AUTONOMOUS DRIVING COURSE

ULTRASONIC, RADAR AND LIDAR SENSORS

Bunciu Elena

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   - Principles of operation (SRR, MRR, LRR)

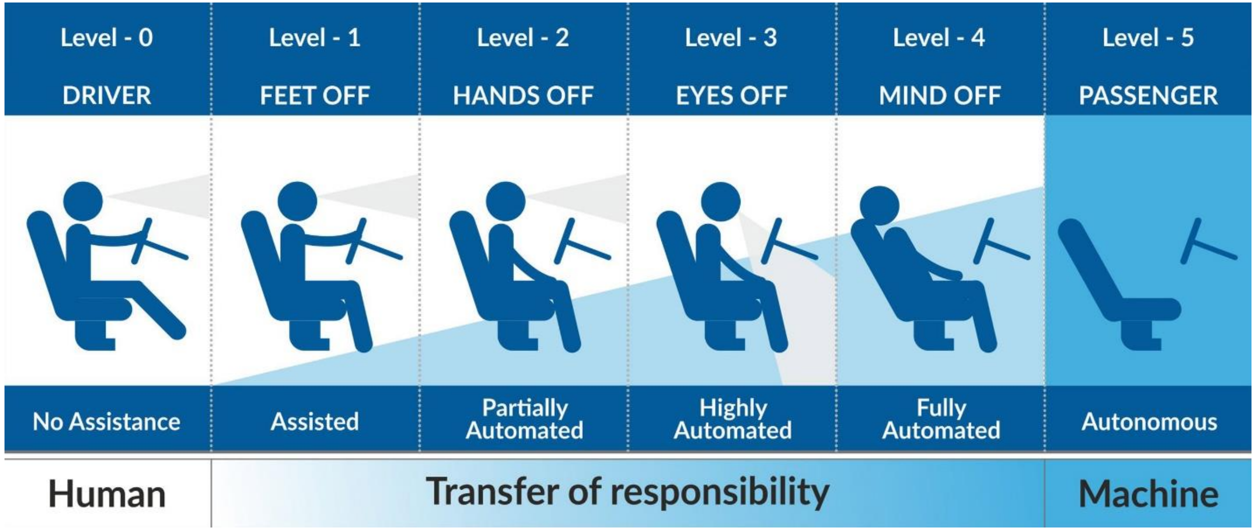
3. **Lidar sensors**
   - Principles of operation

4. **Software architecture**

Autonomous Driving
Course Objectives

- What an ultrasonic sensor is?
- How does a sensor ultrasonic works?
- What functionality base on ultrasonic sensors we have?
- How a RADAR system works?
- What are the differences between USS and RADAR?
- How a LIDAR system works?
- What are the differences between LIDAR and RADAR?

Autonomous Driving
Levels of automation



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ULTRASONIC SENSORS

Ultrasonic Sensors
Physical principles

- An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic waves.

- Ultrasonic waves are sounds waves with a higher frequency than the upper audible limit of human hearing

- Sound waves are mechanical waves that require a medium through which to propagate. Sound waves cannot travel through a vacuum

Ultrasonic Sensors
Physical principles

- Different materials have different acoustic properties
  - Varies the ability to transmit sound waves
  - Varies the ability to reflect sound at interfaces

- An ultrasonic sensor uses a transducer that evaluates targets by measuring the time between sending a signal and receiving an echo the distance of an object can be calculated

- High-frequency sound waves reflect from boundaries to produce distinct echo patterns.

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Ultrasonic Sensors
Physical principles

- Ultrasonic sensors can convert electrical energy into acoustic wave and vice versa.

- The transducer of the sensor sends the ultrasonic waves and receives the reflected wave (echo) from the object in the near proximity.

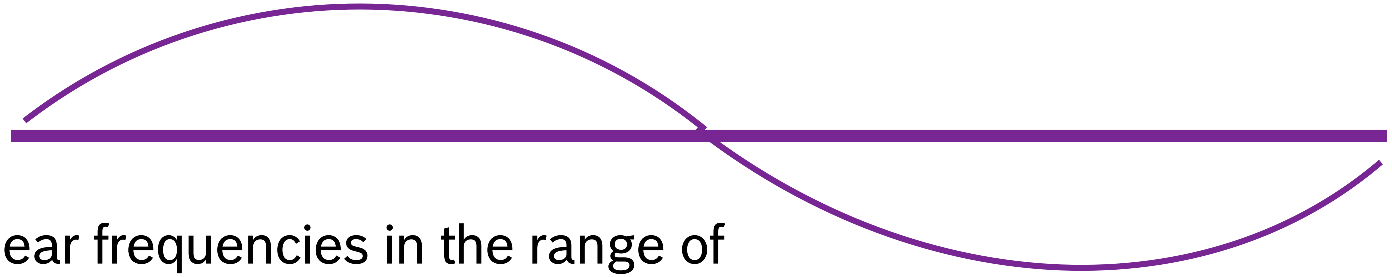
- The sensor determines the distance to a target by measuring time lapses between the sending and receiving of the ultrasonic pulse.

Ultrasonic Sensors
Physical principles

Frequency

The number of cycles completed per second.

1 cycle per second is called Hertz (Hz)



- Humans hear frequencies in the range of

  infrasound<20Hz – 20kHz<ultrasounds

  Bats => 10kHz – 200kHz

  Dolphins => 75kHz – 150kHz

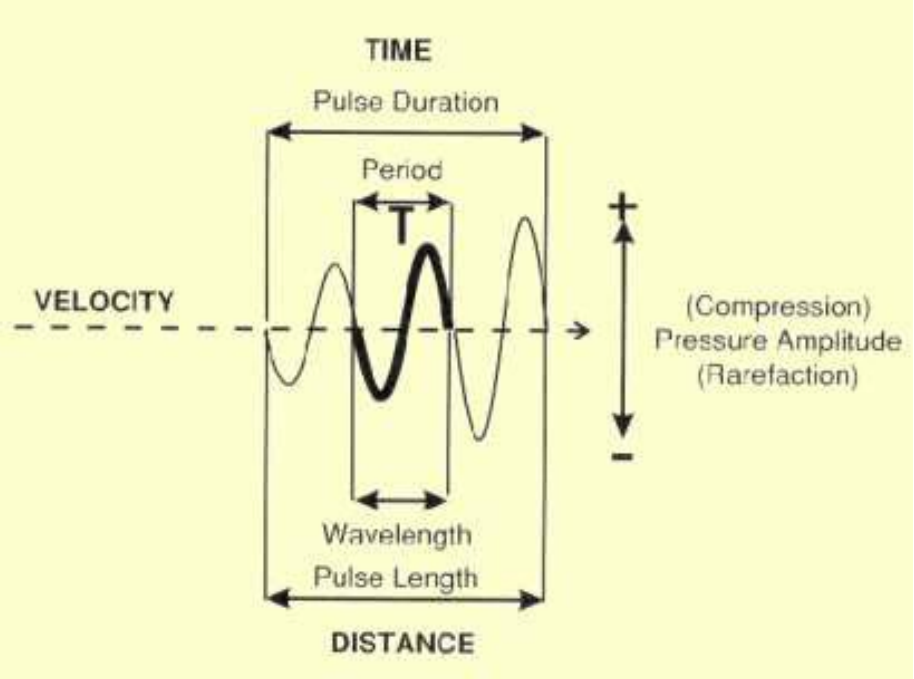
- Sound above the level of human hearing is called ***ultrasound***

Ultrasonic Sensors
Characteristic parameters

- The frequency of sound is determined by its source.

$$\lambda = v \cdot T \leftrightarrow \lambda = \frac{v}{f}$$

- If the frequency increases then the wave length must decrease as they are inversely proportional to each other.



https://www.slideshare.net/RakeshCa2/ultrasound-physics-39841154

Ultrasonic Sensors

Bosch sensors

USS1

1995

USS2

1996

USS3

1998

USS4

2004

USS5

2011

USS6

2016/2017

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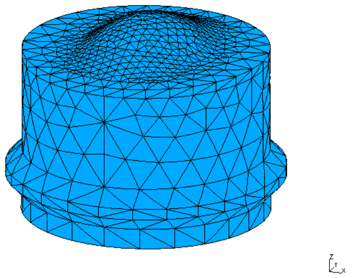
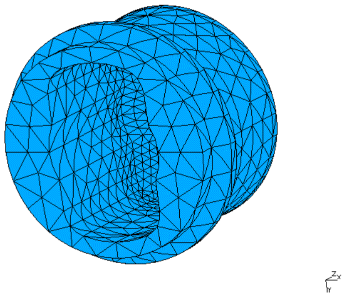
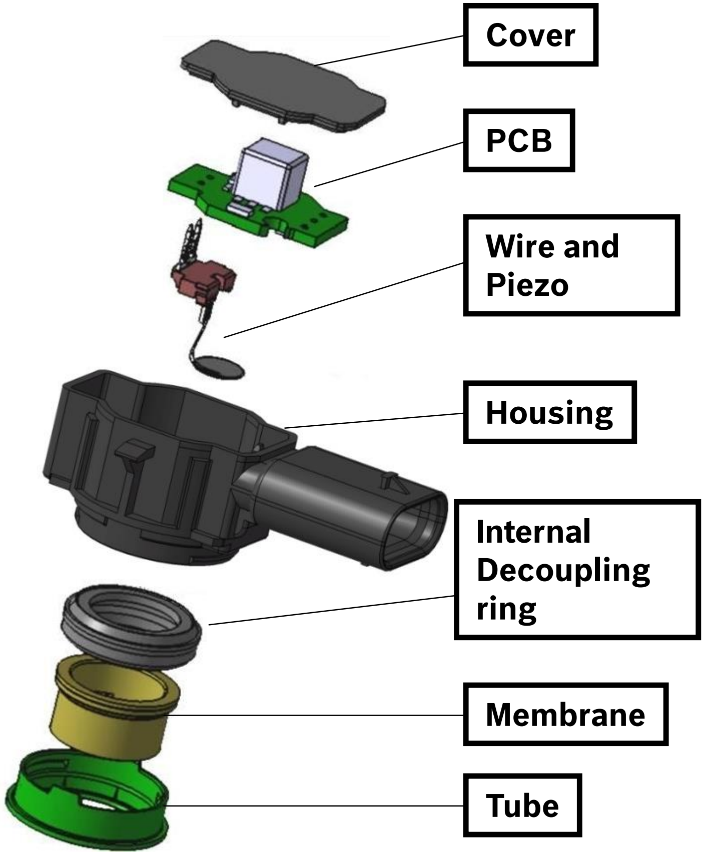
Ultrasonic Sensors
Structure

- Maximal distance up to 6.5 m
- Compact sensors for different connectors
- Wide range in installation in different cars
- Different surfaces of membrane
- **Add-on parts handling like license plate holder, trailer hitch, spare wheel etc…→laboratory**







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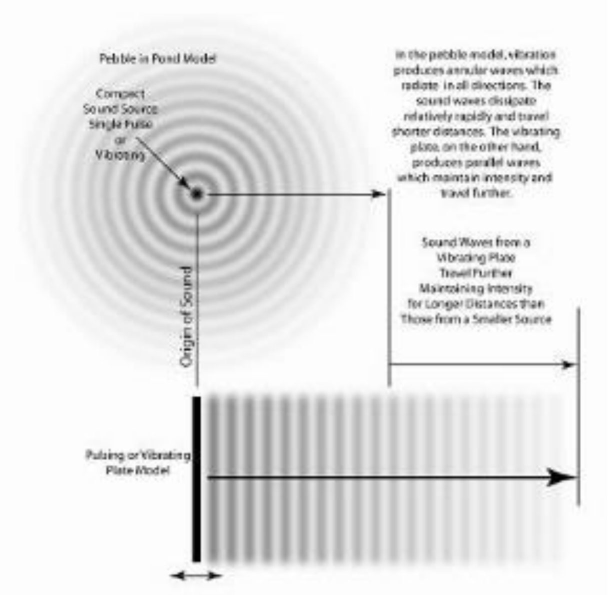
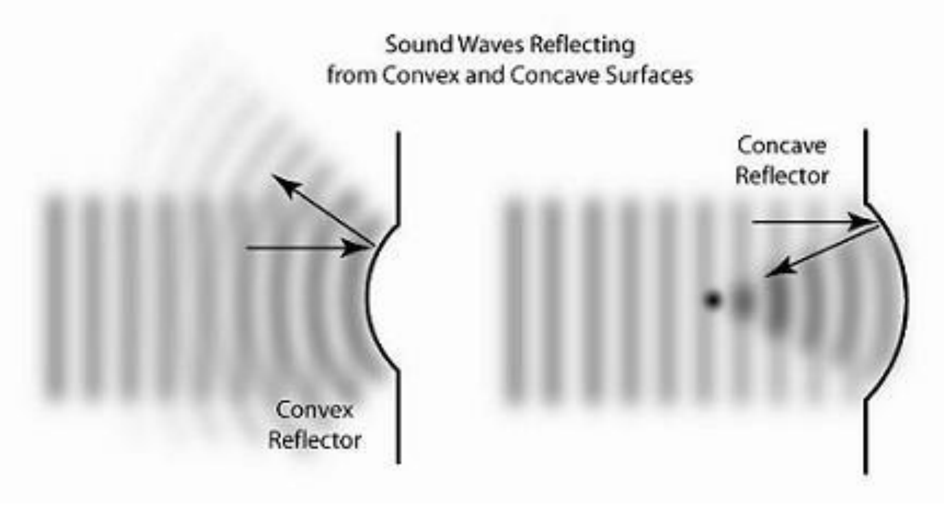
Ultrasonic Sensors
Physical principles





Sound waves generated by a vibrating piezoelectric plate travel further distances maintaining intensity than those generated by a smaller vibrating source.

Sound waves can be concentrated and deviate much the same as light waves from convex and concave surfaces.

http://www.ctgclean.com/tech-blog/ultrasonics-understanding-sound-waves-1

Ultrasonic Sensors
Physical principles

Types and shapes of detection objects (reflective type)

Detected objects can be classified as follows:

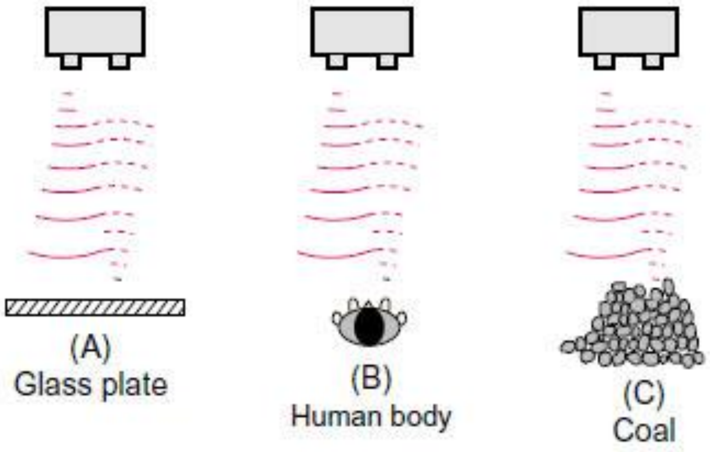
(A) Flat-surface objects such as fluids, boxes, plastic sheets, paper, and glass.

(B) Cylindrical objects such as cans, bottles, and human bodies.

(C) Powders and chunk-like objects such as minerals, rocks, coal, coke, and plastic.

The reflective efficiency varies depending on the shape of these objects. In the case of (A), the greatest amount of reflected waves return, however, this is strongly affected by the inclination of the object.

In the case of (B) and (C), stray reflections occur and the reflected sound is not uniform, however, the effect of inclination is small.



http://www.omron-ap.com/service_support/technical_guide/ultrasonic_sensor/index.asp

Ultrasonic Sensors
Physical principles of operation

Bosch USS Gen6 sensors

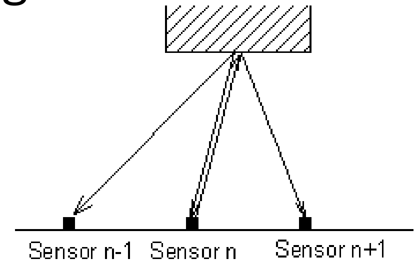
- 47 - 50 kHz Ultrasonic sound
- Induction with Piezo electronic
- v= 340 m/s – temperature dependent
- Distance calculation:

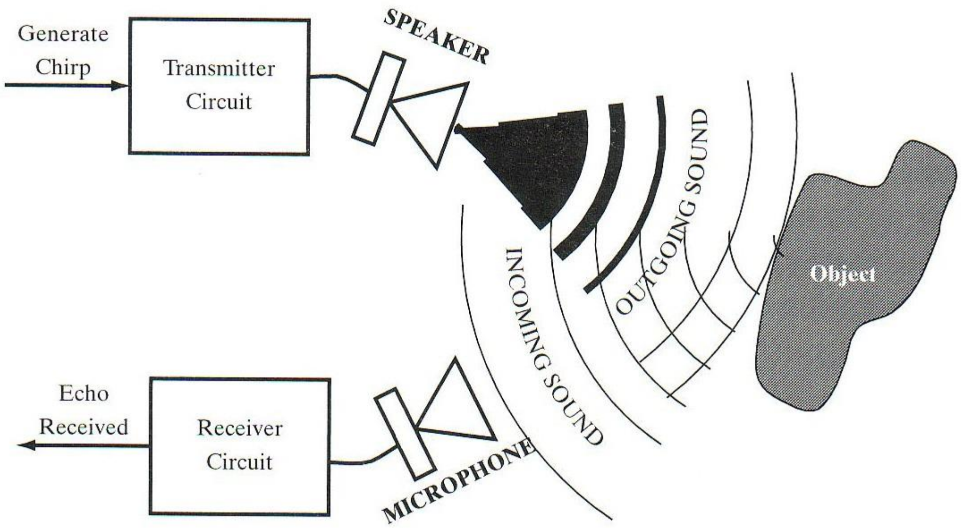
$$D = v * t$$

D = round-trip distance

v = speed of wave propagation

t = elapsed time





Example of signal propagation

https://www.google.de/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&ved=0ahUKEwjKweKl9MTWAhXEZ1AKHbDkDkUQjhwIBQ&url=http%3A%2F%2Fslideplayer.com%2Fslide%2F6365487%2F&psig=AFQjCNEWpF3ekDkhMhBZPjgqkOtg7XzCAQ&ust=1506585314959443

Applications and System architecture

Applications:

- Distance Measurement
- Level measurement
- Object detection
- Medical imaging (sonography)

Example:

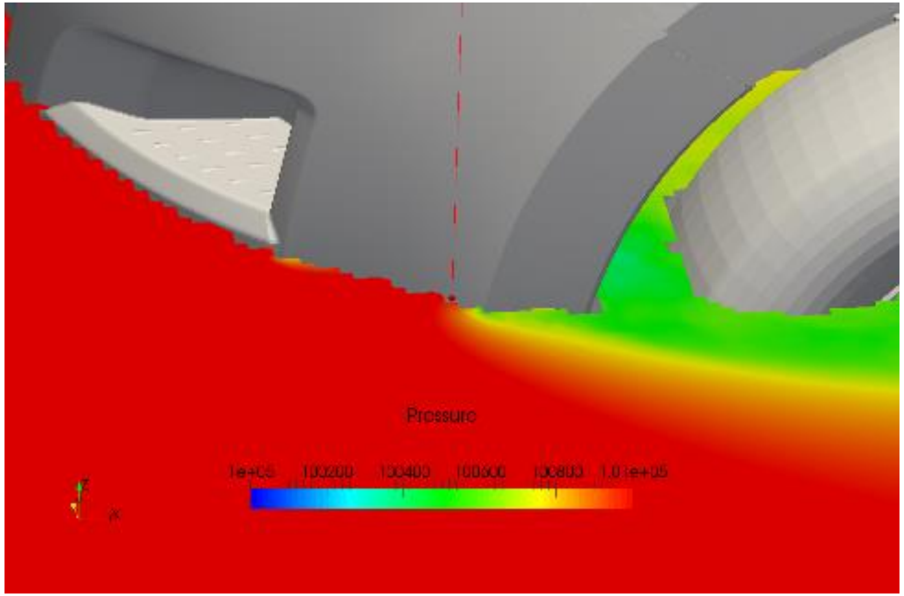
https://www.youtube.com/watch?v=9MlfxqAmQ9s

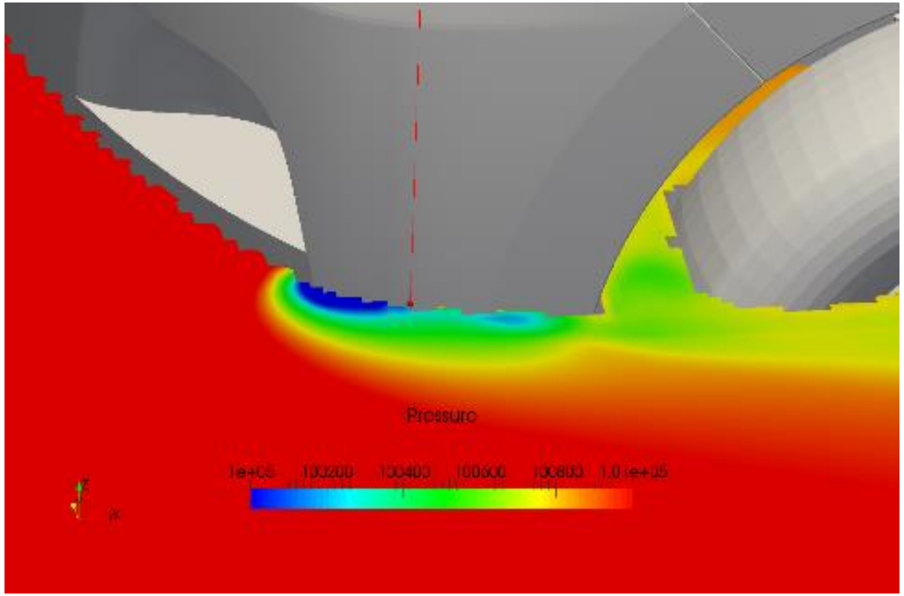
Ultrasonic Sensors
Environmental influences

- Air temperature (speed of sound changes by 0.17% per degree Kelvin)
- Humidity
- Air pressure
- External noise (tire noise, exhaust, as an example.)

Ultrasonic Sensors
Air currents

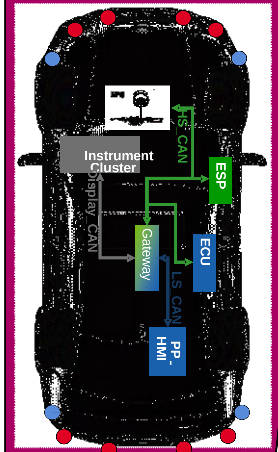
- Air currents (regular air currents (wind) have effect on ultrasonic measurement at speeds over (50-61.5 km/h). → aerodynamically simulation





Ultrasonic Sensors
Parking functions

Functions based on Ultrasonic Park Assist System Configuration



Side Distance Warning (SDW)
- Tracking of obstacles at the side of the car. Driver is warned dependent on steering angle

Park Steering Control (pPSC/cPSC/ dPSC)
- Automatic recognition of suitable parallel, cross, diagonal spaces
- Reverse parking in one or – if necessary – in multiple moves

Pull-out Control (POC)
- System supports pull-out situations by taking over all necessary steering moves when maneuvering forward and backward

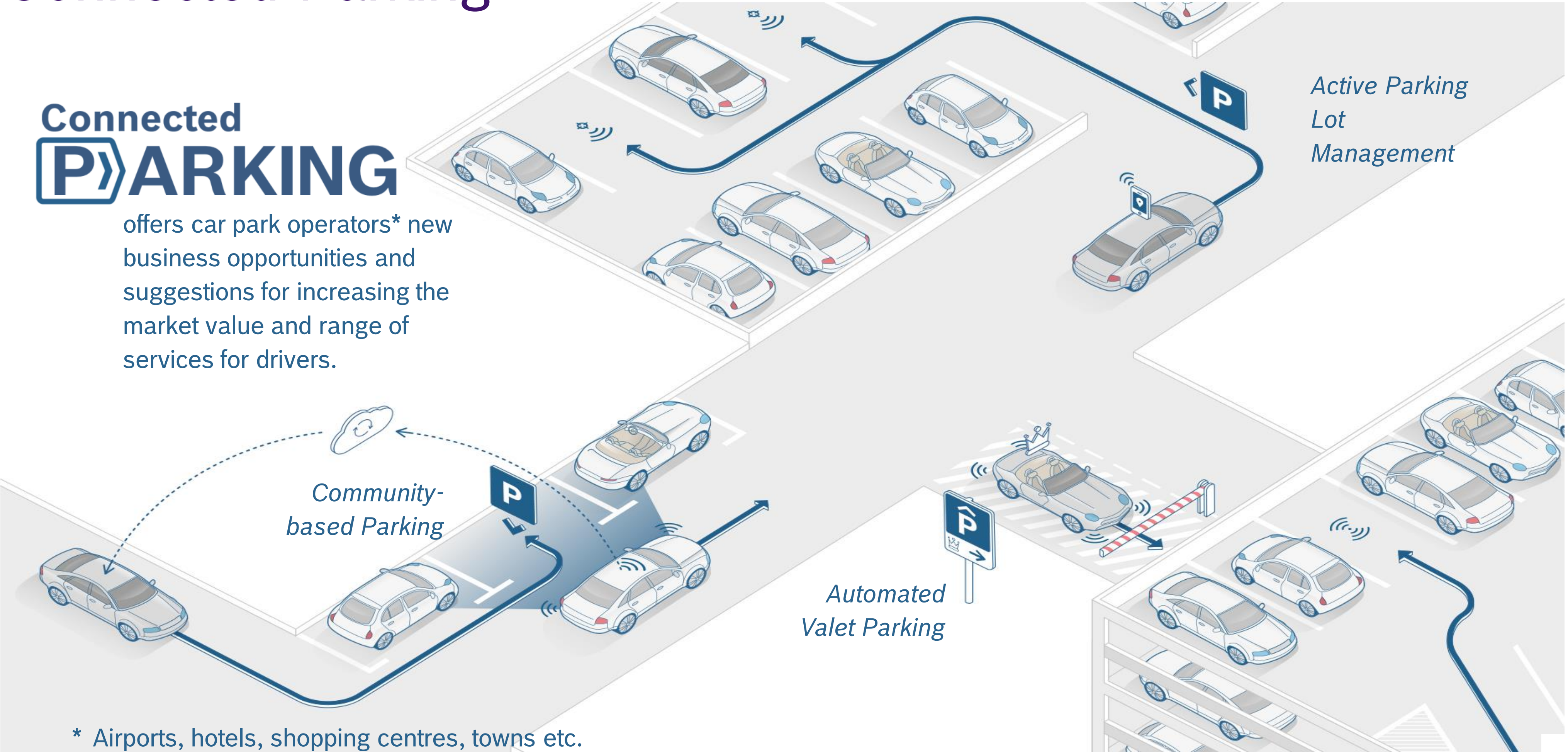
Side View Assist (SVA)
- System warns the driver in case of vehicles bypassing or staying in the blind spot area.

Remote parking, Home zone park assist etc.
- No supervision by driver required. Robust surround sensing necessary.

Ultrasonic Sensors
Connected Parking

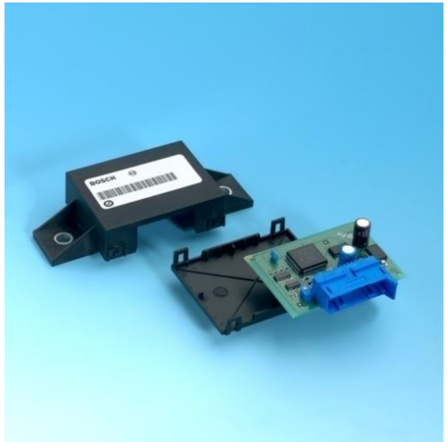
Connected PARKING

offers car park operators* new business opportunities and suggestions for increasing the market value and range of services for drivers.



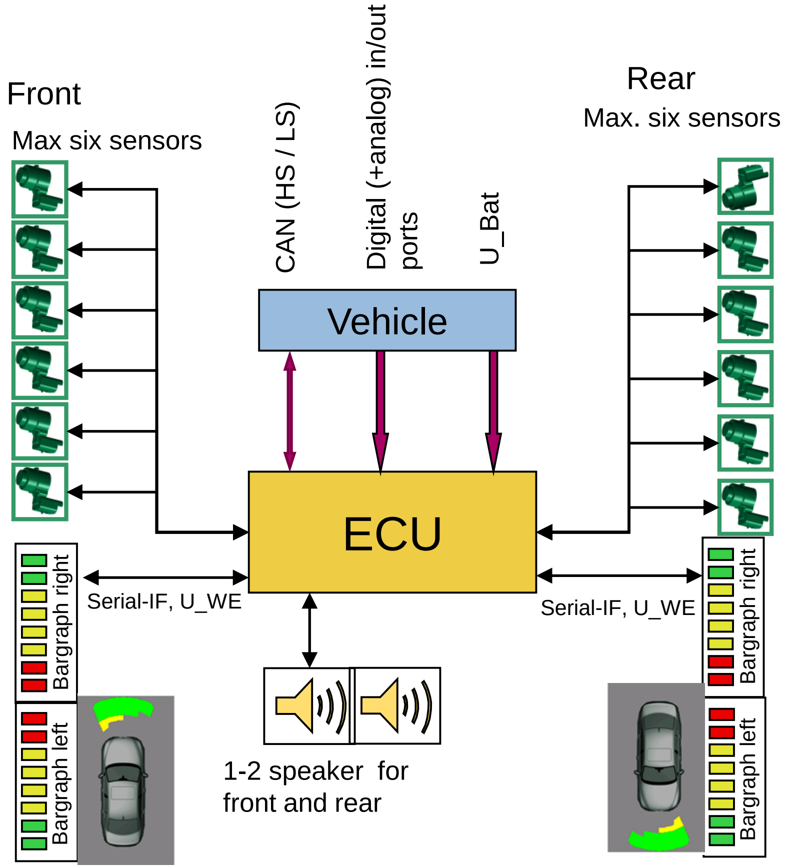
* Airports, hotels, shopping centres, towns etc.

Ultrasonic Sensors
Electronic Control Unit



Ultrasonic Sensors

System architecture-example



Ultrasonic Sensors
System configurations

Basic function

➔ Park Pilot (PP-PAS)

- 4 Ch Rear PP
- 8 Ch Front/Rear PP
- 12 Ch Front/Rear PP

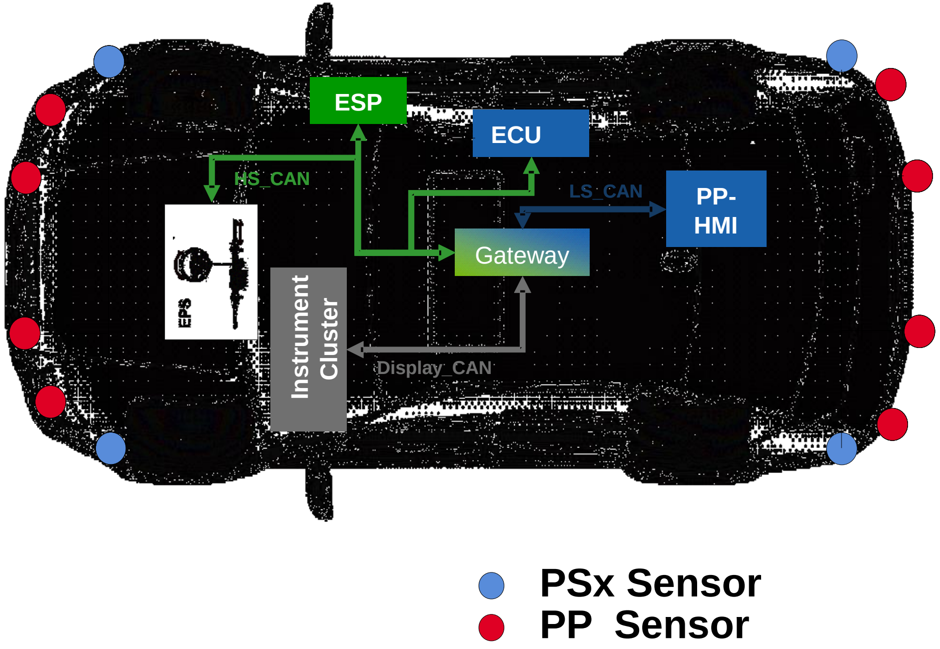
Advanced functions

➔ Park Steering Control (PSC - HFP)

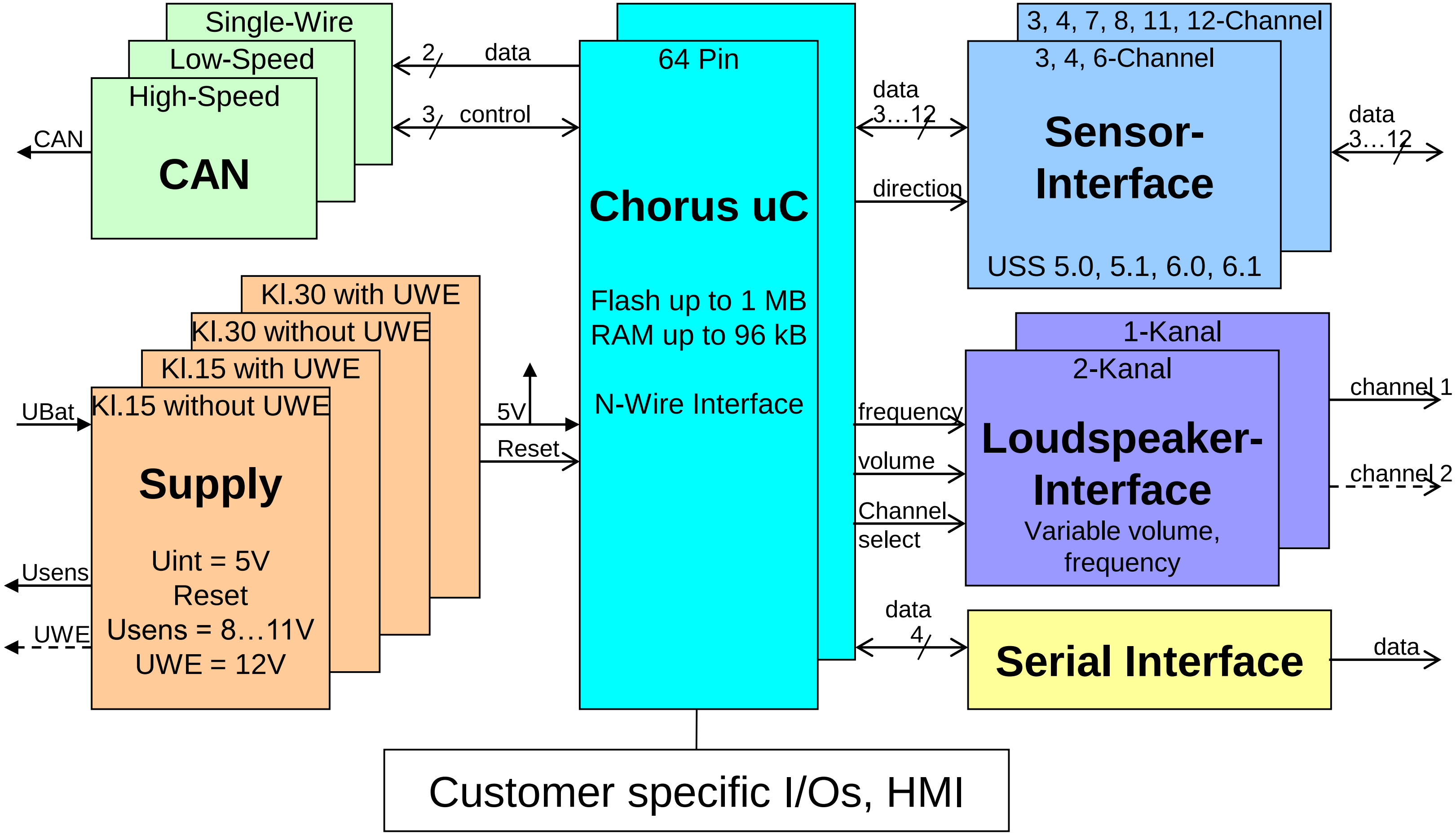
➔ Pull Out Control (POC)

➔ Side View Assist (SVA-BSW)

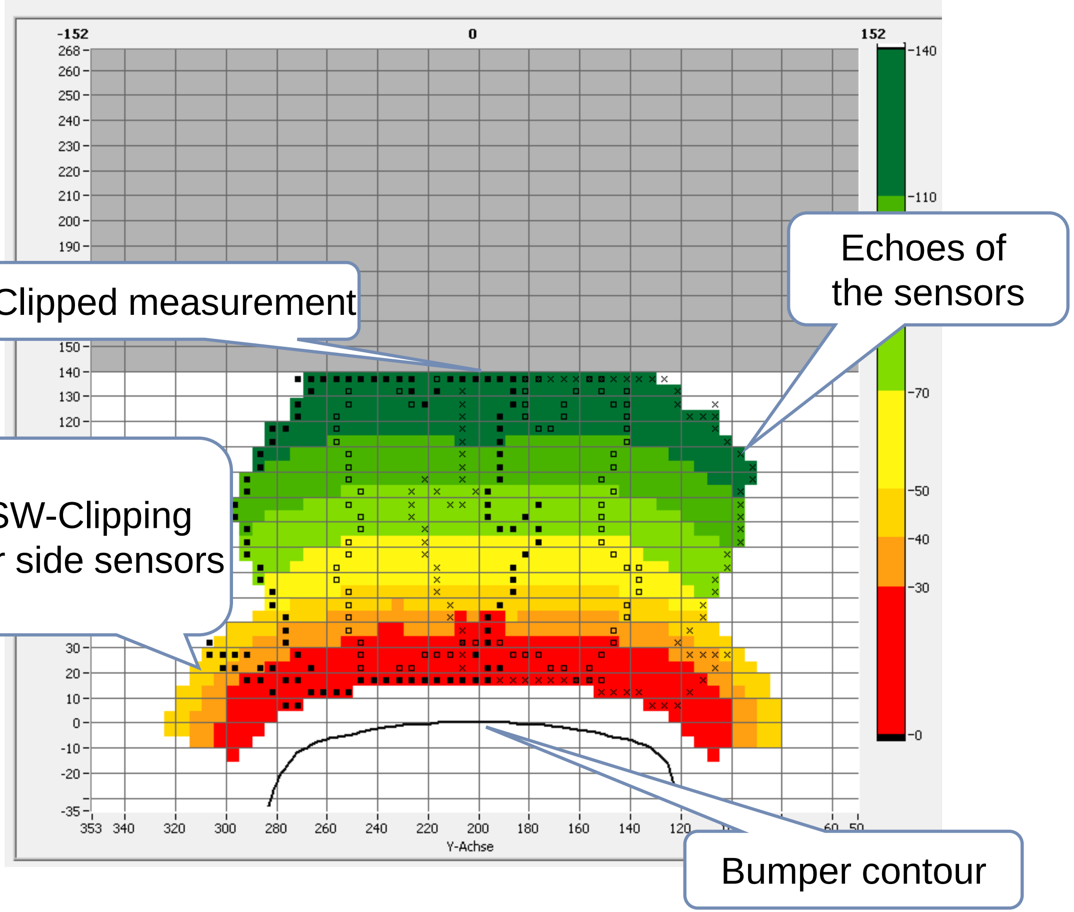
➔ Side distance warning (SDW-FKP)



Ultrasonic Sensors
ECU Block Diagram -Example



Ultrasonic Sensors
Basic function-Park Pilot



RBRO/ESA2.2 | 09.10.2020

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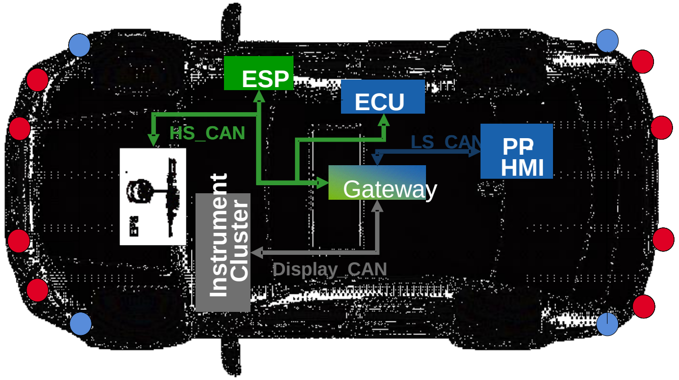
Ultrasonic Sensors
Tracking Algorithms

What is a tracking algorithm?

- Is a software strategy for performance enhancement for radar, ultrasonic, sonar, etc. technologies.
- Provide the ability to calculate and predict the future position of static/moving obstacles, based on historical positions reported by the sensors.



PSx Sensor
PP Sensor

Why do we need tracking algorithms in Autonomous Driving systems?

- Implementation of complex functions, using minimum number of sensors (ex: side protection of the car).
- Covering of unwanted holes and gaps in the field of view, generated by poor sensitivity of the sensors in certain zones, due the multiple factors.
- Calculating and predicting of obstacles position, based on the car movement, speed, wheels direction, etc.

RBRO/ESA2.2 | 09.10.2020

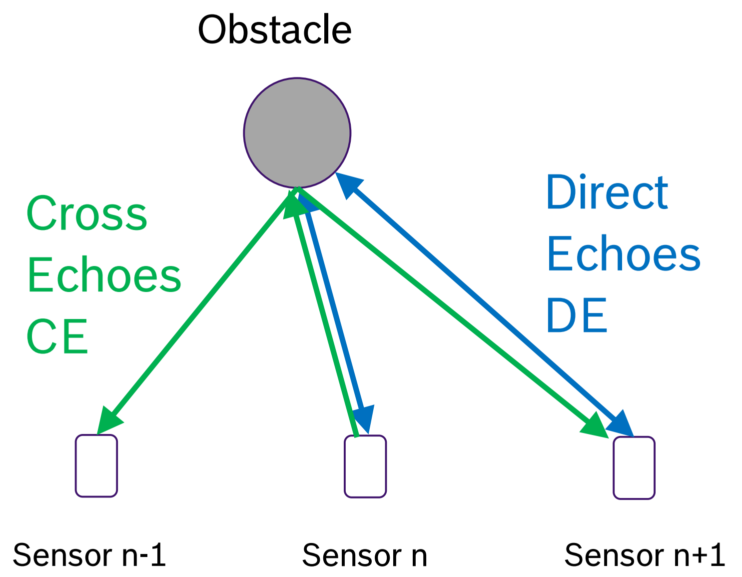
Tracking Algorithms

Concept:

1. Using the triangulation algorithm, the position of the obstacle is detected and the distance by the car is provided by the sensors.

Direct Echoes and Cross Echoes

- Triangulation algorithm for object position.



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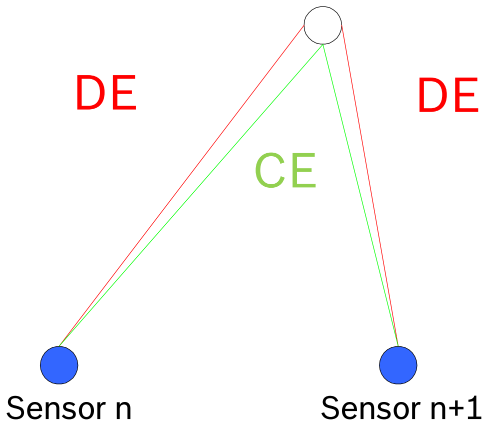
Ultrasonic Sensors
Tracking Algorithms

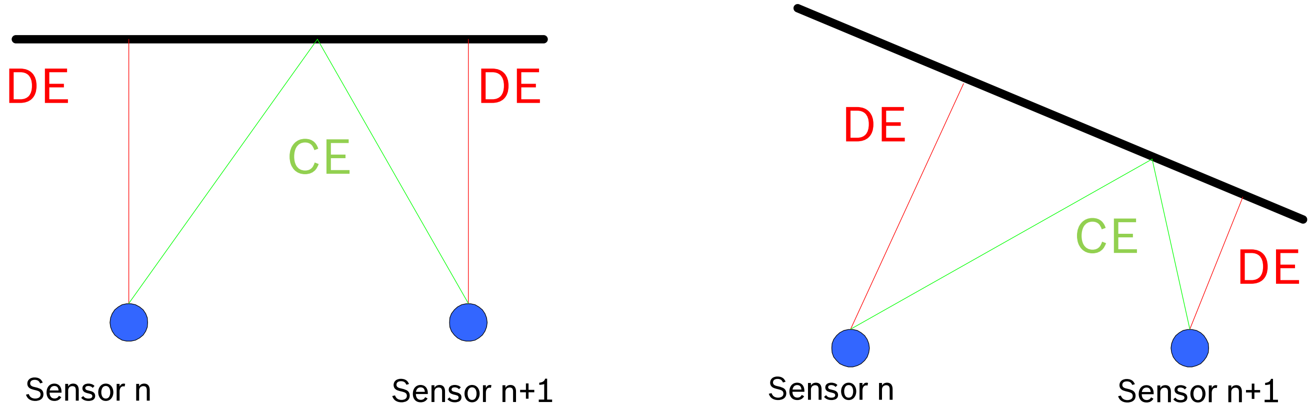
Concept:

2. Detecting the type and the orientation of the obstacle using the information received from the sensors (DE and CE) and position of the obstacle (triangulation).

- Including the obstacle in a category and, starting with this step, software will treat it as an **object**.



Ex: **Round pole**



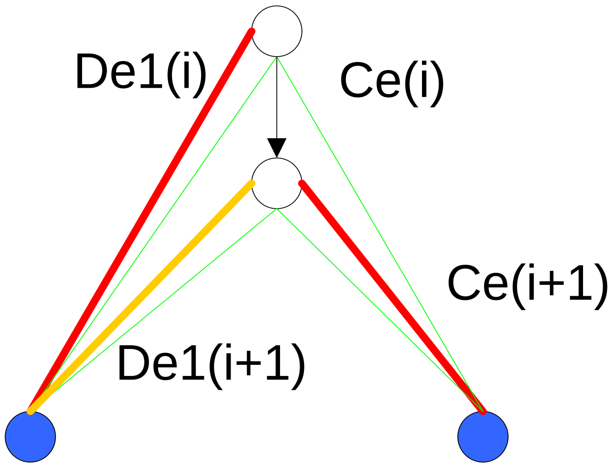
Ex: **Walls**

RBRO/ESA2.2 | 09.10.2020

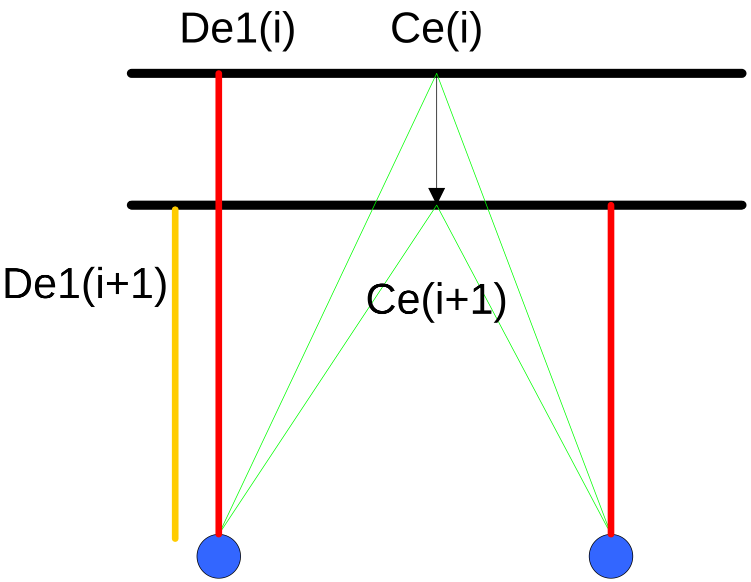
Ultrasonic Sensors
Tracking Algorithms

Concept:

3. Predicting the next position of the objects, using the data received from sensors, position, type, speed of the car, wheel directions.



Ex: **Round pole**



Ex: **Walls**

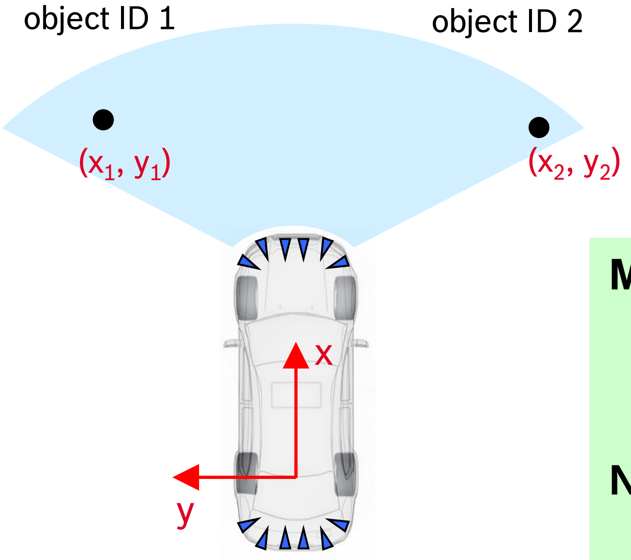
Ultrasonic Sensors

Tracking Algorithms

Concept:

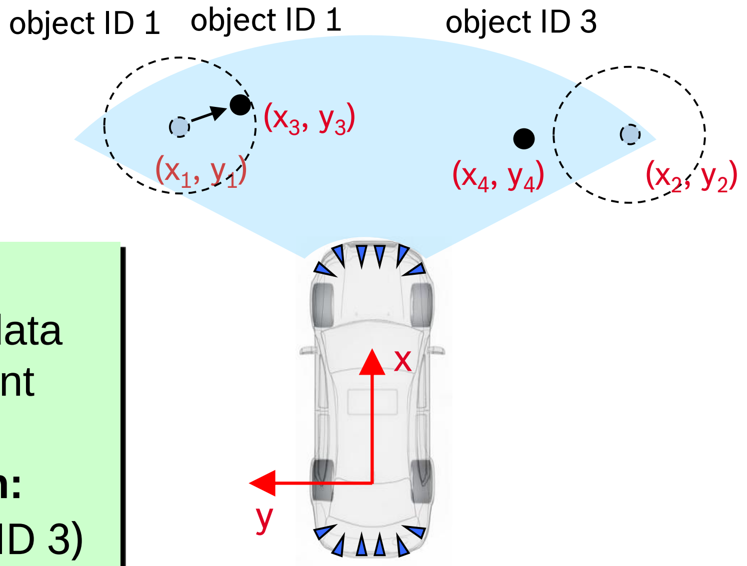
Initial situation

measurement time t_0



Tracking and matching

measurement time t_1



Matching decision:
→ take-over position data of new measurement (object ID 1)

Non matching decision:
→ new object (object ID 3)

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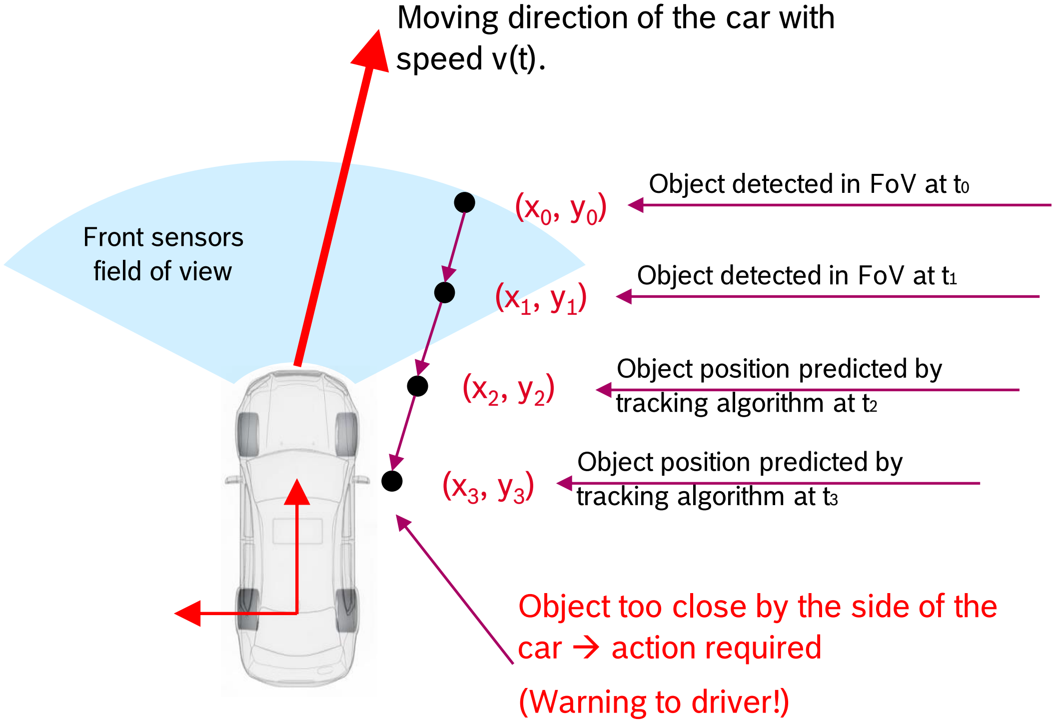
Ultrasonic Sensors

Tracking Algorithms

Tracking of static obstacles (e.g. Side Distance Warning)



- Tracking the obstacles on the sides of the car.
- Driver is warned according with the position of the obstacle, wheel angle, speed.

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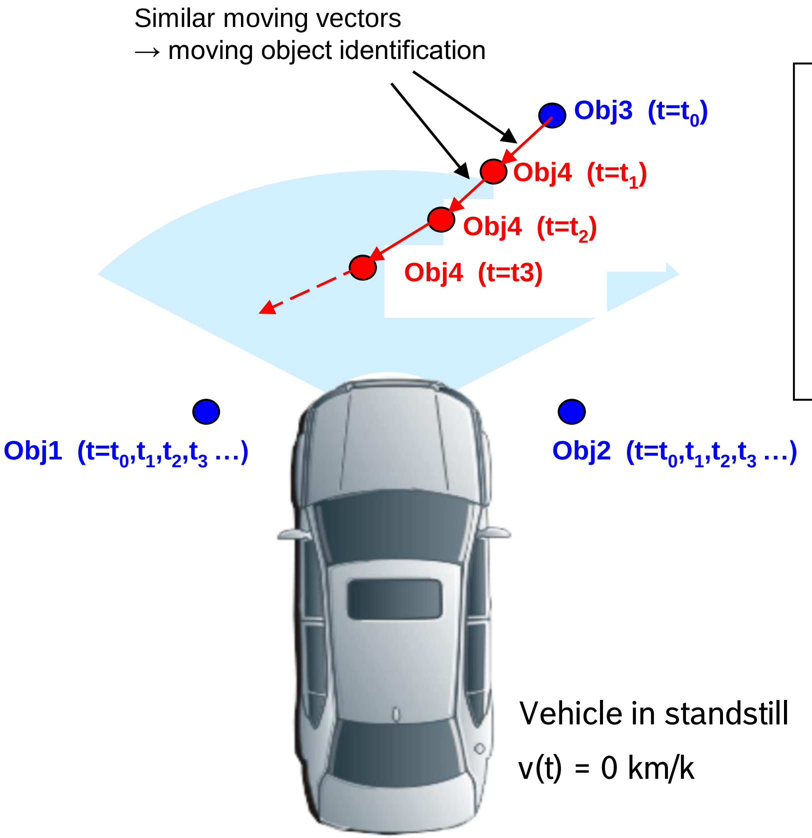
Ultrasonic Sensors

Tracking Algorithms

Tracking of moving obstacles



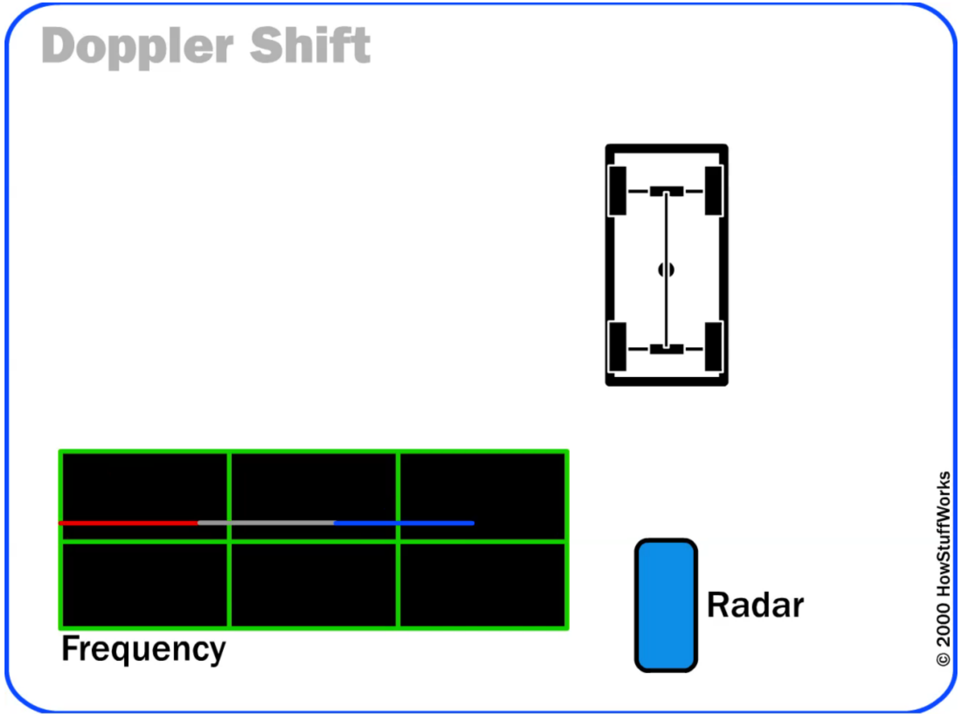
Obj1,2: static objects
Obj3: moving object, but not yet identified
→ short time of presence
Obj4: identified moving object.

RADAR SENSORS

Radar Sensors

The master of motion measurement

- The simplest function of radar is to tell you how far away an object is.
- To do this, the radar device emits a concentrated radio wave and listens for any **echo**.
- If there is an object in the path of the radio wave, it will reflect some of the electromagnetic energy, and the radio wave will bounce back to the radar device.



Radar Sensors
The master of motion measurement

- Radio waves move through the air at a constant speed, so the radar device can calculate how far away the object is based on how long it takes the radio signal to return.

- Radar can also be used to measure the speed of an object, due to a phenomenon called **Doppler shift**. Like sound waves, radio waves have a certain **frequency**, the number of oscillations per unit of time.

- https://www.youtube.com/watch?v=VHR8AeZrlVc

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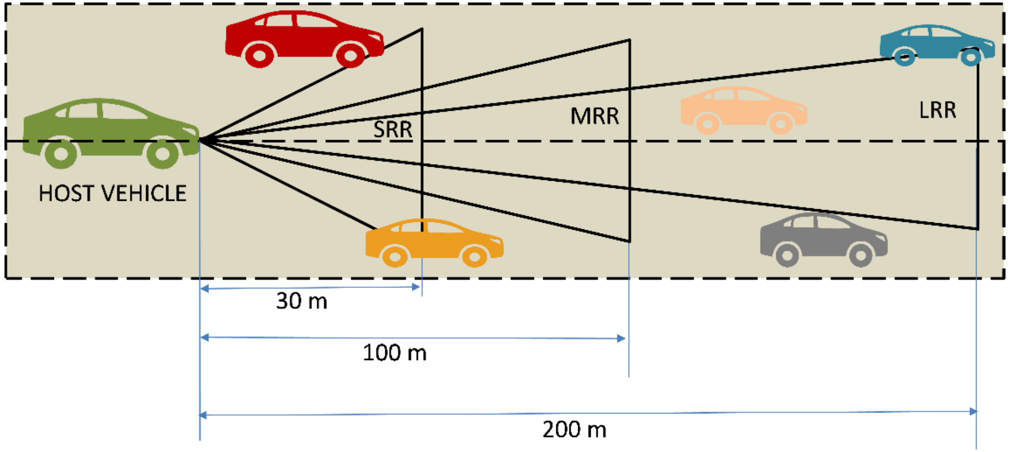
Radar Sensors
SRR, MRR, LRR

- **Long Range RADAR-** Long-range RADARs have the capability to detect objects situated in a wide geographical area, as they can easily cover a range of 10–200m.
- **Mid-Range RADAR-** Mid-range RADAR sensors operate at a range of 100-150m.
- **Short Range RADAR**- Short range RADAR is a technology which uses transceivers with the signal processing equipment in the vehicle and mounted behind the bumper.



Type	SRR	MRR	LRR
Frequency Band	76 -77 GHz	77- 79 GHz	77 – 81 GHz

http://automotive.electronicspecifier.com/sensors/what-is-driving-the-automotive-lidar-and-radar-market

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Radar Sensors

Evolution of Bosch radar sensors

LRR1	LRR2	LRR3	MRR Front	MRR Rear
				
SOP: 2000	SOP: 2004	SOP: 2009	SOP: 2013	SOP: 2014
• Range: up to 150 m • GaAs Oscillator (Gunn Diode) • Opening Angle: 8° • Dimensions (HxWxD) 124 x 91 x 97 mm • Weight: 600 g	• Range: up to 200 m • GaAs Oscillator (Gunn Diode) • Opening Angle: 16° • Dimensions (HxWxD) 73 x 70 x 60 mm • Weight: 300 g	• Range: up to 250 m • SiGe MMICs (bare chip) • Opening Angle: 30° • Dimensions (HxWxD) 77 x 74 x 58 mm • Weight: 285 g	• Range: up to 160 m • SiGe MMICs (packaged chip) • Opening Angle: 45° • Dimensions (HxWxD) 60 x 70 x 30 mm • Weight: 200 g	• Range: up to 100 m • SiGe MMICs (packaged chip) • Opening Angle: 150° • Dimensions (HxWxD) 60 x 70 x 30 mm • Weight: 190 g

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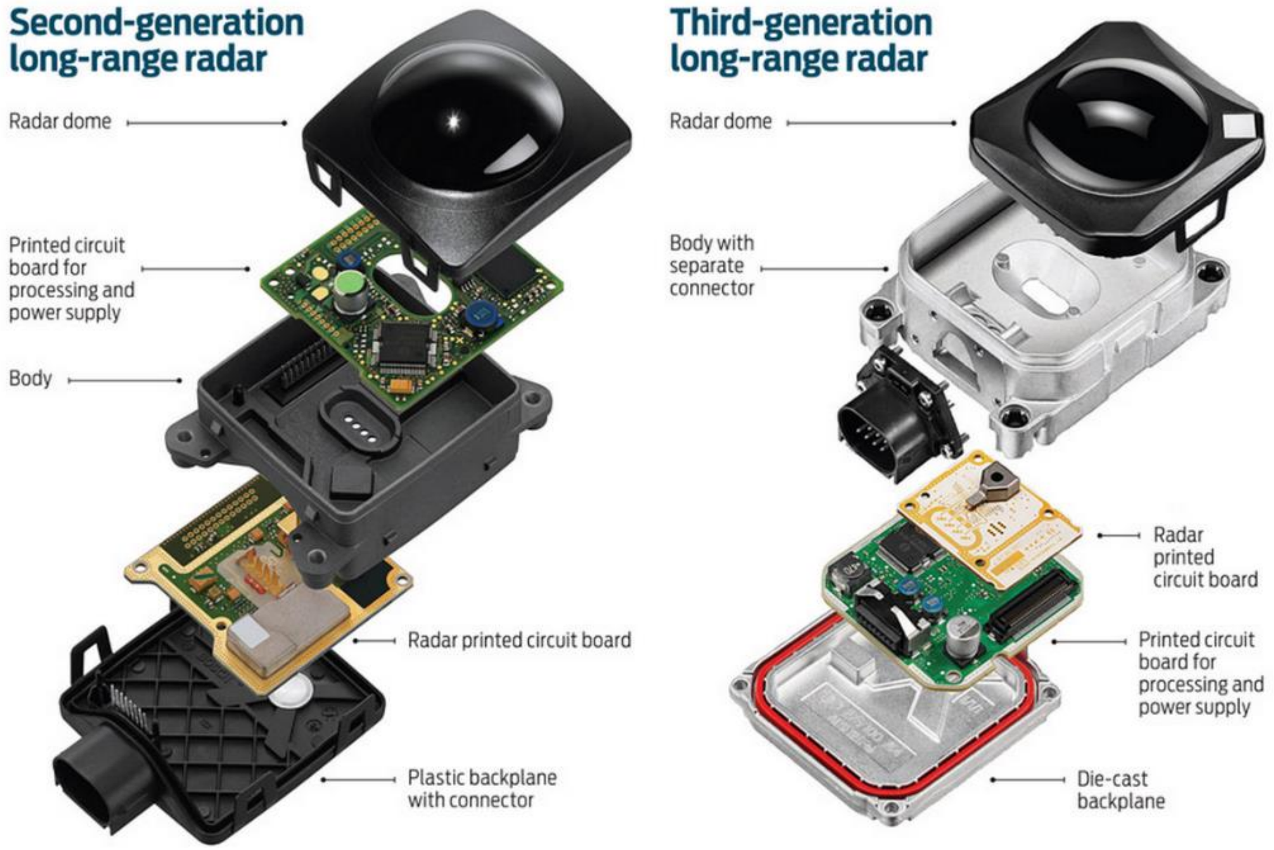
Radar Sensors

Evolution of Bosch radar sensors

Bosch's latest long-range system greatly simplifies the radar's printed circuit board. Instead of handful of gallium arsenide chips to generate, amplify and detect the 77-gigahertz microwaves, the system uses just one or two (as shown) of Infineon's silicon germanium chips.



Radar Sensors

Application in automotive

- Adaptive Cruise Control (ACC/ACC Stop&Go)
- Predictive Collision Warning (PCW)
- Emergency Break Assist (EBA)
- Blind Spot Detection (BSD)
- Blind Spot Detection Extended (BSDE)
- Lane Change Assist (LCA)
- Rear cross traffic alert (rCTA)
- Front Cross Traffic Start Prevention (fCT-P)
- Cross Traffic Emergency Brake Assist (fCT-BA)
- Cross Traffic AEB (fCT-AEB)

Radar Sensors

RADAR vs Ultrasonic

- Ultrasonic:
  - Smaller and flexible
  - excellent longevity.
  - are usually cheaper than radar.
  - More accurate close range surroundings is created

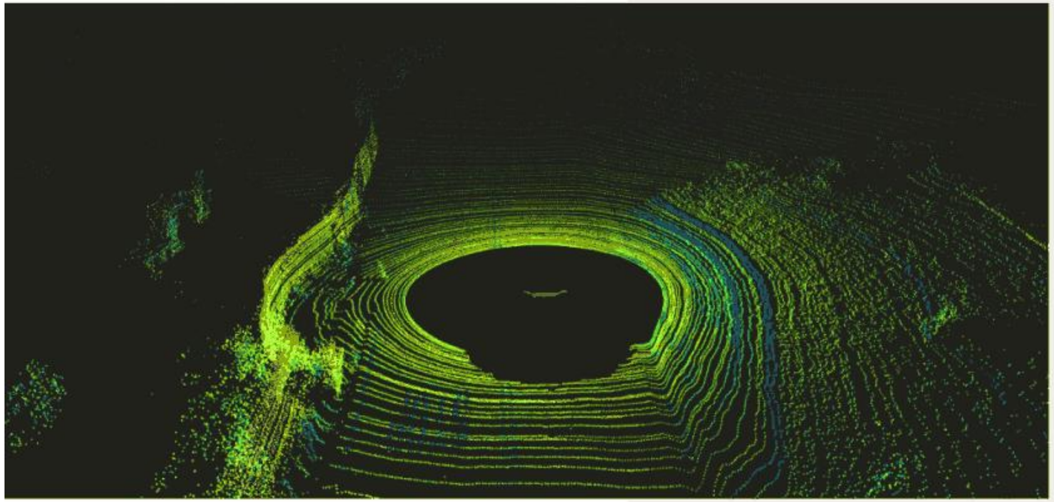
- RADAR
  - Environmental variables just don't affect radar measurements the way they do ultrasonic sensors.
  - More reliable
  - Longer distance

- Ultrasonic and radar sensors don't compete with each other, they complement each other. Neither one is a one-size-fits-all level measurement solution.

LIDAR SENSORS

Lidar Sensors
The master of 3D mapping

- Lidar, short for light detection and ranging, is a technology that measures distance using laser light.
- The technology can scan more than 100 meters in all directions, generating a precise 3D map of the car's surroundings.
- This information is then used by car to make intelligent decisions about what to do next.
- The problem with lidar is that they generate a large amount of data and are still quite expensive for OEMs to cheaply implement.



https://news.voyage.auto/an-introduction-to-lidar-the-key-self-driving-car-sensor-a7e405590cff

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Lidar Sensors
LIDAR Operational Theory

- Is based on the Time of Flight (ToF) method

- A pulse of light is emitted and the precise time is recorded.
- The reflection of that pulse is detected and the precise time is recorded.
- Using the constant speed of light, the delay can be converted into a “slant range” distance.
- Knowing the position and orientation of the sensor, the XYZ coordinate of the reflective surface can be calculated.

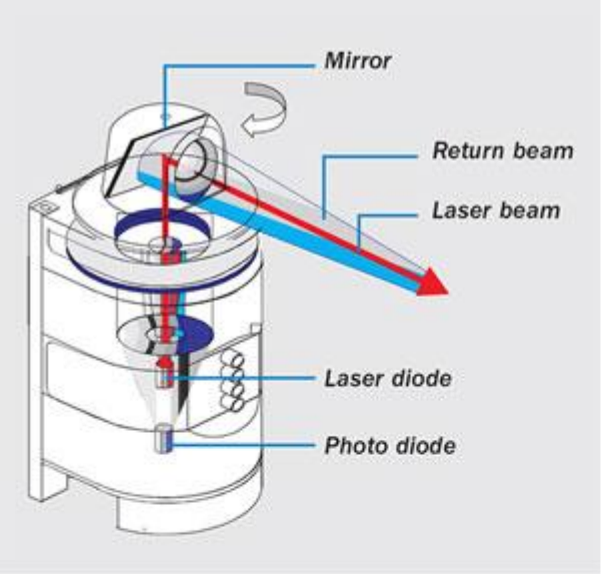


Illustration of LIDAR sensor demonstrating the time of flight principle. *(Courtesy of SICK, Inc.)*

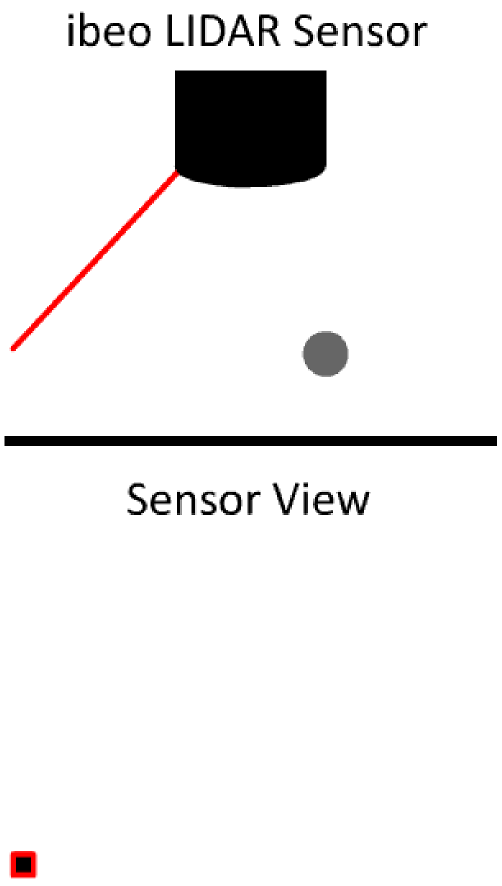
Lidar Sensors

LIDAR Operational Theory

- In the automotive sector, laser pulses with a length of 3 to 20 nanoseconds are used for the ToF method whereas the shorter laser pulses provide a better accuracy.
- The tracking algorithms contained in the sensor's software are able to determine the position and shape, the velocity, yaw rate, heading direction and many other attributes of the objects. Therefore, the LIDAR sensors can be used as system for measuring distance and velocity.

$$Range = \sqrt{\frac{P \cdot A \cdot T_a \cdot T_o}{D_s \cdot P \cdot B}}$$

P = Laser Power
A = Rx Optics Area (lens or mirror)
T_a = Transmittance of the atmosphere
T_o = Transmittance of the optics
D_s = Detector Sensitivity
B = Beam Divergence in Radians



https://www.ibeo-as.com

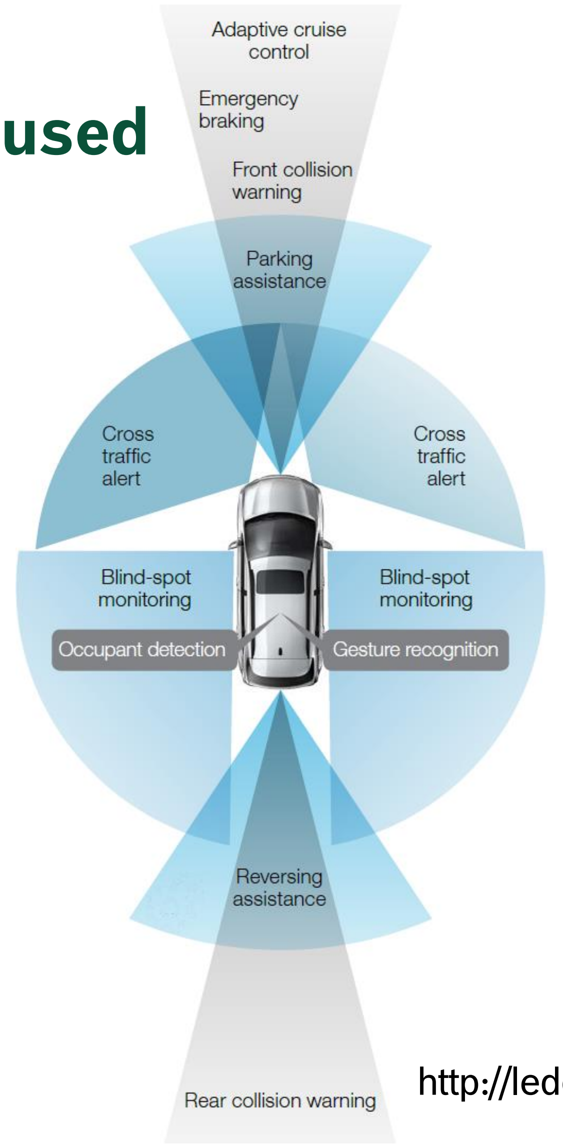
Lidar Sensors
Stats

	Long range Automotive Lidar	Mid-range Automotive Lidar
Detection range: vehicles	Front-facing vehicles: 65 m Rear-facing vehicles: 150 m	Front-facing vehicles: 15 m Rear-facing vehicles: 40 m
Detection range: pedestrians	60 m	12 m
Field of view	20°	90°
Detection segment number	16	16
Operating temperature	-40° C to + 105° C	-40° C to + 105° C
Typical applications	Front/rear collision warning Adaptive cruise control Automatic emergency breaking Traffic jam assistance	Blind spot monitoring Cross-traffic alert Lane change assistance Parking assistance

Lidar Sensors

Applications where the sensor is best to be used

- Forward/rear collision warning
- Blind-spot monitoring
- Cross traffic alert
- Parking assistance
- Automatic emergency braking
- Adaptive cruise control
- Traffic jam assistance
- Gesture recognition
- Occupant detection



http://leddartech.com

LIGHT DETECTION AND RANGING (LiDAR)

Applications where the sensor is best to be used

- **Agriculture**
- LiDAR also can be used to help farmers determine which areas of their fields to apply costly fertilizer.
- **Archaeology**
- LiDAR has many applications in the field of archaeology including aiding in the planning of field campaigns, mapping features beneath forest canopy, and providing an overview of broad, continuous features that may be indistinguishable on the ground.
- **Autonomous vehicles**
- Autonomous vehicles use LiDAR for obstacle detection and avoidance to navigate safely through environments
- **Atmospheric remote sensing and meteorology**
- Atmospheric LiDAR is used to study atmospheric properties from the ground up to the top of the atmosphere. Such instruments have been used to study, among other, atmospheric gases, aerosols, clouds, and temperature.

Radar Sensors

LIDAR vs RADAR

- LIDAR:
  - More accurate for creating 3D objects
  - High density
  - Faster
  - Safer

- RADAR
  - Have much further range
  - Much Cheaper
  - Prettier
  - Unaffected by whether
  - Better adaptability

SOFTWARE ARCHITECTURE

Ultrasonic Sensors

Software architecture

- Real world systems are large and complex => Need to divide and conquer
- Software architecture is used for:
  - Understanding the big-picture of the system
  - Communication among stakeholders
  - Generate the project files structure
  - Integrating components
  - Project management, developing, testing, customer requirements tracking
  - Distributing work to teams for developing components
  - Planning and defining strategies for software testing
  - Create the system configuration and builders

Ultrasonic Sensors

Layered architecture

- The system is organized as a collection of layers based on abstraction levels
- Typically, components of the lowest-level layer interacts with the underlying OS and hardware
- A layer uses services offered by its adjacent low-level layer via API's
- Control-flow is from the top layer to the bottom layer
- At run-time, due to callbacks the control can flow from the bottom layer to the top layer

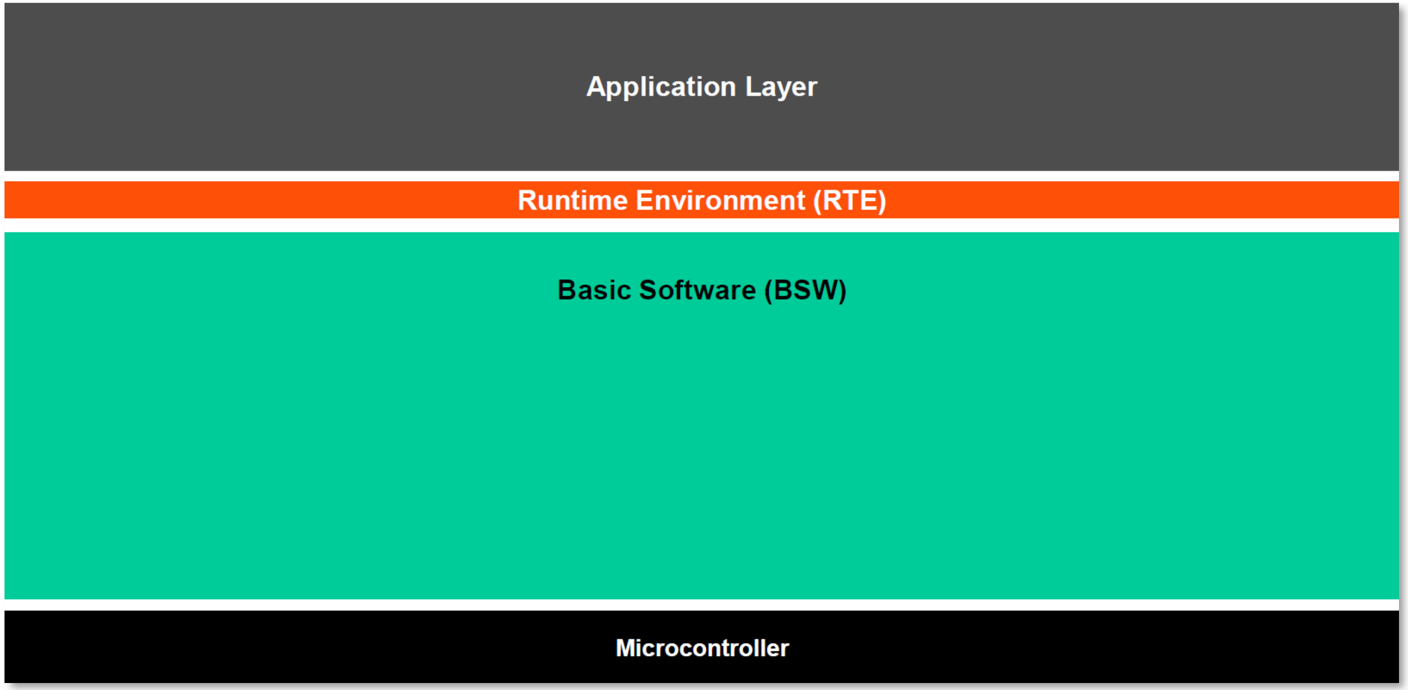
Benefits

- Enables incremental testing from the bottom to top layer
- Plug-out and Plug-in of a layer with a new layer conforming the same API (helpful in producing variants of a product)
- Helps to distribute the work to different teams (often different teams work on different layers)

Ultrasonic Sensors

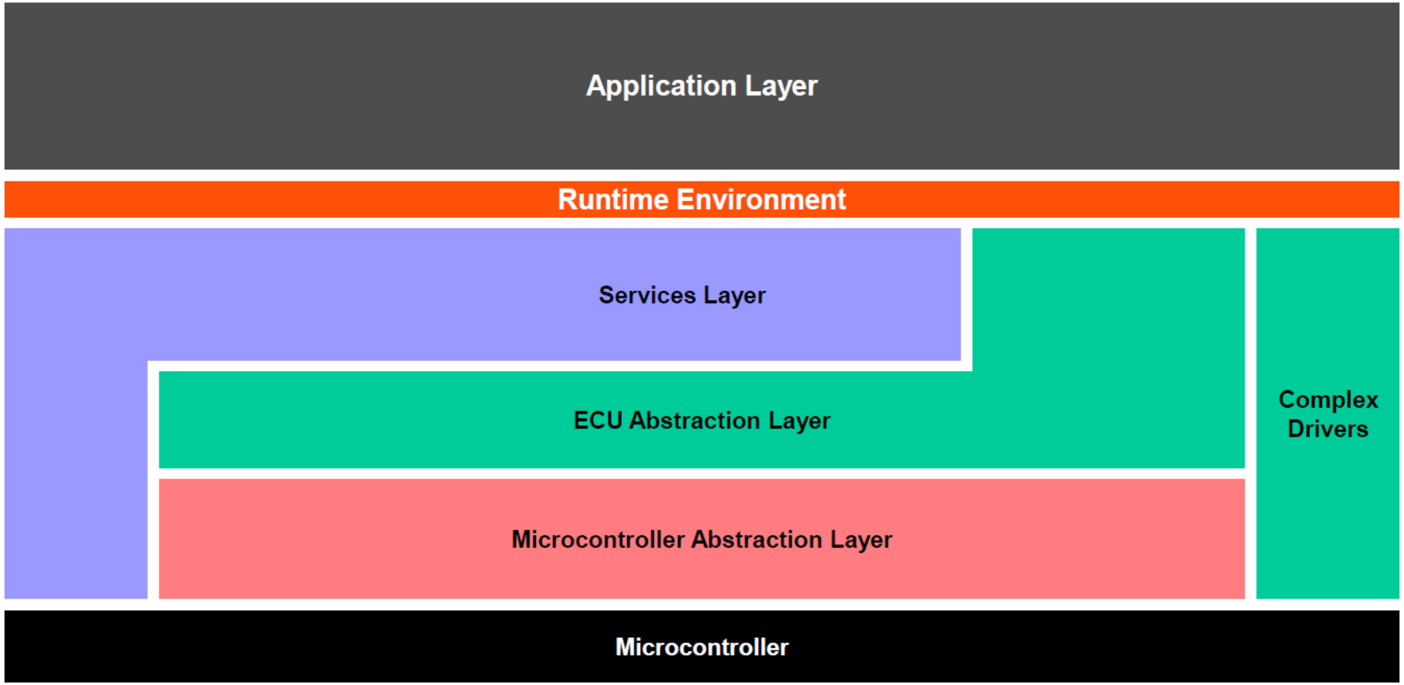
Software architecture AUTOSAR

The AUTOSAR Architecture distinguishes on the highest abstraction level between three software layers: Application, Runtime Environment and Basic Software which run on Microcontroller.



Ultrasonic Sensors
Basic Software Layer

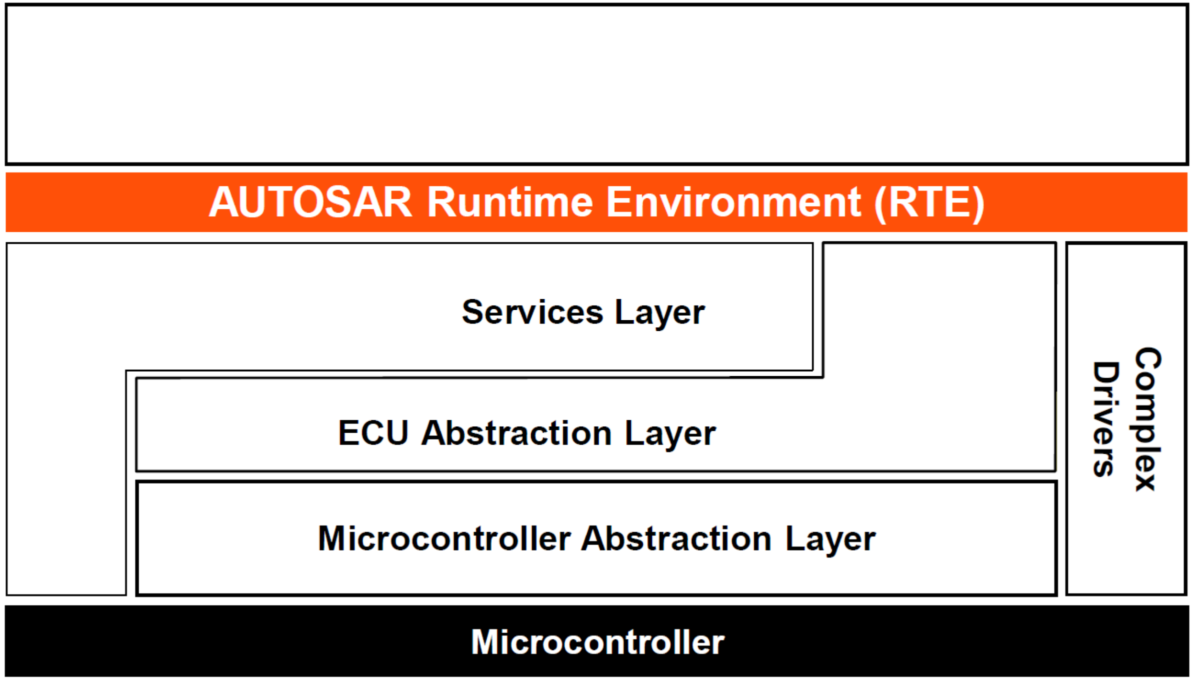
The Basic Software is further divided in the layers: Services, ECU Abstraction, Microcontroller Abstraction and Complex Drivers.



Runtime Environment

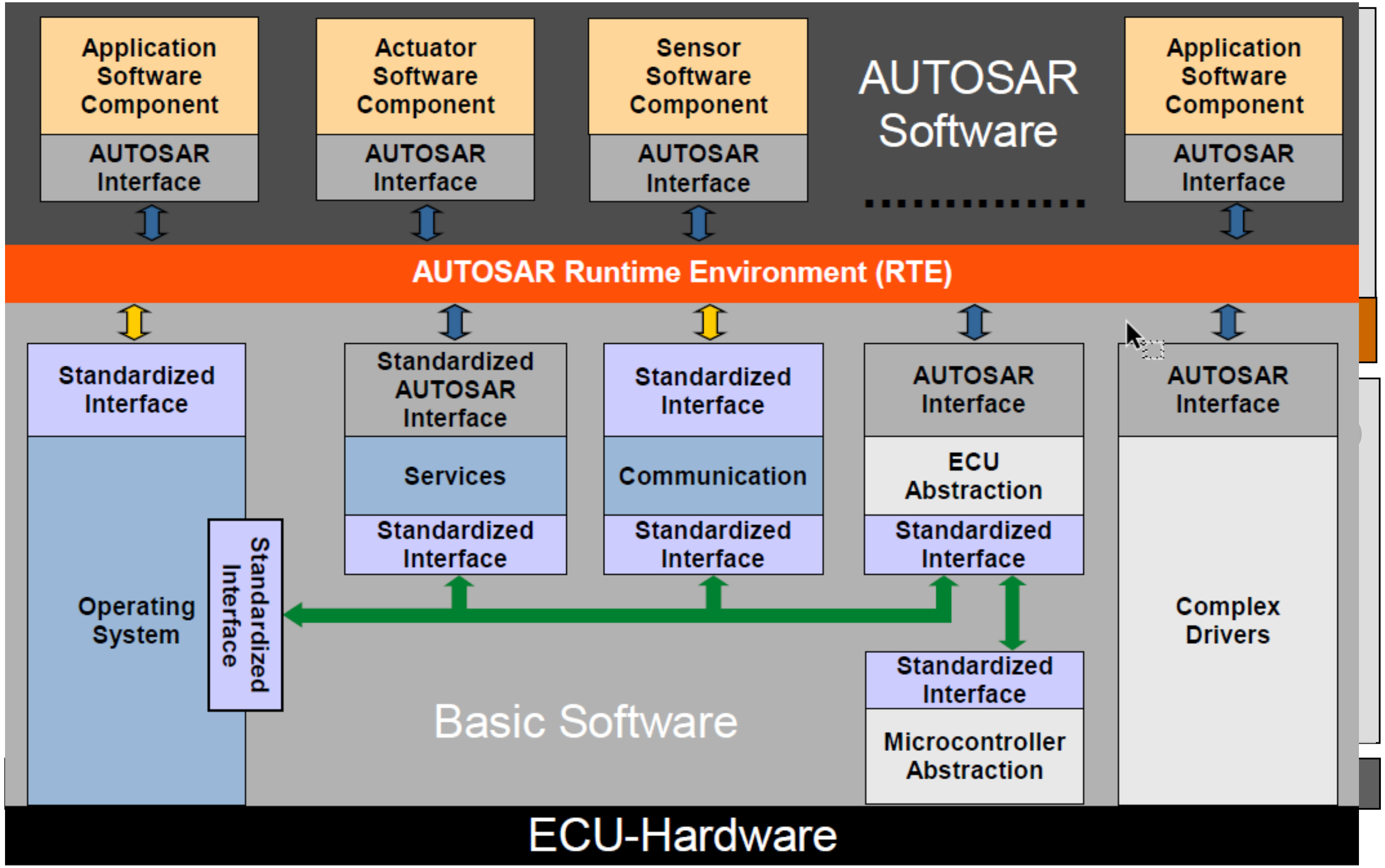
The RTE is a layer providing communication services to the Application software (software components).

Make AUTOSAR Software Components independent from the mapping to a specific ECU.



BOSCH

Ultrasonic Sensors
Top level-Application



Ultrasonic Sensors
Top level-Application

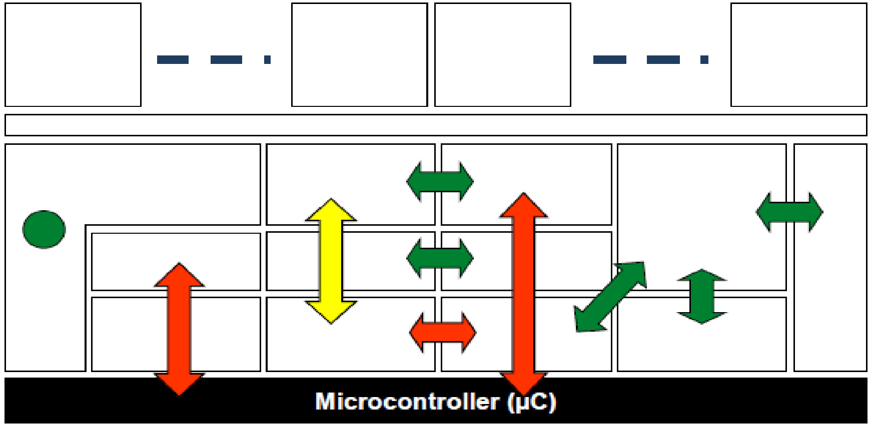
Horizontal Interfaces

Services Layer: horizontal interfaces are allowed
Example: Error Manager saves fault data using the NVRAM manager

ECU Abstraction Layer: horizontal interfaces are allowed

A complex driver may use selected other BSW modules

µC Abstraction Layer: horizontal interfaces are not allowed. Exception: configurable notifications are allowed due to performance reasons.



Vertical Interfaces

One Layer may access all interfaces of the SW layer below

Bypassing of one software layer should be avoided

Bypassing of two or more software layers is not allowed

Bypassing of the µC Abstraction Layer is not allowed

A module may access a lower layer module of another layer group (e.g. SPI for external hardware)

All layers may interact with system services.

THANK YOU FOR YOUR ATTENTION!