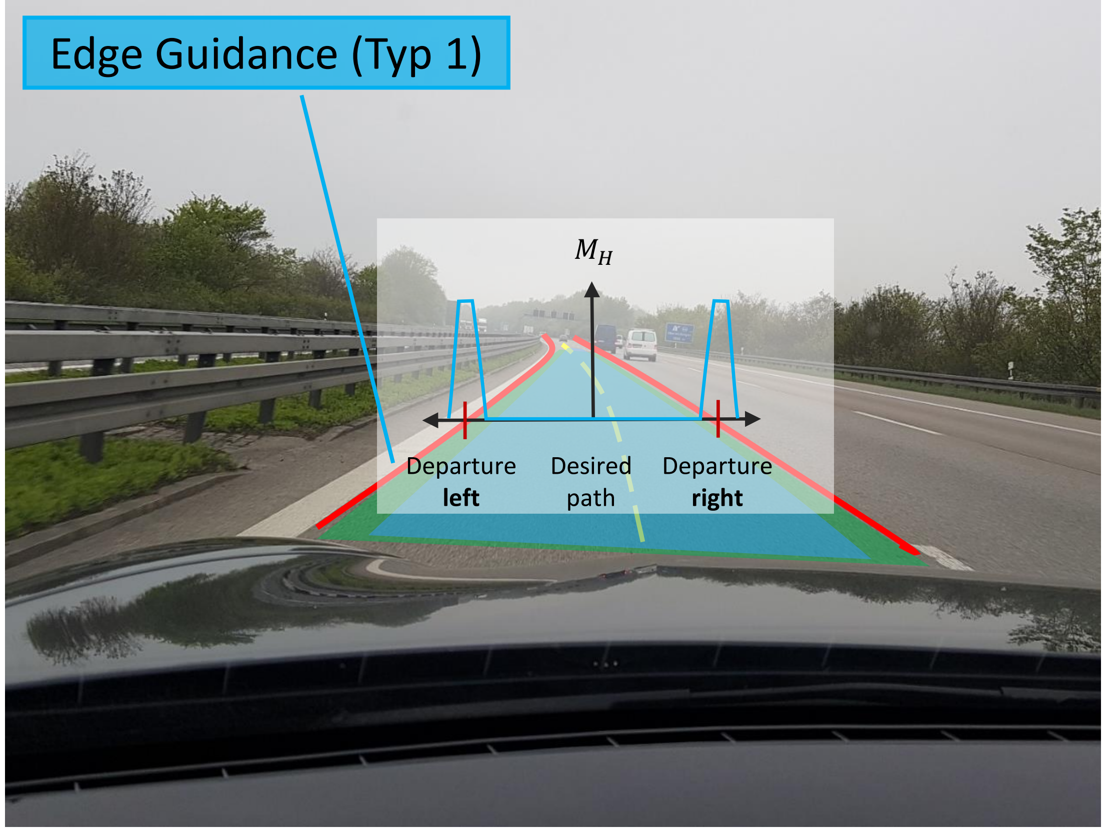
Actuator

Warning systems

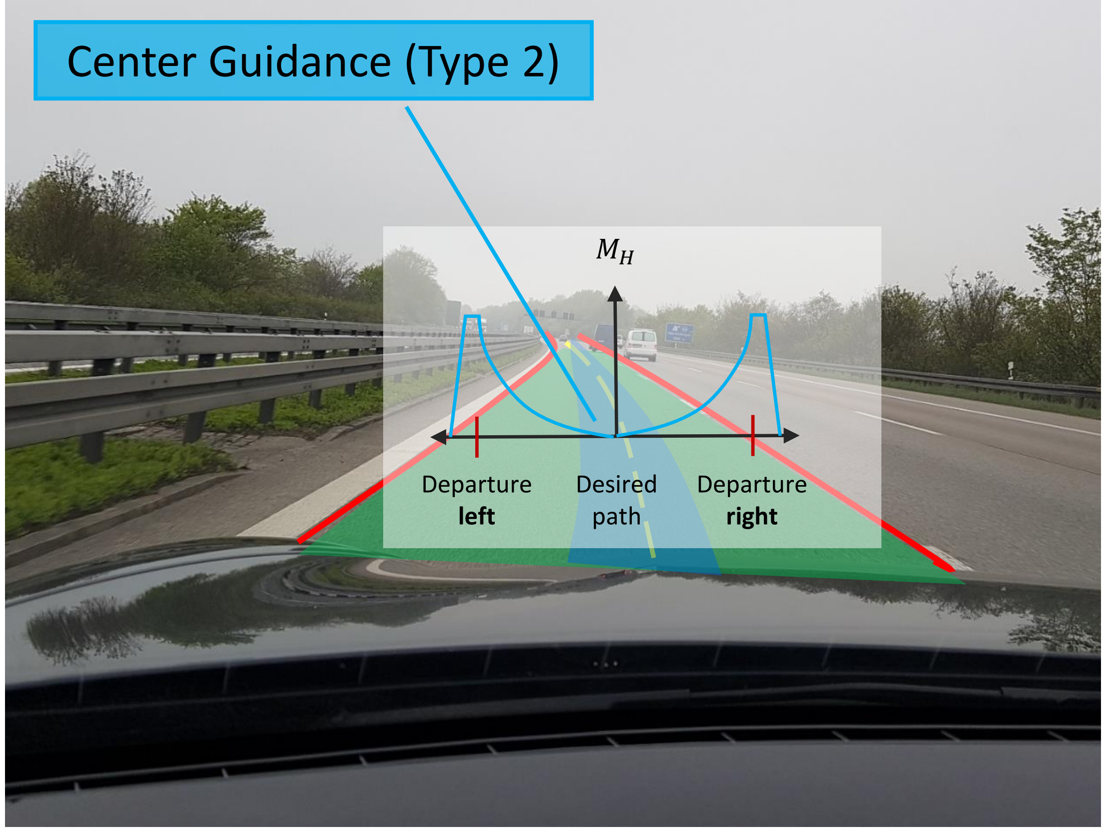
Intervening systems

# Lateral Control Function: Lane Keeping Assistance Systems

## Lane Keeping Assistance System



## Active Lane Guidance



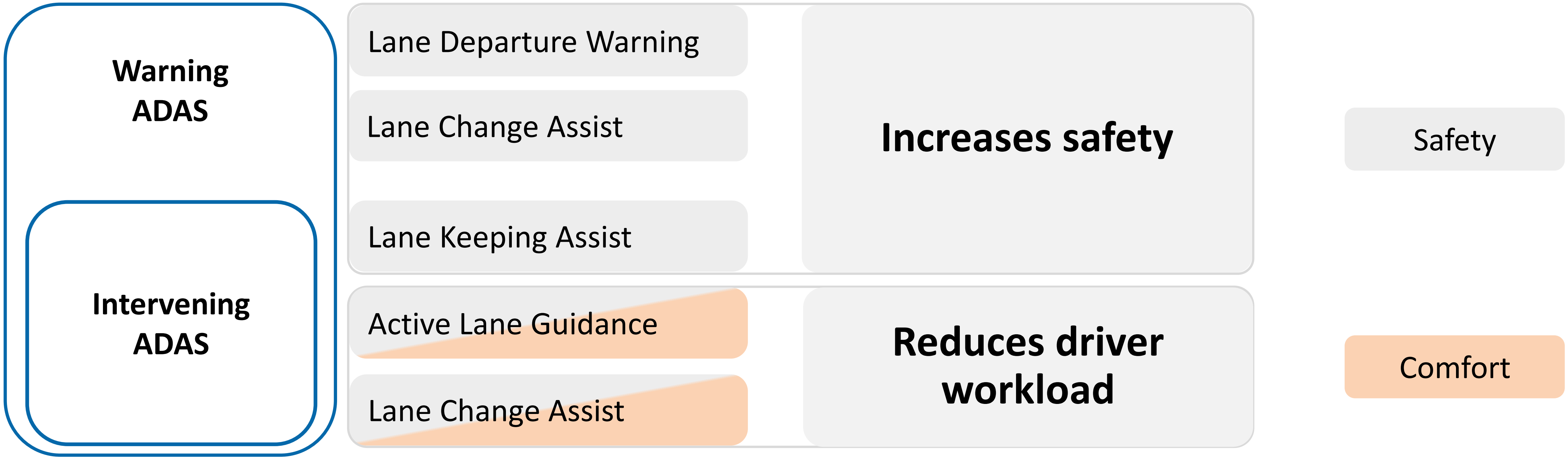
# Motivation?

# Motivation

**Benefits:**

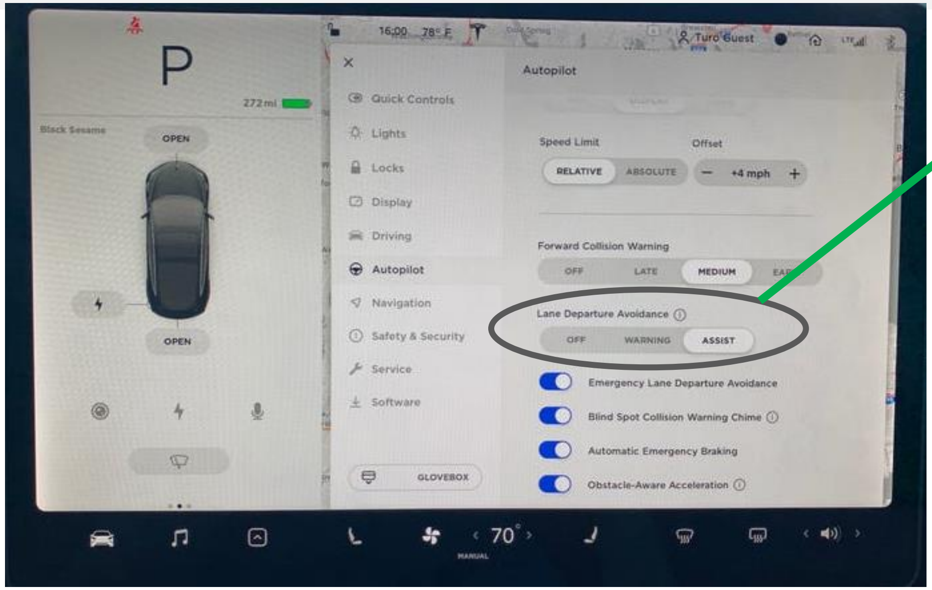
The current systems for lateral guidance are a step towards autonomous driving.

Offside the known benefits of autonomous driving (benefits in personal mobility, more efficient transport, more free time, less workload) the current systems has the advantage of increasing the road safety and already reducing the driver workload a bit.



# Setting options for different cars

VW Golf 8: Travel Assist



Autopilot

Speed Limit: RELATIVE | ABSOLUTE — Offset: +4 mph

Forward Collision Warning: OFF | LATE | MEDIUM | EA…

Lane Departure Avoidance: OFF | WARNING | ASSIST

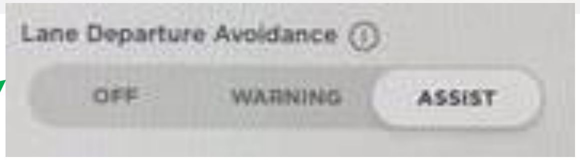
Emergency Lane Departure Avoidance

Blind Spot Collision Warning Chime

Automatic Emergency Braking

Obstacle-Aware Acceleration

Tesla: Active Lane Assist



Lane Departure Avoidance: OFF | WARNING | ASSIST

Mercedes C-Klasse: Lenk-Assistent

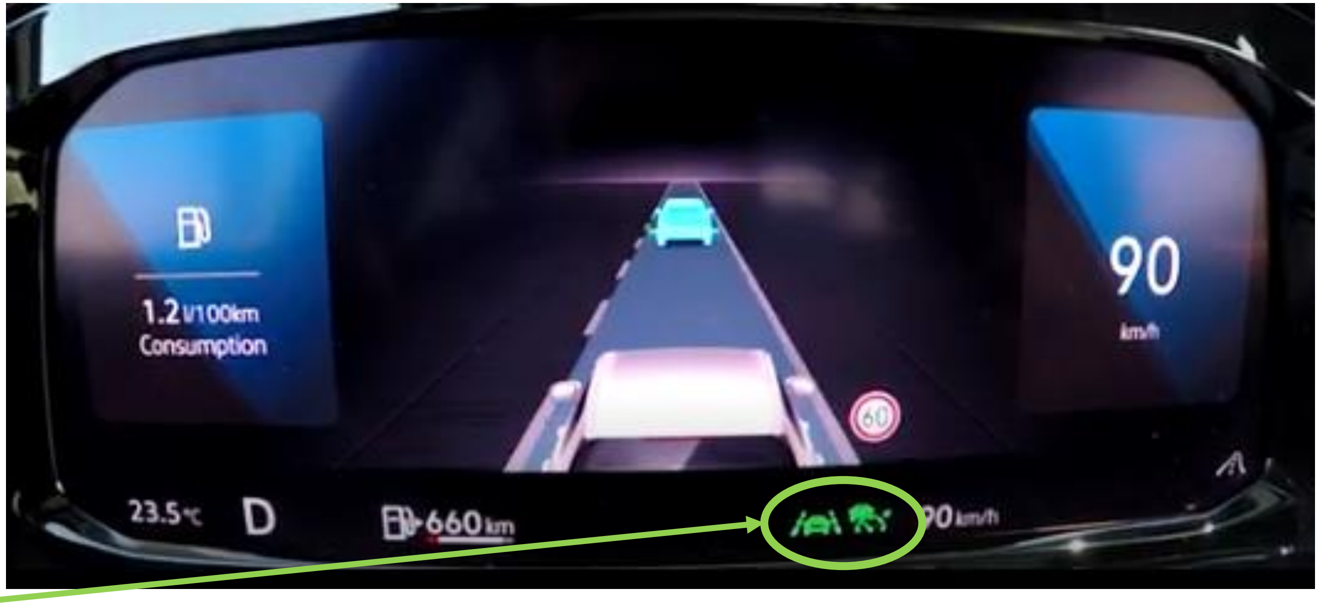
Audi: Active Lane Assist

BMW: Active Lane Keeping Assist

# HMI Concepts VW Golf 8

System aktiv und bereit zu regeln

System regelt
(korrigierender Lenkeingriff)

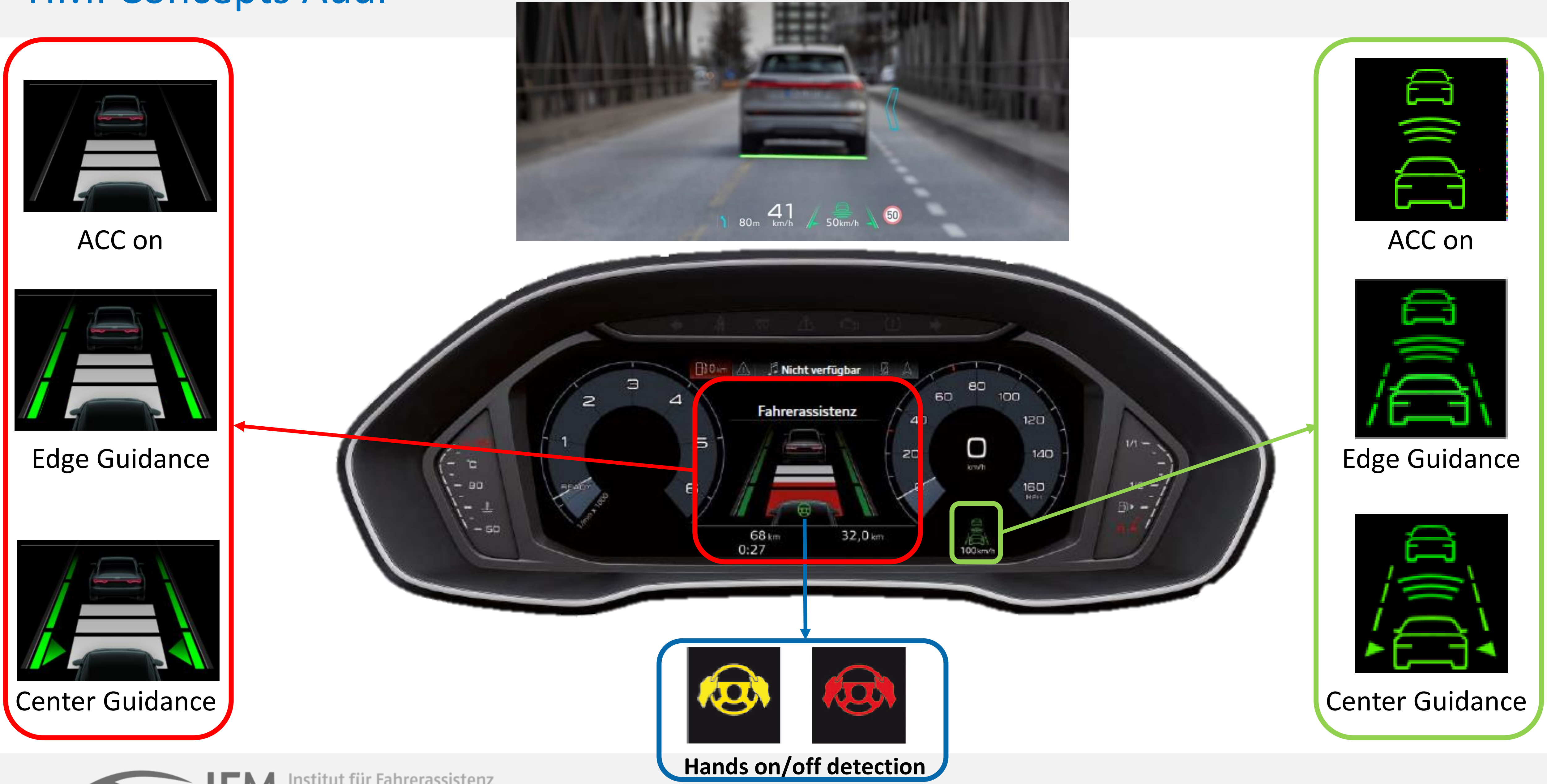


Take over steering!

Take over steering!

**Hands on/off detection**

# HMI Concepts Audi



ACC on

Edge Guidance

Center Guidance

ACC on

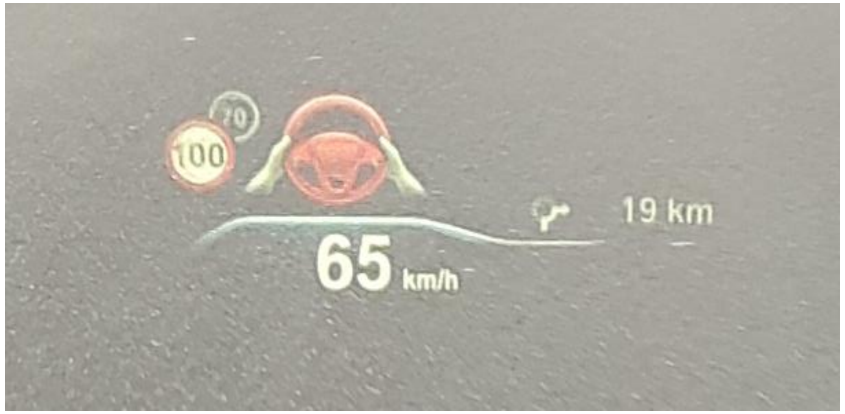
Edge Guidance

Center Guidance

**Hands on/off detection**

# HMI concepts Mercedes

# HMI concepts BMW



Hands on/off detection

# HMI concepts Tesla

Driving between 64 and 145km/h

Corrective steering applied for your safety
Potential collision detected

Take Control Immediately
Vehicle departing lane

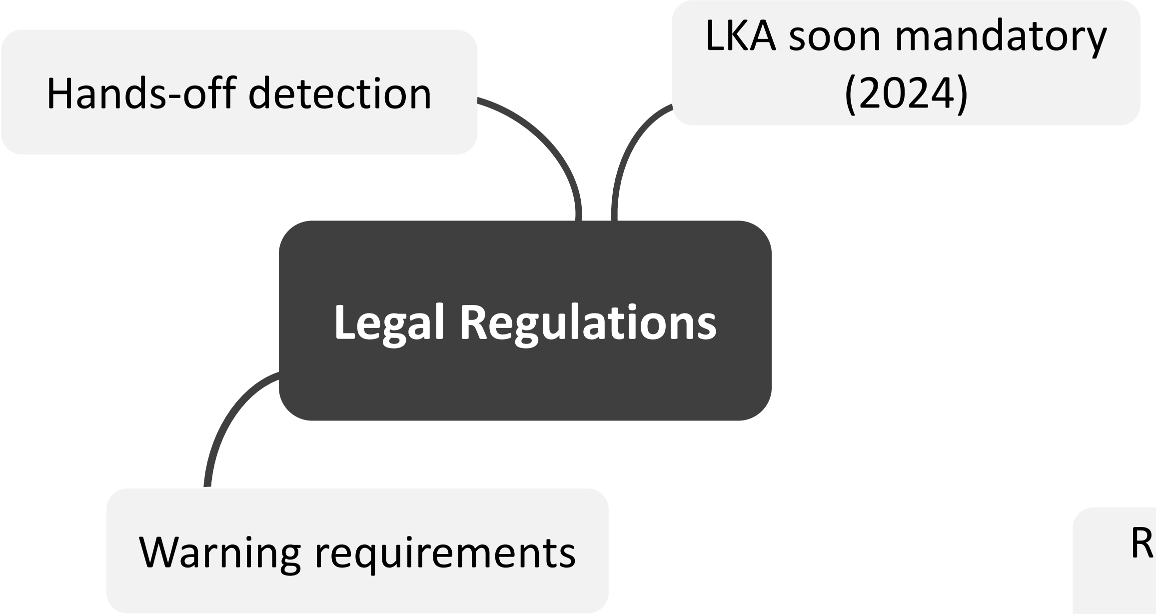
Lane Departure Avoidance

Corrective steering applied for your safety
Potential collision detected

Emergency Lane Departure Avoidance

# Regulations

# Regulations

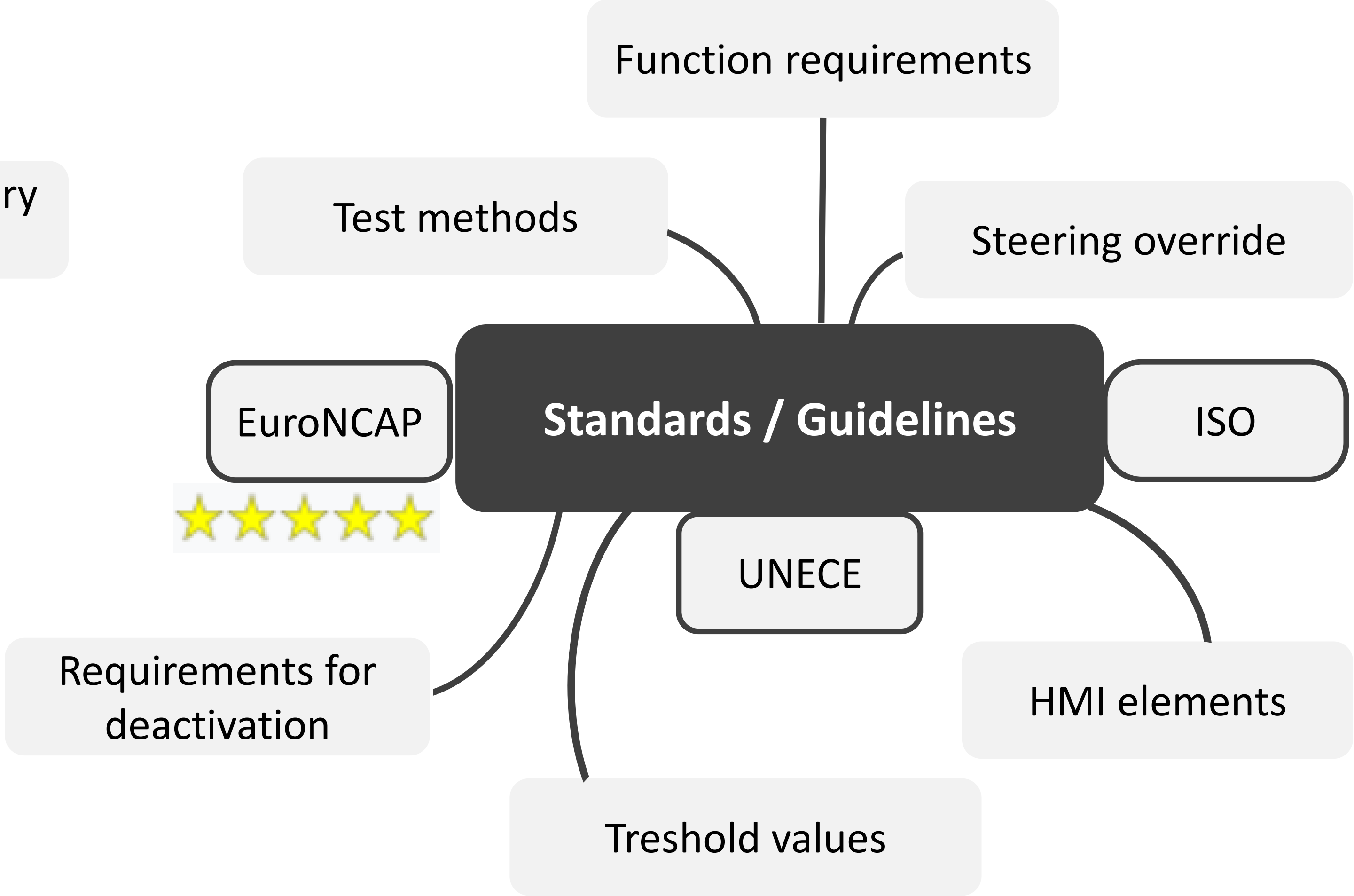


**Legal Regulations**

Hands-off detection

LKA soon mandatory (2024)

Warning requirements



**Standards / Guidelines**

EuroNCAP

☆☆☆☆☆

UNECE

ISO

Function requirements

Test methods

Steering override

Requirements for deactivation

Treshold values

$a_y$, SWT, jerk

HMI elements

# EuroNCAP Lane Support Systems (2015)

## Test Scenarios

**6.4 Test Execution**

6.4.1 Accelerate the VUT to 72 km/h.

6.4.2 The test shall start at $T_0$ and is valid when all boundary conditions are met between $T_0$ and $T_{LKA}/T_{LDW}$:

| | |
|---|---|
| - Speed of VUT (GPS-speed) | 72 ± 1.0km/h |
| - Lateral deviation from test path | 0 ± 0.05m |
| - Steady state lane departure lateral velocity | ± 0.05m/s |
| - Steering wheel velocity | ± 15.0°/s |

6.4.2.1 Steer the vehicle as appropriate to achieve the lateral velocity in a smooth controlled manner and with minimal overshoot

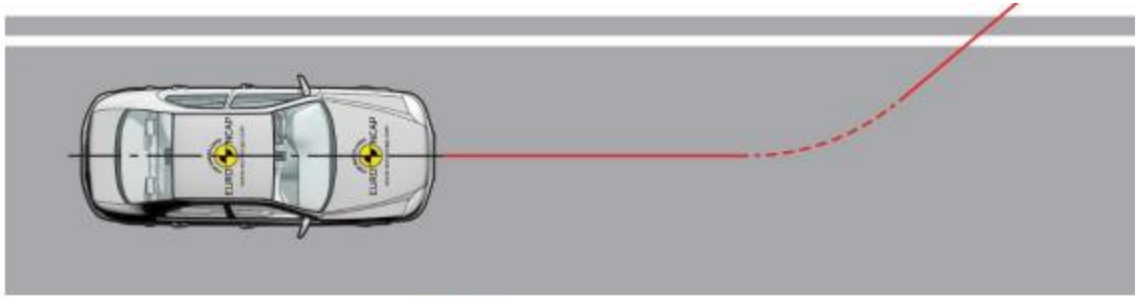
6.4.3 The end of an LDW test is considered as when the warning commences.

6.4.4 The end of an LKA test is considered as when one of the following occurs:

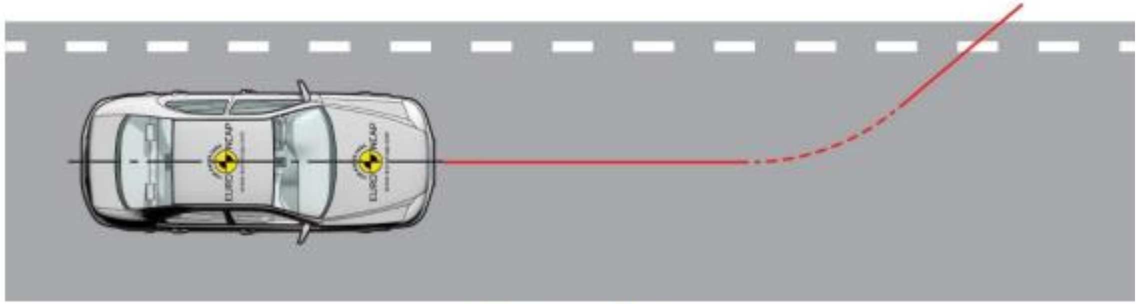
- The LKA system fails to maintain the VUT within the permitted lane departure distance.
- The LKA system intervenes to maintain the VUT within permitted lane departure distance, such that a maximum lateral position is achieved that subsequently diminishes causing the VUT to turn back towards the lane.

The test is considered complete 2 seconds after one of the above occurs.

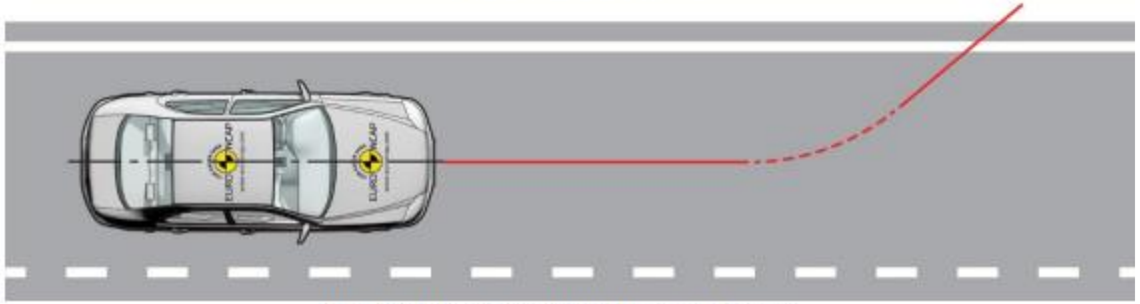
6.4.5 The subsequent lateral velocity for the next test is incremented with 0.1m/s.



LDW-Solid Line



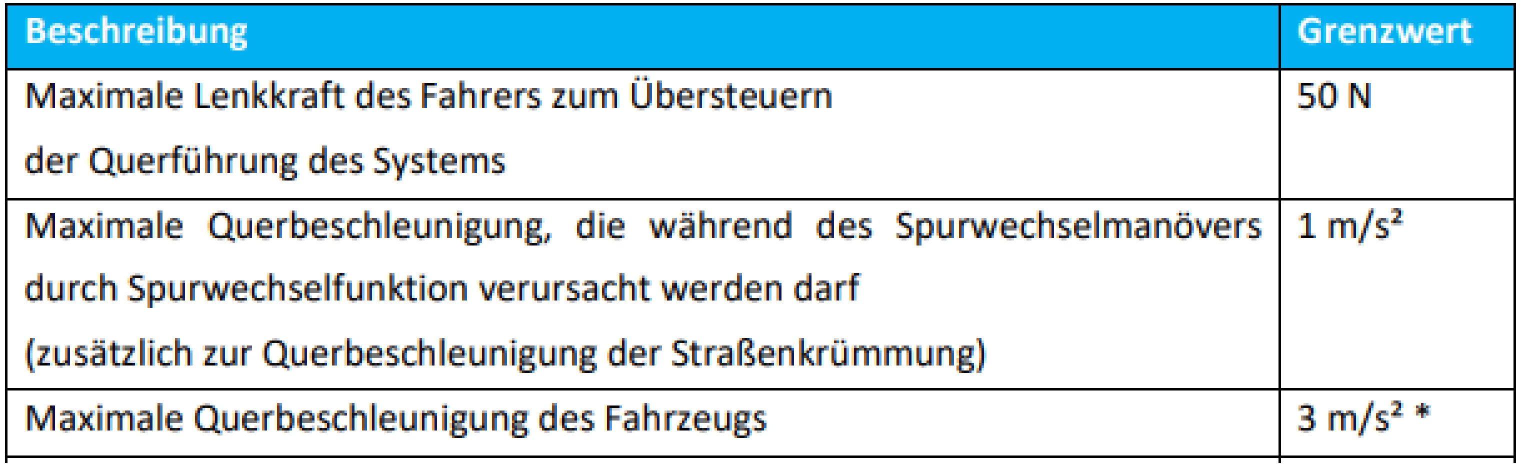
LDW-Dashed Line



LKA-Solid Line (Full lane marking)

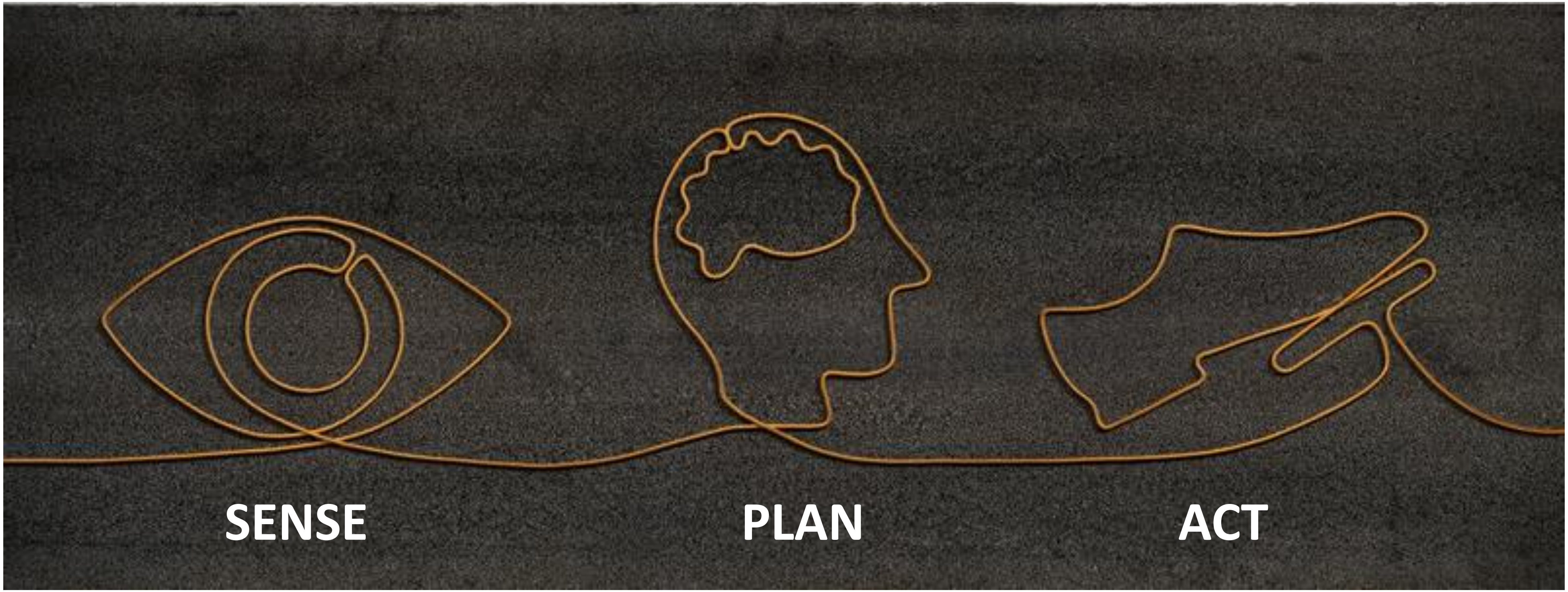
# UNECE (United Nations Economic Commission for Europe)

## UNECE Regelung Nr. 79: Limits for Lane Change Assist



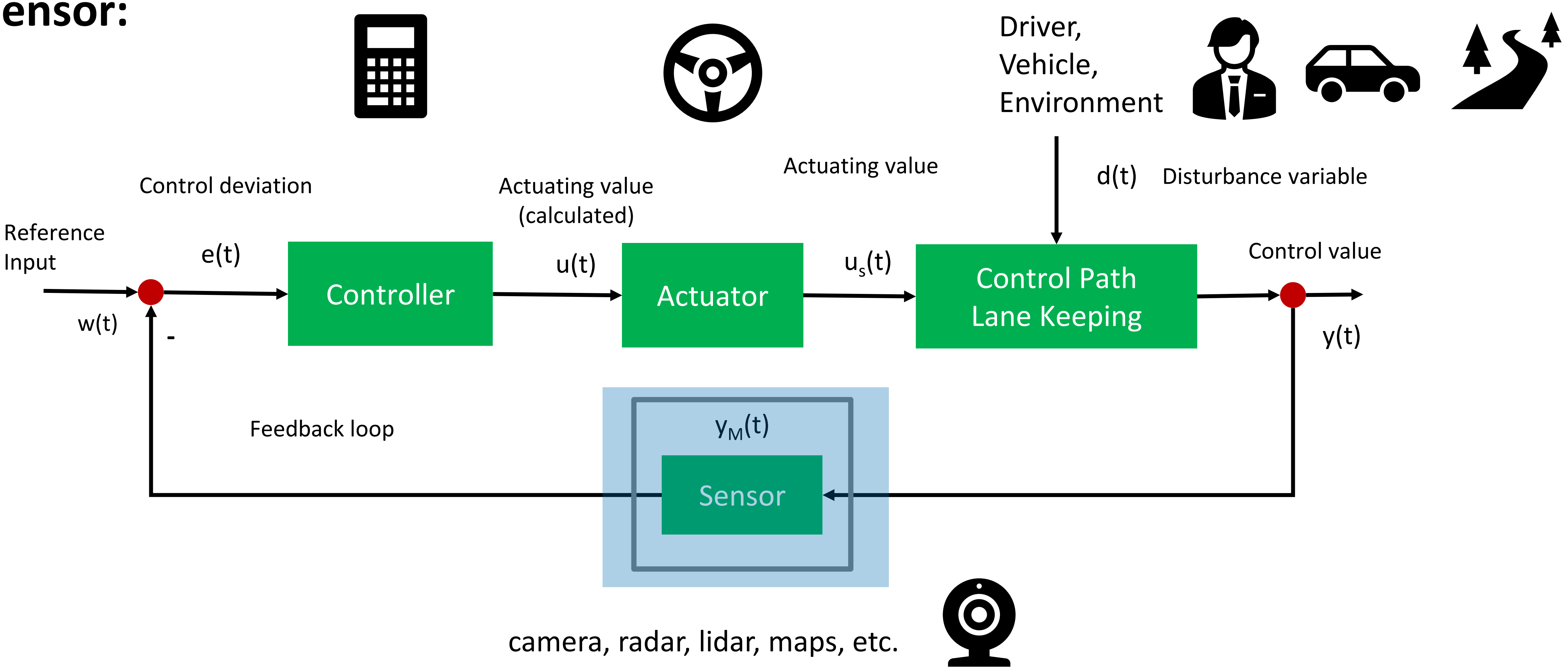
| Beschreibung | Grenzwert |
|---|---|
| Maximale Lenkkraft des Fahrers zum Übersteuern der Querführung des Systems | 50 N |
| Maximale Querbeschleunigung, die während des Spurwechselmanövers durch Spurwechselfunktion verursacht werden darf (zusätzlich zur Querbeschleunigung der Straßenkrümmung) | 1 m/s² |
| Maximale Querbeschleunigung des Fahrzeugs | 3 m/s² * |

# Sense – Plan – Act



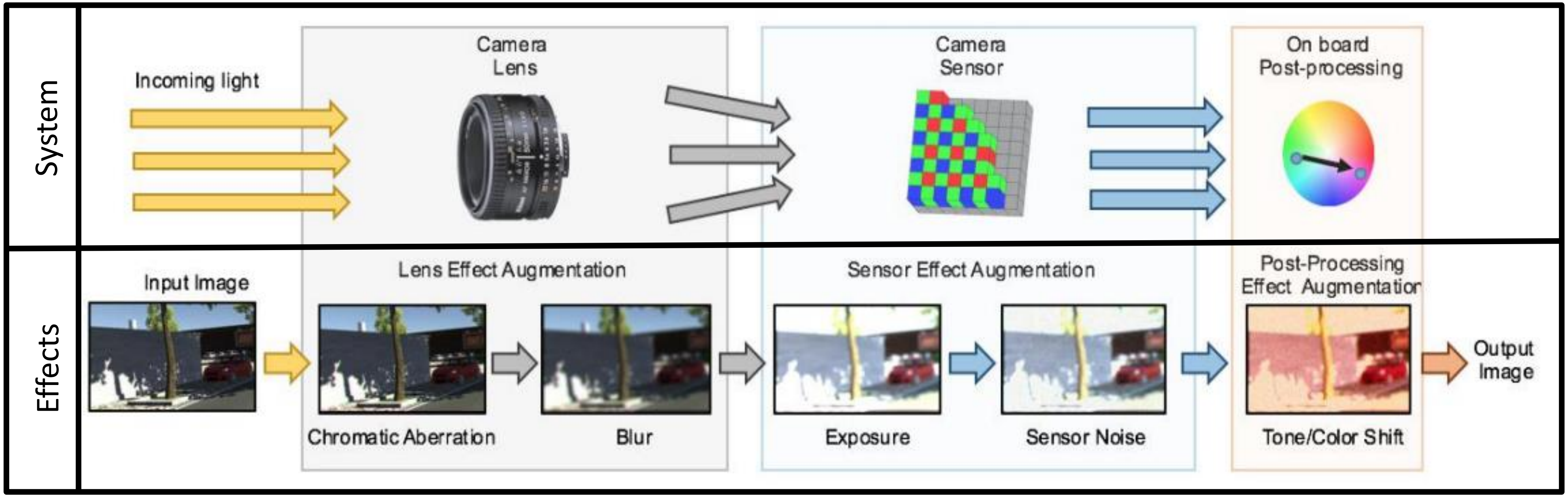
# Sense – Plan – Act

## Sensor:



# Sense – Plan – Act

## For the lateral guidance the camera is the most important sensor!



[31] A. Carlson, K. A. Skinner, R. Vasudevan, and M. Johnson-Roberson, *Modeling camera effects to improve visual learning from synthetic data.* [Online]. Available: `http://arxiv.org/pdf/1803.07721v6`.

# Sense

## Sense: The output of the camera sensor is a object list.

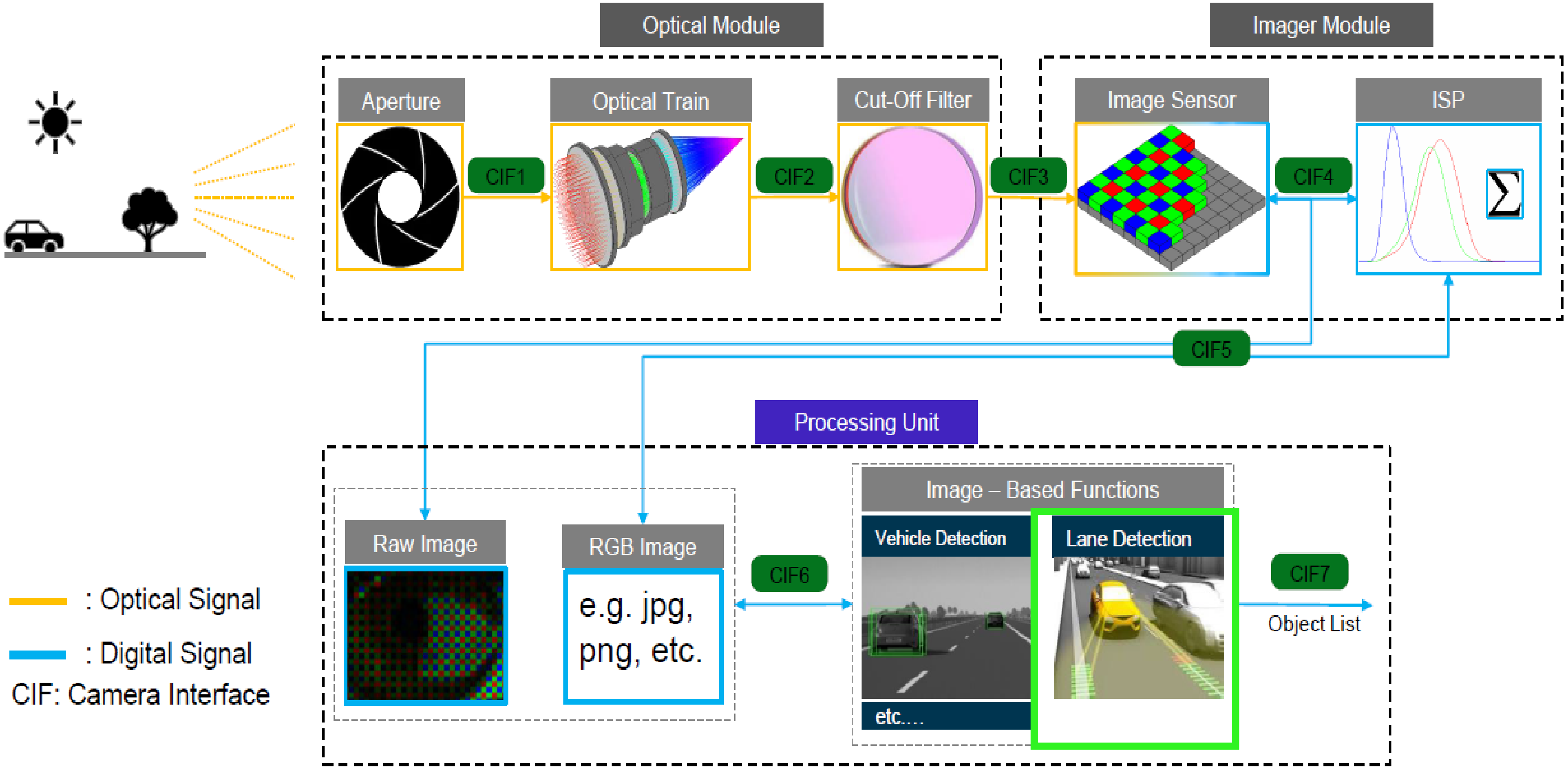


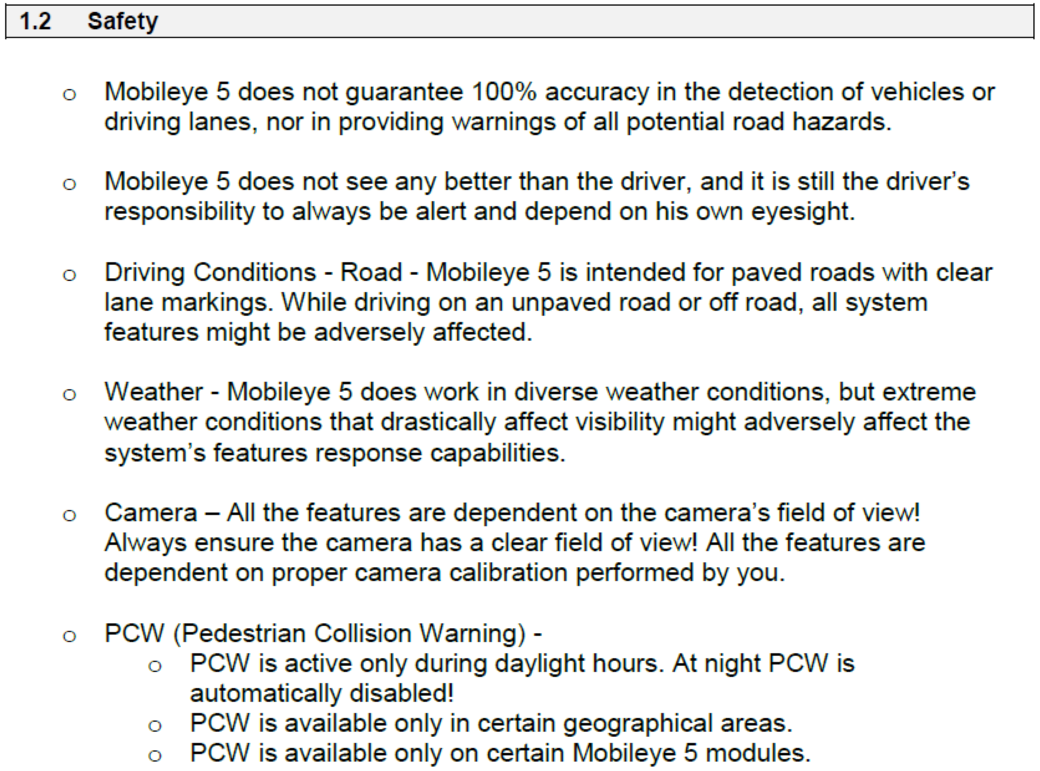
Figure 3.7: Camera interfaces.

# MobilEye as a Sensor System leader in automotive industry

[(183) Mobileye 8 Connect™: Quick Tour of all the Features - YouTube]()

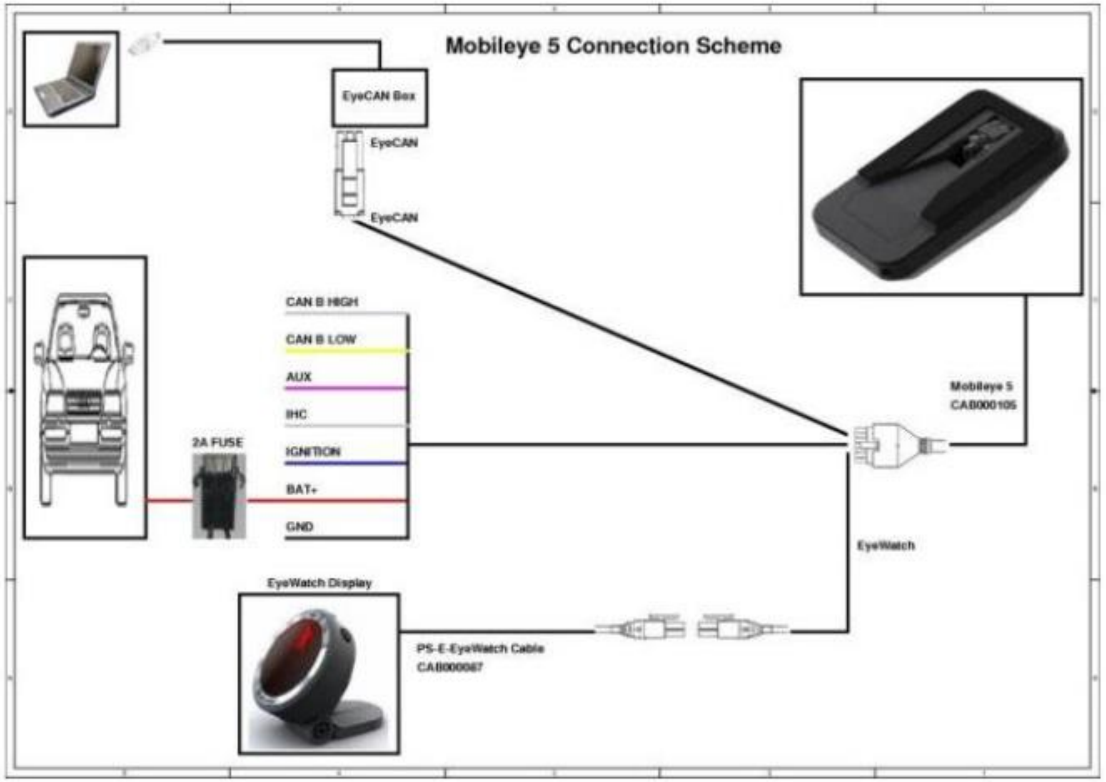
# MobilEye 5 Safety and Connection Scheme

## The perspective of the sensor system producer.



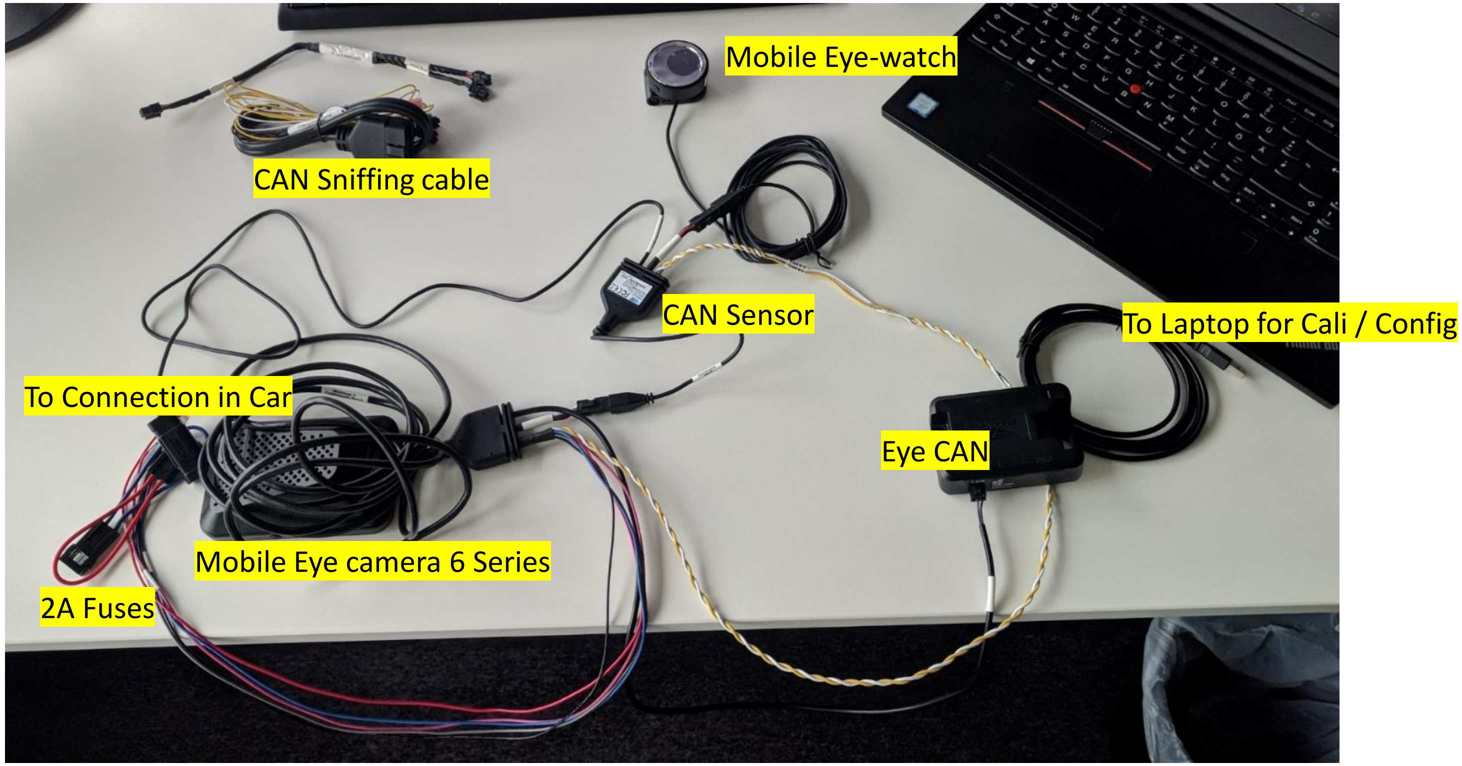
### 1.2 Safety

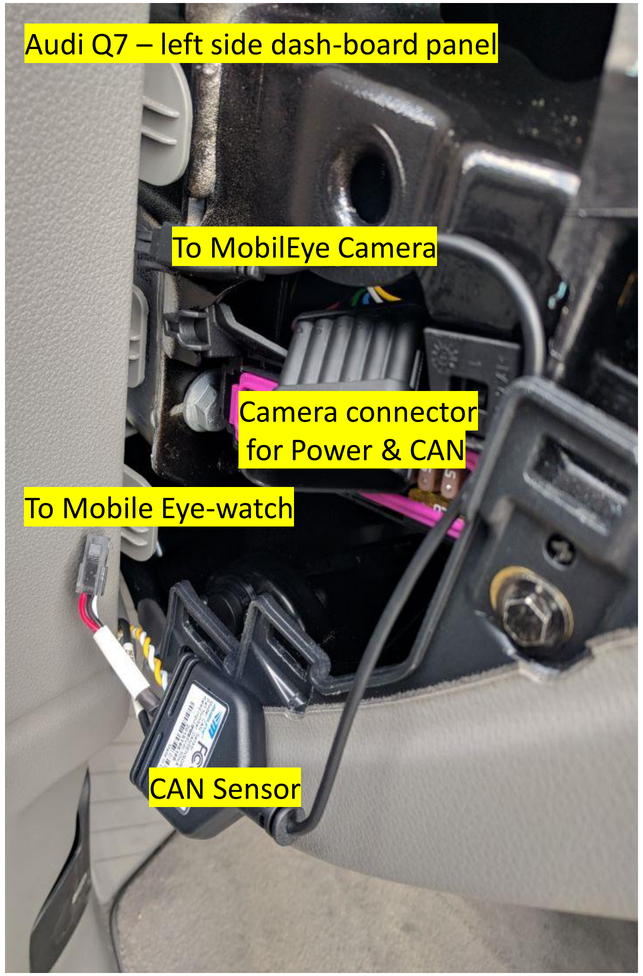
- Mobileye 5 does not guarantee 100% accuracy in the detection of vehicles or driving lanes, nor in providing warnings of all potential road hazards.
- Mobileye 5 does not see any better than the driver, and it is still the driver's responsibility to always be alert and depend on his own eyesight.
- Driving Conditions - Road - Mobileye 5 is intended for paved roads with clear lane markings. While driving on an unpaved road or off road, all system features might be adversely affected.
- Weather - Mobileye 5 does work in diverse weather conditions, but extreme weather conditions that drastically affect visibility might adversely affect the system's features response capabilities.
- Camera – All the features are dependent on the camera's field of view! Always ensure the camera has a clear field of view! All the features are dependent on proper camera calibration performed by you.
- PCW (Pedestrian Collision Warning) -
  - PCW is active only during daylight hours. At night PCW is automatically disabled!
  - PCW is available only in certain geographical areas.
  - PCW is available only on certain Mobileye 5 modules.



# Mobile Eye – HW Connection Setup

## MobilEye



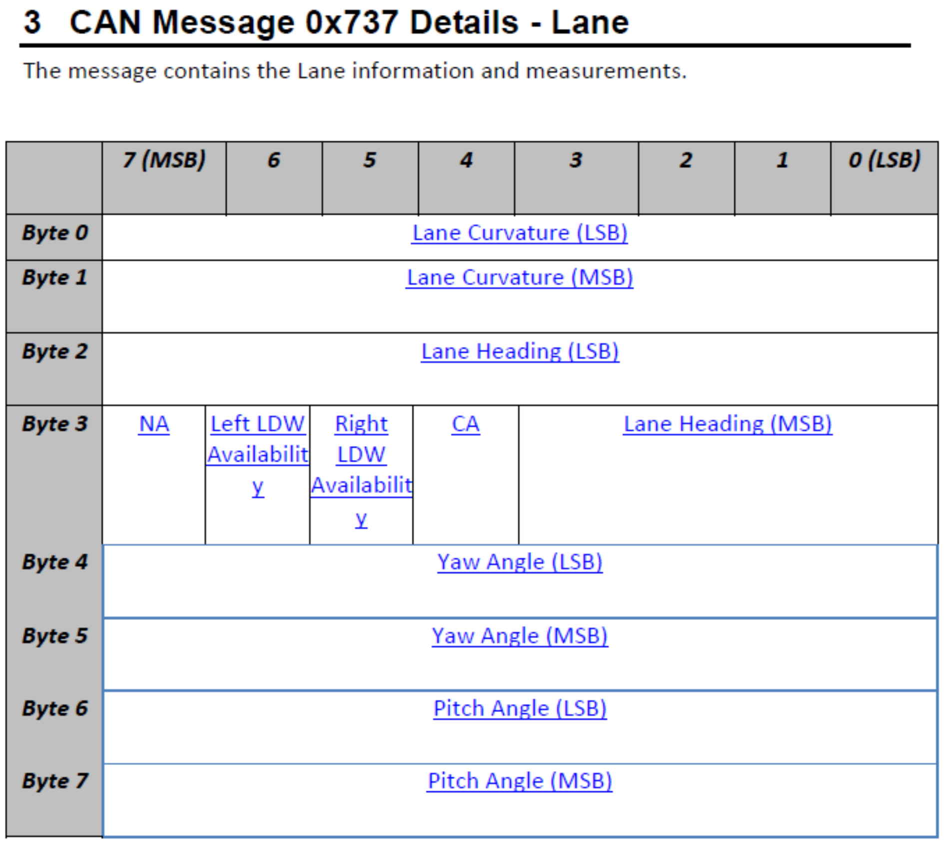


# Mobile Eye – CAN Messages Lane Detection

## This is the CAN Message for the lane detection.

### 1.4.2 Lane Detection

- Detection of solid or dashed lane markings.
- Detection of continuous road markings.



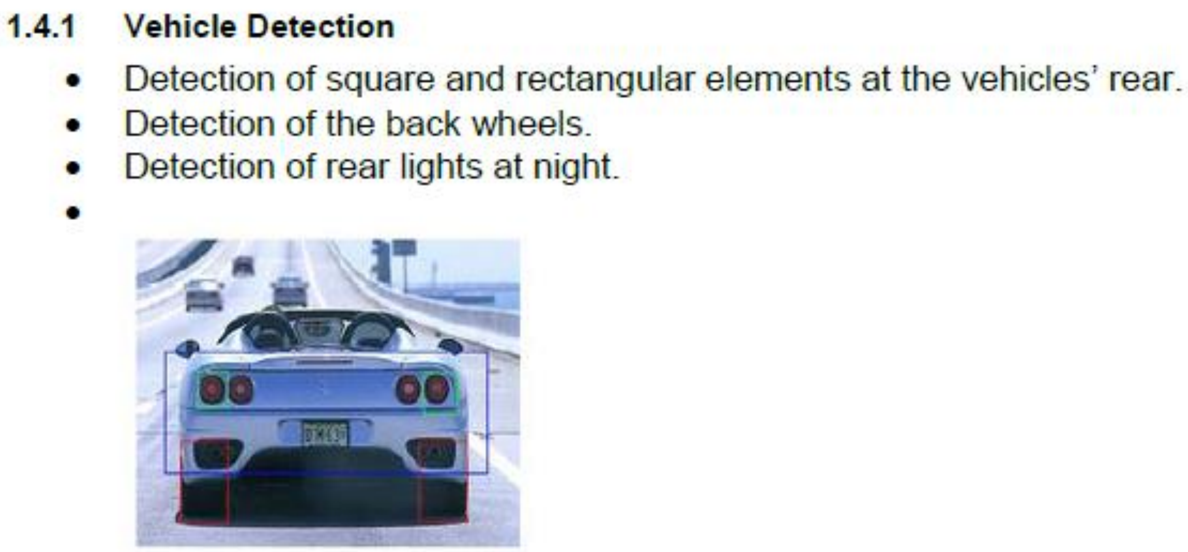
### 3 CAN Message 0x737 Details - Lane

The message contains the Lane information and measurements.

| | 7 (MSB) | 6 | 5 | 4 | 3 | 2 | 1 | 0 (LSB) |
|---|---|---|---|---|---|---|---|---|
| **Byte 0** | Lane Curvature (LSB) | | | | | | | |
| **Byte 1** | Lane Curvature (MSB) | | | | | | | |
| **Byte 2** | Lane Heading (LSB) | | | | | | | |
| **Byte 3** | NA | Left LDW Availability | Right LDW Availability | CA | Lane Heading (MSB) | | | |
| **Byte 4** | Yaw Angle (LSB) | | | | | | | |
| **Byte 5** | Yaw Angle (MSB) | | | | | | | |
| **Byte 6** | Pitch Angle (LSB) | | | | | | | |
| **Byte 7** | Pitch Angle (MSB) | | | | | | | |

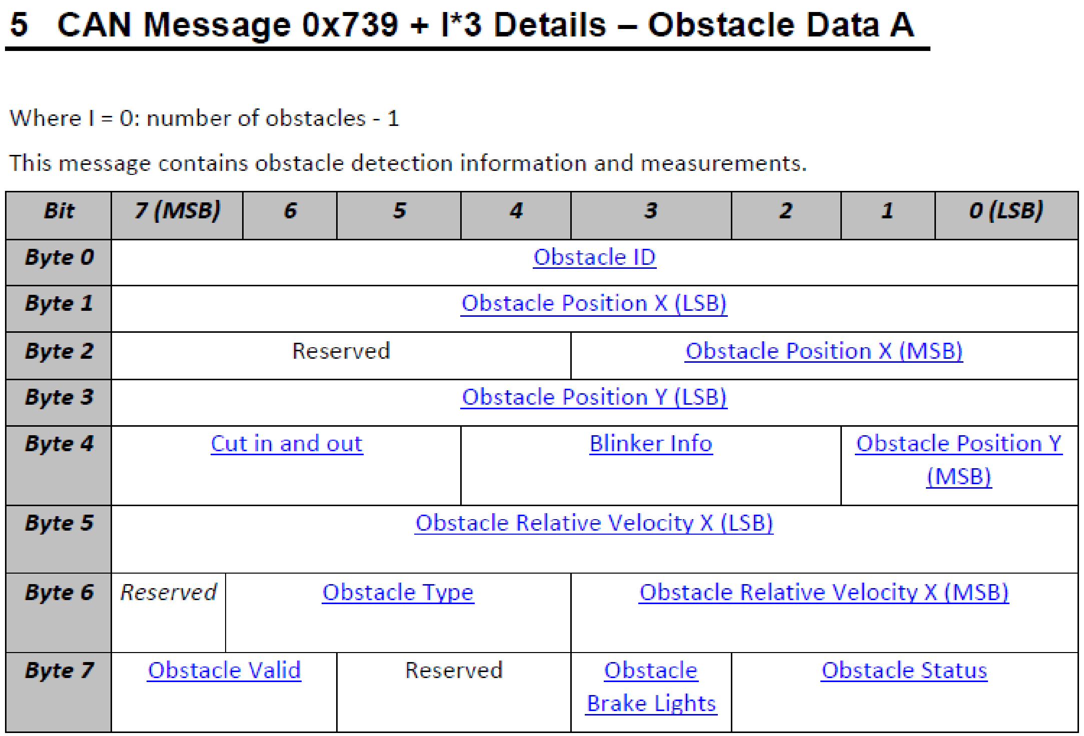
# Mobile Eye – CAN Messages Lane Detection

## This is the CAN Message for the object detection.



### 1.4.1 Vehicle Detection

- Detection of square and rectangular elements at the vehicles' rear.
- Detection of the back wheels.
- Detection of rear lights at night.
-



### 5 CAN Message 0x739 + I*3 Details – Obstacle Data A

Where I = 0: number of obstacles - 1

This message contains obstacle detection information and measurements.

| Bit | 7 (MSB) | 6 | 5 | 4 | 3 | 2 | 1 | 0 (LSB) |
|---|---|---|---|---|---|---|---|---|
| Byte 0 | Obstacle ID | | | | | | | |
| Byte 1 | Obstacle Position X (LSB) | | | | | | | |
| Byte 2 | Reserved | | | | Obstacle Position X (MSB) | | | |
| Byte 3 | Obstacle Position Y (LSB) | | | | | | | |
| Byte 4 | Cut in and out | | | Blinker Info | | | Obstacle Position Y (MSB) | |
| Byte 5 | Obstacle Relative Velocity X (LSB) | | | | | | | |
| Byte 6 | *Reserved* | Obstacle Type | | | Obstacle Relative Velocity X (MSB) | | | |
| Byte 7 | Obstacle Valid | | Reserved | | Obstacle Brake Lights | Obstacle Status | | |

# Sense

## Sense: Here you can see the camera line detection object list.

**BV1_LIN_01_AbstandY**

**BV1_LIN_01_BeginnX**

**BV1_LIN_01_Breite**

**BV1_LIN_01_EndeX**

**BV1_LIN_01_ExistMass**

**BV1_LIN_01_Farbe**

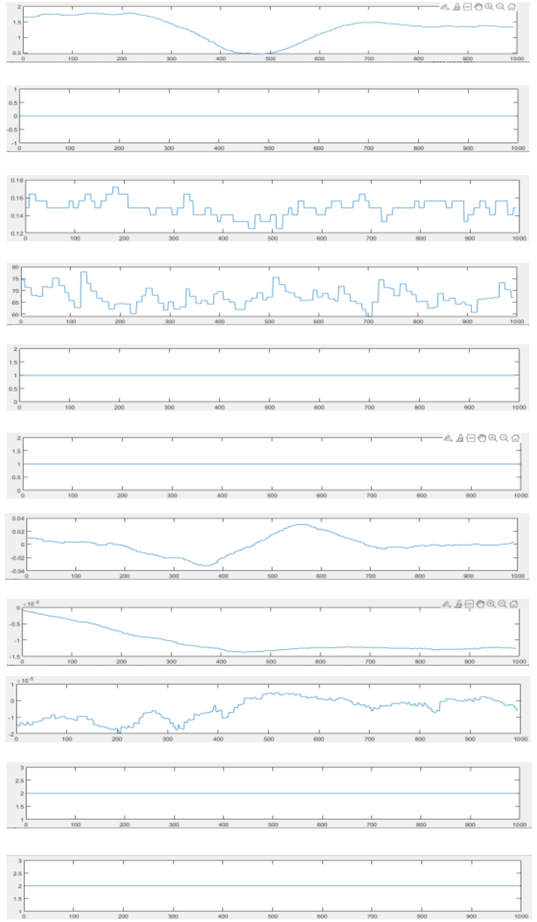
**BV1_LIN_01_GierWnkl**

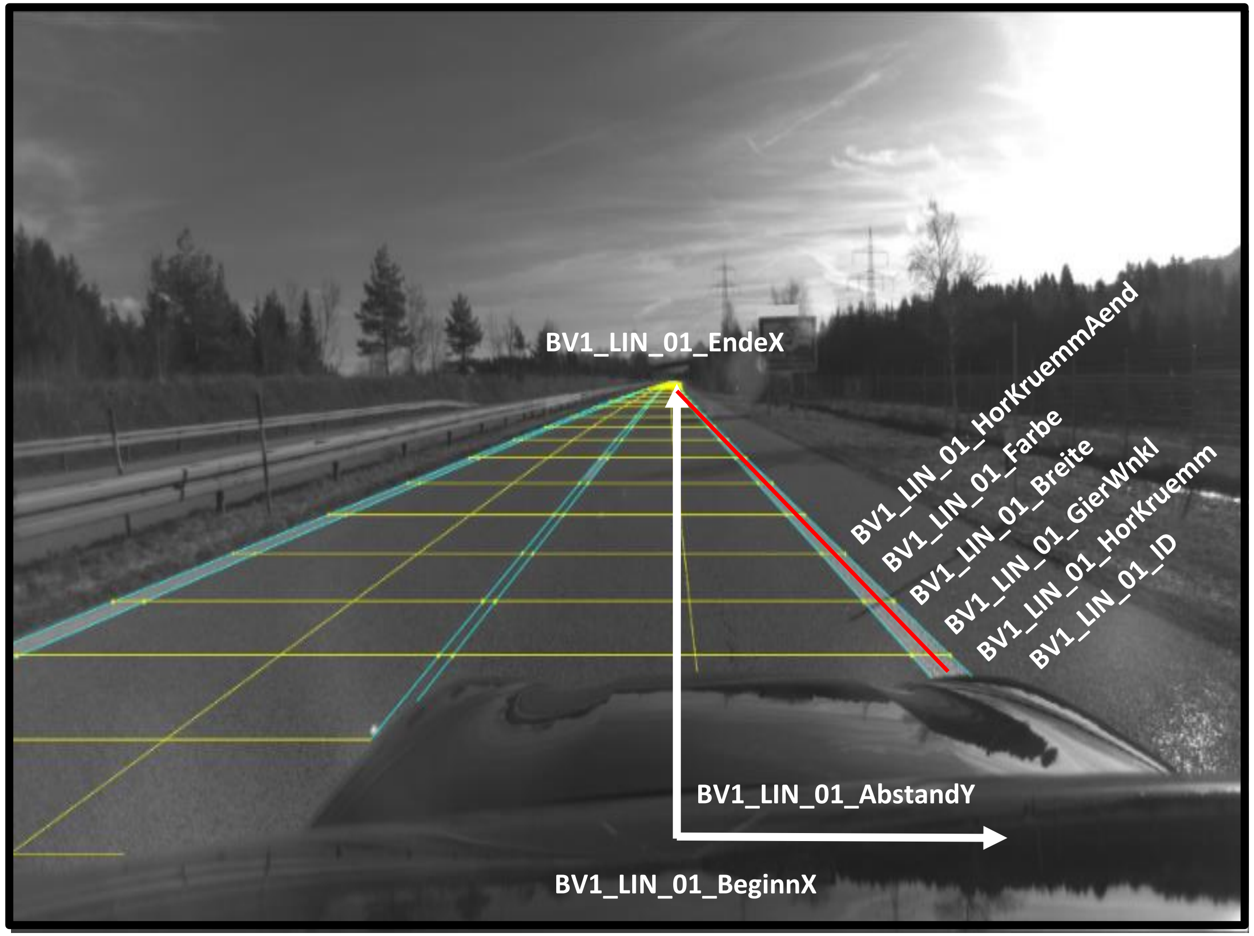
**BV1_LIN_01_HorKruemm**

**BV1_LIN_01_HorKruemmAend**

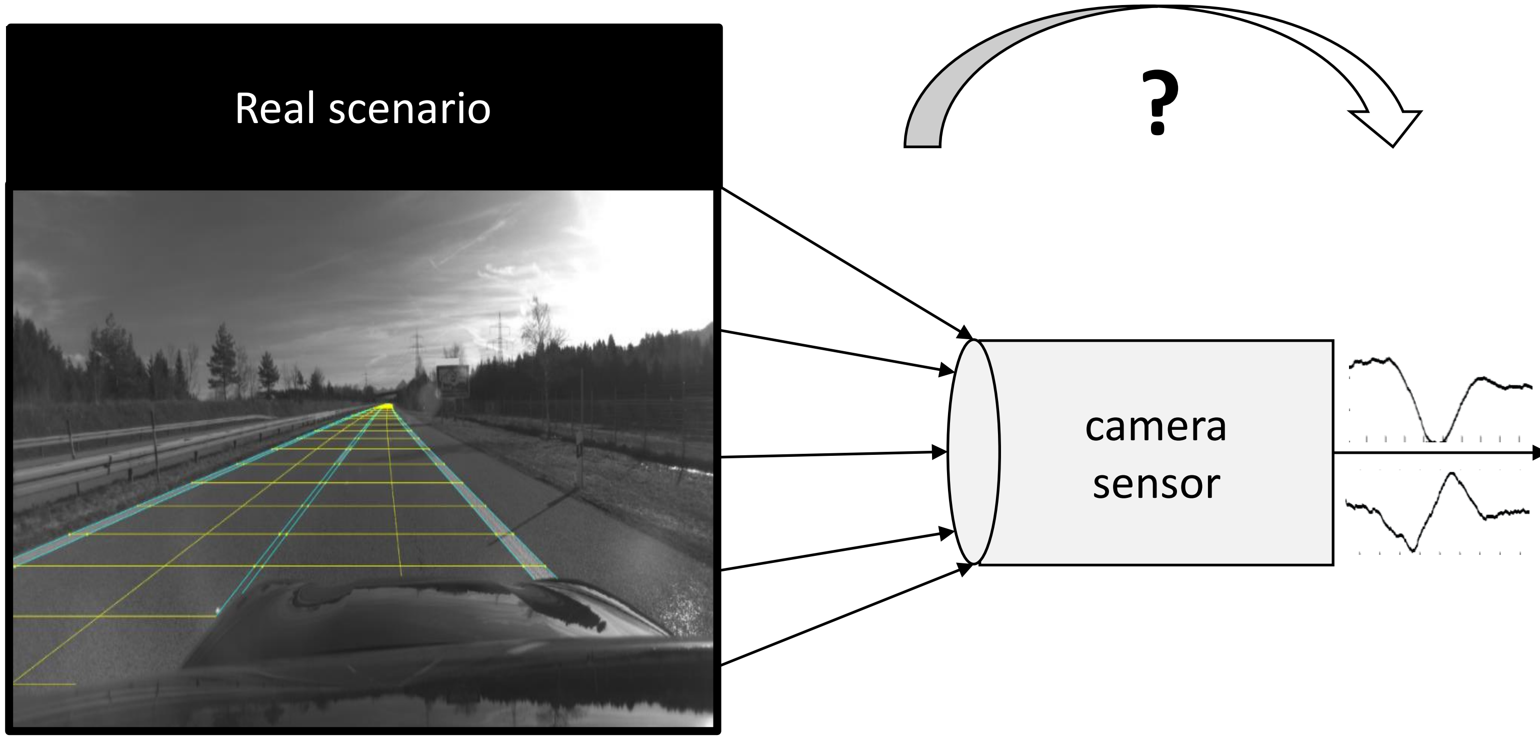
**BV1_LIN_01_ID**

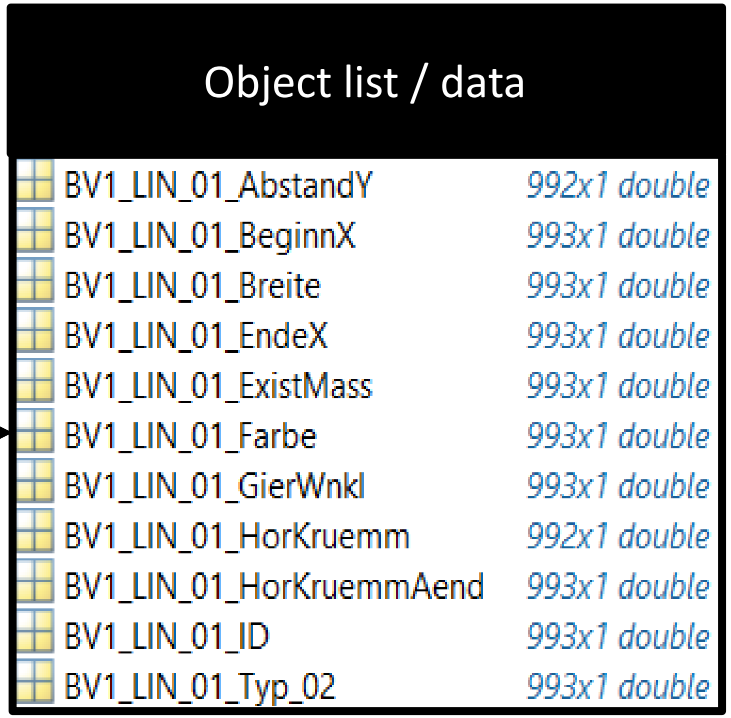
**BV1_LIN_01_Typ_02**





# Sense: What can affect the quality of a camera sensor in a vehicle?





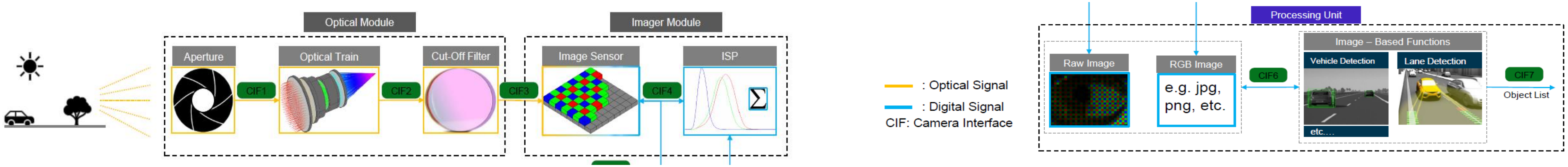
Object list / data

| | |
|---|---|
| BV1_LIN_01_AbstandY | 992x1 double |
| BV1_LIN_01_BeginnX | 993x1 double |
| BV1_LIN_01_Breite | 993x1 double |
| BV1_LIN_01_EndeX | 993x1 double |
| BV1_LIN_01_ExistMass | 993x1 double |
| BV1_LIN_01_Farbe | 993x1 double |
| BV1_LIN_01_GierWnkl | 993x1 double |
| BV1_LIN_01_HorKruemm | 992x1 double |
| BV1_LIN_01_HorKruemmAend | 993x1 double |
| BV1_LIN_01_ID | 993x1 double |
| BV1_LIN_01_Typ_02 | 993x1 double |

# Sense: What can affect the sensor quality? Think about the signal flow.

Brainstorming ca. 5 Minuten

# Sense: What can affect the sensor quality?



**Conditions:**

- Light
- Traffic
- Vehicle
- Driver
- Weather
- Road

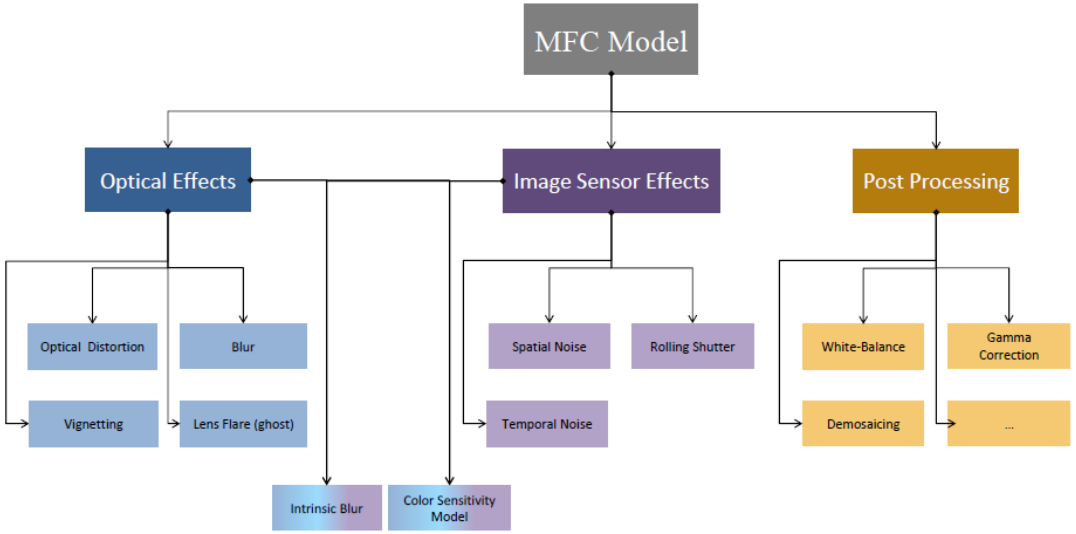


Figure 4.4: Block definition diagram for camera effects classification.

**We have no information about the algorithm of the Object and Line Detection.**

# Radial and tangential distortion

**Distortion Effect**

For an ideal optical system, the formed image should be geometrically similar to the object, i.e., image dimensions should be linearly related to those of the object. However, in practice, optical modules currently fail to maintain a linear relationship between the object and its image. This phenomenon, referred to as image distortion, occurs when the rays from an off-axis point do not converge perfectly at the image point; this is also known as radial distortion, as shown in Fig. 4.5.

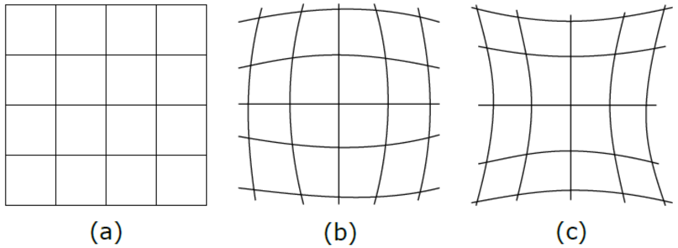

(a) (b) (c)

Figure 4.5: Radial Distortion: (a) No Distortion, (b) Barel Distortion, (c) Pincushion Distortion.

Radial distortion is considered a negative distortion when the actual image is closer to the optical axis, and a positive distortion when the image lies further from the axis than the ideal image. Fig. 4.5 (a) represents the undistorted image of an object consisting of a rectangular wire mesh; when suffering a negative distortion, the image takes on a barrel-like appearance in which the image magnification decreases with an increasing distance from the optical axis (Fig. 4.5 (b)). By contrast, when suffering a positive distortion, the image takes on a pincushion-like shape (pincushion distortion), where the image magnification increases with an increasing distance from the optical axis (Fig. 4.5 (c)).

Additionally, tangential distortion occurs when the lens and the image plane (image sensor) are not parallel or if the image is not formed on the focal plane as predicted by the paraxial equations as shown in Fig. 4.6.

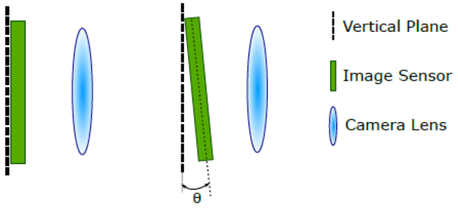


Figure 4.6: Tangential distortion.

Distortion due to false object representation may play an essential role in deceiving several ADAS/AD functions in image data extraction and interpretation. For example, to estimate the distance of the ego vehicle inside a driving lane, an LD function may rely on detected lane markings and on the camera's mounting position to evaluate its position. Fig. 4.7, illustrates the influence of distortion on estimating the vehicle's central offset between the solid yellow and the dashed white lane, where a difference of 0.05 m can be measured.

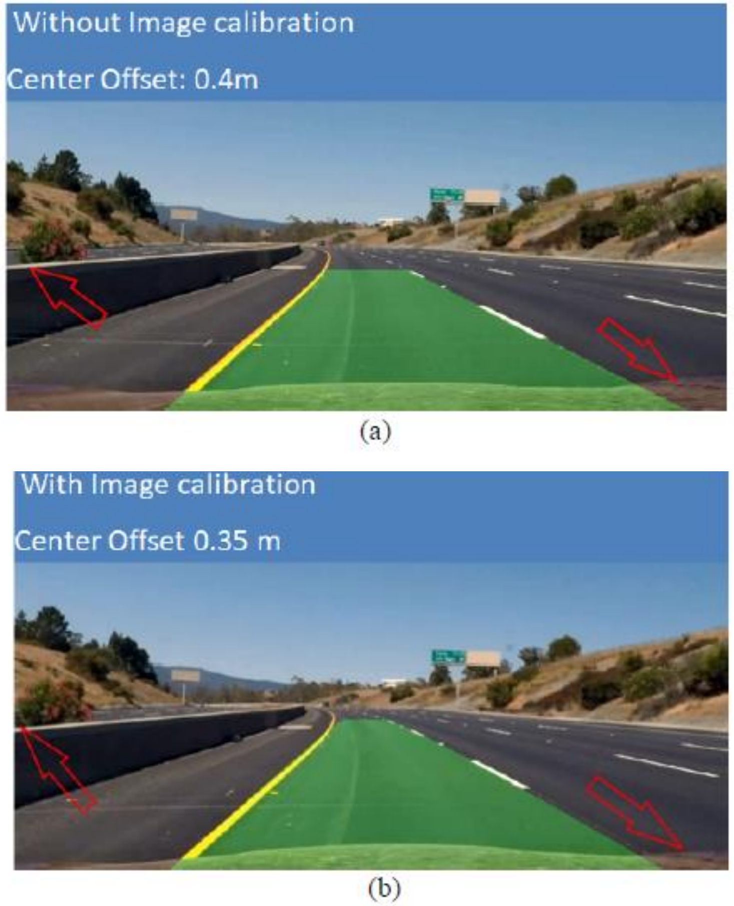
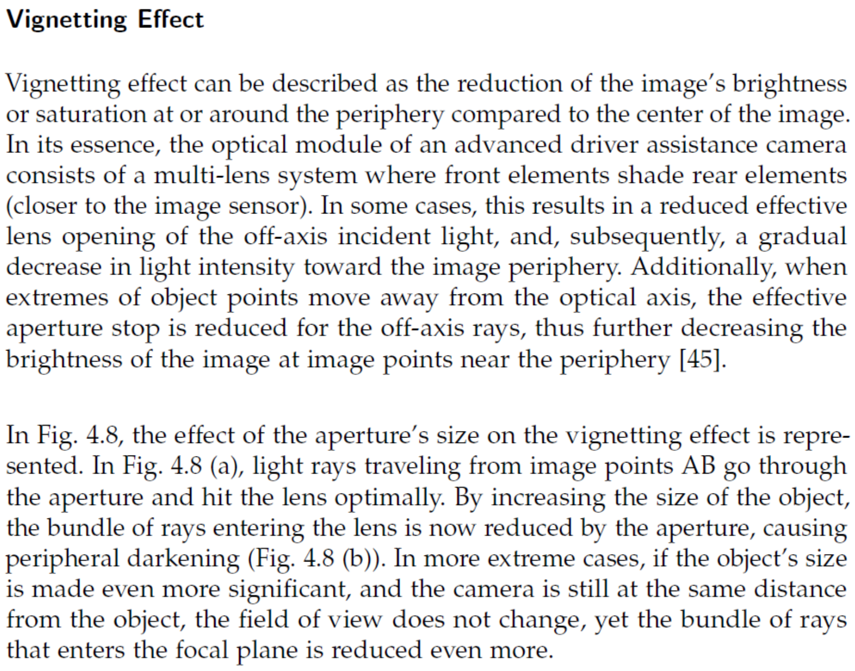


Figure 4.7: Distortion effects on image perception, calibration done via OpenCV API.

Kmeid Saad 2019, Automotive Camera Modeling and Integration With Standardized Interfaces, PhD, S.48-49

# Vignetting Effect



### Vignetting Effect

Vignetting effect can be described as the reduction of the image's brightness or saturation at or around the periphery compared to the center of the image. In its essence, the optical module of an advanced driver assistance camera consists of a multi-lens system where front elements shade rear elements (closer to the image sensor). In some cases, this results in a reduced effective lens opening of the off-axis incident light, and, subsequently, a gradual decrease in light intensity toward the image periphery. Additionally, when extremes of object points move away from the optical axis, the effective aperture stop is reduced for the off-axis rays, thus further decreasing the brightness of the image at image points near the periphery [45].

In Fig. 4.8, the effect of the aperture's size on the vignetting effect is represented. In Fig. 4.8 (a), light rays traveling from image points AB go through the aperture and hit the lens optimally. By increasing the size of the object, the bundle of rays entering the lens is now reduced by the aperture, causing peripheral darkening (Fig. 4.8 (b)). In more extreme cases, if the object's size is made even more significant, and the camera is still at the same distance from the object, the field of view does not change, yet the bundle of rays that enters the focal plane is reduced even more.

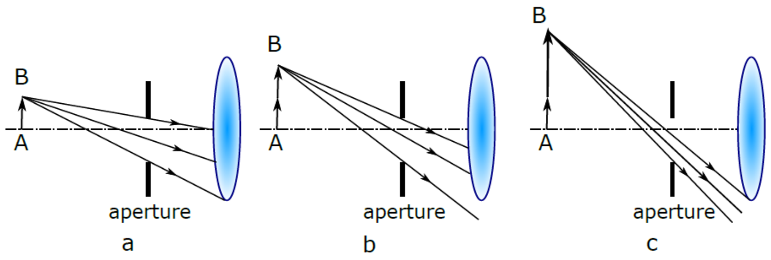
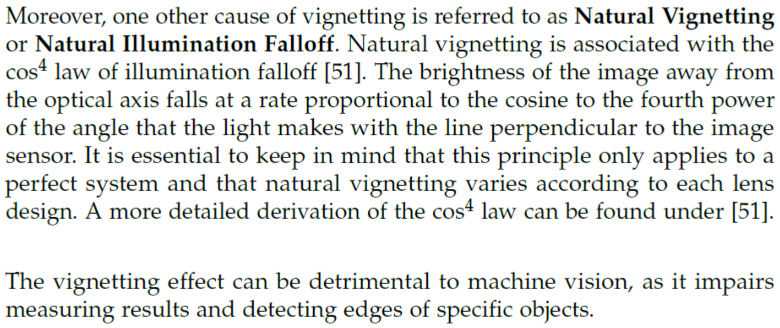


Figure 4.8: Effect of aperture size on vignetting.



Moreover, one other cause of vignetting is referred to as **Natural Vignetting** or **Natural Illumination Falloff**. Natural vignetting is associated with the $\cos^4$ law of illumination falloff [51]. The brightness of the image away from the optical axis falls at a rate proportional to the cosine to the fourth power of the angle that the light makes with the line perpendicular to the image sensor. It is essential to keep in mind that this principle only applies to a perfect system and that natural vignetting varies according to each lens design. A more detailed derivation of the $\cos^4$ law can be found under [51].

The vignetting effect can be detrimental to machine vision, as it impairs measuring results and detecting edges of specific objects.

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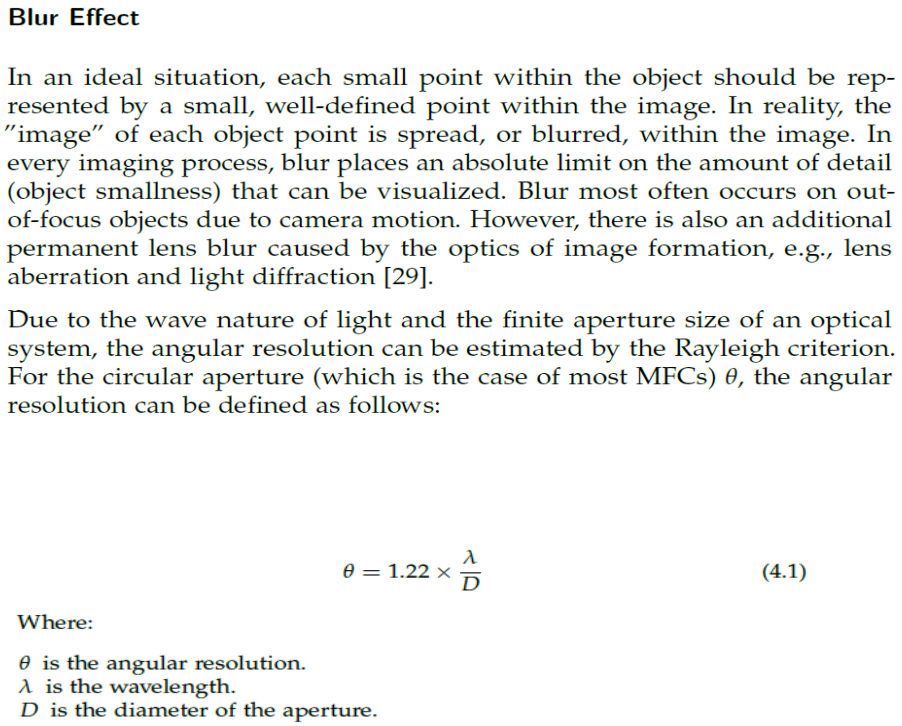
# Blur Effect



**Blur Effect**

In an ideal situation, each small point within the object should be represented by a small, well-defined point within the image. In reality, the "image" of each object point is spread, or blurred, within the image. In every imaging process, blur places an absolute limit on the amount of detail (object smallness) that can be visualized. Blur most often occurs on out-of-focus objects due to camera motion. However, there is also an additional permanent lens blur caused by the optics of image formation, e.g., lens aberration and light diffraction [29].

Due to the wave nature of light and the finite aperture size of an optical system, the angular resolution can be estimated by the Rayleigh criterion. For the circular aperture (which is the case of most MFCs) $\theta$, the angular resolution can be defined as follows:

$$\theta = 1.22 \times \frac{\lambda}{D} \qquad (4.1)$$

Where:

$\theta$ is the angular resolution.
$\lambda$ is the wavelength.
$D$ is the diameter of the aperture.

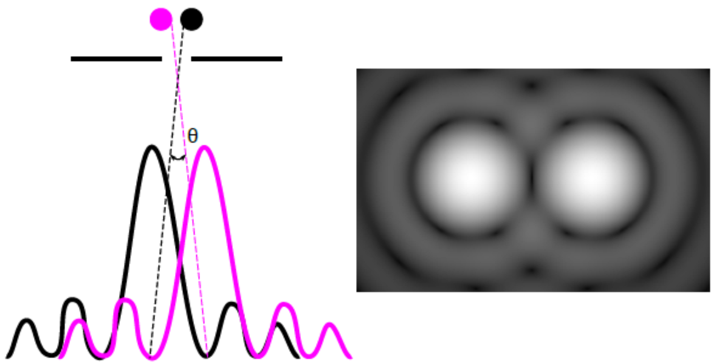
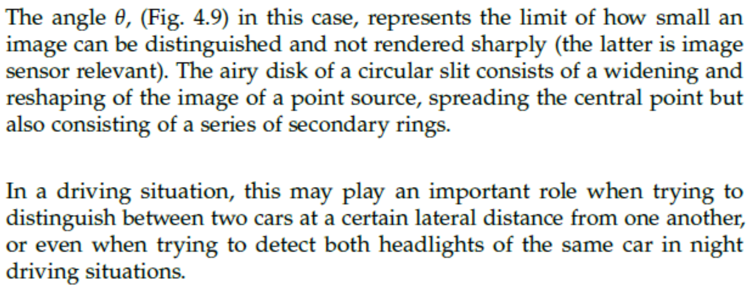
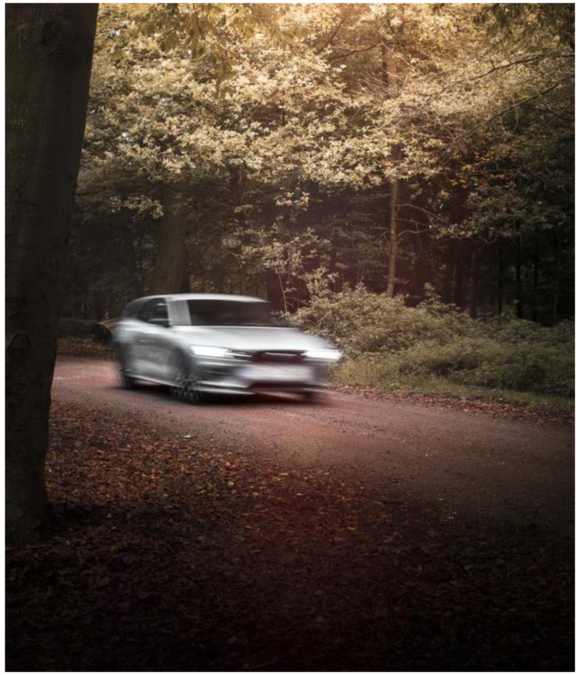


Figure 4.9: Angular resolution for two point objects.



The angle $\theta$, (Fig. 4.9) in this case, represents the limit of how small an image can be distinguished and not rendered sharply (the latter is image sensor relevant). The airy disk of a circular slit consists of a widening and reshaping of the image of a point source, spreading the central point but also consisting of a series of secondary rings.

In a driving situation, this may play an important role when trying to distinguish between two cars at a certain lateral distance from one another, or even when trying to detect both headlights of the same car in night driving situations.



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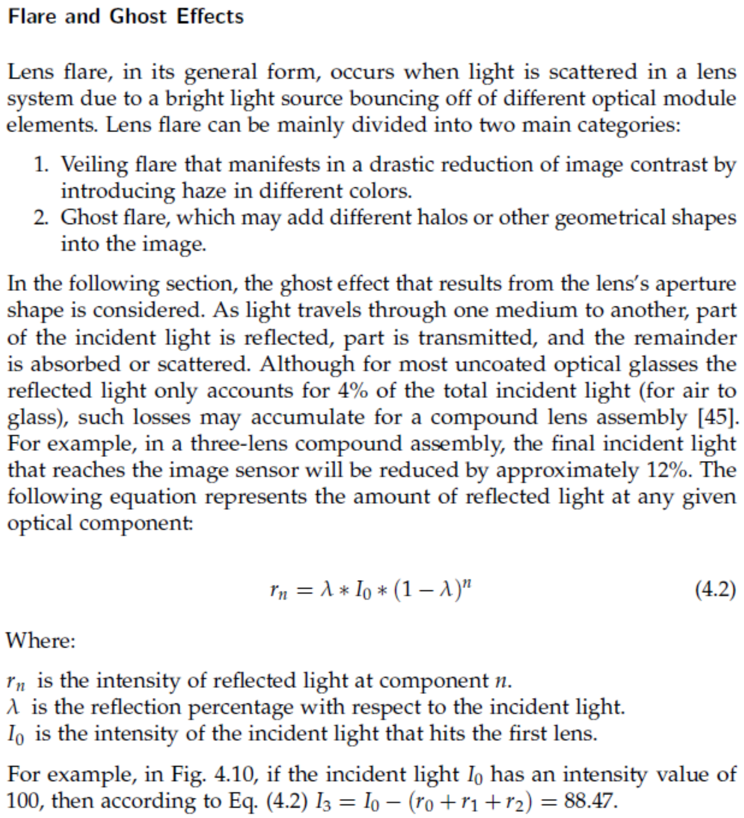
# Flare and Ghost Effects



**Flare and Ghost Effects**

Lens flare, in its general form, occurs when light is scattered in a lens system due to a bright light source bouncing off of different optical module elements. Lens flare can be mainly divided into two main categories:

1. Veiling flare that manifests in a drastic reduction of image contrast by introducing haze in different colors.
2. Ghost flare, which may add different halos or other geometrical shapes into the image.

In the following section, the ghost effect that results from the lens's aperture shape is considered. As light travels through one medium to another, part of the incident light is reflected, part is transmitted, and the remainder is absorbed or scattered. Although for most uncoated optical glasses the reflected light only accounts for 4% of the total incident light (for air to glass), such losses may accumulate for a compound lens assembly [45]. For example, in a three-lens compound assembly, the final incident light that reaches the image sensor will be reduced by approximately 12%. The following equation represents the amount of reflected light at any given optical component:

$$r_n = \lambda * I_0 * (1-\lambda)^n \tag{4.2}$$

Where:

$r_n$ is the intensity of reflected light at component $n$.
$\lambda$ is the reflection percentage with respect to the incident light.
$I_0$ is the intensity of the incident light that hits the first lens.

For example, in Fig. 4.10, if the incident light $I_0$ has an intensity value of 100, then according to Eq. (4.2) $I_3 = I_0 - (r_0 + r_1 + r_2) = 88.47$.

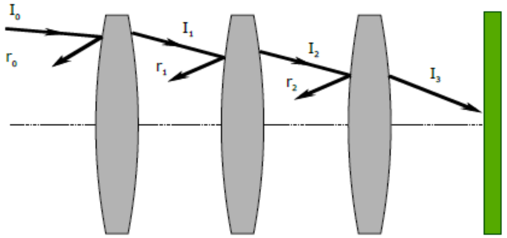


Figure 4.10: Reflection and refraction in a multi-lens optical system.

Furthermore, in an encapsulated optical system, the weak reflected rays represented in Fig. 4.11 might create ghost images superimposed on the image generated by the transmitted rays. For example, $r_2$ in Fig. 4.11 indicated in blue may undergo a total internal reflection and reach the image sensor, thus forming a ghost image.

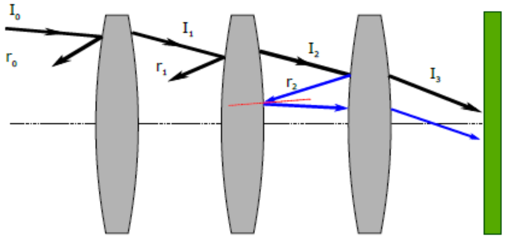


Figure 4.11: Ghost image formation.

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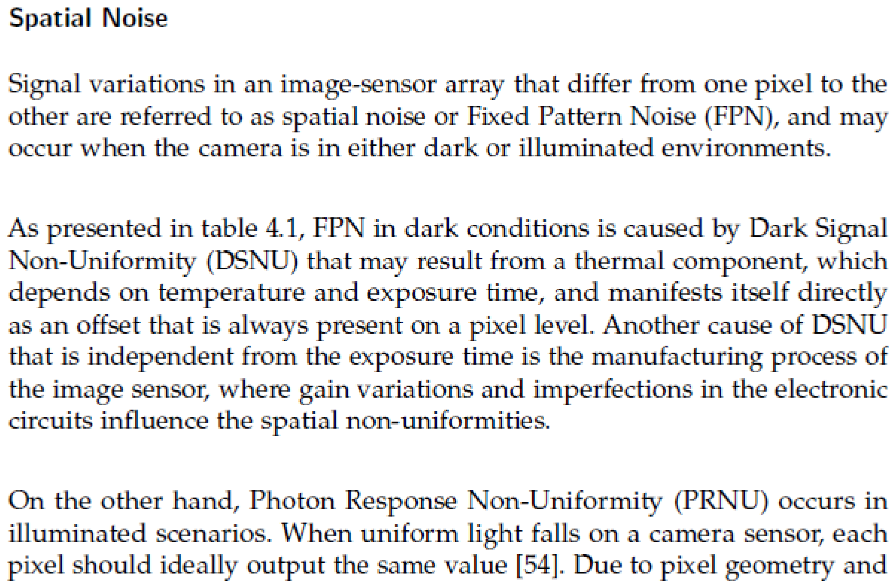
# Spatial Noise

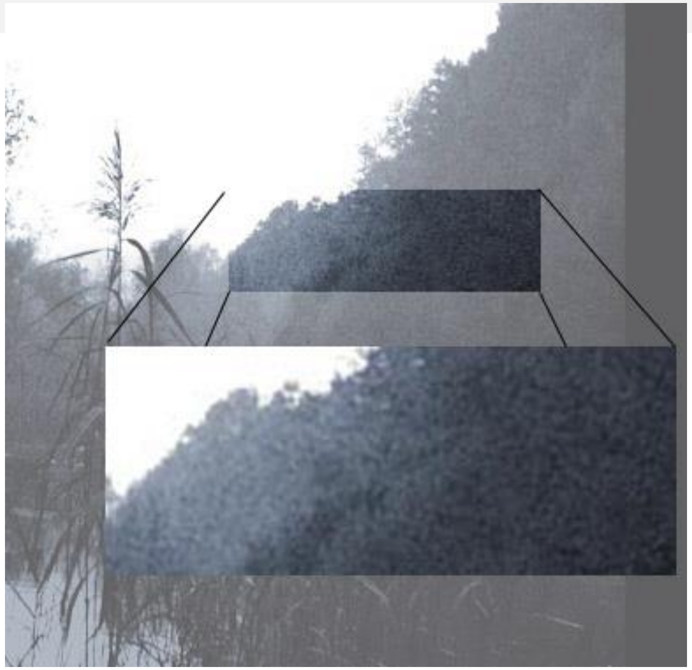


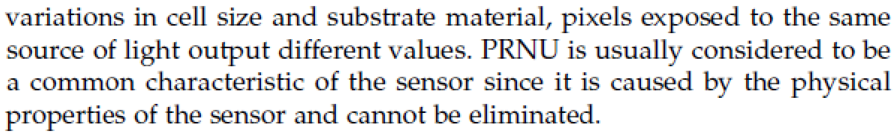
### Spatial Noise

Signal variations in an image-sensor array that differ from one pixel to the other are referred to as spatial noise or Fixed Pattern Noise (FPN), and may occur when the camera is in either dark or illuminated environments.

As presented in table 4.1, FPN in dark conditions is caused by Dark Signal Non-Uniformity (DSNU) that may result from a thermal component, which depends on temperature and exposure time, and manifests itself directly as an offset that is always present on a pixel level. Another cause of DSNU that is independent from the exposure time is the manufacturing process of the image sensor, where gain variations and imperfections in the electronic circuits influence the spatial non-uniformities.

On the other hand, Photon Response Non-Uniformity (PRNU) occurs in illuminated scenarios. When uniform light falls on a camera sensor, each pixel should ideally output the same value [54]. Due to pixel geometry and





variations in cell size and substrate material, pixels exposed to the same source of light output different values. PRNU is usually considered to be a common characteristic of the sensor since it is caused by the physical properties of the sensor and cannot be eliminated.

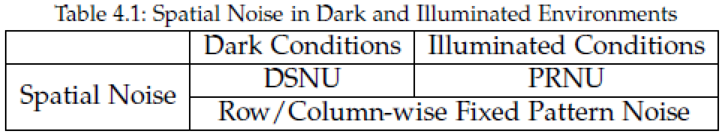


Table 4.1: Spatial Noise in Dark and Illuminated Environments

| | Dark Conditions | Illuminated Conditions |
|---|---|---|
| Spatial Noise | DSNU | PRNU |
| | Row/Column-wise Fixed Pattern Noise | |

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# Tesla Autopilot

## Checking real world situation!

Tesla Autopilot

## Checking real world situation!

# Tesla Autopilot

## Checking real world situation!

# SensIndex | Line Detection Evaluation with KPI‘s

## Comparison in different visibility conditions with Ground Truth

Vehicle: AudiQ5

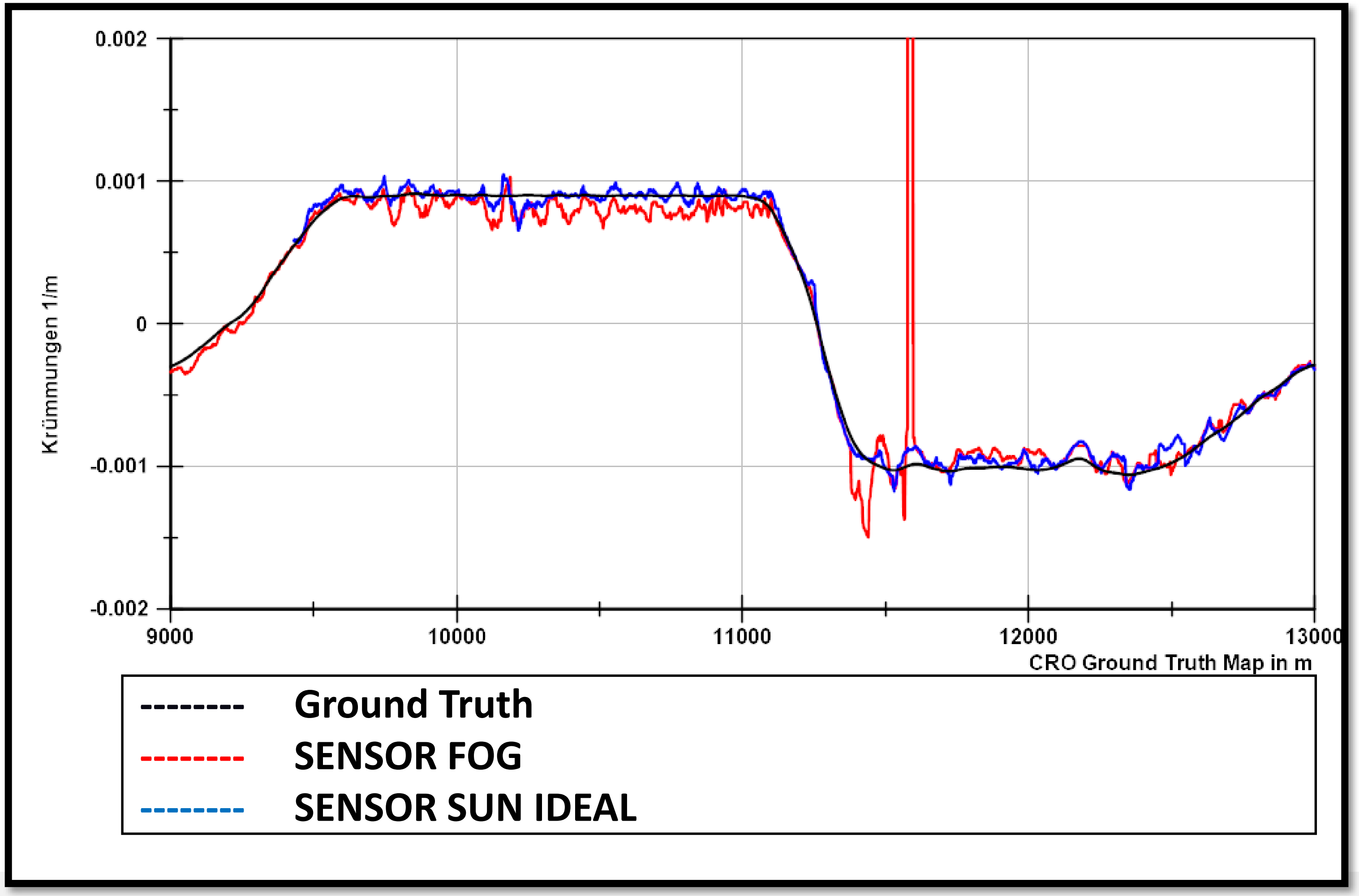
Speed: 180 km/h

Road: A7

Radius: 1000 m

Camera: MobilEye

Environment:
- Sun / bright
- Fog / dark



# SensIndex |Road Measurement

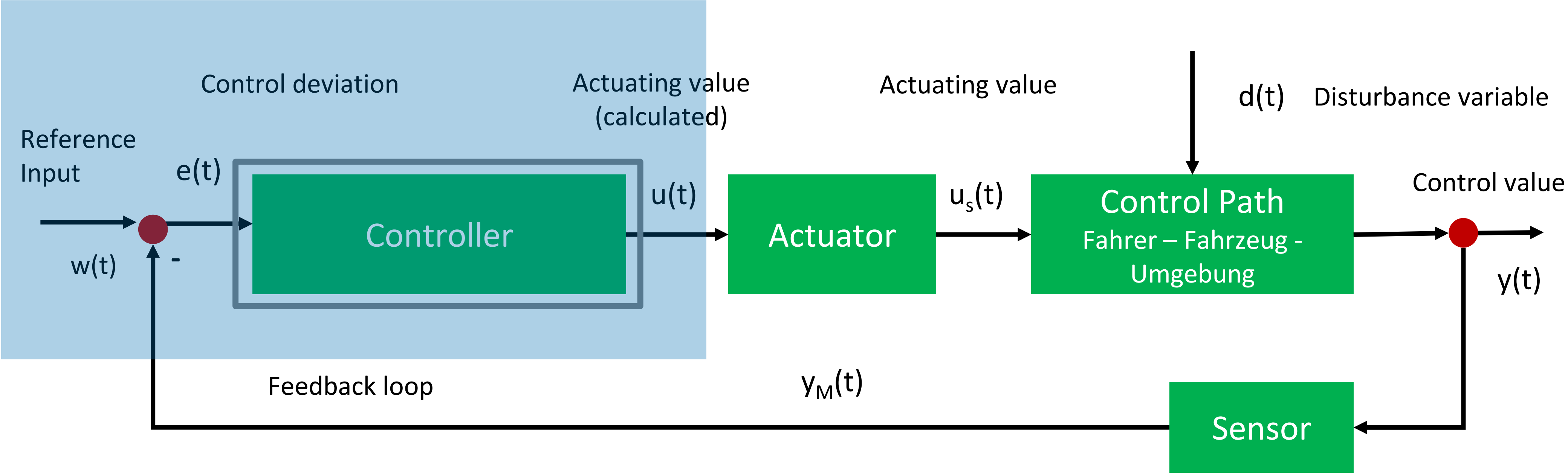
## A7 1000 meter curve with 180 km/h in sunny and foggy condition.

# Plan

**Break 10 min.**

# Plan

## Plan:



Control deviation

Actuating value (calculated)

Actuating value

$d(t)$ Disturbance variable

Reference Input

$e(t)$

Controller

$u(t)$

Actuator

$u_s(t)$

Control Path

Fahrer – Fahrzeug - Umgebung

Control value

$w(t)$

-

$y(t)$

Feedback loop

$y_M(t)$

Sensor

# Lane Keeping Controller

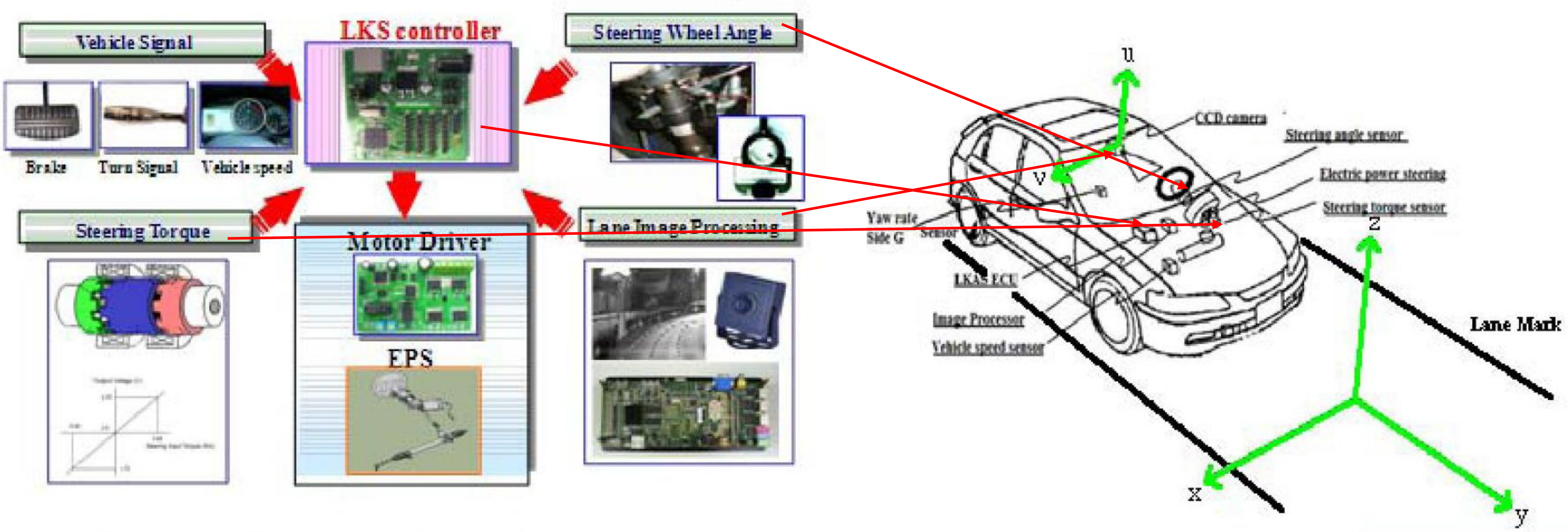
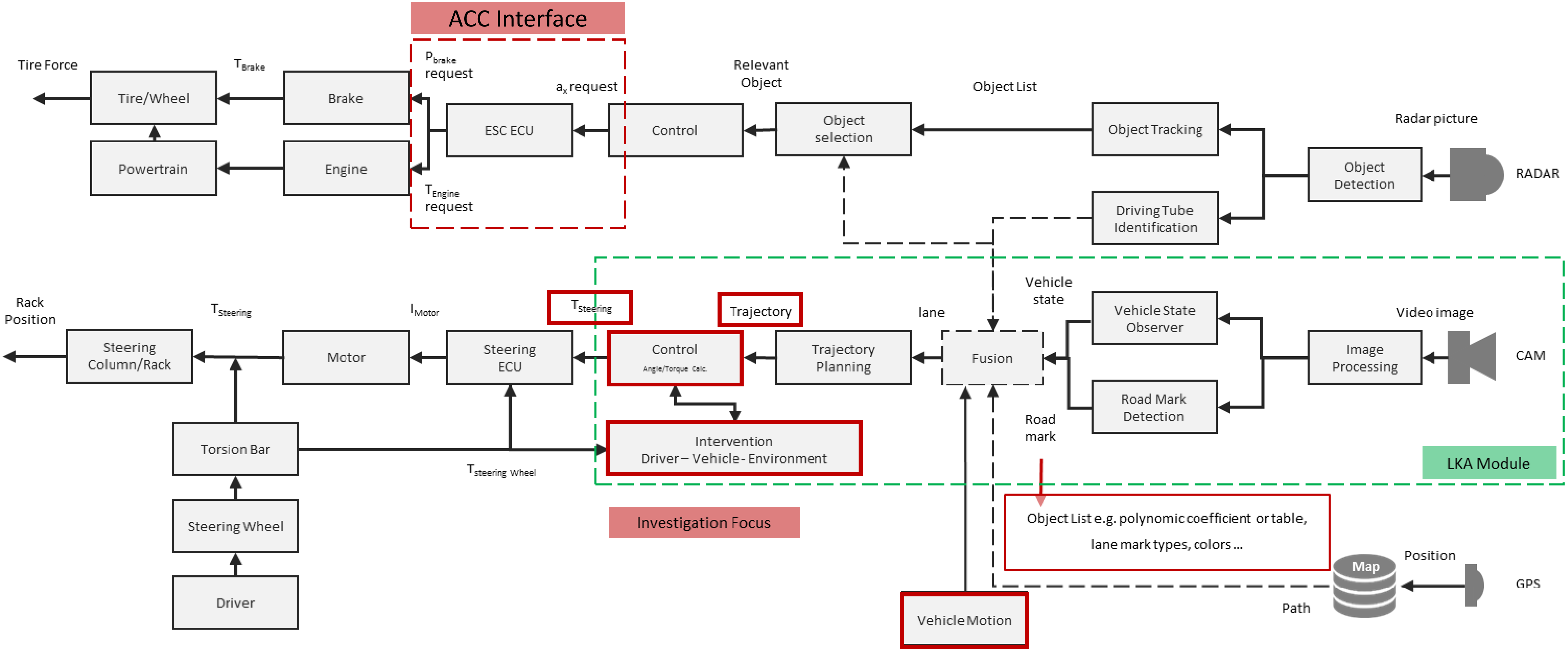


Fig. 1 Configuration of the lane keeping system.

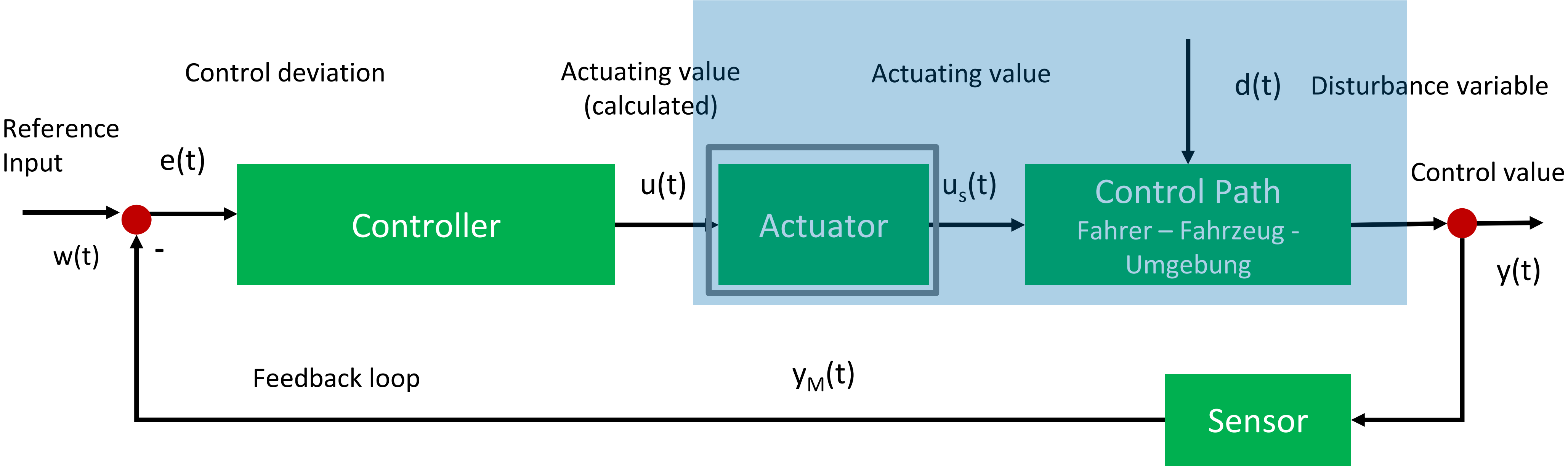
# Sense – Plan – Act Schematic



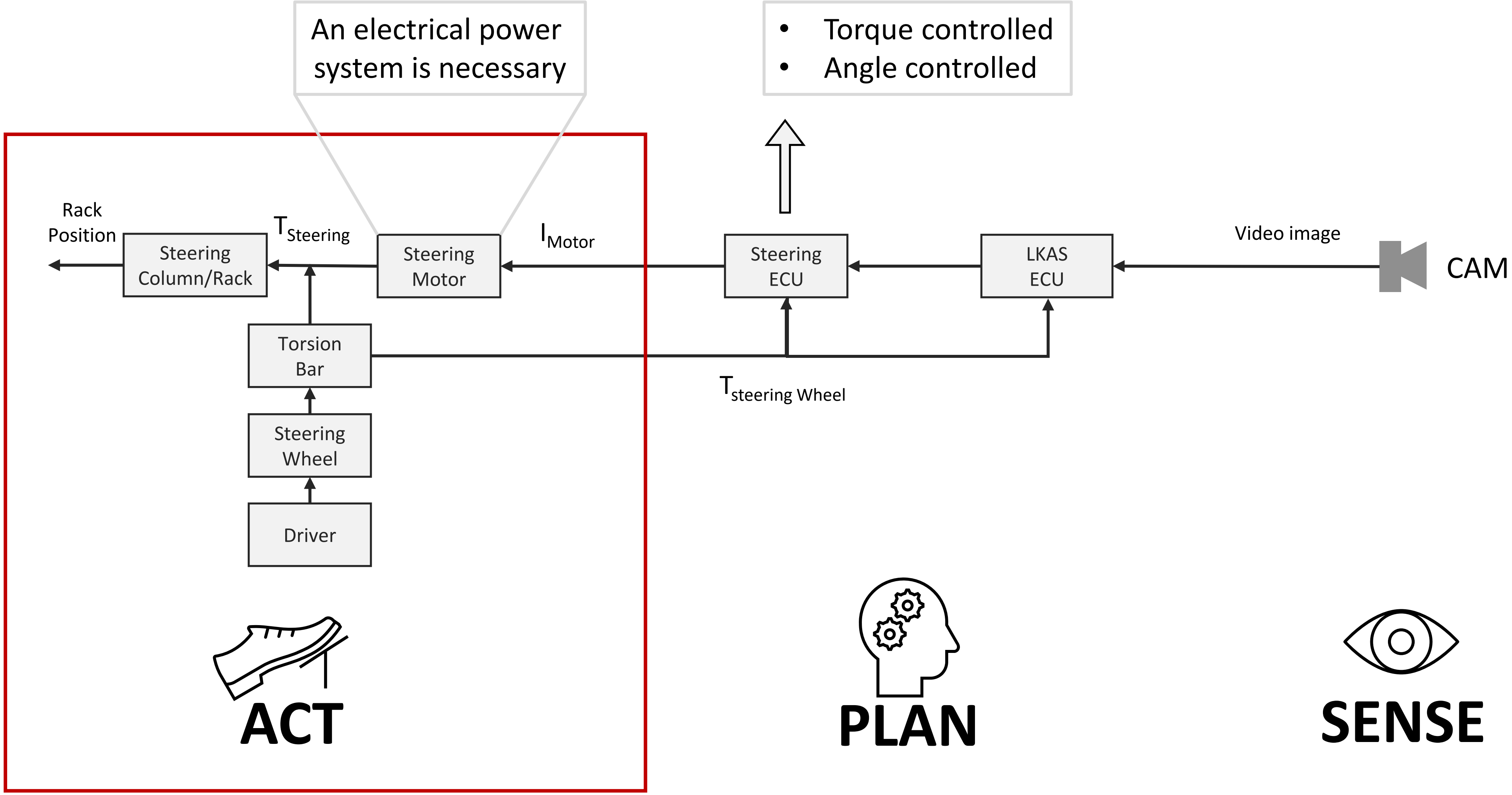
Simple way to get Time to line crossing: $t_{LC} = d_{LC} / v_x*\sin(\psi)$ but Information about the track, like curvature, missing

# Act

## Act:


Control deviation
Actuating value (calculated)
Actuating value
d(t)
Disturbance variable
Reference Input
e(t)
Controller
u(t)
Actuator
$u_s(t)$
Control Path
Fahrer – Fahrzeug - Umgebung
Control value
w(t)
-
y(t)
Feedback loop
$y_M(t)$
Sensor

# Act



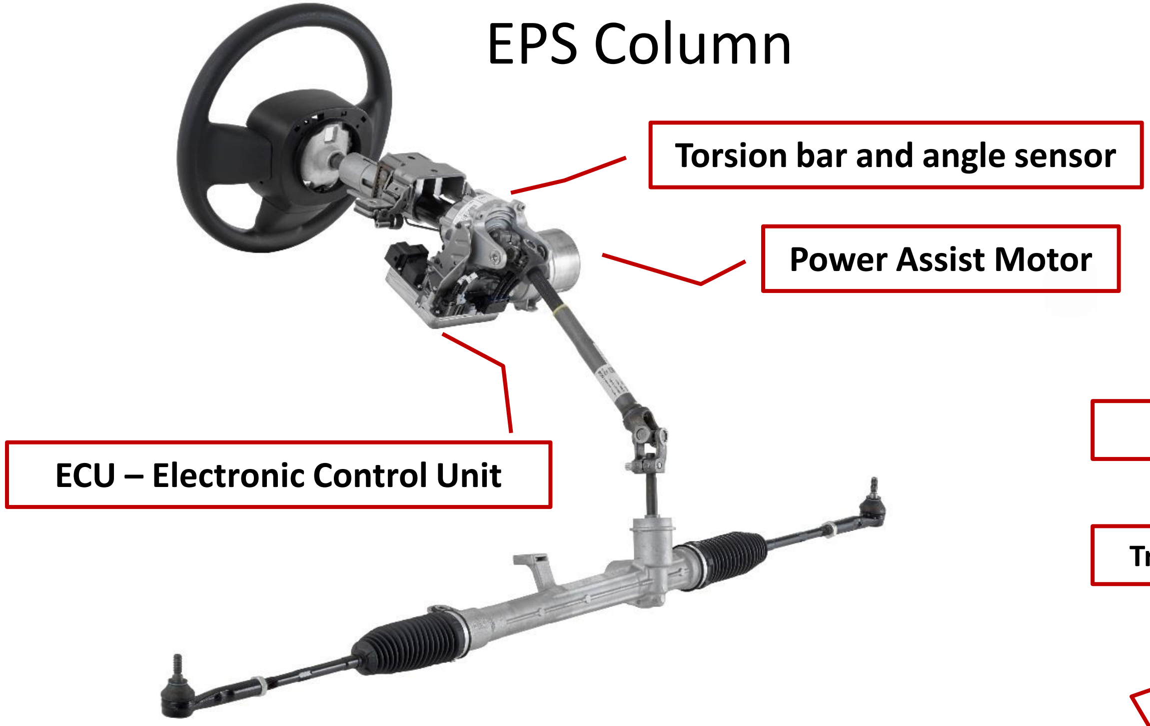
An electrical power system is necessary

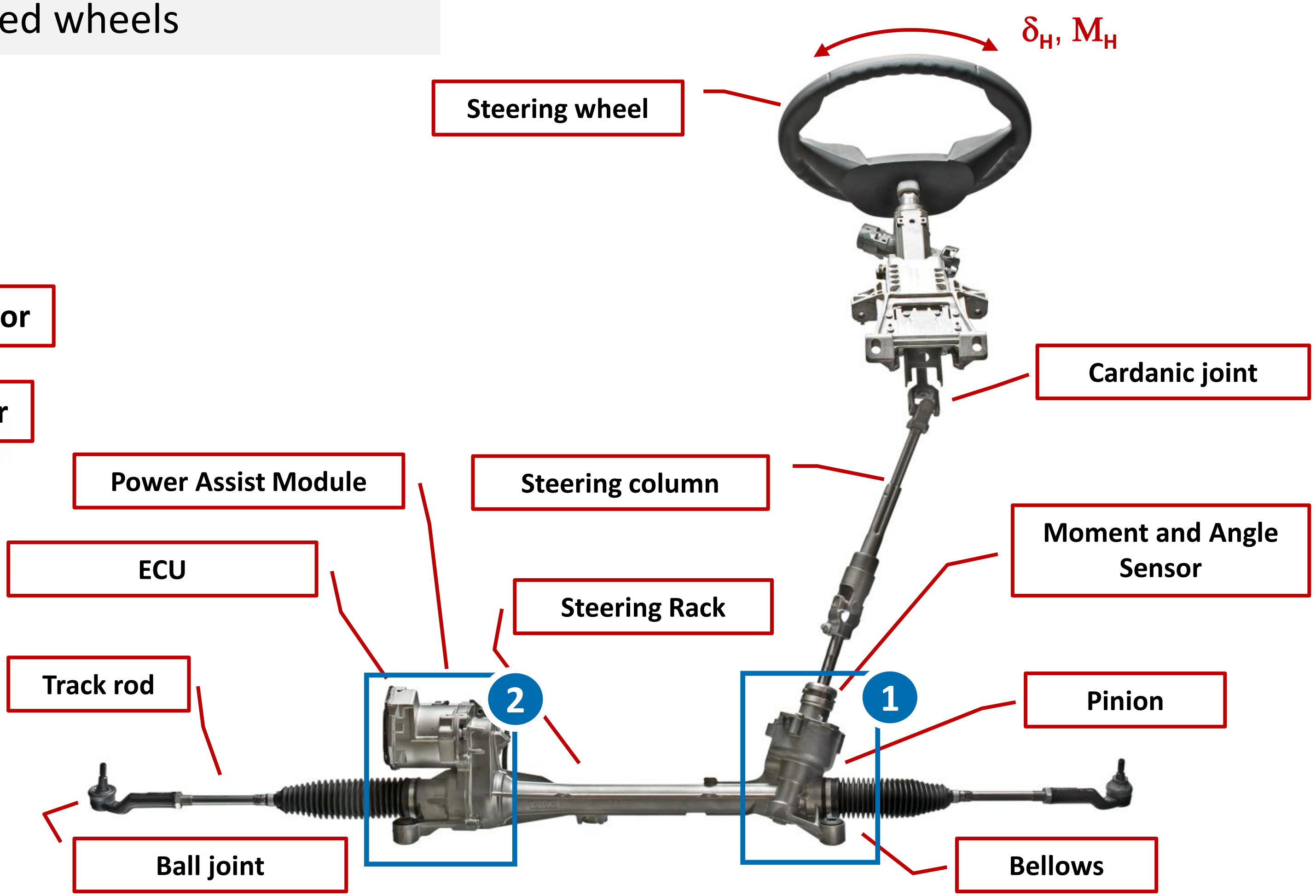
- Torque controlled
- Angle controlled

# Steering Systems

The steering system converts the rotary motion applied to the steering wheel into a change in the steering angle of the steered wheels

EPS Column





# Steering Systems

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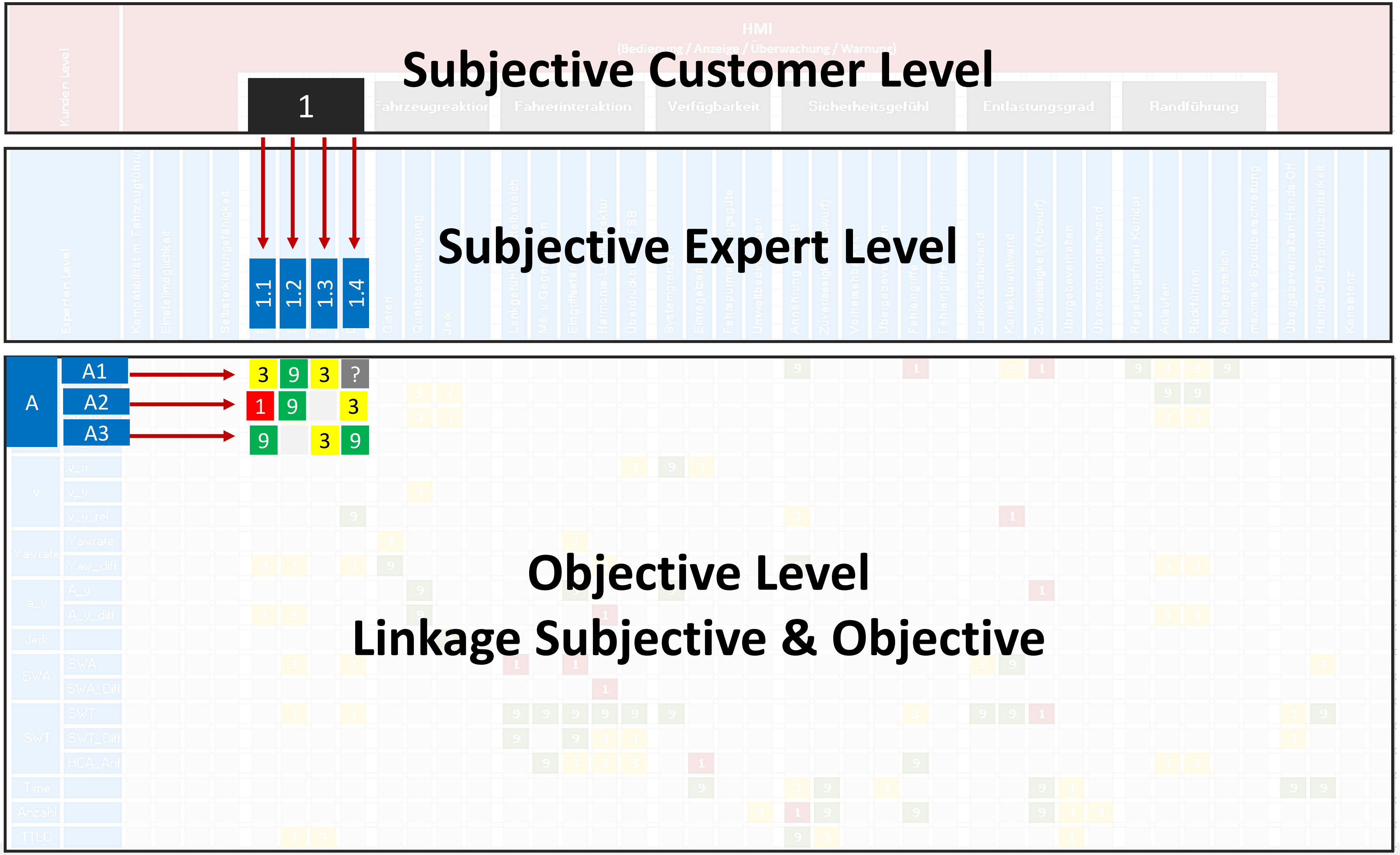
# Steering Systems – Steer by wire

# Evaluation Method

# Evaluation of Function



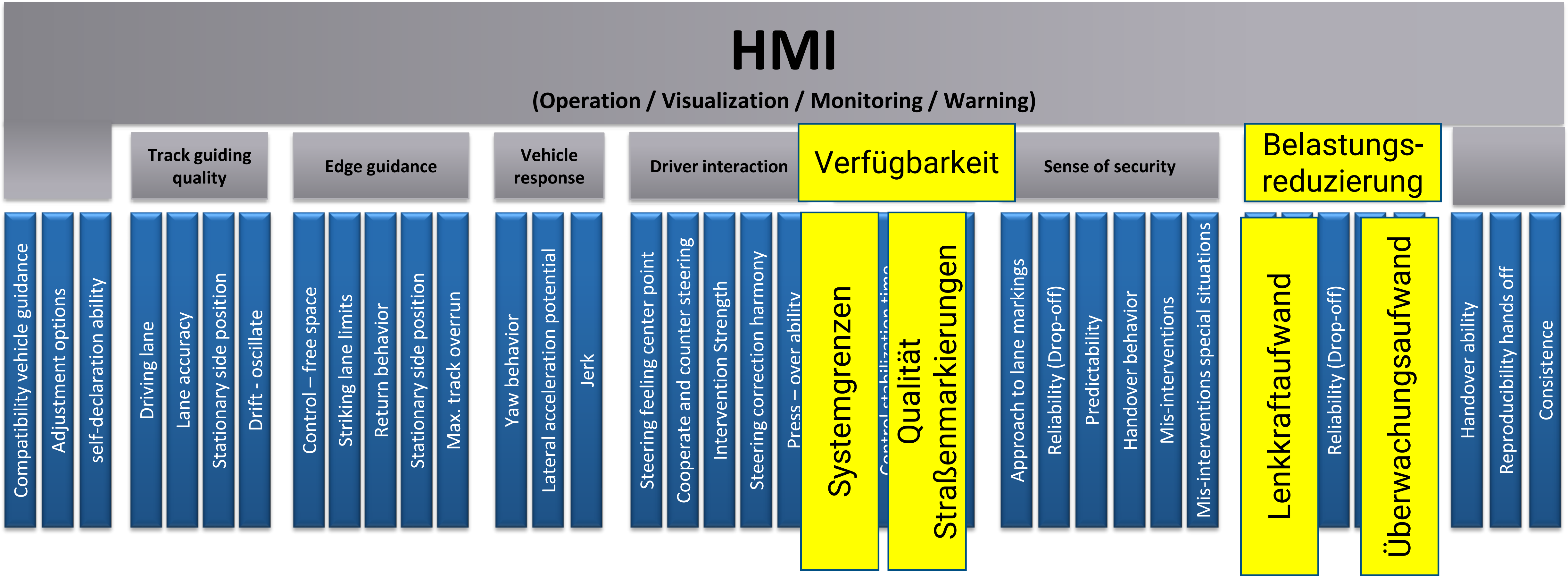
Subjective Customer Level

Subjective Expert Level

Objective Level

Linkage Subjective & Objective

# Layer Model – subjectiv Layer



**HMI**

**(Operation / Visualization / Monitoring / Warning)**

- Compatibility vehicle guidance
- Adjustment options
- self-declaration ability

**Track guiding quality**

- Driving lane
- Lane accuracy
- Stationary side position
- Drift - oscillate

**Edge guidance**

- Control – free space
- Striking lane limits
- Return behavior
- Stationary side position
- Max. track overrun

**Vehicle response**

- Yaw behavior
- Lateral acceleration potential
- Jerk

**Driver interaction**

- Steering feeling center point
- Cooperate and counter steering
- Intervention Strength
- Steering correction harmony
- Press – over ability
- Control stabilization time

Verfügbarkeit

- Systemgrenzen
- Qualität Straßenmarkierungen

**Sense of security**

- Approach to lane markings
- Reliability (Drop-off)
- Predictability
- Handover behavior
- Mis-interventions
- Mis-interventions special situations

Belastungs-reduzierung

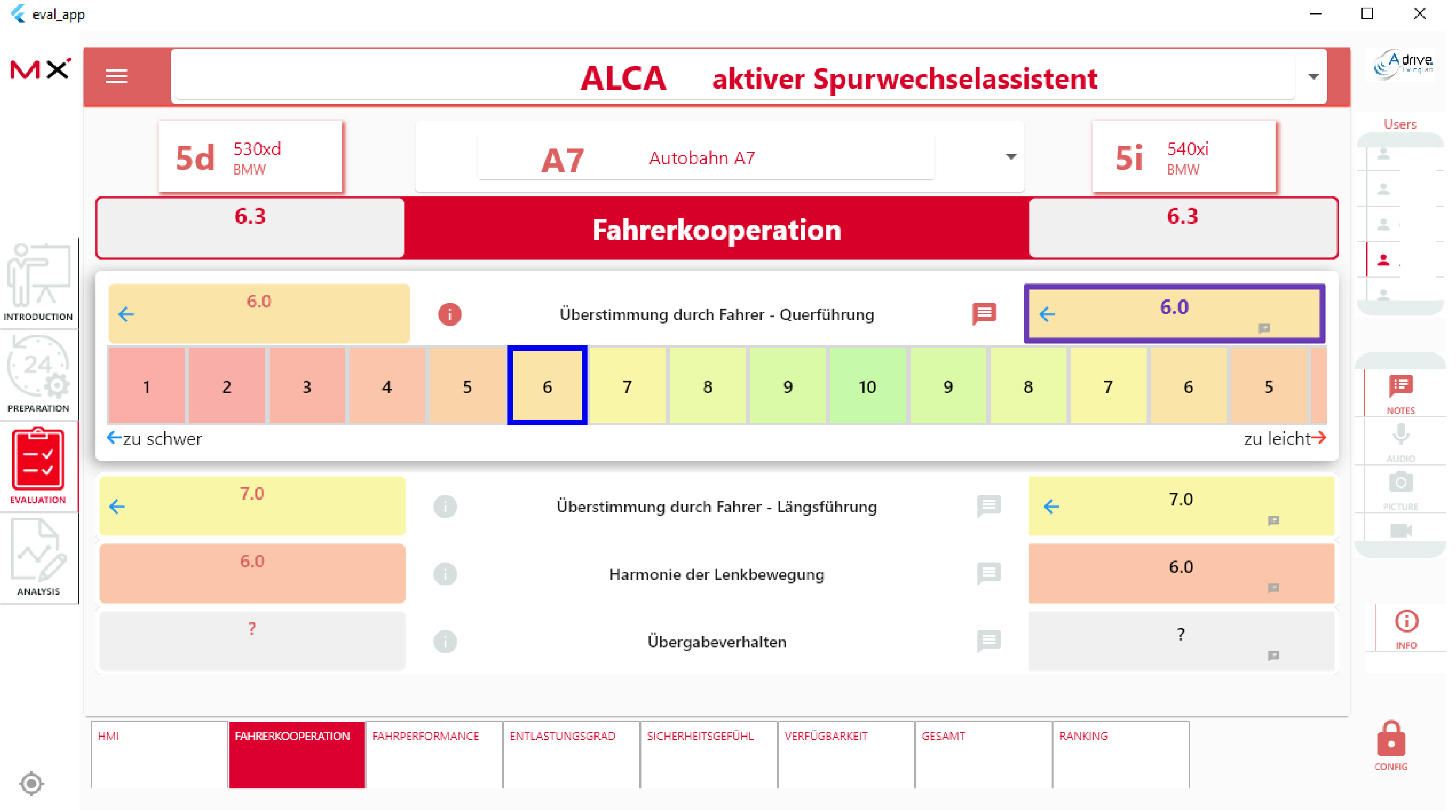
- Lenkkraftaufwand
- Reliability (Drop-off)
- Überwachungsaufwand

- Handover ability
- Reproducibility hands off
- Consistence

# Subjective Questions by using eval app

Fragenkatalog

- HMI
- Fahrerkooperation
- Fahrperformance
- Entlastungsgrad
- Sicherheitsgefühl
- Verfügbarkeit
- Gesamt
- Ranking



**ALCA** aktiver Spurwechselassistent

5d 530xd BMW

A7 Autobahn A7

5i 540xi BMW

6.3 **Fahrerkooperation** 6.3

| | | |
|---|---|---|
| 6.0 | Überstimmung durch Fahrer - Querführung | 6.0 |
| 7.0 | Überstimmung durch Fahrer - Längsführung | 7.0 |
| 6.0 | Harmonie der Lenkbewegung | 6.0 |
| ? | Übergabeverhalten | ? |

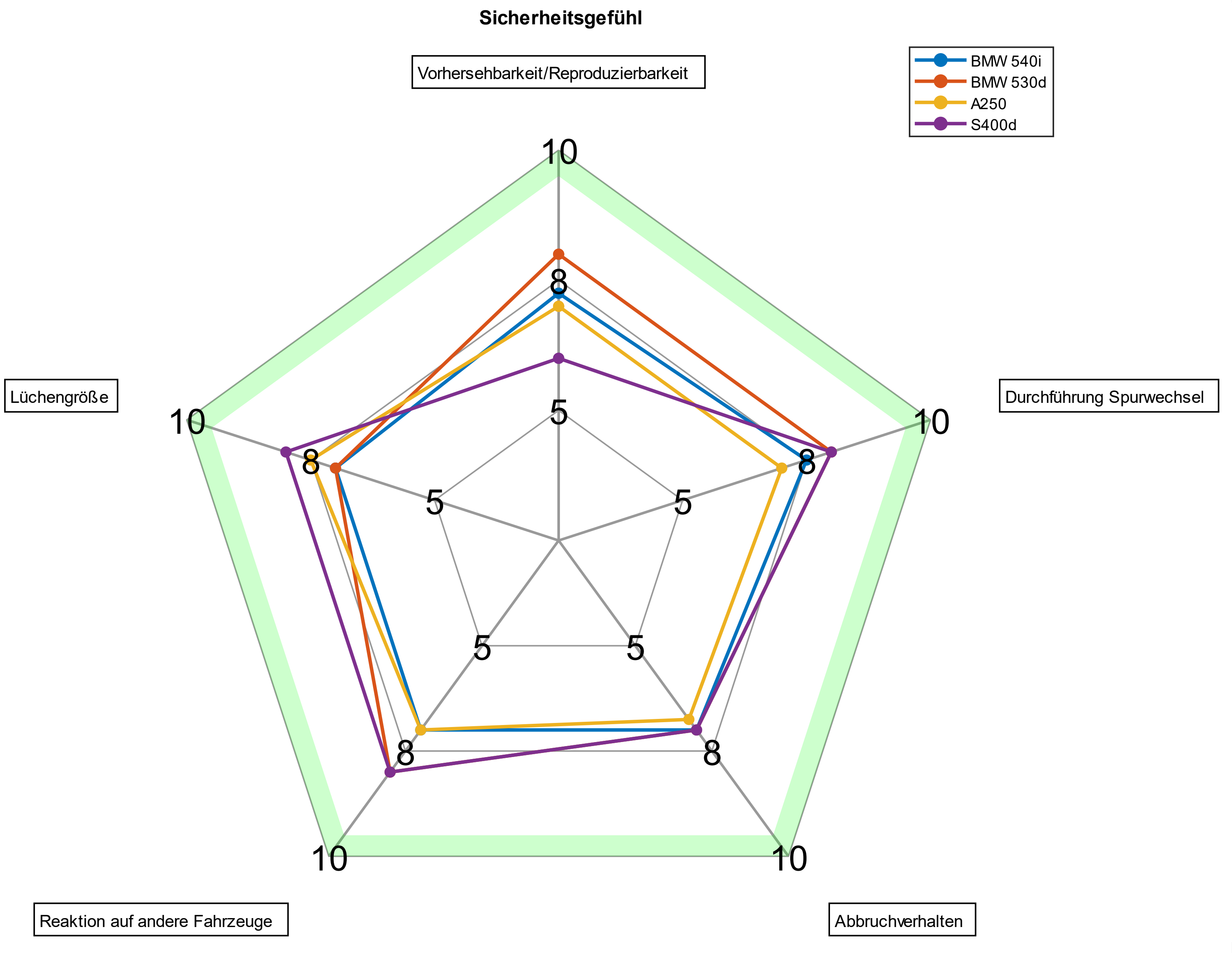
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 9 | 8 | 7 | 6 | 5 |

←zu schwer zu leicht→

# Results of subject study

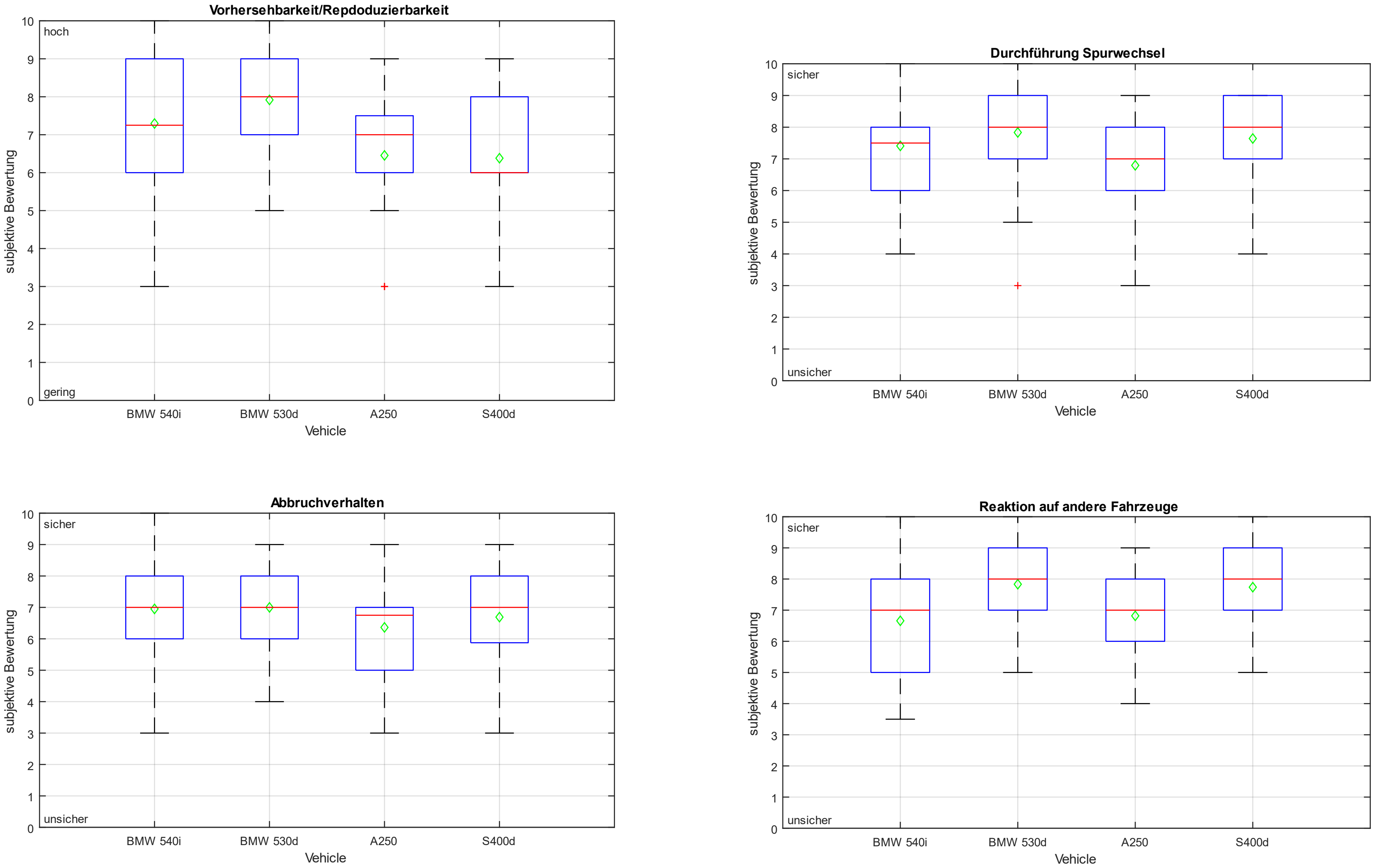
Fragenkatalog

- HMI
- Fahrerkooperation
- Fahrperformance
- Entlastungsgrad
- **Sicherheitsgefühl**
- Verfügbarkeit
- Gesamt
- Ranking

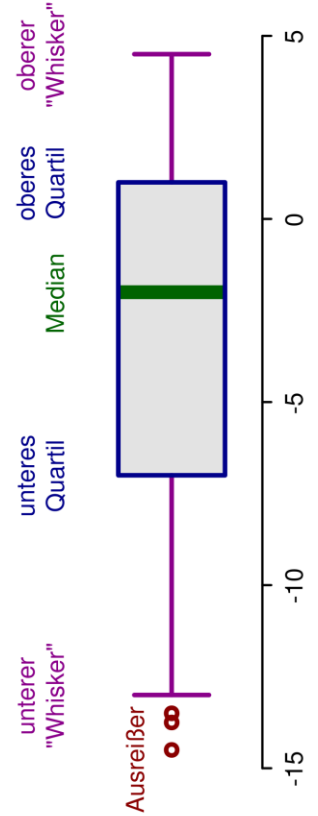


# Results of subject study

Sicherheitsgefühl (1)

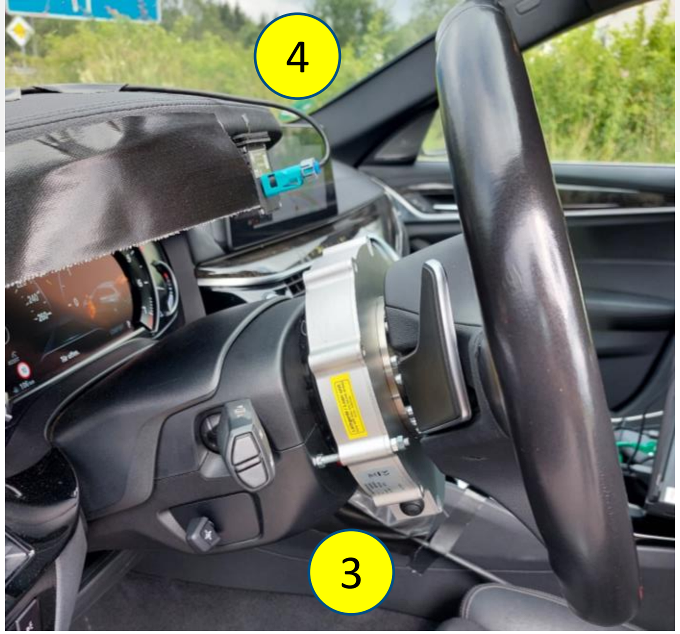


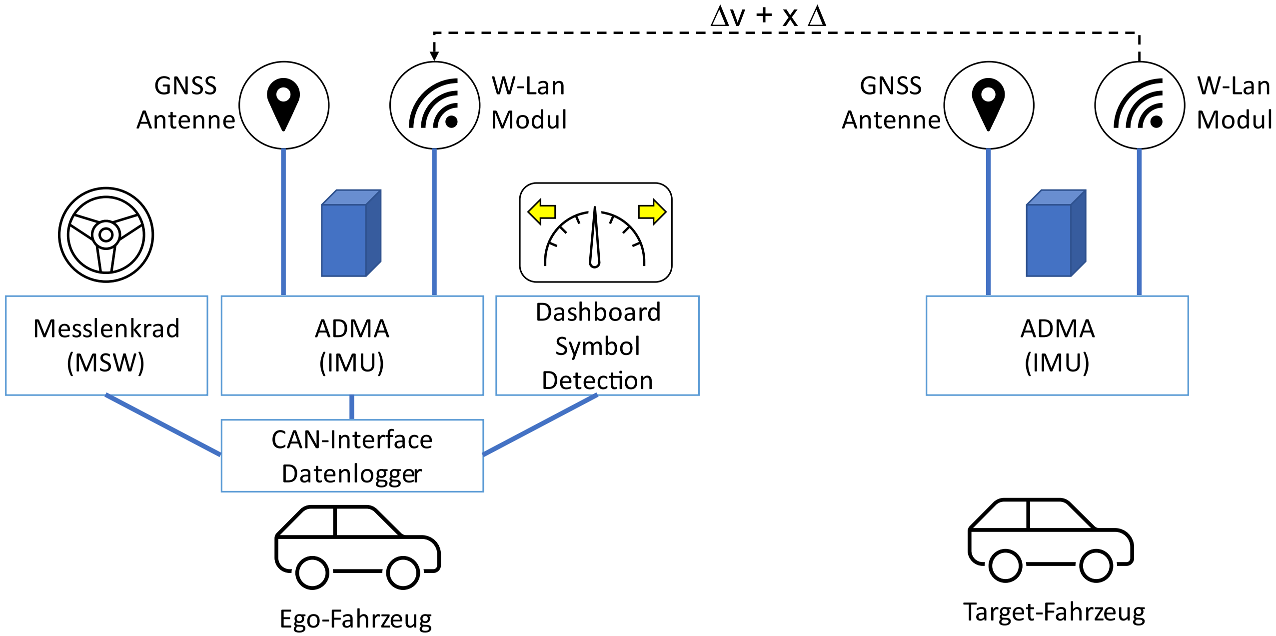
Boxplot diagram



# Measurement Method

- Bill of material:
  1. Inertial measurement unit (IMU)
  2. Differential-GPS Modem (DGPS) → +/- 2cm
  3. Measurement steering wheel (MSW)
  4. Dashboard Symbol Detection
  5. Bus + CAN Interface
  6. Manual binary Trigger (optional)




$\Delta v + x\ \Delta$

GNSS Antenne

W-Lan Modul

GNSS Antenne

W-Lan Modul

Messlenkrad (MSW)

ADMA (IMU)

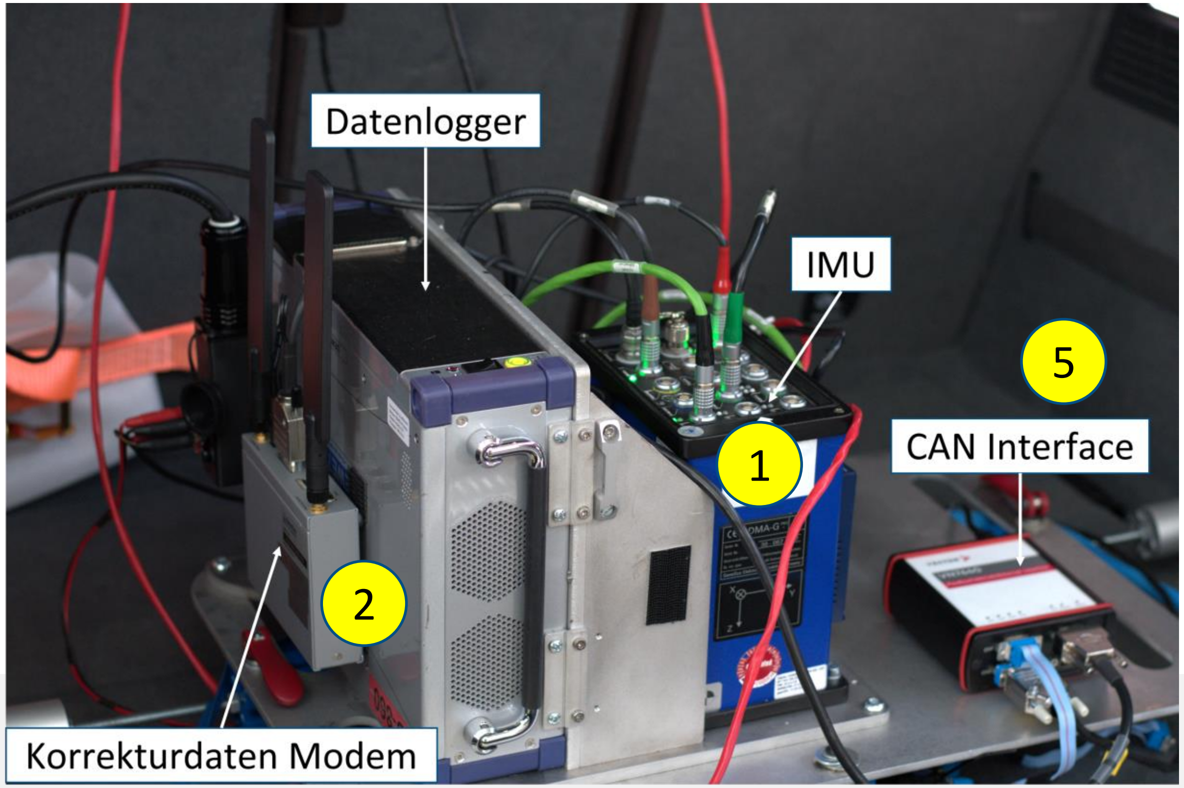
Dashboard Symbol Detection

ADMA (IMU)

CAN-Interface Datenlogger

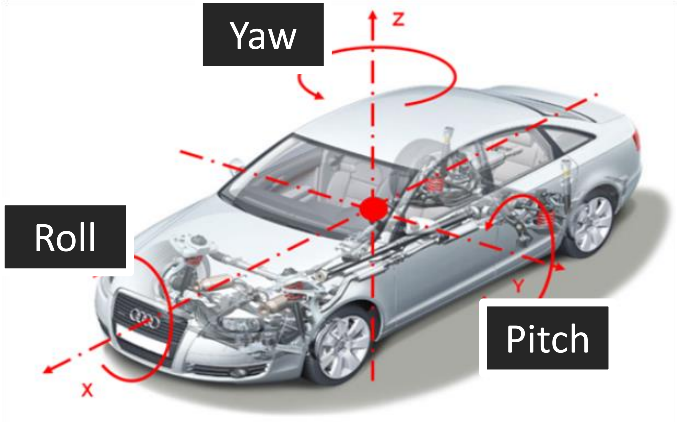
Ego-Fahrzeug

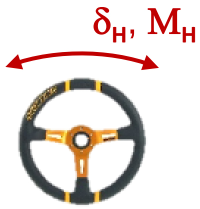
Target-Fahrzeug



# Measurement Equipment

- Required Channels:
  - Accelerations
  - Velocities
  - Rates
  - GPS-Positions for every POI
  - Steering Torque, Angle, Speed
  - LKAS Status
  - Signal color and warning signal (UN/ECE R79)
  - Bus Signals (optional)
- Sample rate const. 100 Hz
- Video data synchronized (optional)





# Test Conduction

## Impression of Test Conduction

# Procedure of objective evaluation

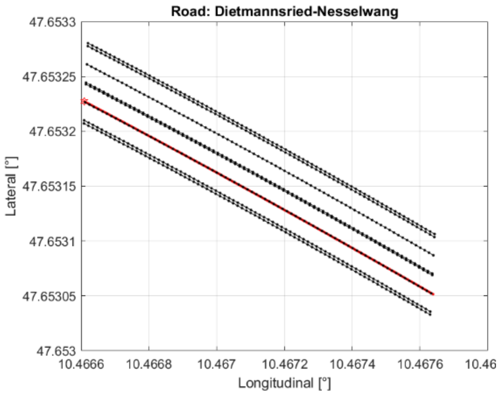
| | |
|---|---|
| Consider maneuver and KPI‘s | Develop or choose relevant of existing evaluation procedures |
| Set up measurement devices and check everything | Check functionality of each measurement device and correct setup of the data aquisition system |
| Execute test drives | Also safe meta data |
| Preprocess recorded data | • Renaming<br>• Shorten data<br>• add information out of Ground Truth method |
| Define evaluation routine to get KPI | Choose routine or build up evaluation script |
| Evaluate data | Rethink output. Does it make sense. What does the value mean |

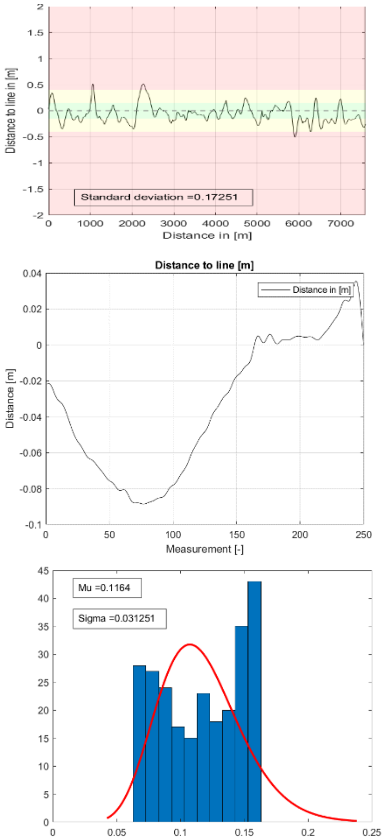
# Evaluation

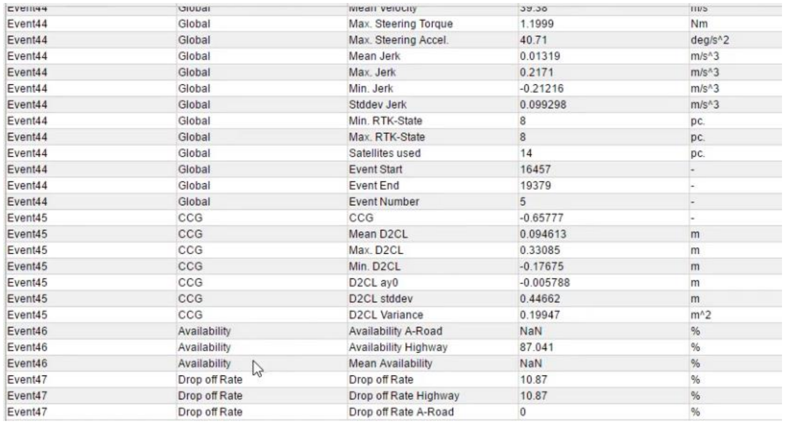
Localization

Calculation

Evaluation/Rating



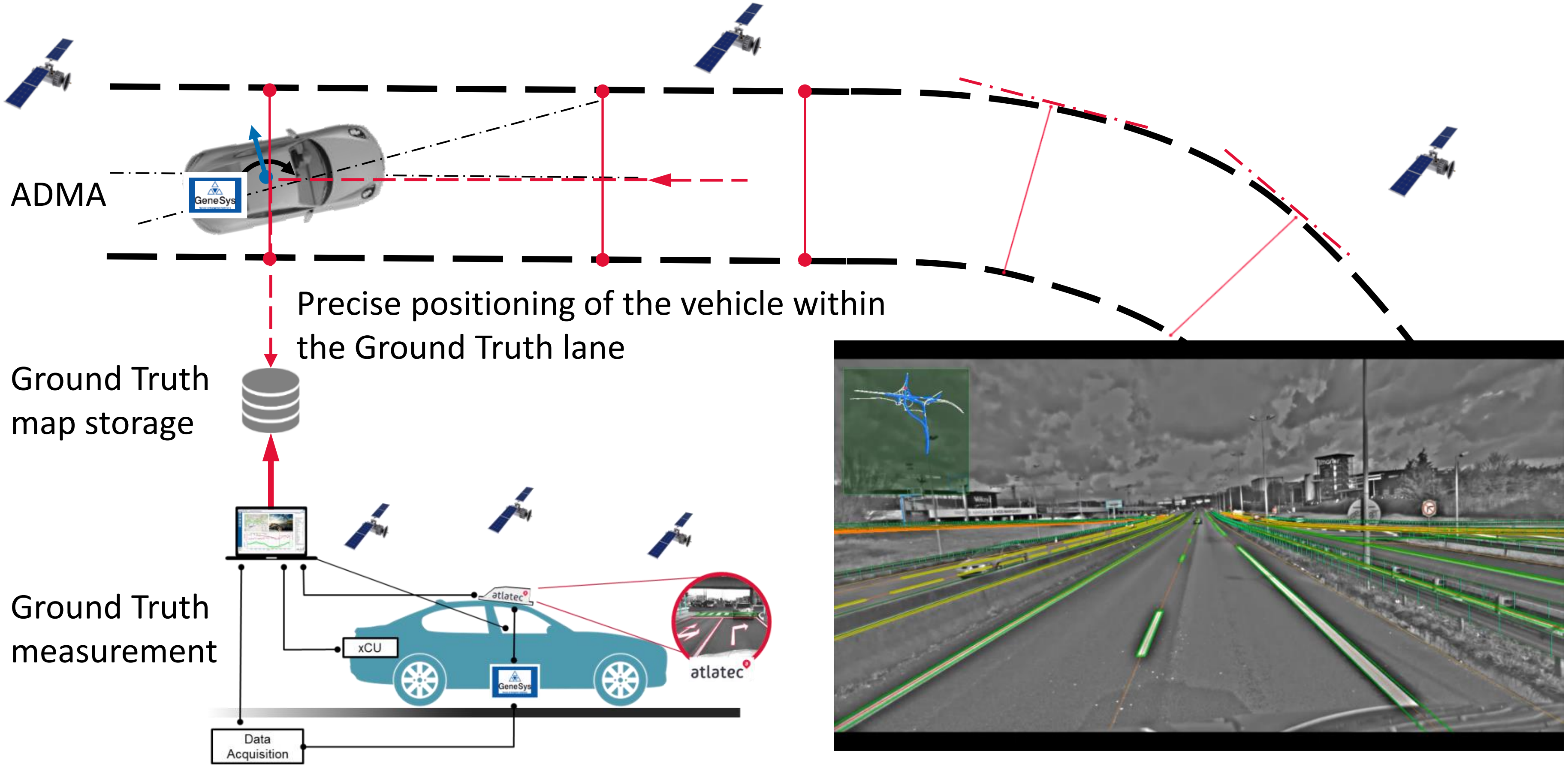




| | | | | |
|---|---|---|---|---|
| Event44 | Global | Mean Velocity | 39.38 | m/s |
| Event44 | Global | Max. Steering Torque | 1.1999 | Nm |
| Event44 | Global | Max. Steering Accel. | 40.71 | deg/s^2 |
| Event44 | Global | Mean Jerk | 0.01319 | m/s^3 |
| Event44 | Global | Max. Jerk | 0.2171 | m/s^3 |
| Event44 | Global | Min. Jerk | -0.21216 | m/s^3 |
| Event44 | Global | Stddev Jerk | 0.099298 | m/s^3 |
| Event44 | Global | Min. RTK-State | 8 | pc. |
| Event44 | Global | Max. RTK-State | 8 | pc. |
| Event44 | Global | Satellites used | 14 | pc. |
| Event44 | Global | Event Start | 16457 | - |
| Event44 | Global | Event End | 19379 | - |
| Event44 | Global | Event Number | 5 | - |
| Event45 | CCG | CCG | -0.65777 | - |
| Event45 | CCG | Mean D2CL | 0.094613 | m |
| Event45 | CCG | Max. D2CL | 0.33085 | m |
| Event45 | CCG | Min. D2CL | -0.17675 | m |
| Event45 | CCG | D2CL ay0 | -0.005788 | m |
| Event45 | CCG | D2CL stddev | 0.44662 | m |
| Event45 | CCG | D2CL Variance | 0.19947 | m^2 |
| Event46 | Availability | Availability A-Road | NaN | % |
| Event46 | Availability | Availability Highway | 87.041 | % |
| Event46 | Availability | Mean Availability | NaN | % |
| Event47 | Drop off Rate | Drop off Rate | 10.87 | % |
| Event47 | Drop off Rate | Drop off Rate Highway | 10.87 | % |
| Event47 | Drop off Rate | Drop off Rate A-Road | 0 | % |

# Ground Truth Method

**Road knowledge is very important!** Exact positioning & heading data is the basis for objective evaluation criteria



ADMA

Precise positioning of the vehicle within the Ground Truth lane

Ground Truth map storage

Ground Truth measurement

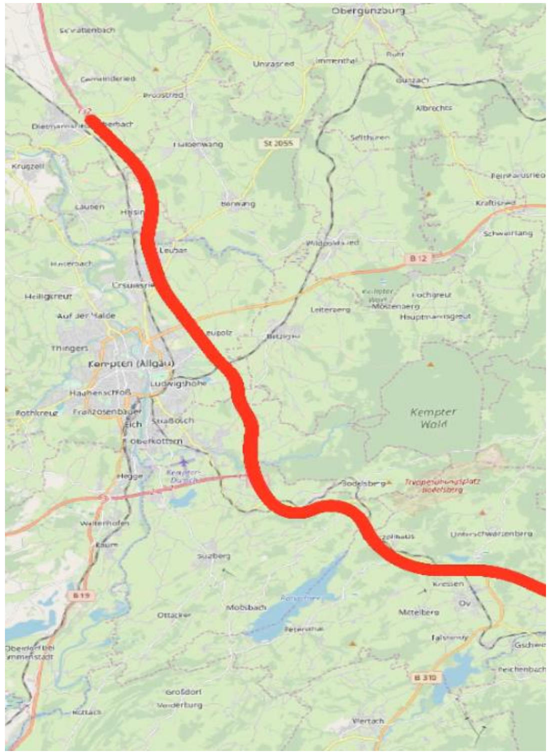
# Ground Truth Method

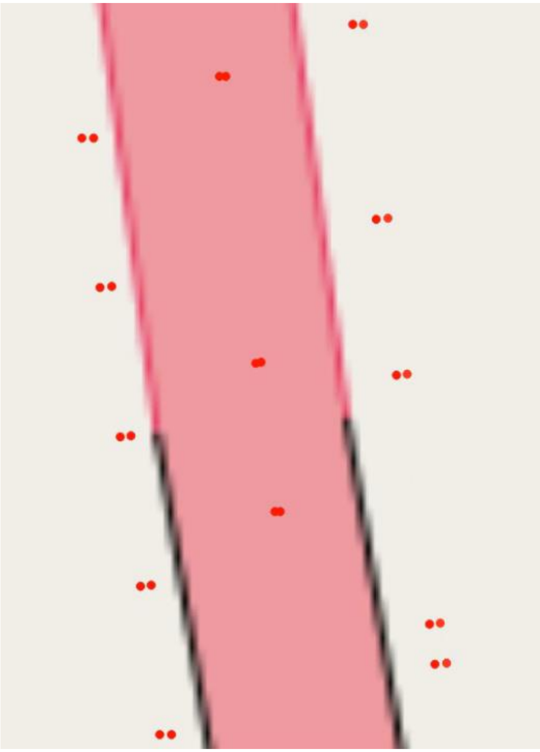
**Road survey sensors: DGPS, IMU and stereo camera.**

DGPS/ RTK →

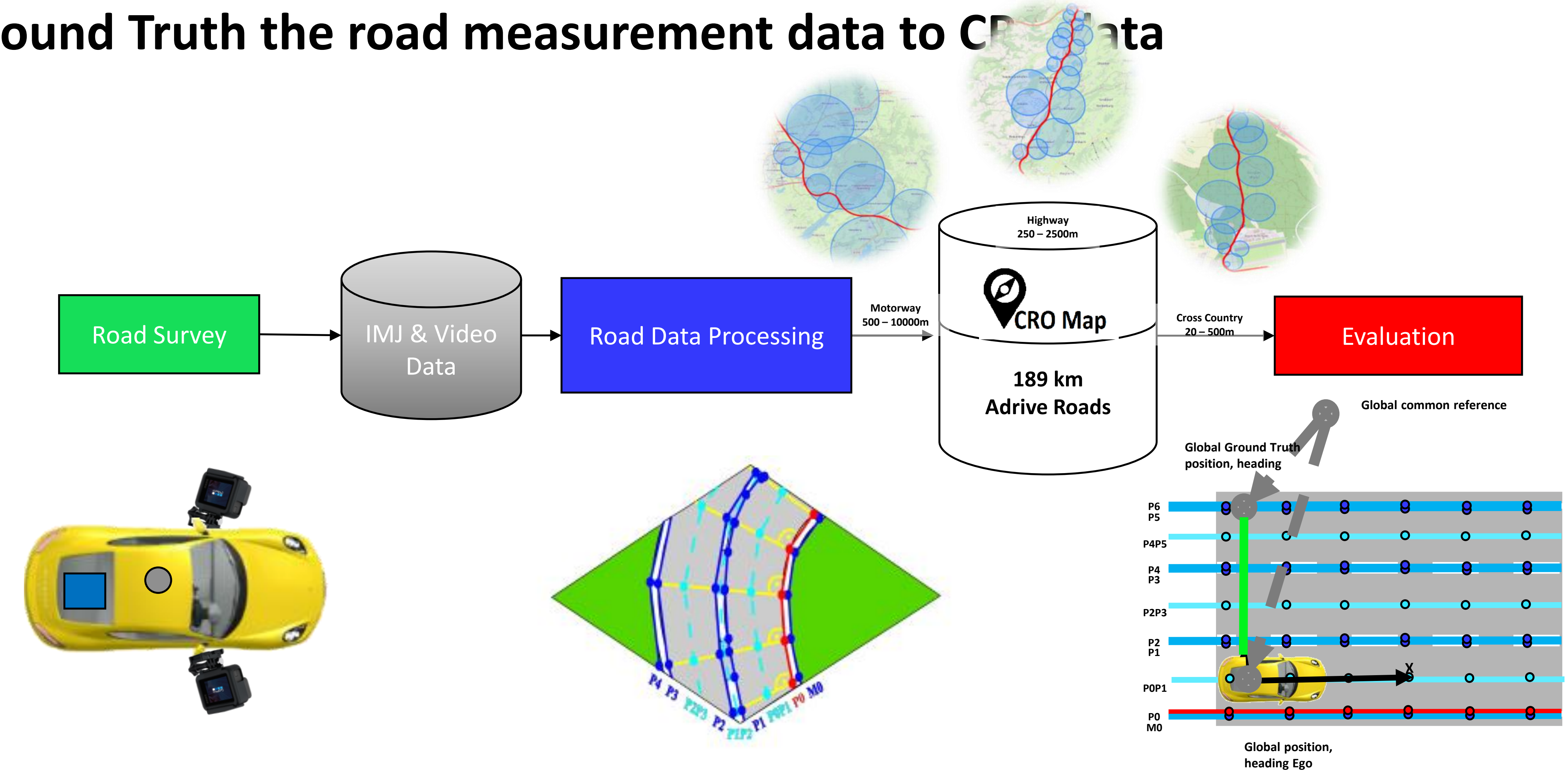
IMU →

Camera →





# Ground Truth the road measurement data to CR ata



Road Survey

IMJ & Video Data

Road Data Processing

Motorway
500 – 10000m

Highway
250 – 2500m

CRO Map

189 km
Adrive Roads

Cross Country
20 – 500m

Evaluation

Global common reference

Global Ground Truth
position, heading

Global position,
heading Ego

# Scheme of the used structure CRO (a) and based grid-map (b)

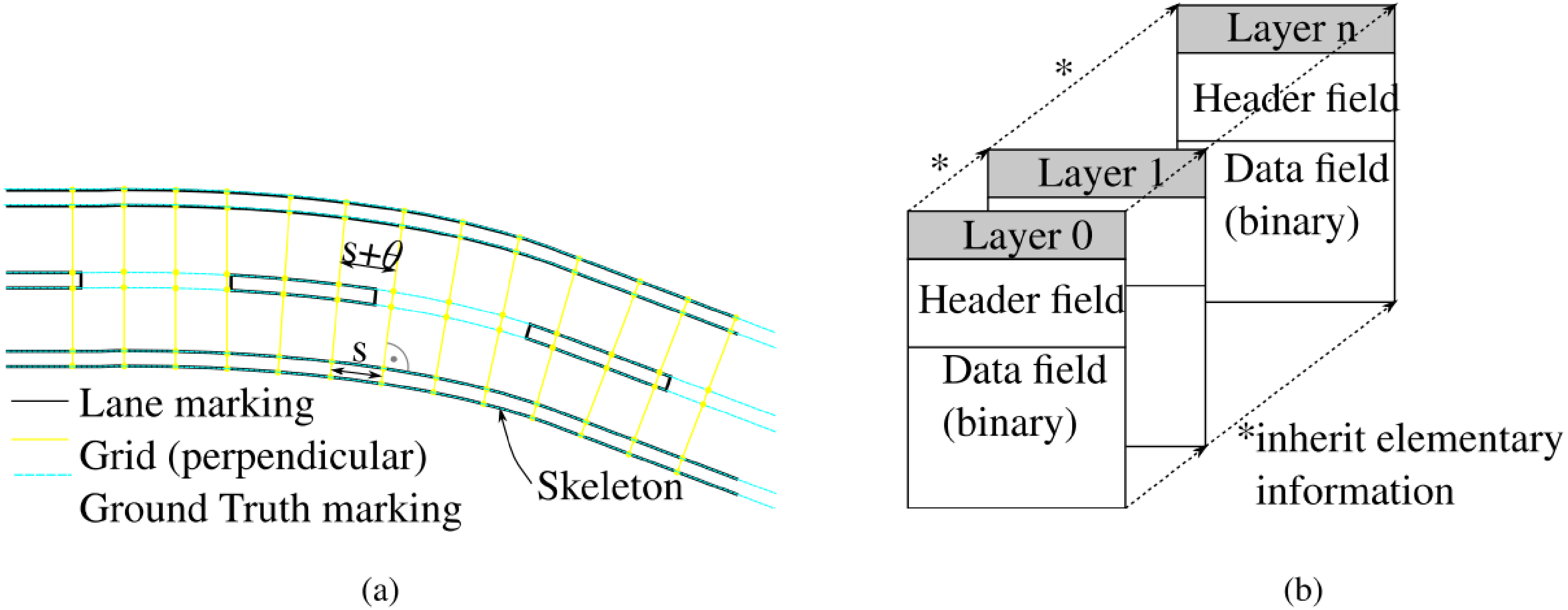
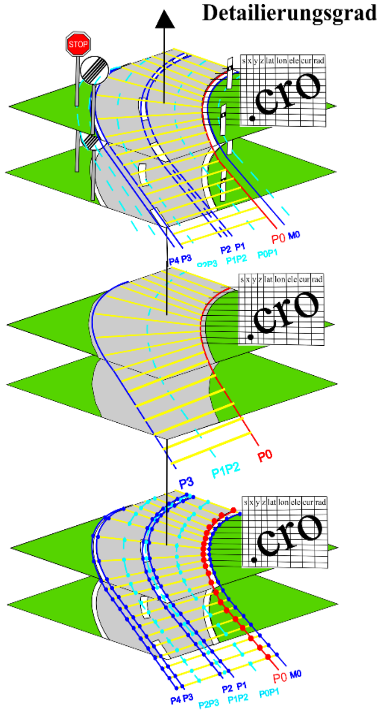


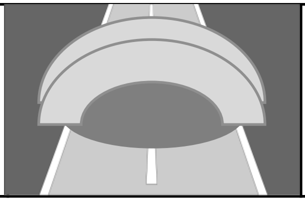
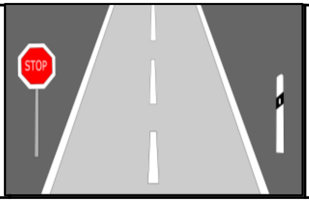
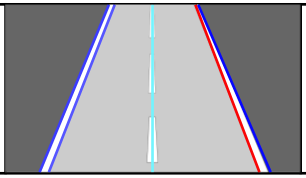
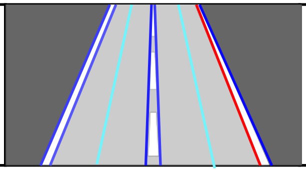
Figure 7: Scheme of the used road structure (CRO) (a) and based grid-map (b).

# Ground Truth and Camera Evaluation

## Each CRO layer contains different data.

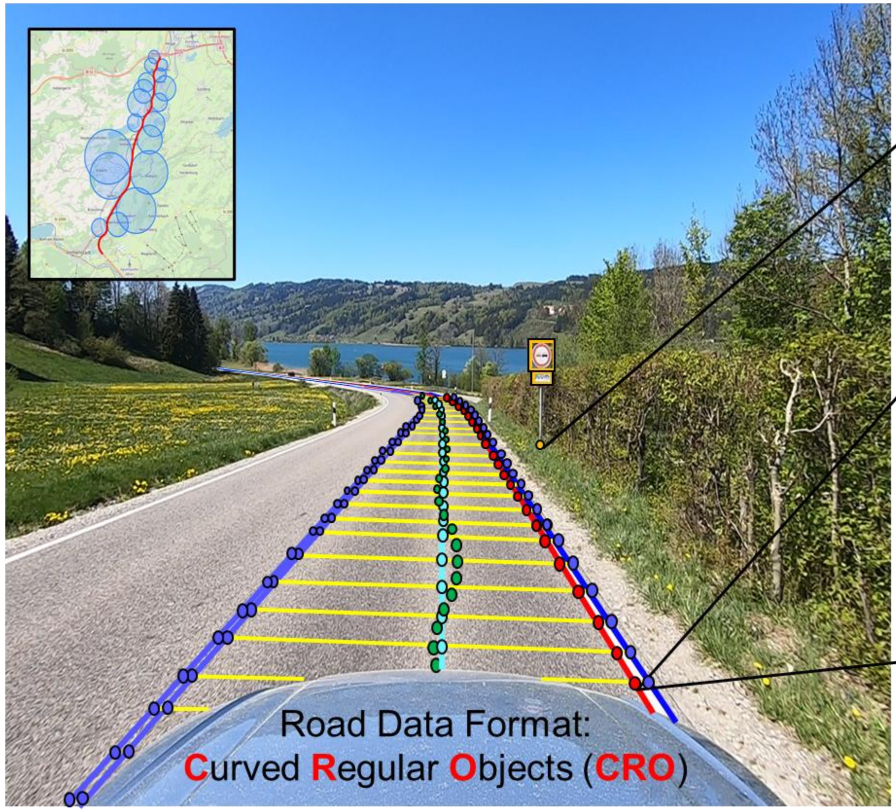
⋮



| | | |
|---|---|---|
| Layer 3: |  | road object data (longitude, latitude, elevation, distance x, distane y, hight, shape, colour, key descriptor, road signs ID) |
| Layer 2: |  | road object data (longitude, latitude, elevation, distance x, distane y, hight, shape, colour, key descriptor, road signs ID) |
| Layer 1: |  | relative metric data (increment, curvature, radius, azimuth angle, road width, cross slope) |
| Layer 0: |  | absolute geographical data (longitude, latitude, elevation) |

# Ground Truth Method

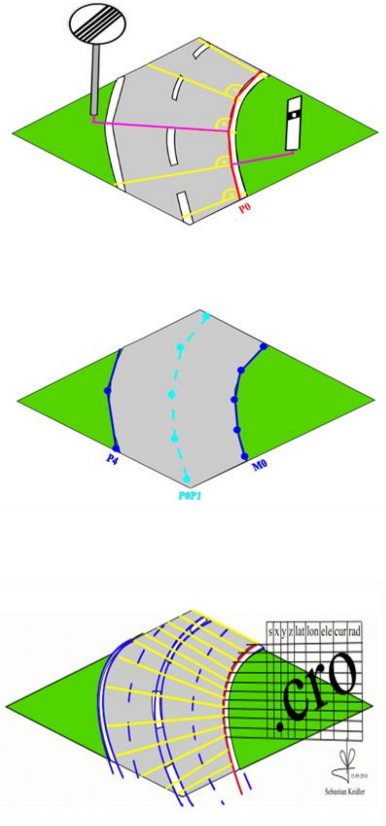
## Combination of layer-based map material and regular grid.



| sign | sx | sy | azimut |
|---|---|---|---|
| String | m | m | deg |
| DE/131 | 11.11 | 2.96 | 15.41 |
| DE/274 | 11.12 | 2.94 | 15.36 |
| DE/317 | 3.57 | -3.42 | 252.25 |

| s | curvature | width | cross slope |
|---|---|---|---|
| m | 1/m | m | % |
| 1 | 0.0002 | 8.30 | 5.00 |
| 2 | 0.0002 | 8.28 | 5.05 |
| 3 | 0.0002 | 8.27 | 5.10 |

| latitude | longitude | elevation |
|---|---|---|
| deg | deg | m |
| 47.2154 | 10.5648 | 655.21 |
| 47.2155 | 10.5649 | 655.22 |
| 47.2156 | 10.5650 | 656.23 |



Sebastian Keidler, Kaushal Patel

21.06.2021

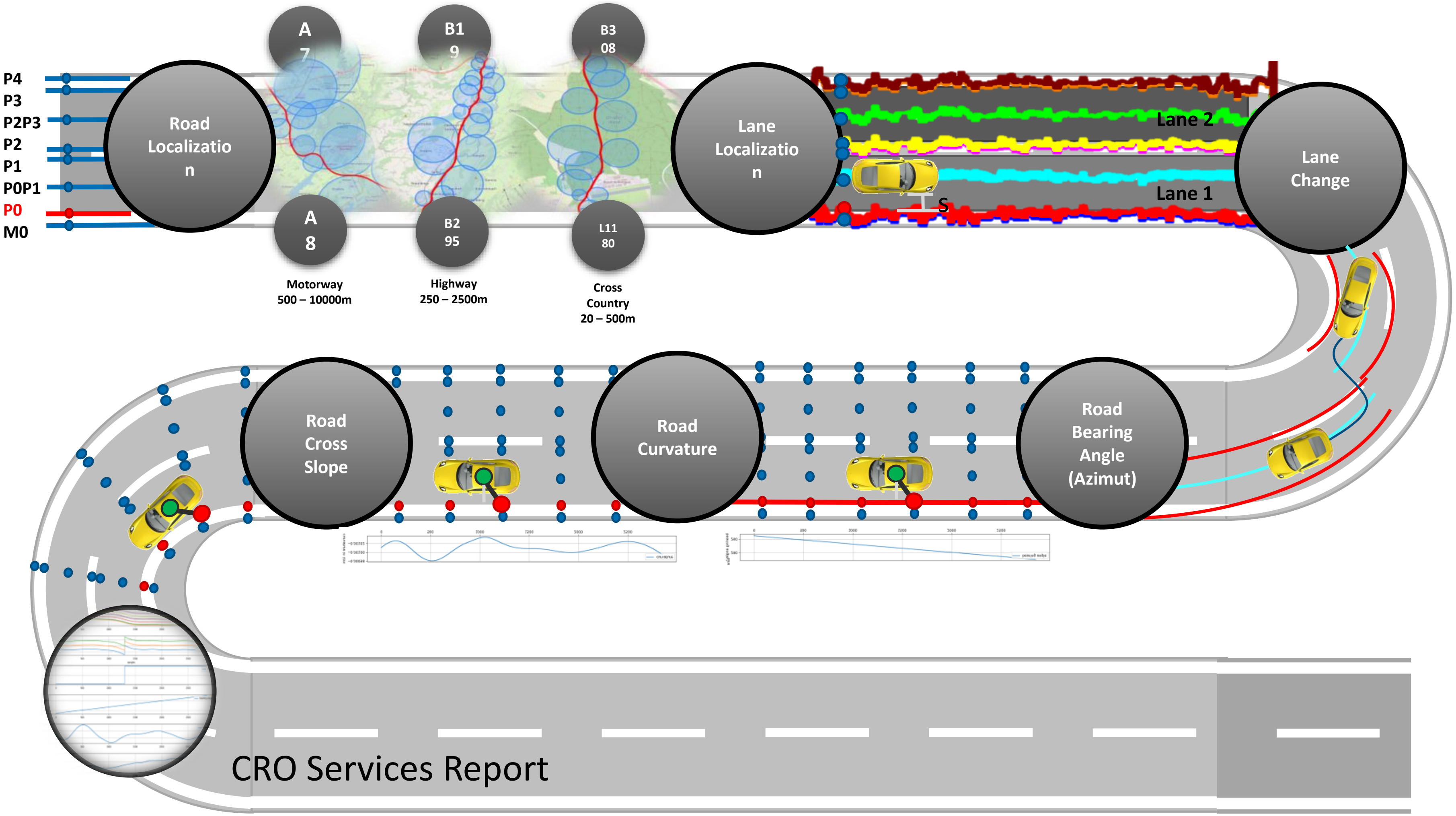
https://www.linkedin.com/posts/adrive-living-lab_gettoknow-cromaps-measurement-activity-6826828744540344320-VzQV?utm_source=linkedin_share&utm_medium=member_desktop_web

# Ground Truth Method

## LD CRO Road Measurement - Zubringerstraße – IFM - Memmingen

# Ground Truth Method

## CRO Road Map



P4
P3
P2P3
P2
P1
P0P1
P0
M0

Road Localization

A7
B19
B308
A8
B295
L1180

Motorway
500 – 10000m

Highway
250 – 2500m

Cross Country
20 – 500m

Lane Localization

Lane 2
Lane 1
S

Lane Change

Road Cross Slope

Road Curvature

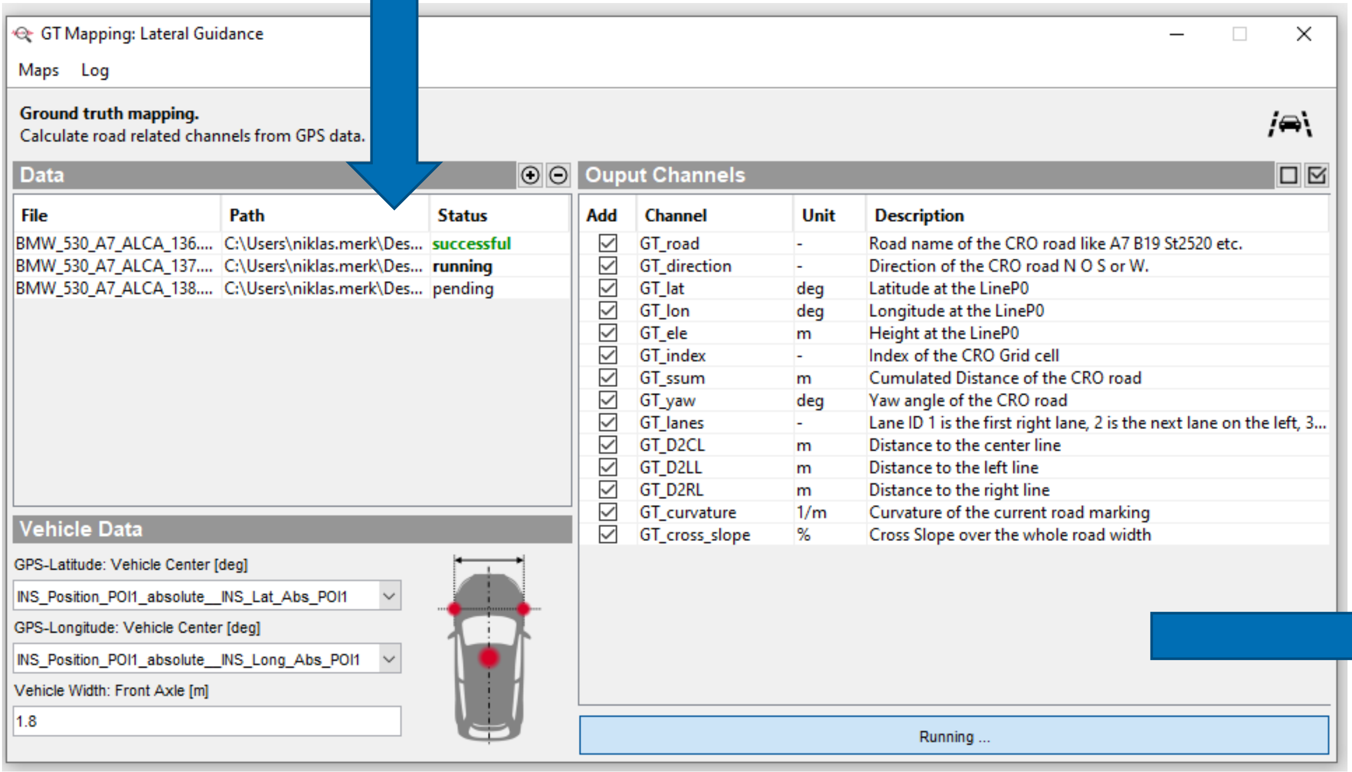
Road Bearing Angle (Azimut)

CRO Services Report

# GT Mapping Toolbox - MXeval

| Name | Änderungsdatum | Typ | Größe |
|---|---|---|---|
| BMW_530_A7_ALCA_136 | 06.07.2022 09:37 | MATLAB Data | 892 KB |
| BMW_530_A7_ALCA_136_gt | 18.05.2023 18:42 | Microsoft Excel-C... | 2.037 KB |
| BMW_530_A7_ALCA_136_gt | 18.05.2023 18:42 | MATLAB Data | 1.722 KB |
| BMW_530_A7_ALCA_137 | 06.07.2022 09:37 | MATLAB Data | 1.229 KB |

Workflow
- Import data into toolbox
- Select output channels
- Select Vehicle Data
- Start



GT Mapping: Lateral Guidance

**Ground truth mapping.**
Calculate road related channels from GPS data.

**Data**

| File | Path | Status |
|---|---|---|
| BMW_530_A7_ALCA_136.... | C:\Users\niklas.merk\Des... | successful |
| BMW_530_A7_ALCA_137.... | C:\Users\niklas.merk\Des... | running |
| BMW_530_A7_ALCA_138.... | C:\Users\niklas.merk\Des... | pending |

**Ouput Channels**

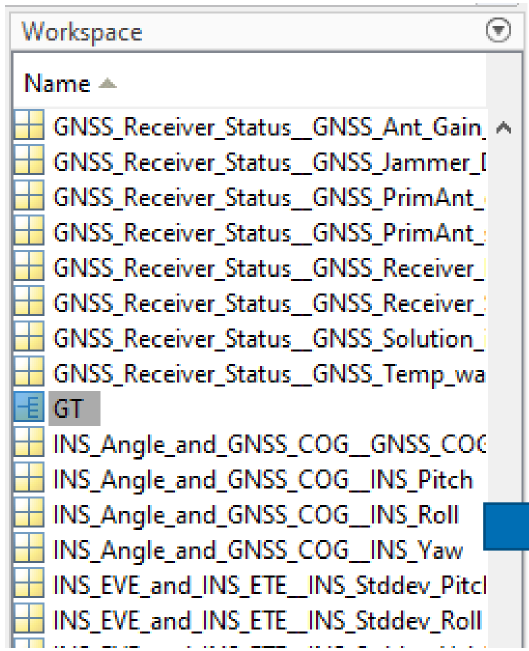
| Add | Channel | Unit | Description |
|---|---|---|---|
| ☑ | GT_road | - | Road name of the CRO road like A7 B19 St2520 etc. |
| ☑ | GT_direction | - | Direction of the CRO road N O S or W. |
| ☑ | GT_lat | deg | Latitude at the LineP0 |
| ☑ | GT_lon | deg | Longitude at the LineP0 |
| ☑ | GT_ele | m | Height at the LineP0 |
| ☑ | GT_index | - | Index of the CRO Grid cell |
| ☑ | GT_ssum | m | Cumulated Distance of the CRO road |
| ☑ | GT_yaw | deg | Yaw angle of the CRO road |
| ☑ | GT_lanes | - | Lane ID 1 is the first right lane, 2 is the next lane on the left, 3... |
| ☑ | GT_D2CL | m | Distance to the center line |
| ☑ | GT_D2LL | m | Distance to the left line |
| ☑ | GT_D2RL | m | Distance to the right line |
| ☑ | GT_curvature | 1/m | Curvature of the current road marking |
| ☑ | GT_cross_slope | % | Cross Slope over the whole road width |

**Vehicle Data**

GPS-Latitude: Vehicle Center [deg]: INS_Position_POI1_absolute__INS_Lat_Abs_POI1

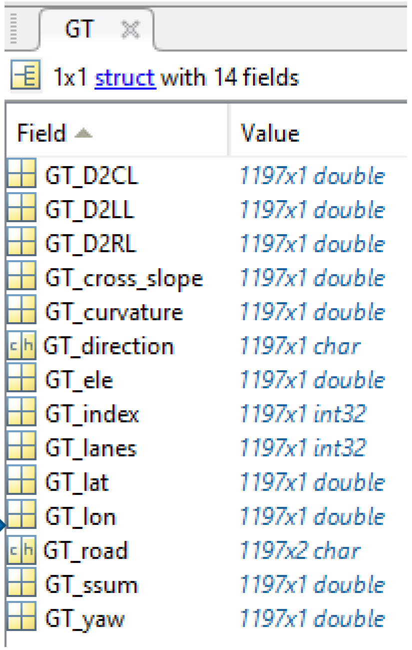
GPS-Longitude: Vehicle Center [deg]: INS_Position_POI1_absolute__INS_Long_Abs_POI1

Vehicle Width: Front Axle [m]: 1.8



Workspace

| Name |
|---|
| GNSS_Receiver_Status__GNSS_Ant_Gain_ |
| GNSS_Receiver_Status__GNSS_Jammer_I |
| GNSS_Receiver_Status__GNSS_PrimAnt_ |
| GNSS_Receiver_Status__GNSS_PrimAnt_ |
| GNSS_Receiver_Status__GNSS_Receiver_ |
| GNSS_Receiver_Status__GNSS_Receiver_ |
| GNSS_Receiver_Status__GNSS_Solution_ |
| GNSS_Receiver_Status__GNSS_Temp_wa |
| GT |
| INS_Angle_and_GNSS_COG__GNSS_COG |
| INS_Angle_and_GNSS_COG__INS_Pitch |
| INS_Angle_and_GNSS_COG__INS_Roll |
| INS_Angle_and_GNSS_COG__INS_Yaw |
| INS_EVE_and_INS_ETE__INS_Stddev_Pitcl |
| INS_EVE_and_INS_ETE__INS_Stddev_Roll |

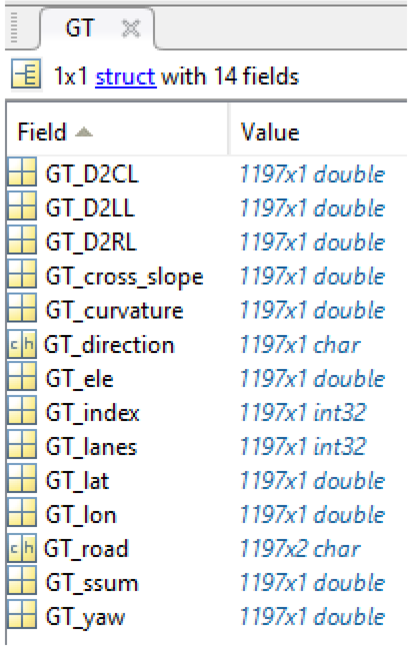


GT

1x1 struct with 14 fields

| Field | Value |
|---|---|
| GT_D2CL | 1197x1 double |
| GT_D2LL | 1197x1 double |
| GT_D2RL | 1197x1 double |
| GT_cross_slope | 1197x1 double |
| GT_curvature | 1197x1 double |
| GT_direction | 1197x1 char |
| GT_ele | 1197x1 double |
| GT_index | 1197x1 int32 |
| GT_lanes | 1197x1 int32 |
| GT_lat | 1197x1 double |
| GT_lon | 1197x1 double |
| GT_road | 1197x2 char |
| GT_ssum | 1197x1 double |
| GT_yaw | 1197x1 double |

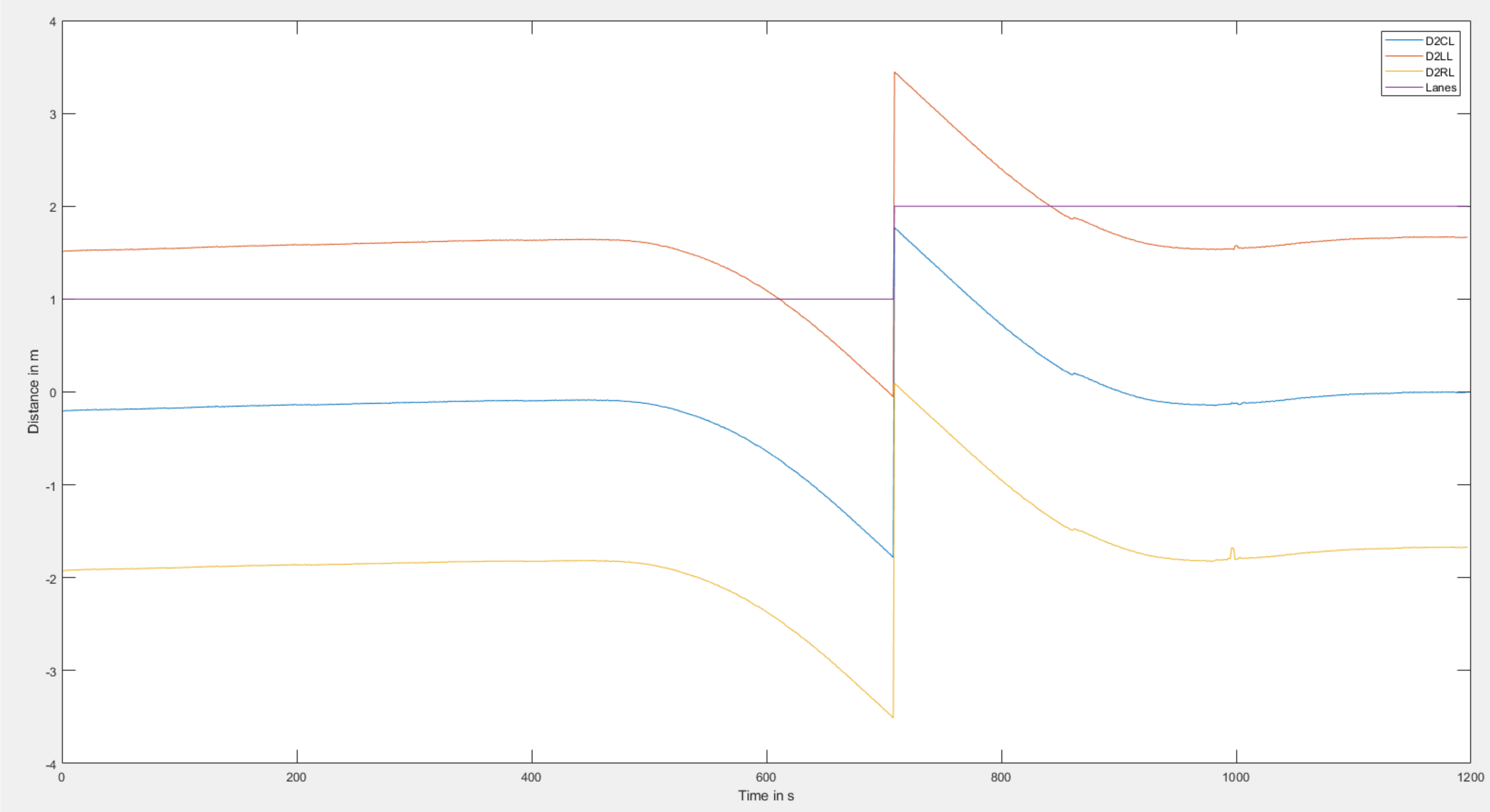
# GT Mapping Toolbox – Output Channels



GT

1x1 struct with 14 fields

| Field | Value |
|---|---|
| GT_D2CL | 1197x1 double |
| GT_D2LL | 1197x1 double |
| GT_D2RL | 1197x1 double |
| GT_cross_slope | 1197x1 double |
| GT_curvature | 1197x1 double |
| GT_direction | 1197x1 char |
| GT_ele | 1197x1 double |
| GT_index | 1197x1 int32 |
| GT_lanes | 1197x1 int32 |
| GT_lat | 1197x1 double |
| GT_lon | 1197x1 double |
| GT_road | 1197x2 char |
| GT_ssum | 1197x1 double |
| GT_yaw | 1197x1 double |

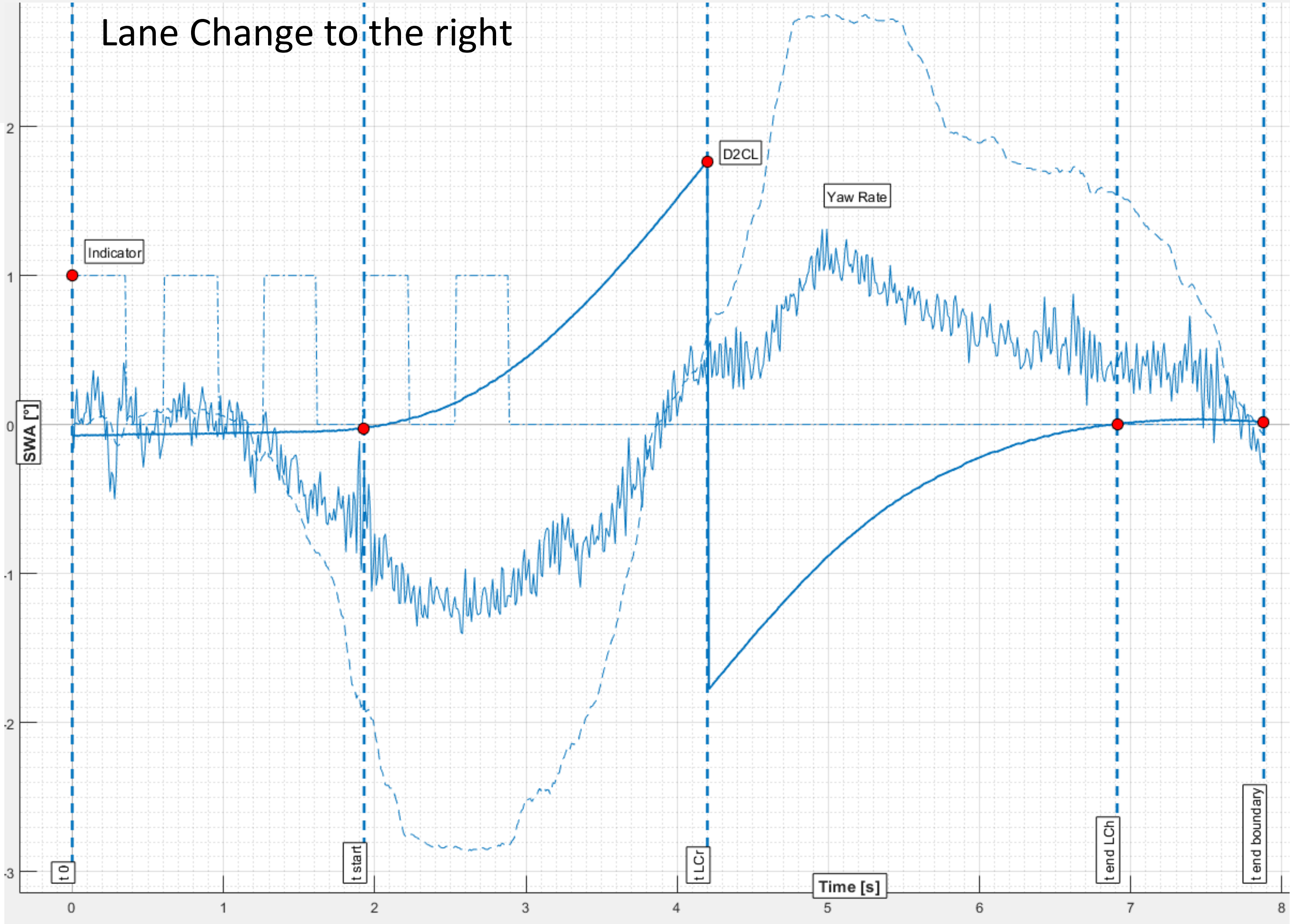


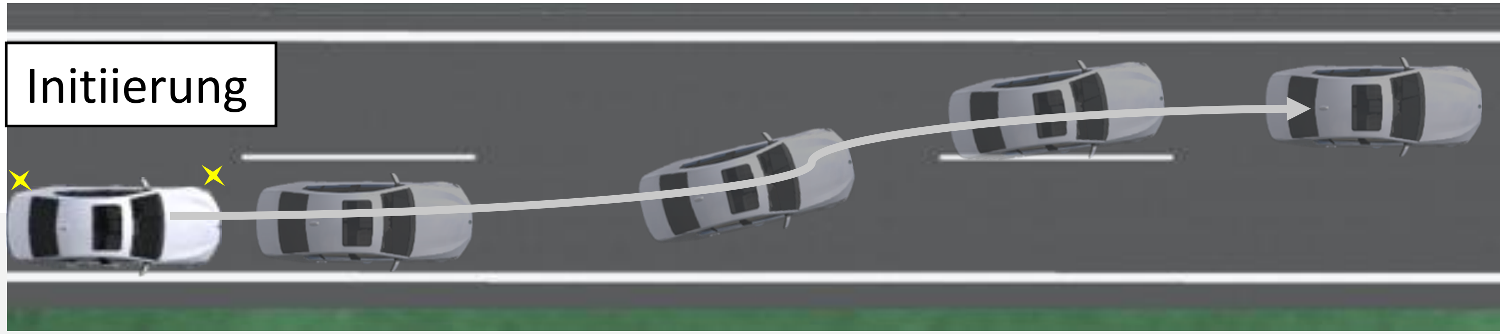
Lane Change to the left

# Use Case: Active Lane Change

Signals
- Indicator
- SWA
- D2CL
- Yaw Rate

Time
- t_0
- t_start
- t_lane_cross
- t_lane_change_end
- t_end_boundary

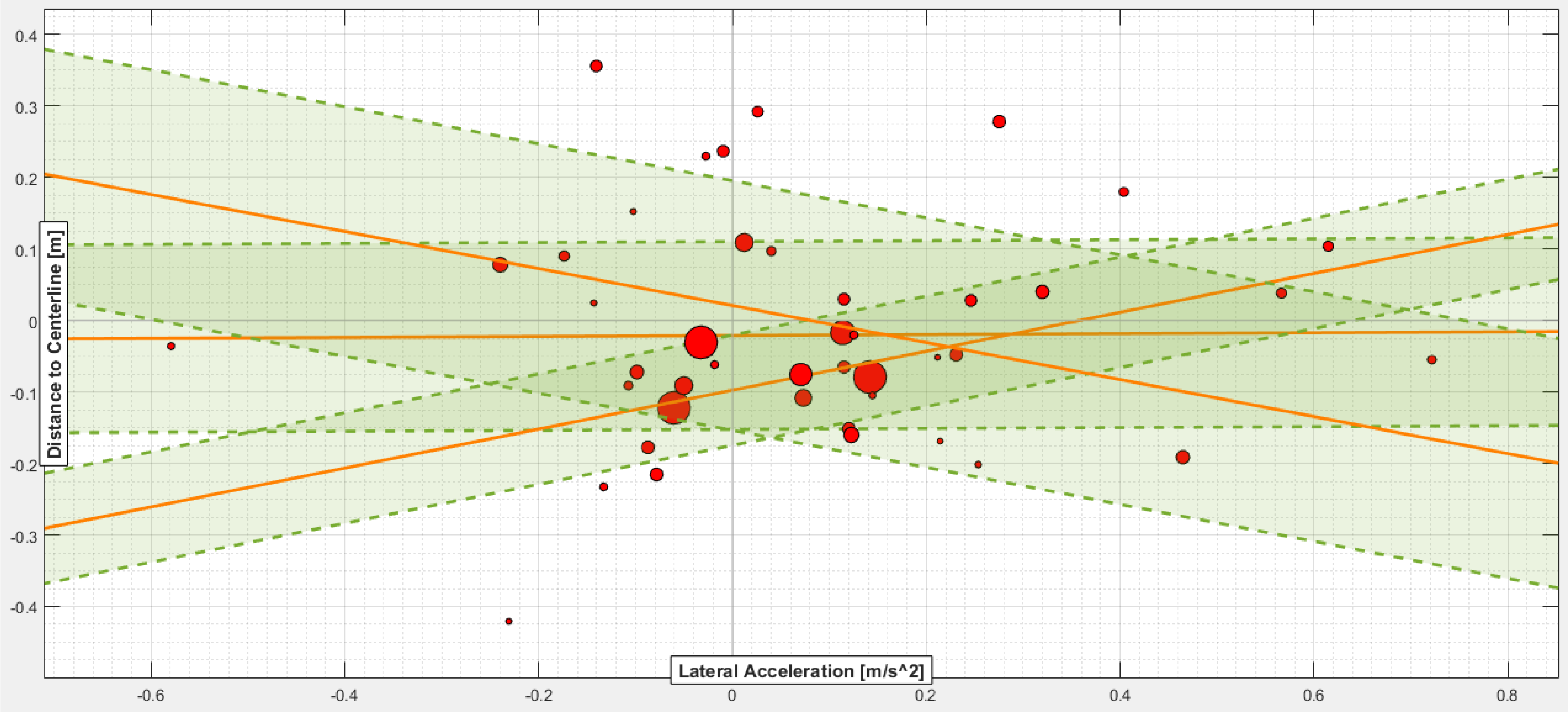


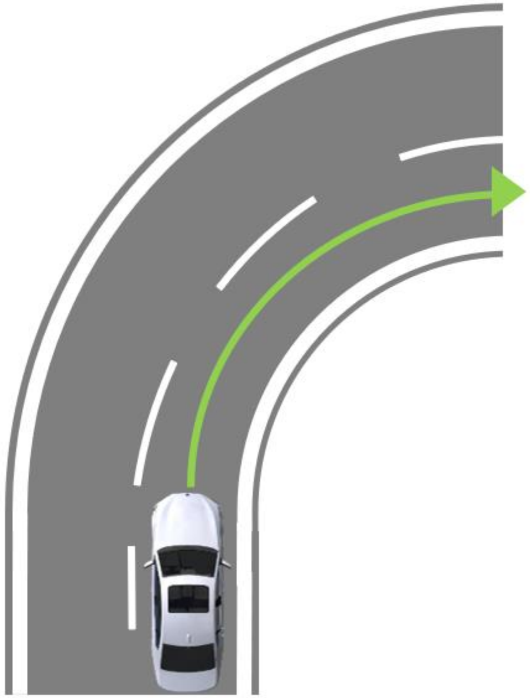


# Curve Cutting Gradient

**A positiv Curve Cutting Gradient means the vehicle cuts the curve.**

**A negativ Curve Cutting Gradient means the vehicle is driving through the curve on the outer side.**





Used in the MXeval test: Free Run

# Workshop

**Think of possible maneuvers and KPI's to evaluate Active Lane Change Assistance (ALCA) (15 minutes)**

1. **What maneuvers can be performed → making sketches**
2. **What are possible parameters for objective evaluation → chose measuring devices?**

**Consider efficient and resource-saving execution**

IFM
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Kempten
University of Applied Sciences

www.hs-kempten.de/ifm