Sensors for Automated Road Vehicles

Dr. Sven Beiker
External Advisor to SAE International

Perception of objects can be challenging in everyday situations

Object obstruction
e.g. tree or umbrella make pedestrian detection difficult

Object unclear, unclassified
e.g. unidentifiable object or combination lacks precedence

Misleading sensor returns
e.g. human or soda can have similar radar image

Multiple objects combined
e.g. two motorcycles assumed to be one car

Image on a moving object
e.g. photograph on a truck resembles road ahead

Faded road signs
e.g. washed out, sprayed, cluttered sign not readable

Large but benign object
e.g. plastic bag blown over road is no obstacle

Small but serious object
e.g. tire debris need to be avoided as they can cause seriously damage

Phantom object
e.g. mirages, shadows, puddles are no obstacle (or…)

Flickering lights
e.g. blinking or pulsed lights can fall between frames

Source: Silicon Valley Mobility

Camera, radar, LiDAR – the key elements of an AVs perception system

CAMERA

- ❑ Imager captures **ambient light, emitted directly or reflected** (sun, streetlight…)
- ❑ Lane keeping assist, pedestrian detection, adaptive cruise control, traffic sign assist
- ➕ Color detection
- ➕ Object classification
- ➕ Lane tracking
- ⛔ Bad weather performance
- ⛔ Velocity estimation
- ⛔ Distance estimation

RADAR

- ❑ Radar waves **emitted and reflected to indicate** objects within path
- ❑ Adaptive cruise control, collision warning, blind spot detection, cross traffic warning
- ➕ Object, distance, velocity detection
- ➕ Bad weather performance
- ➕ Detection range
- ⛔ Object classification
- ⛔ Lane tracking
- ⛔ Angular resolution

LiDAR

- ❑ Light pulses **emitted and reflected to indicate** objects within path
- ❑ All L4 research and development vehicles, emerging in traffic jam assist systems
- ➕ Object detection
- ➕ Distance detection
- ➕ Angular resolution
- ⛔ Lane tracking
- ⛔ Operation in heavy rain / snow
- ⛔ Production readiness

Source: Silicon Valley Mobility

Sensor fusion provides redundancy for automation; Radar + camera most promising

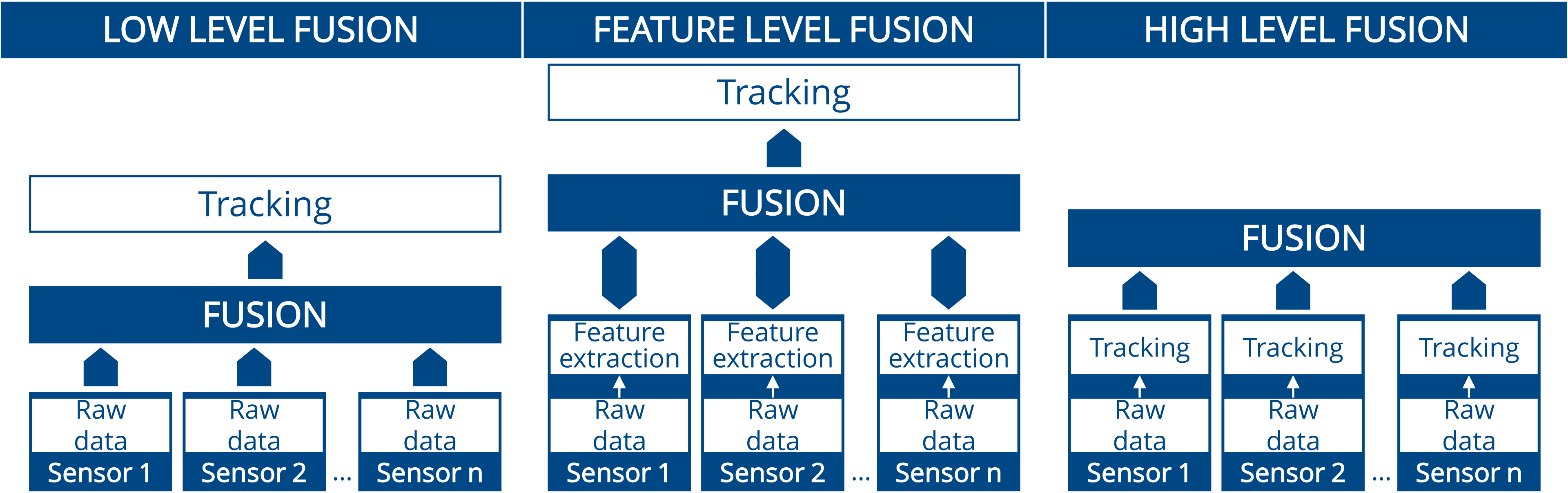
	Camera	Radar	LiDAR	Fusion
Object detection	Medium	Good	Good	Good
Object classification	Good	Weak	Medium	Good
Distance estimation	Medium	Good	Good	Good
Velocity estimation	Weak	Good	Medium	Good
Object-edge precision	Good	Weak	Good	Good
Lane tracking	Good	Weak	Weak	Good
Range of visibility	Medium	Good	Medium	Good
Bad weather performance	Weak	Good	Medium	Good
Poor lighting performance	Medium	Good	Good	Good
Cost	Good	Good	Weak	TBD
Production readiness	Good	Good	Medium	TBD

- Good performance
- Medium performance
- Weak performance
- TBD once underlying technology is ready

Only a combination of sensors and fusion of the data provides the overall performance needed for automated driving of Level 3 and up. However, some of the perception sensor technology is not ready yet.

Source: McKinsey, Aptive (adapted

Sensor data fusion can happen on different levels – a middle-ground approach might bring the best performance for production systems



- (+) possible to classify data at a very early stage
- (−) requires high data bandwidth, can be complex to implement

- (+) uses reduced bandwidth of sensor data to the fusion module
- (+) efficient integration of relevant data into tracking algorithm

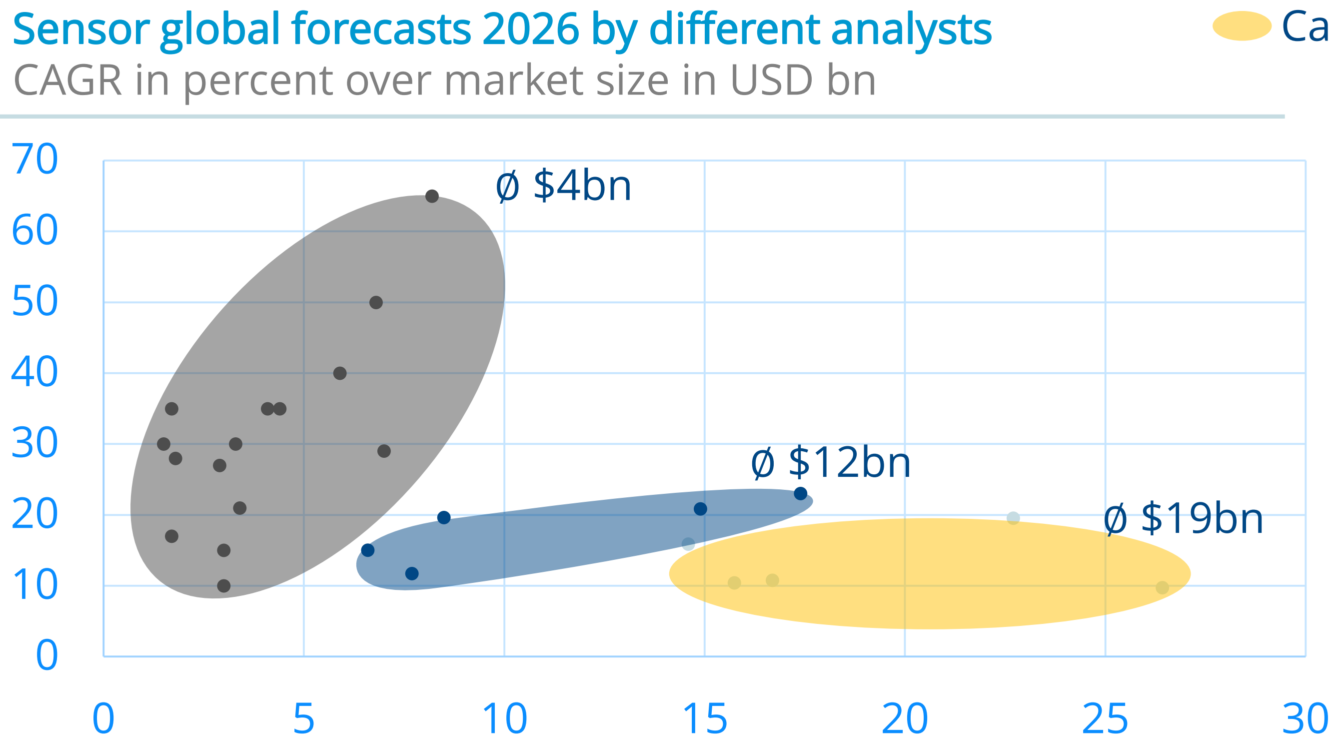
- (+) modularity of sensor specific details offers flexible integration
- (−) classification more difficult due to information of higher abstraction

Source: "High-Level Sensor Data Fusion Architecture for Vehicle Surround Environment Perception", BMW 2020

The market opportunity for ADAS / AD sensors is mostly about cameras because of the high-volume expectations

Sensor global forecasts 2026 by different analysts

CAGR in percent over market size in USD bn

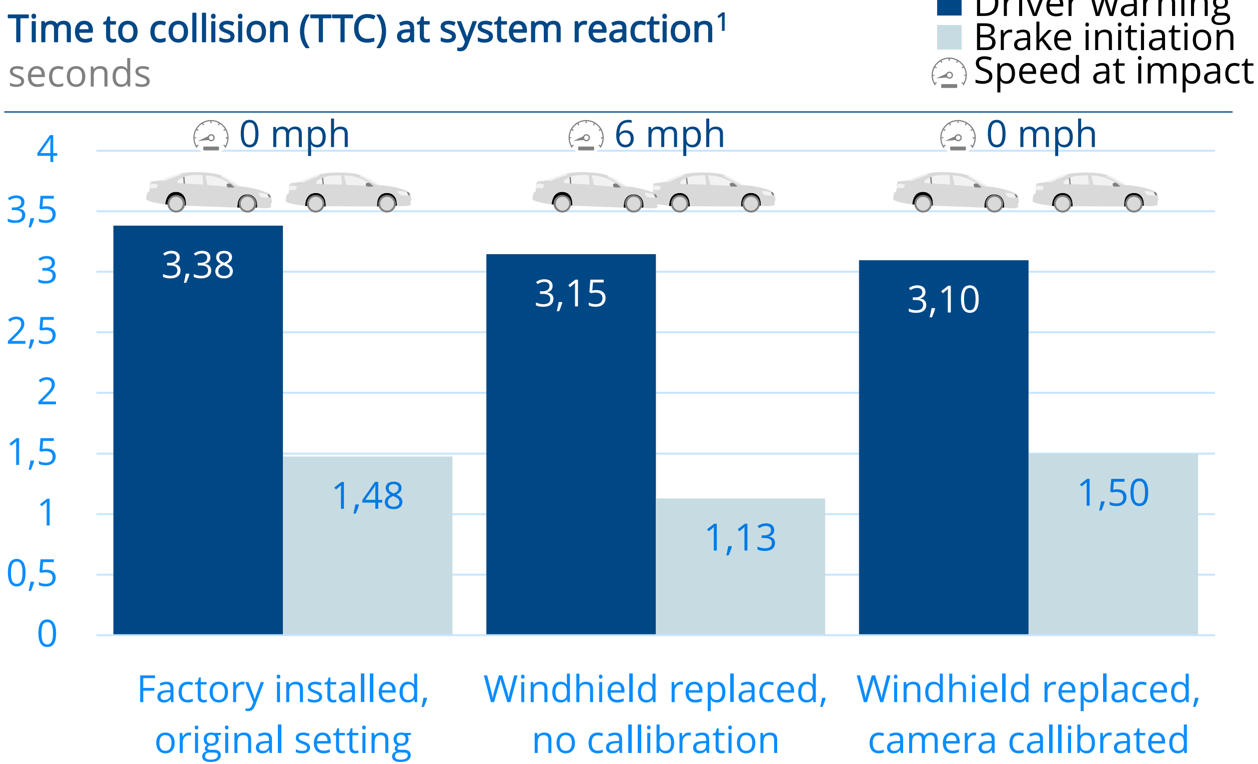


These forecasts in context:

- Assumed unit costs give insights into expected unit volume:
  - Camera $40 ~500m
  - Radar $60 ~200m
  - LiDAR $200 ~20m
- As expected, many more cameras will be used than LiDAR, but all might be needed for AVs
- Top 5 LiDAR startups combined were valued over $15bn in early 2021

Source: Silicon Valley Mobility

ADAS / AD sensors provide essential information on the road ahead – however, they need to be diligently re-calibrated after replacement



- Sensor re-calibration is essential after related repairs (e.g. bumper, windshield, mirror replacement) to ensure proper ADAS functionality.
- Re-calibration efforts vary, a study found for forward-facing cameras a range of:
  - 1 to 6 hours (1.7 hours average)
  - 100 to 780 USD total cost
- Accurate sensor re-calibration is an emerging challenge, especially with ever-more sensors installed and highly-equipped vehicles getting older and owners trying to save cost
- SAE International launched the “Active Safety ADAS Sensor Calibration Task Force” to develop a set of standardized recommended procedures for the repair and aftermarket sectors

1 Average times out of several test runs for a 2016 Honda Civic, which was the most critical model tested

Source: “Windshields – Aftermarket vs. OEM replacement and ADAS camera calibrations”, IIHS 2018

Thank you!

Sven Beiker
sven.beiker@sae.org