AUTONOMOUS DRIVING COURSE

ULTRASONIC, RADAR AND LIDAR SENSORS

Mircea Pintea

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BOSCH

ULTRASONIC SENSORS

Ultrasonic Sensors

Example of USS system - Remote Park Assist -

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

Ultrasonic Sensors
Physical principles

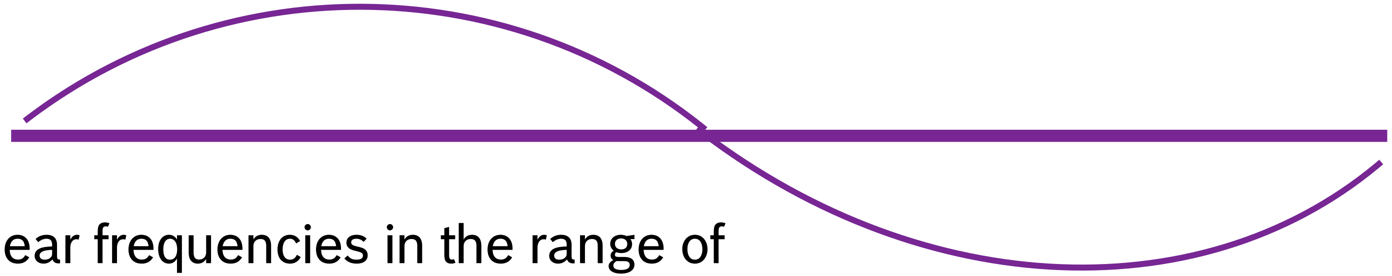
- Sound waves are mechanical waves that require a medium through which to propagate
- Sound cannot travel through a vacuum
- Different materials have different acoustic properties
  - Varies the ability to transmit sound waves
  - Varies the ability to reflect sound at interfaces

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

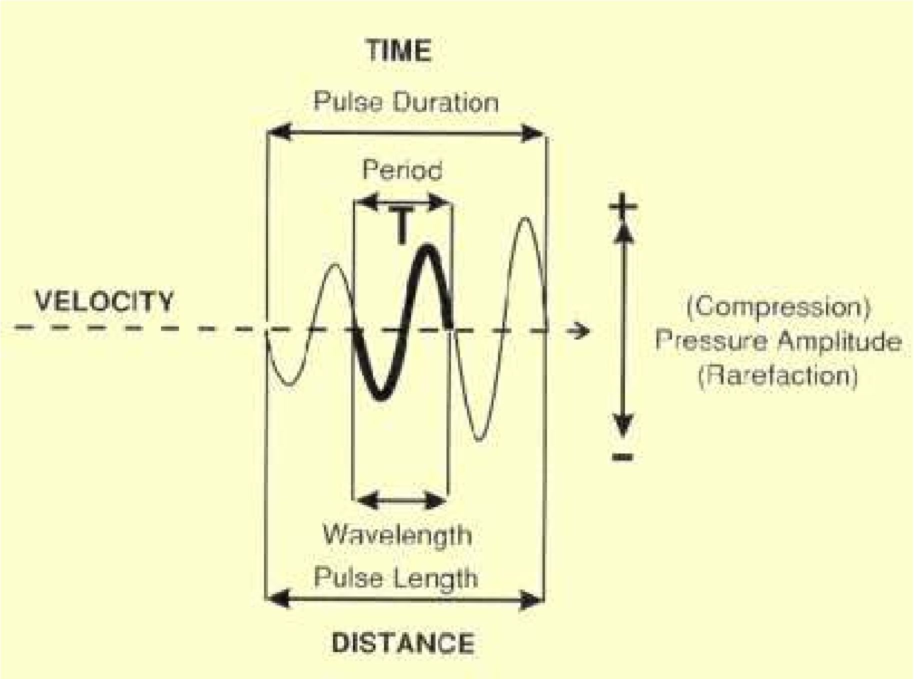
- Sound above the level of human hearing is called ***ultrasound***

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
Physical principles of operation

- Ultrasound pulses are transmitted, as longitudinal waves, ie; the motion of particles in the medium is parallel to direction of wave propagation.

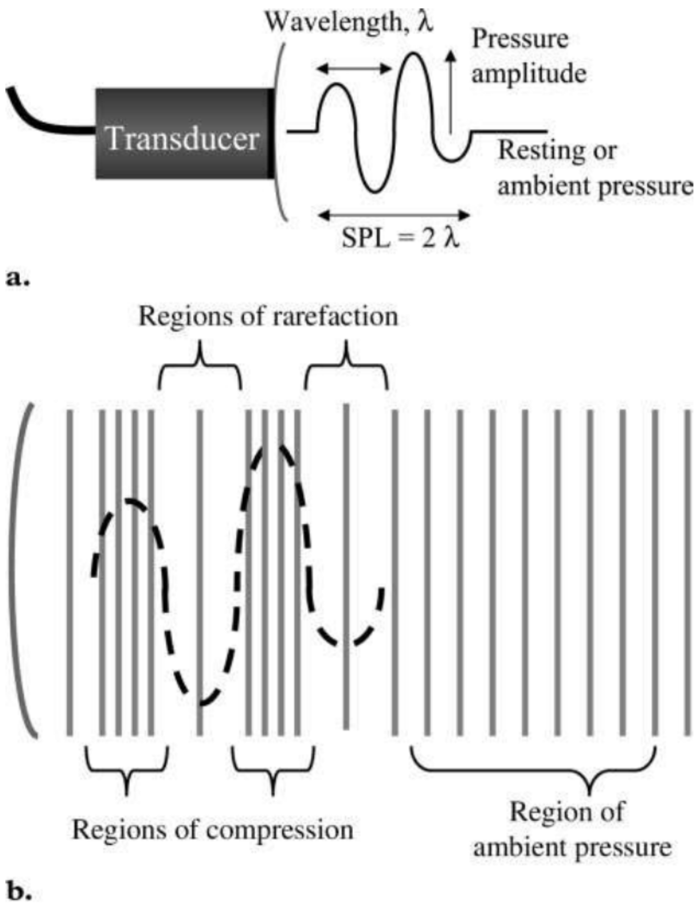
- In each point of the medium, ultrasounds produce a bigger sound pressure compared to the initial p_0 as below

$$p_s = p - p_0 \rightarrow \Delta p_{max} = \underbrace{\rho \cdot c}_{\substack{acoustic\_resist\\ environment}} \cdot \omega \cdot A$$

$\rho -$ air density

$c -$ speed of sound

$v -$ speed of sound in air



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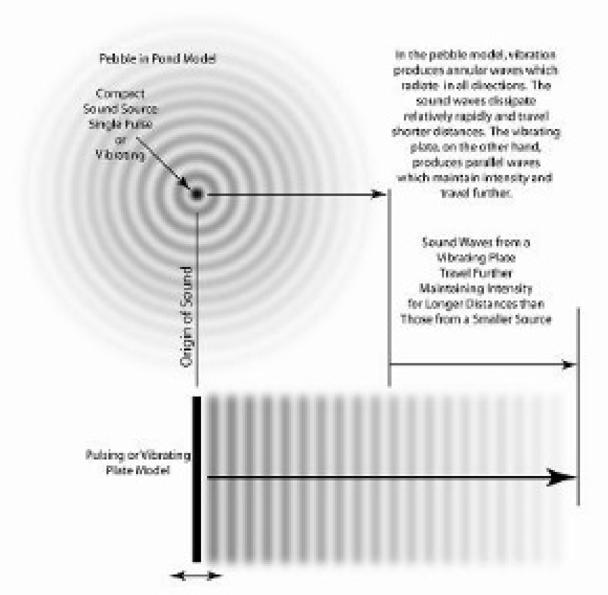
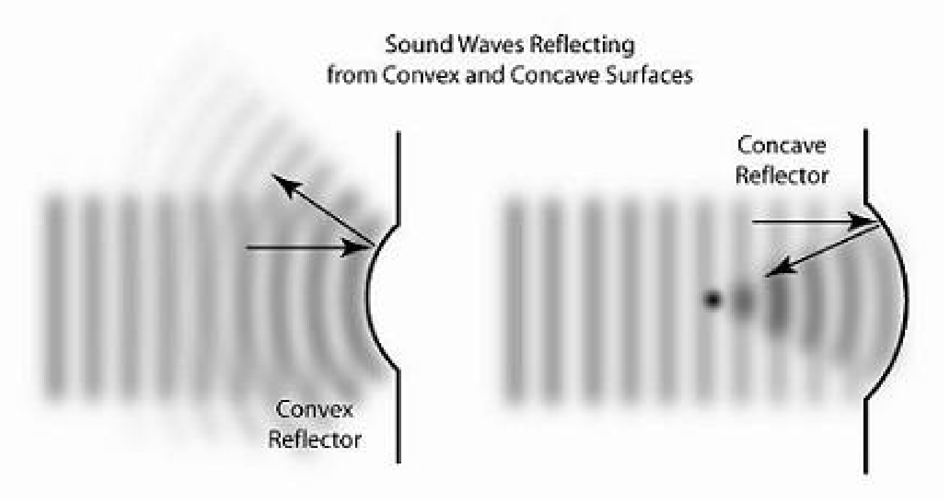
Ultrasonic Sensors
Physical principles





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

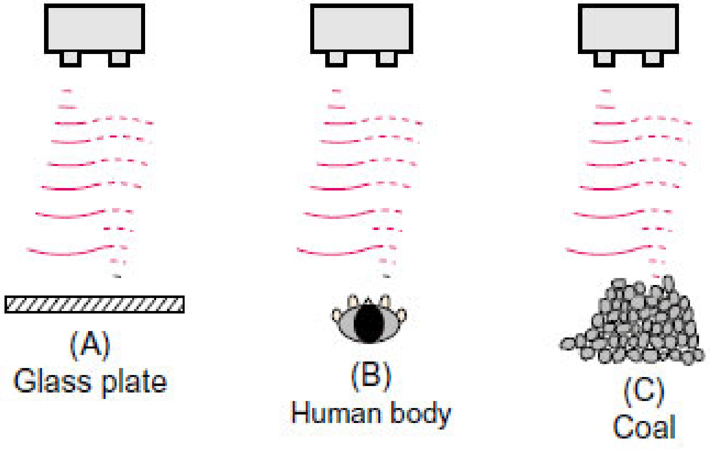
Sound waves can be concentrated and deviate much the same as light waves from convex and concave surfaces.

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 Gen5 sensors

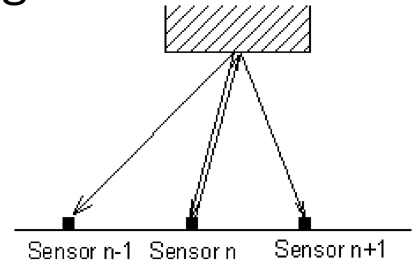
- 48 kHz Ultrasonic sound
- Induction with Piezzoelektronic
- v=340m/s – temperature dependant
- Distance calculation:

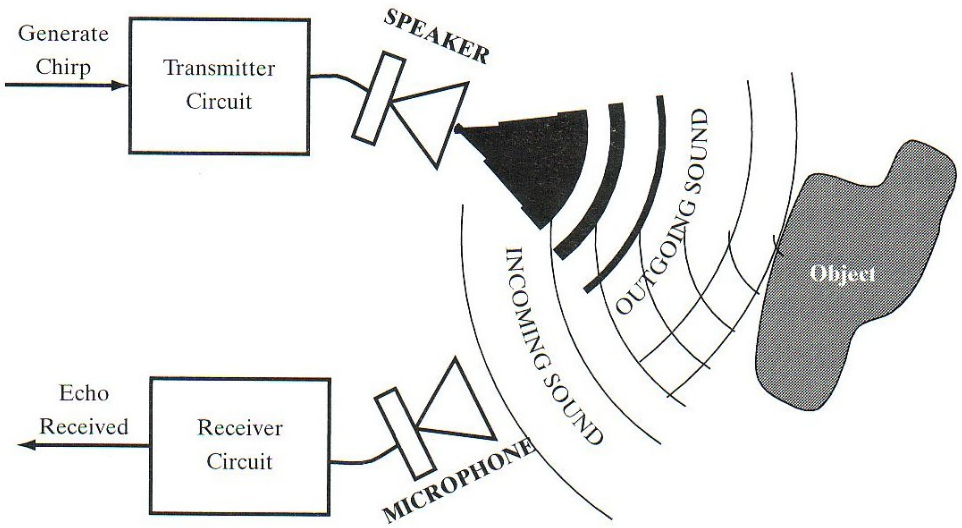
$$D = v * t$$

D = round-trip distance

v = speed of wave propagation

t = elapsed time





Example of signal propagation

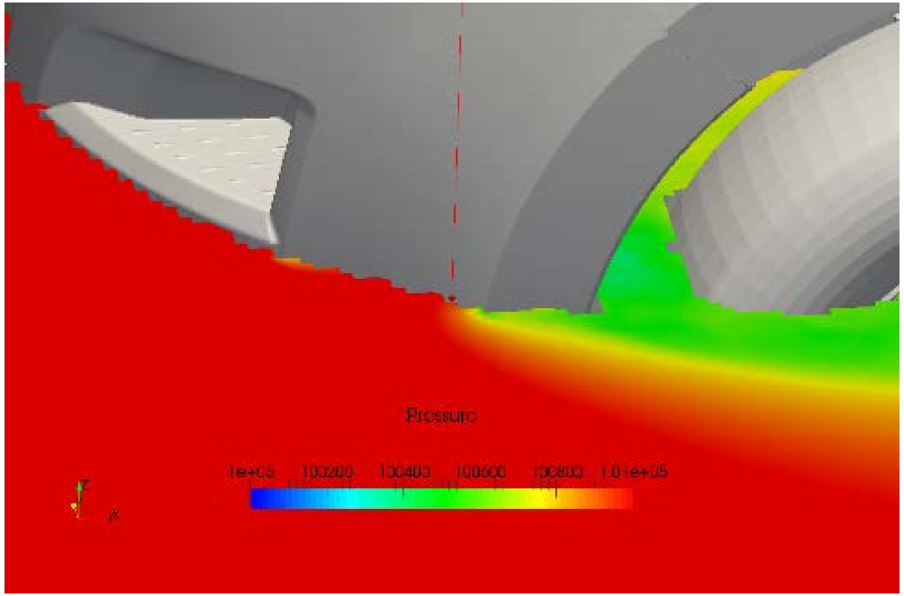
https://www.google.de/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&ved=0ahUKEwjKweKl9MTWAhXEZ1AKHbDkDkUQjhwIBQ&url=http%3A%2F%2Fslideplayer.com%2Fslide%2F6365487%2F&psig=AFQjCNEWpF3ekDkhMhBZPjgqkOtg7XzCAQ&ust=1506585314959443

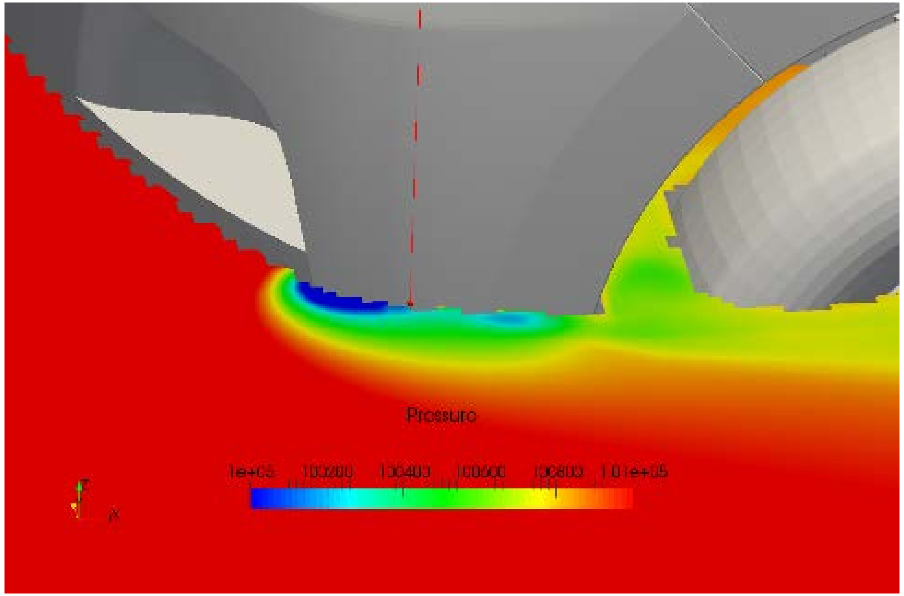
Ultrasonic Sensors
Environmental influences

- 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).   →   aerodynamical simulation





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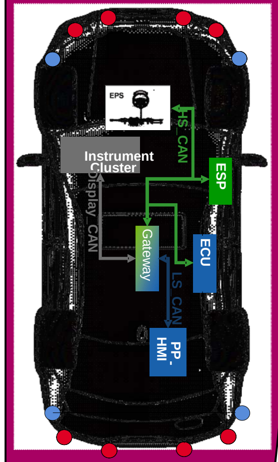
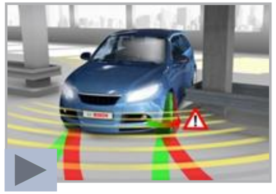
Ultrasonic Sensors
Parking functions

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

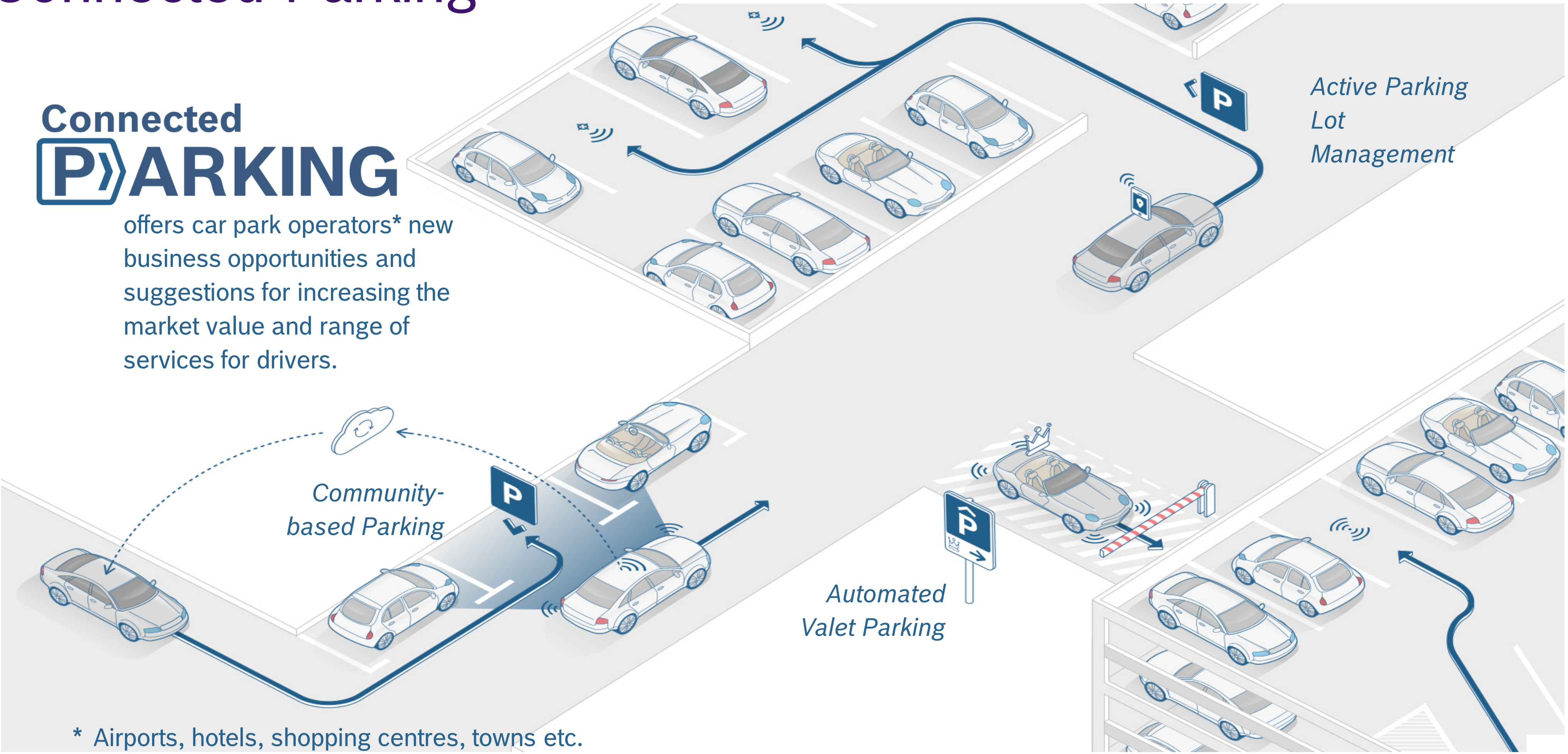
Side View Assist (SVA)
- System warns the driver in case of vehicles bypassing or staying in the blind spot area.

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.

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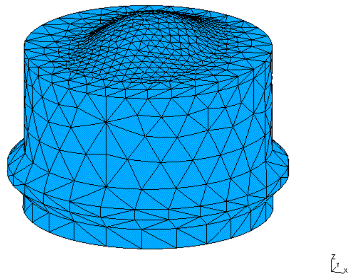
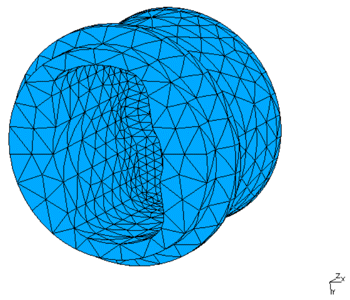
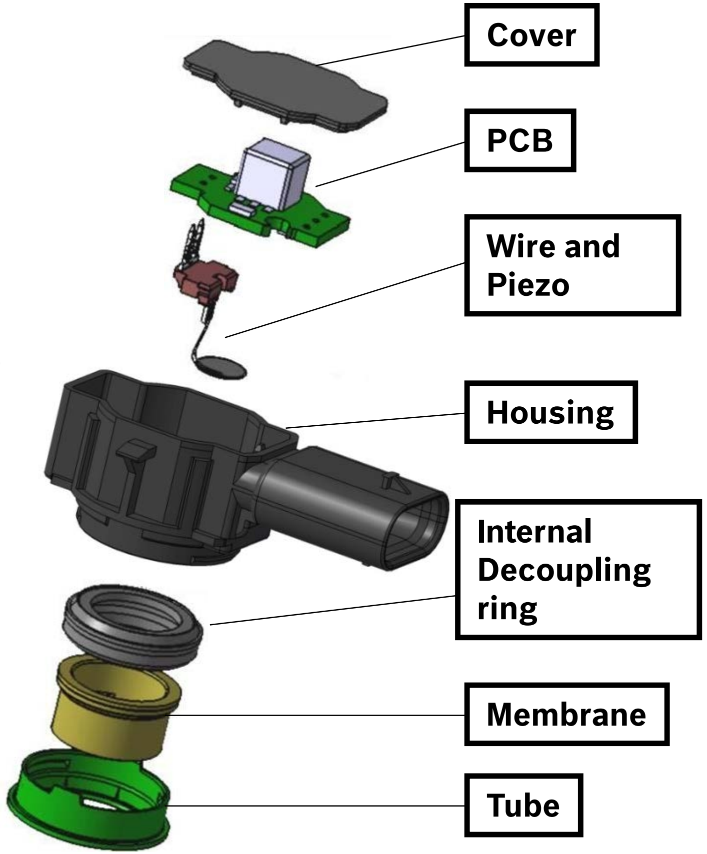
Ultrasonic Sensors
Structure

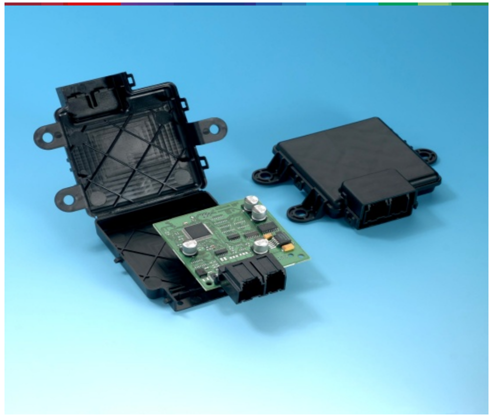
- Maximal distance up to 5m
- Compact sensors for different connectors
- Wide range in installation in different cars
- Different surfaces of membrane
- **Add-on parts handling like license plate holder, trailer hitch, spare wheel etc…→laboratory**

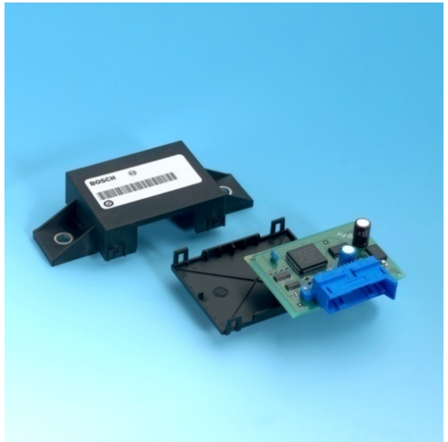


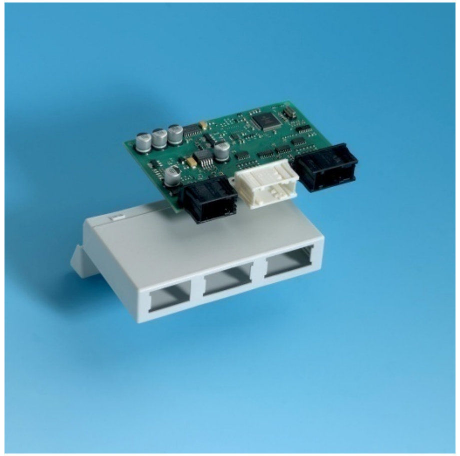




Ultrasonic Sensors
Electronic Control Unit

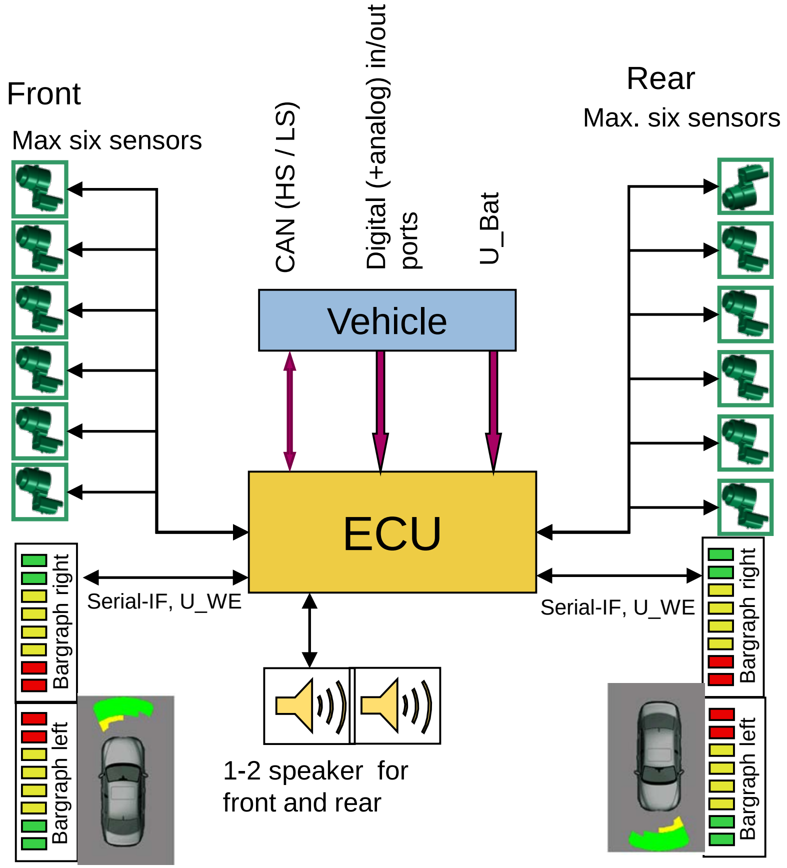




Ultrasonic Sensors

System architecture-example



Ultrasonic Sensors
System configurations

Basic function

➔ Park Pilot (PP-PAS)

- 4Ch Rear PP
- 8Ch Front/Rear PP
- 10Ch Front/Rear PP

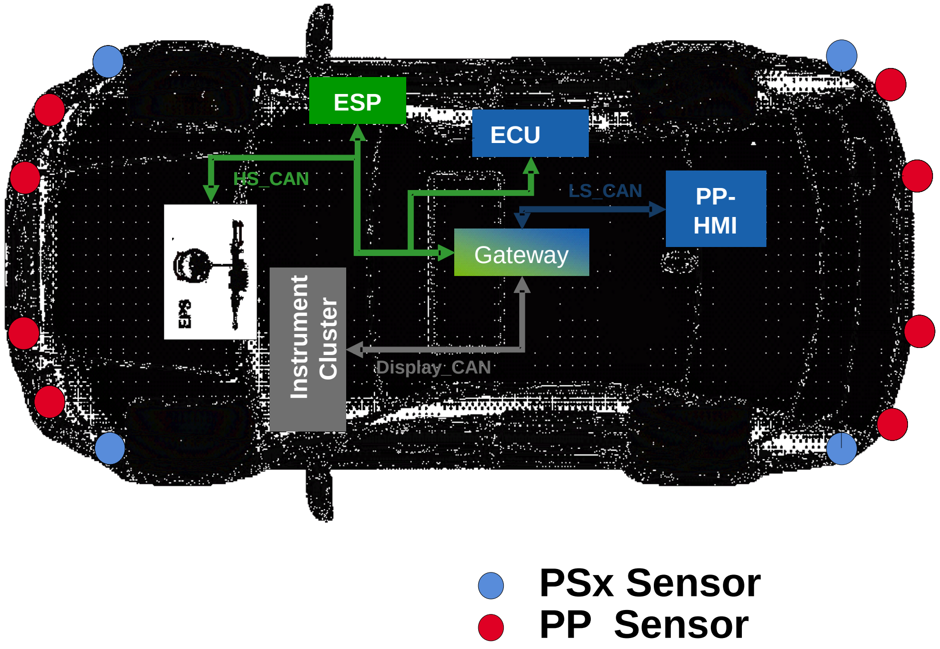
Advanced functions

➔ Park Steering Control (PSC - HFP)

➔ Pull Out Control

➔ Side View Assist (SVA-BSW)

➔ Side distance warning (SDW-FKP)



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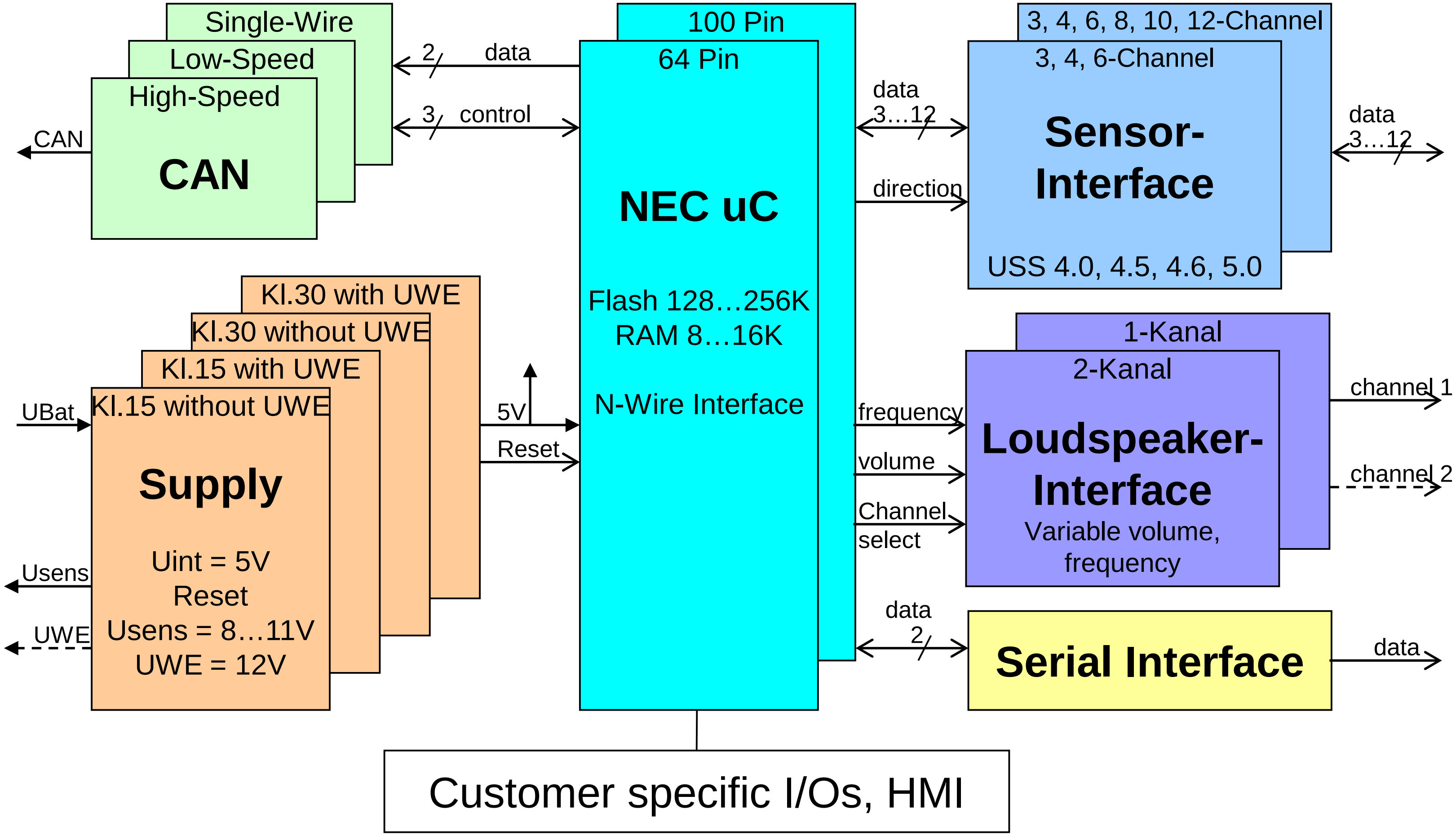
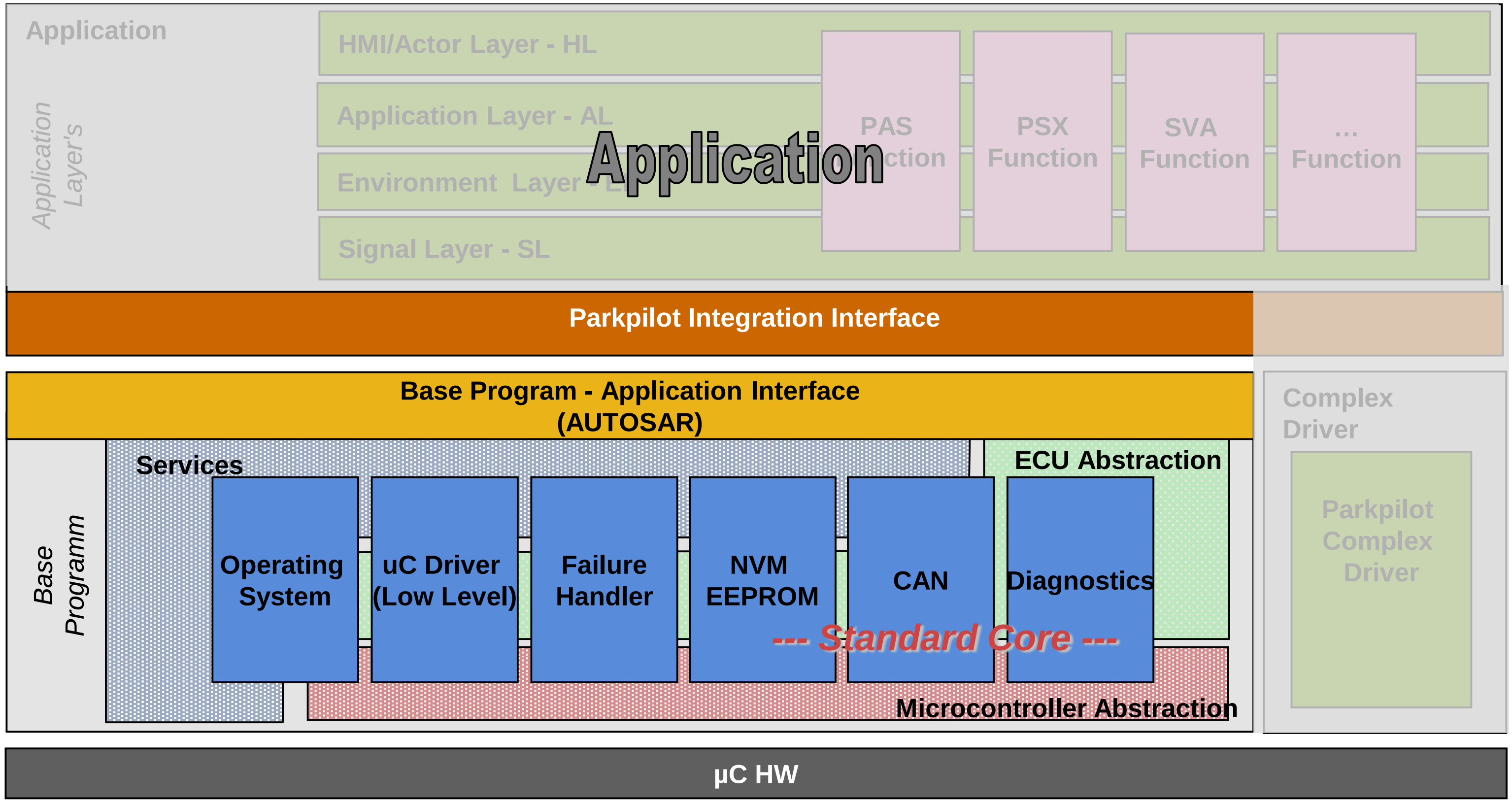
Ultrasonic Sensors
ECU Block Diagram -Example



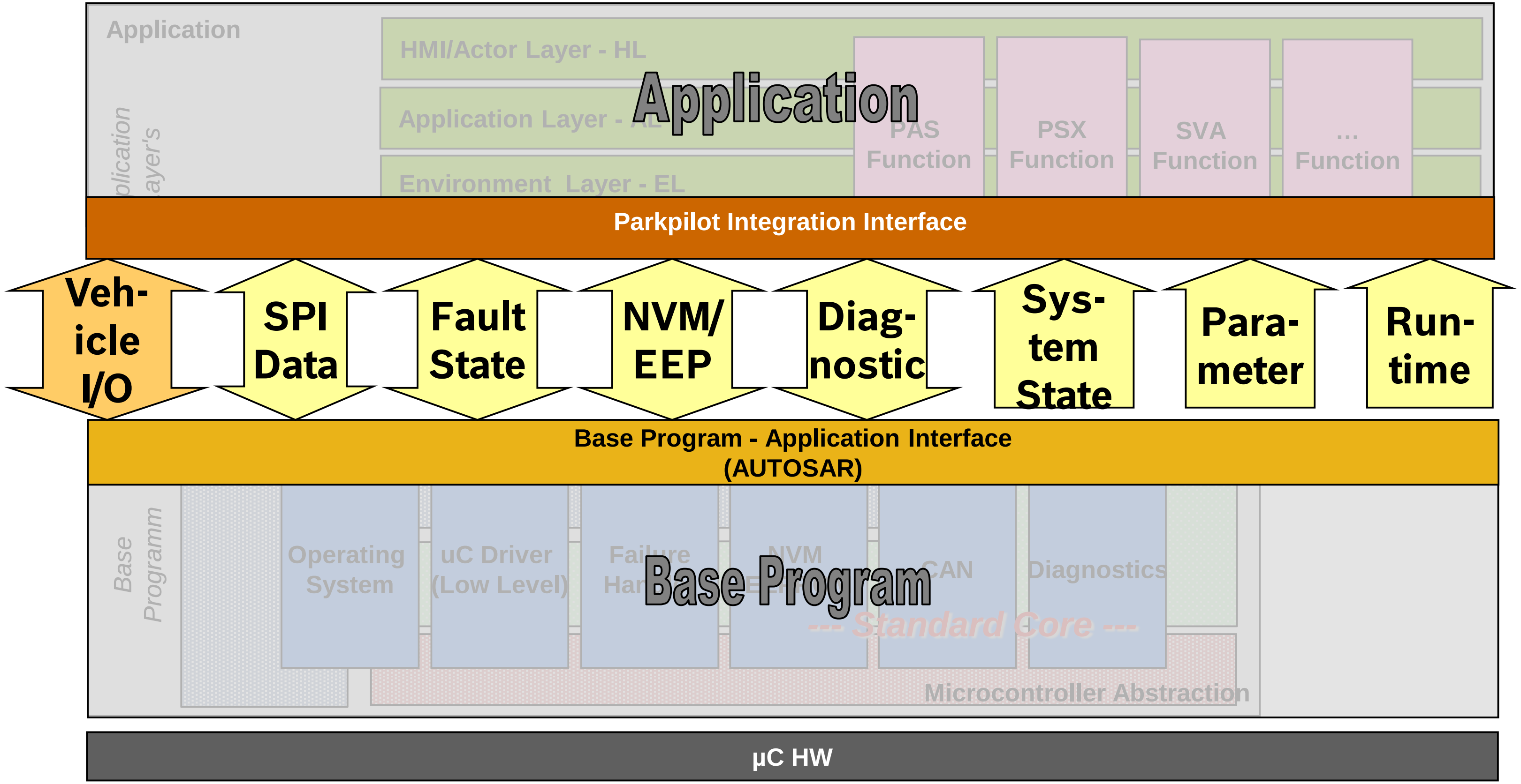
Ultrasonic Sensors

Top level-Base program



Ultrasonic Sensors

Top level –Interface contents



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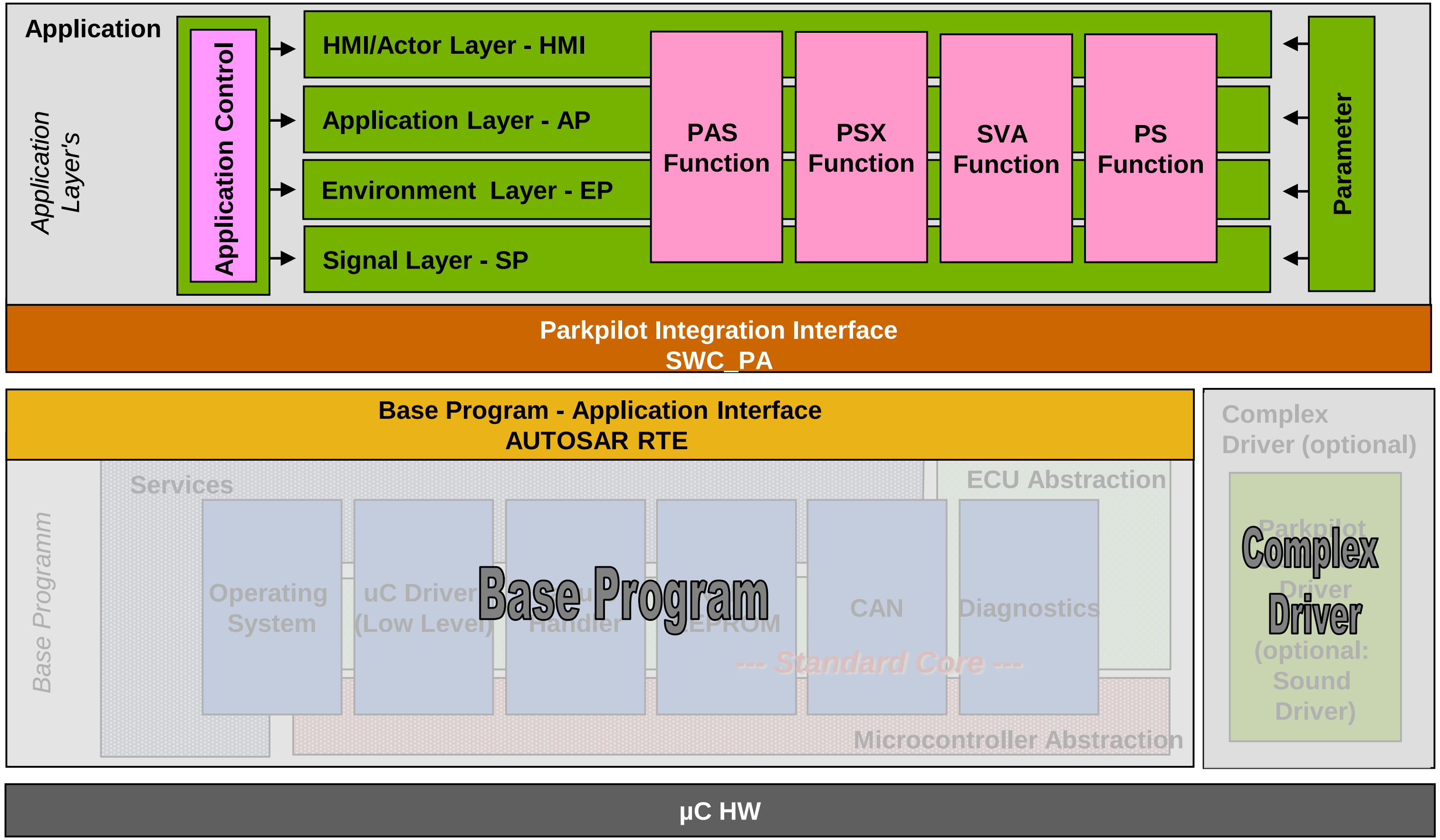
Ultrasonic Sensors
Top level-Application



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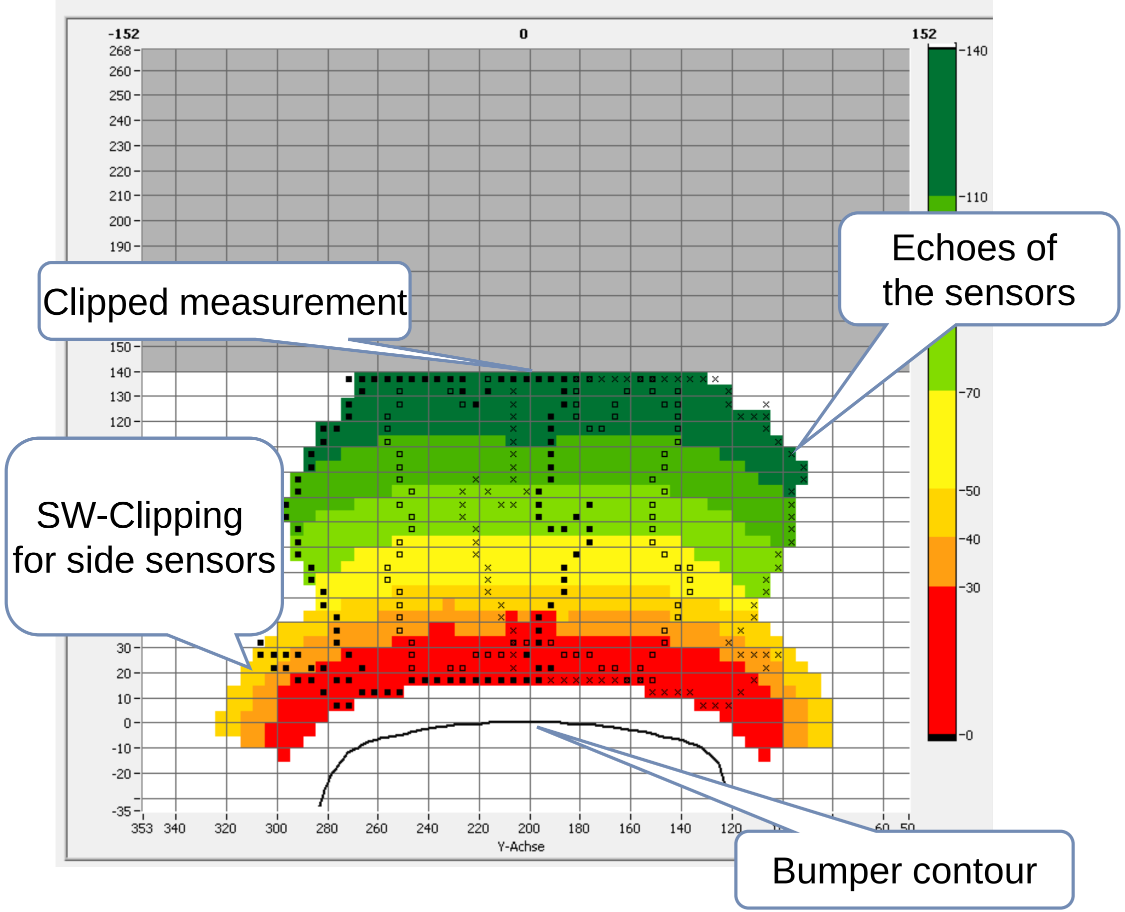
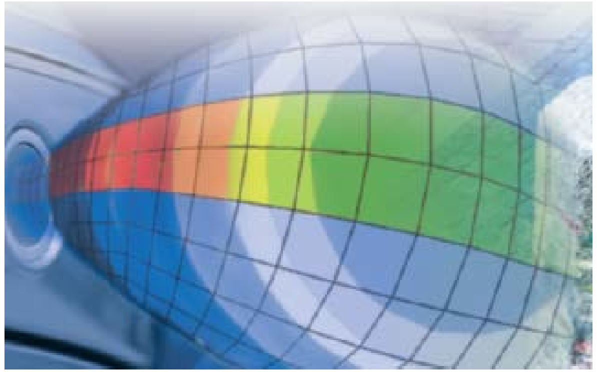
Ultrasonic Sensors
Basic function-Park Pilot





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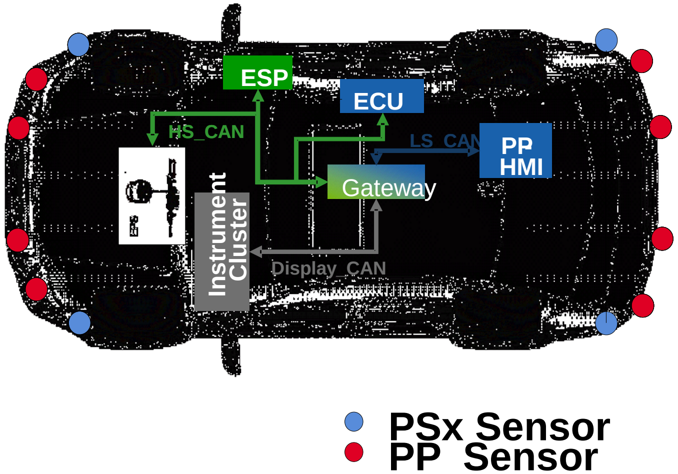
Tracking Algorithms

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.



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.

Ultrasonic Sensors

Tracking Algorithms

Concept:

The tracking algorithms used in ultrasonic driver assistance systems can be performed in one of the following situation:

- Moving car – static obstacle
- Static car – moving obstacle
- Moving car – moving obstacle

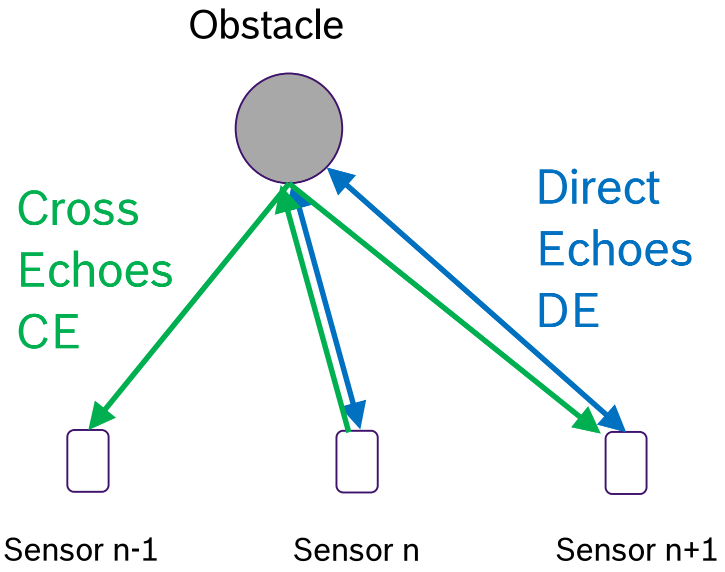
Ultrasonic Sensors
Tracking Algorithms

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.

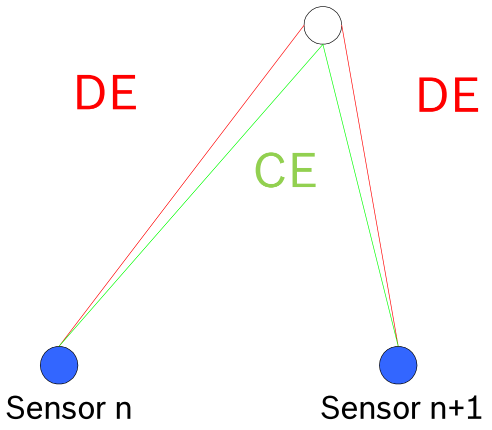


Ultrasonic Sensors
Tracking Algorithms

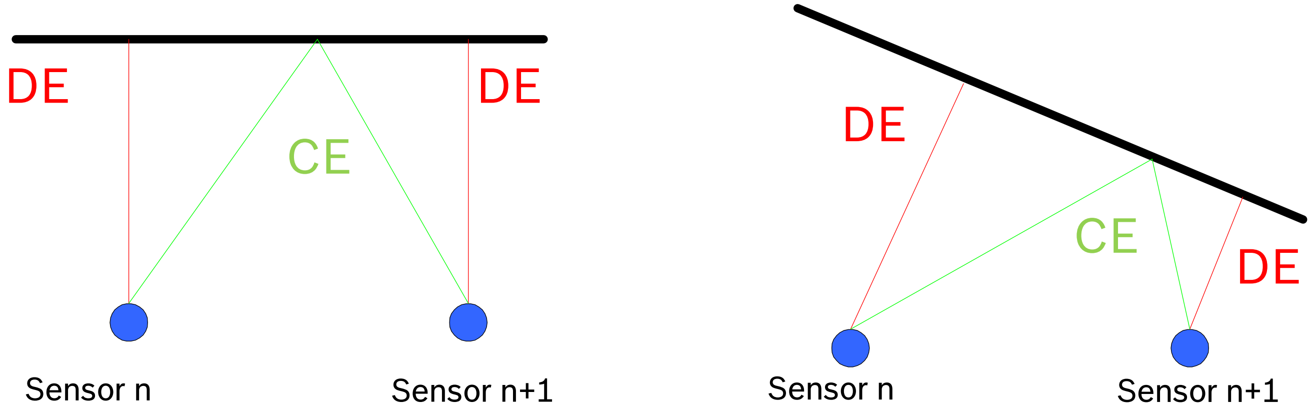
Concept:

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**

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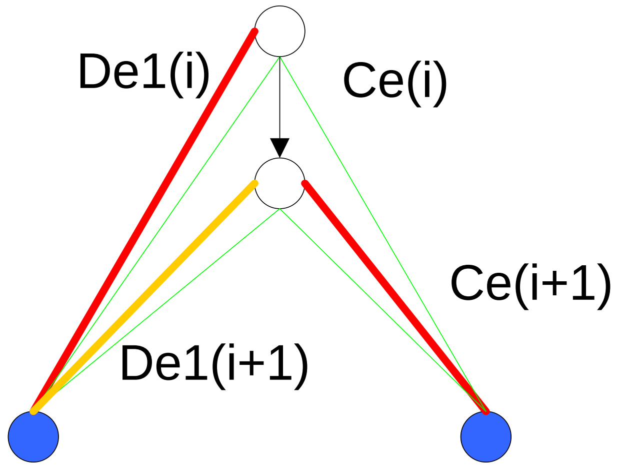
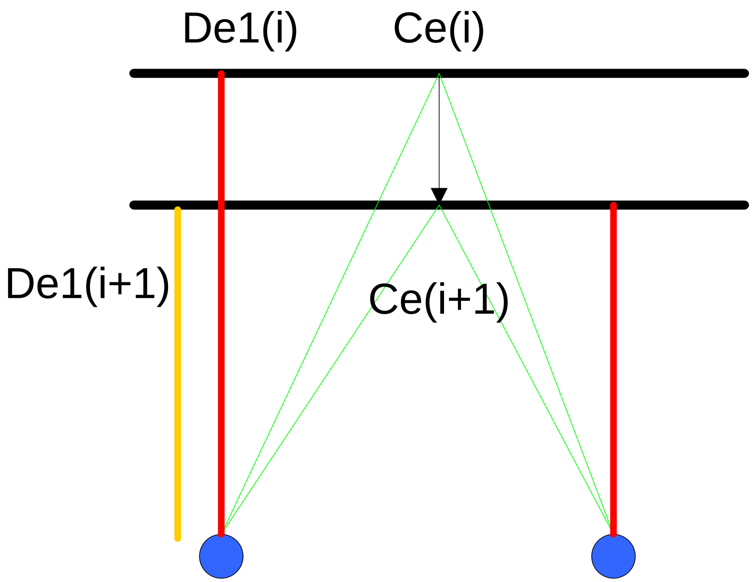
Ultrasonic Sensors
Tracking Algorithms

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**

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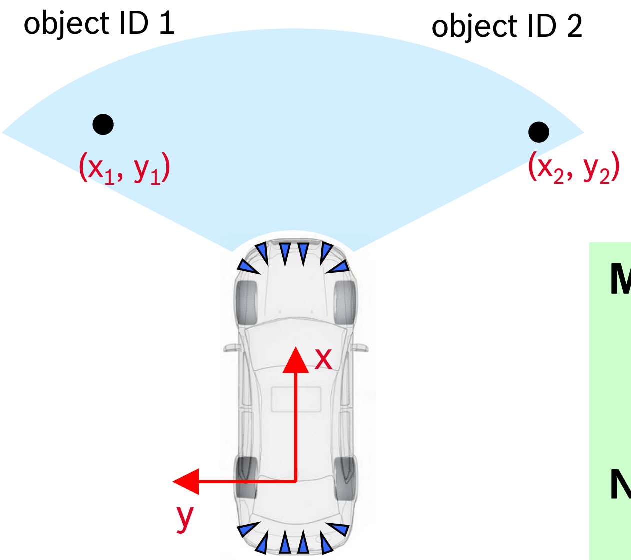
Ultrasonic Sensors
Tracking Algorithms
Concept:

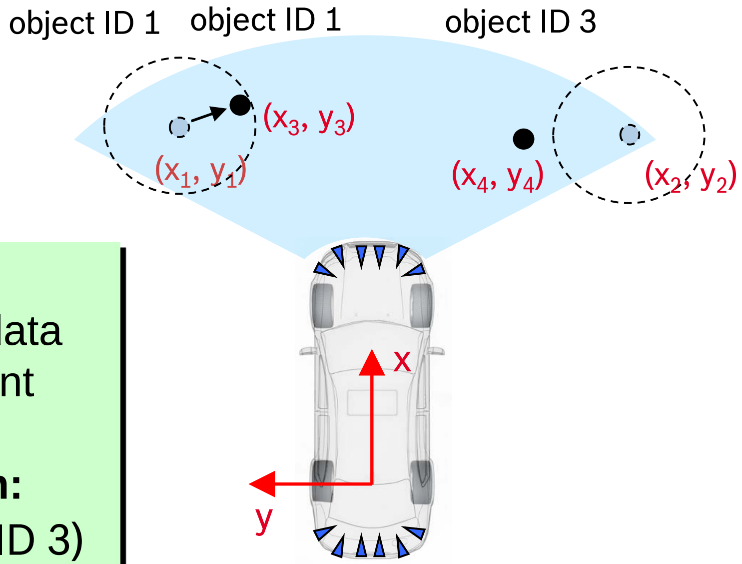
Initial situation

measurement time t_0



Tracking and matching

measurement time t_1



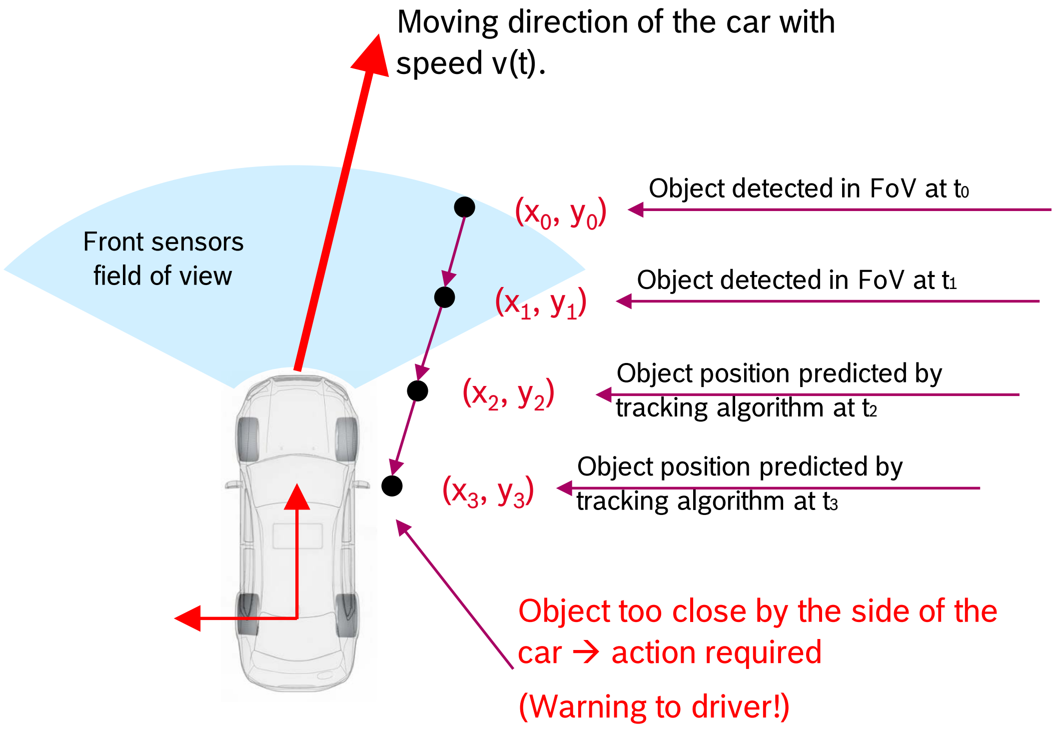
Matching decision:
→ take-over position data of new measurement (object ID 1)

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

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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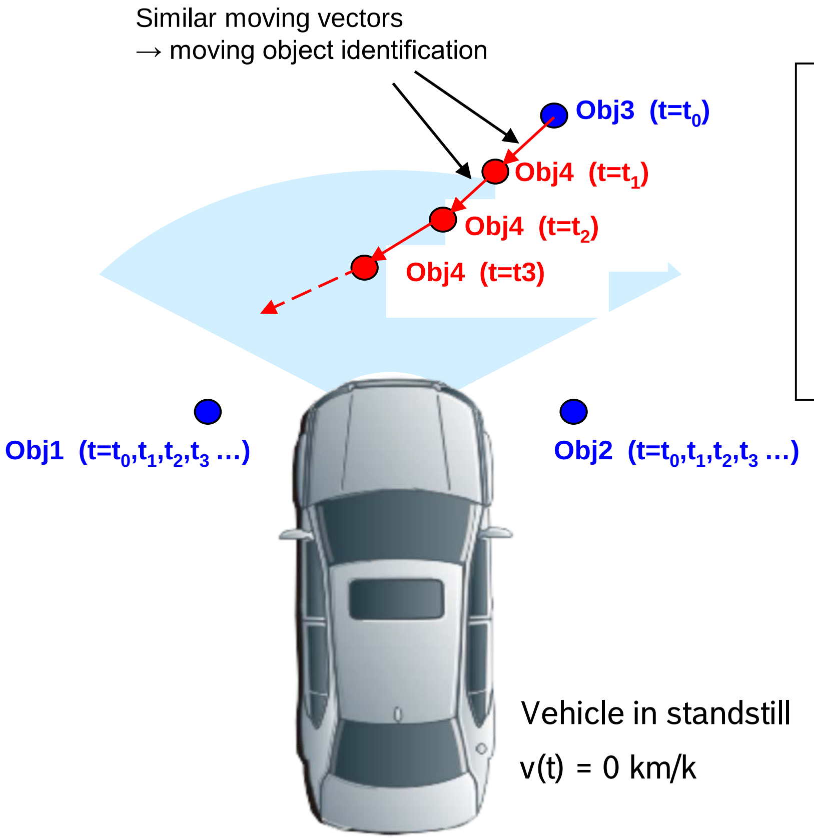
Ultrasonic Sensors

Tracking Algorithms

Tracking of moving obstacles

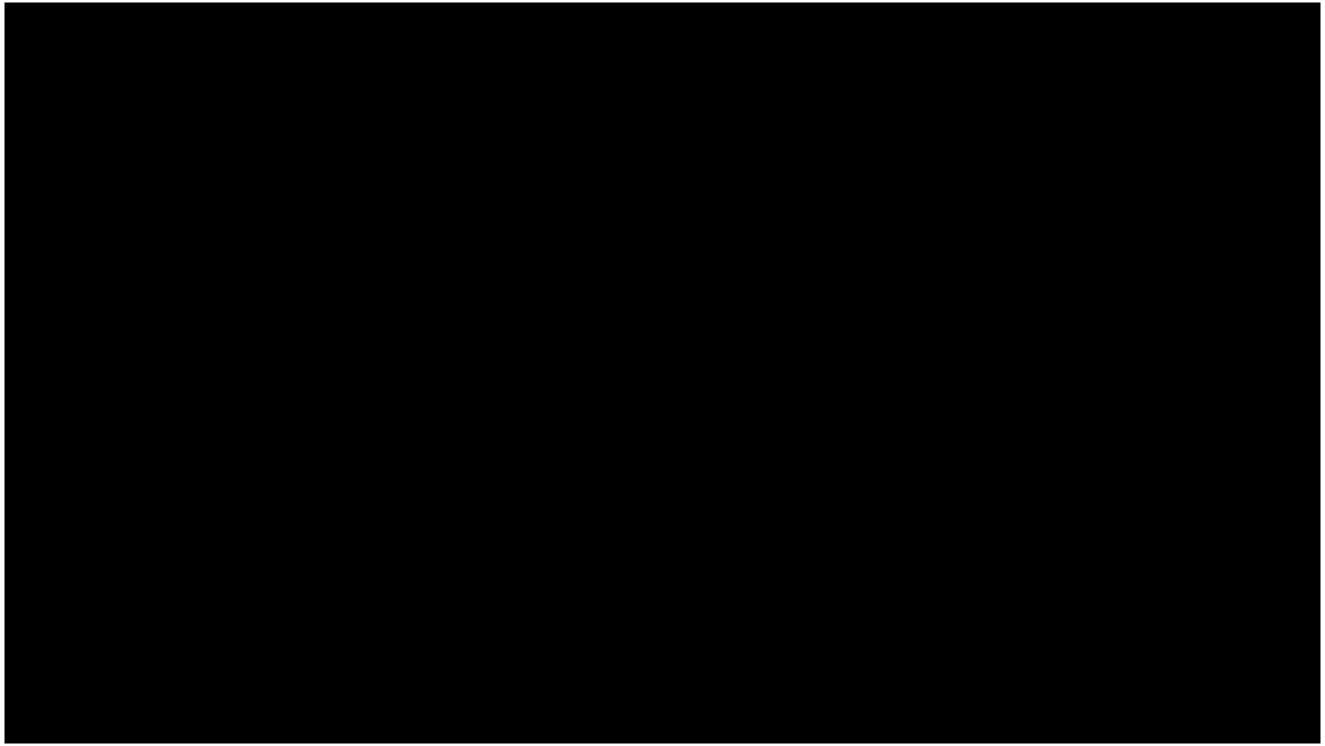


Obj1,2: static objects
Obj3: moving object, but not yet identified
→ short time of presence
Obj4: identified moving object.

RADAR SENSORS

Radar Sensors

Example of Radar System - Predictive Emergency Braking System -

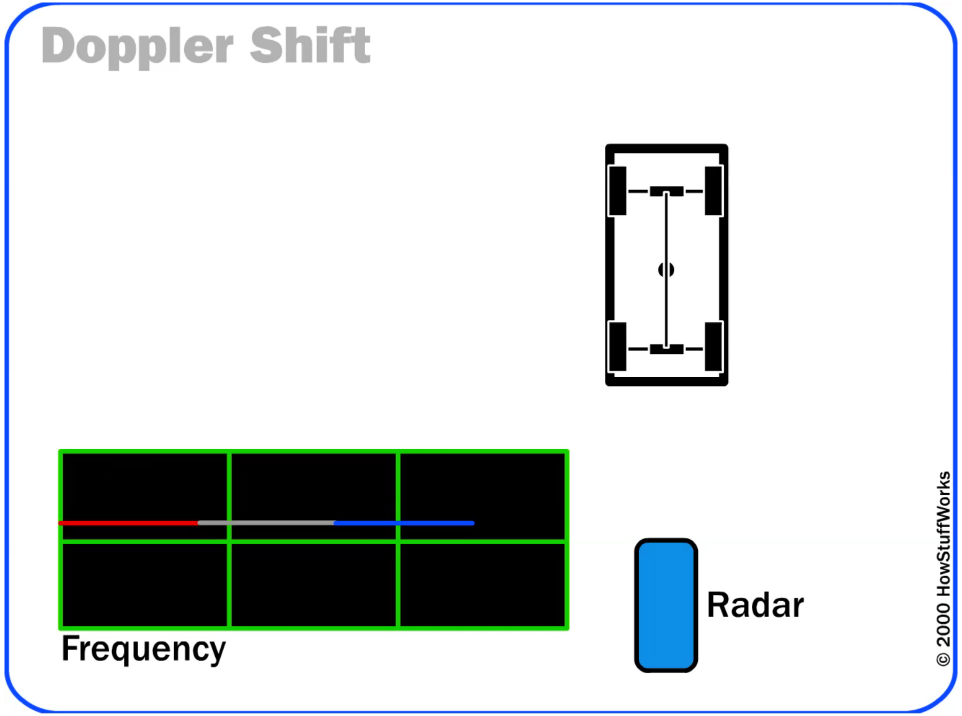


https://www.youtube.com/watch?v=VHR8AeZrlVc

Radar Sensors

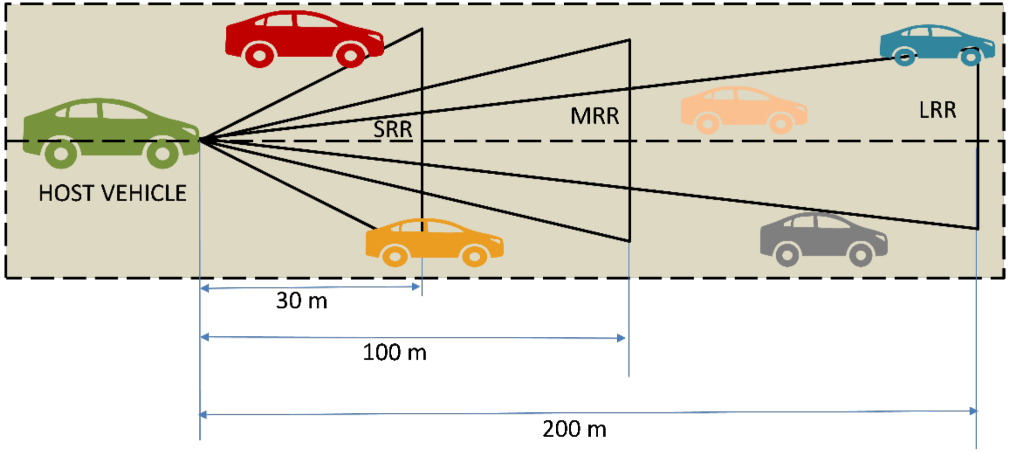
The master of motion measurement

- 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. 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.



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

Radar Sensors

Evolution of Bosch radar sensors

LRR1

SOP: 2000

- Range: up to 150 m
- GaAs Oscillator (Gunn Diode)
- Opening Angle: 8°
- Dimensions (HxWxD) 124 x 91 x 97 mm
- Weight: 600 g

LRR2

SOP: 2004

- Range: up to 200 m
- GaAs Oscillator (Gunn Diode)
- Opening Angle: 16°
- Dimensions (HxWxD) 73 x 70 x 60 mm
- Weight: 300 g

LRR3

SOP: 2009

- Range: up to 250 m
- SiGe MMICs (bare chip)
- Opening Angle: 30°
- Dimensions (HxWxD) 77 x 74 x 58 mm
- Weight: 285 g

MRR Front

SOP: 2013

- Range: up to 160 m
- SiGe MMICs (packaged chip)
- Opening Angle: 45°
- Dimensions (HxWxD) 60 x 70 x 30 mm
- Weight: 200 g

MRR Rear

SOP: 2014

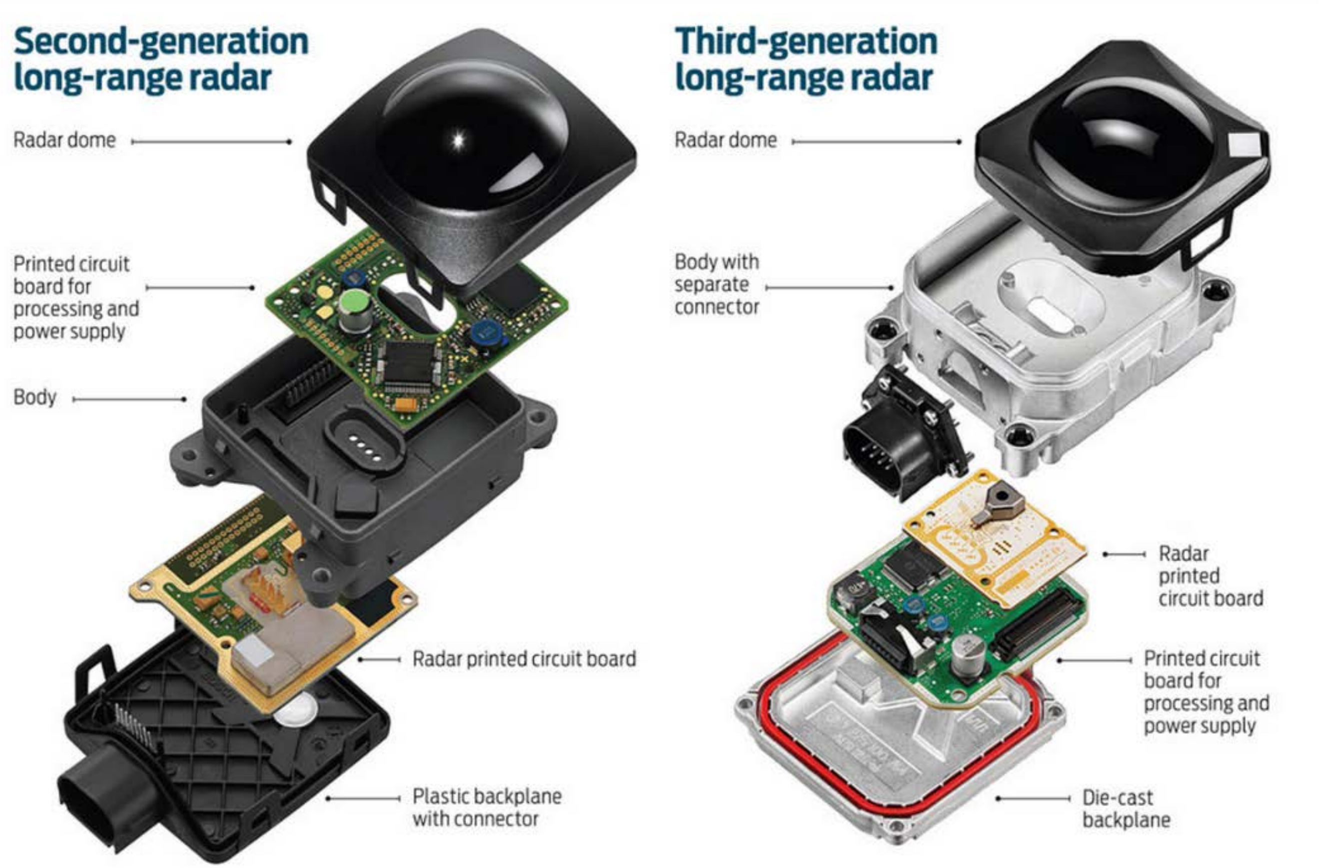
- Range: up to 100 m
- SiGe MMICs (packaged chip)
- Opening Angle: 150°
- Dimensions (HxWxD) 60 x 70 x 30 mm
- Weight: 190 g

BOSCH

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

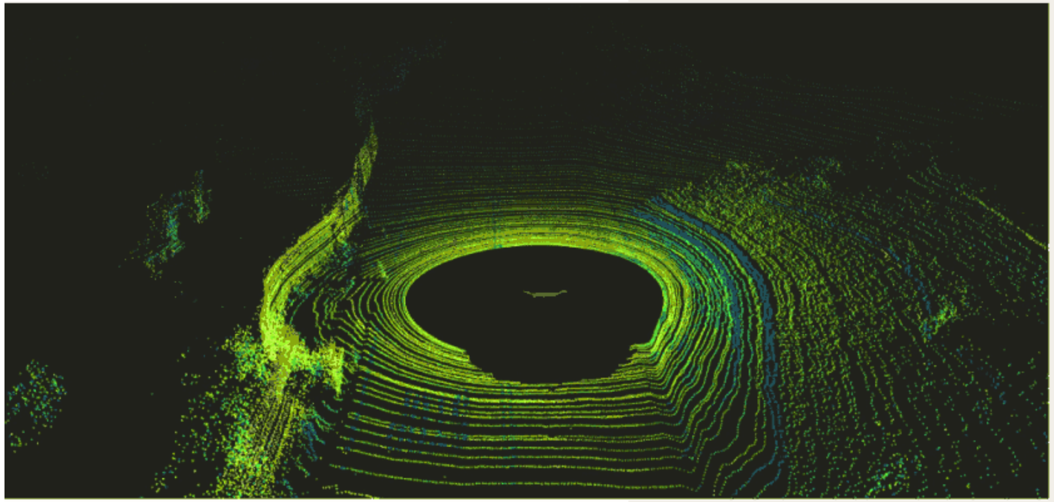
- Adaptive Cruise Control (ACC/ACC Stop&Go)
- Predictive Collision Warning (PCW)
- Emergency Break Assist (EBA)
- Blind Spot Detection (BSD)
- Blind Spot Detection Extended (BSDE)
- Lane Change Assist (LCA)
- Rear cross traffic alert (rCTA)
- Front Cross Traffic Start Prevention (fCT-P)
- Cross Traffic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

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

BOSCH

Lidar Sensors

LIDAR Equation

Number of photons detected in range interval z

Percentage of beam scattered

Transmission thru optics and atmosphere, detector efficiency

$$N(z) = \left(\frac{E_L}{h\nu}\right)\left(\sigma_B n_{mol}(z)\Delta z\right)\left(\frac{A_R}{4\pi \cdot z^2}\right)\left(T_{opt} T_{Atm}^2 \eta\right) + N_B$$

Initial number of photons

Percentage of scattered photons that are collected

Background photons

http://www.ucolick.org/~max/289/Lectures%202016/Lecture%2010%20Laser%20Guide%20Stars/Lecture10.2016.v2.pptx

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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.

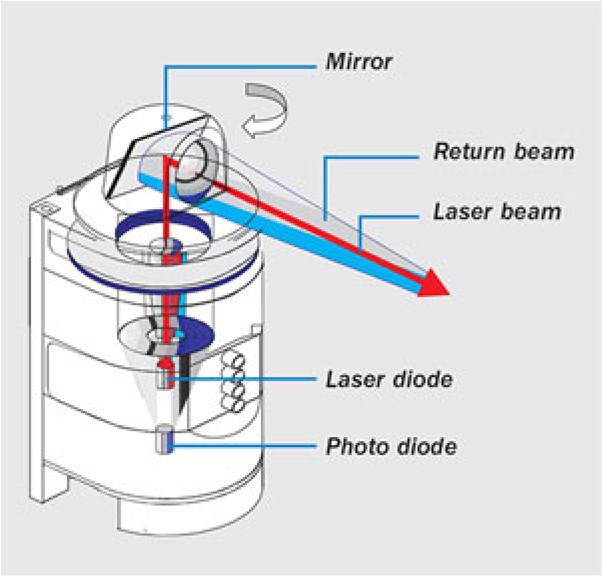

Illustration of LIDAR sensor demonstrating the time of flight principle. *(Courtesy of SICK, Inc.)*

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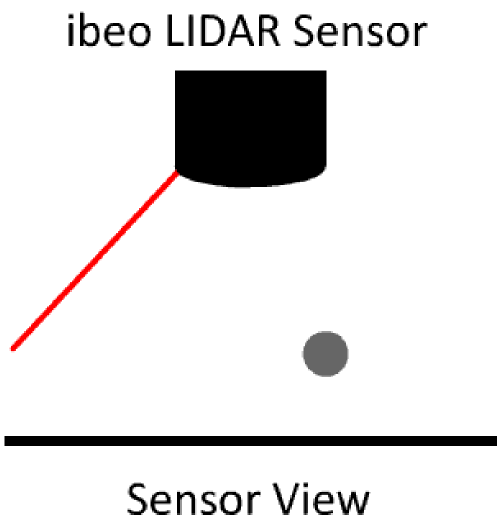
Lidar Sensors

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

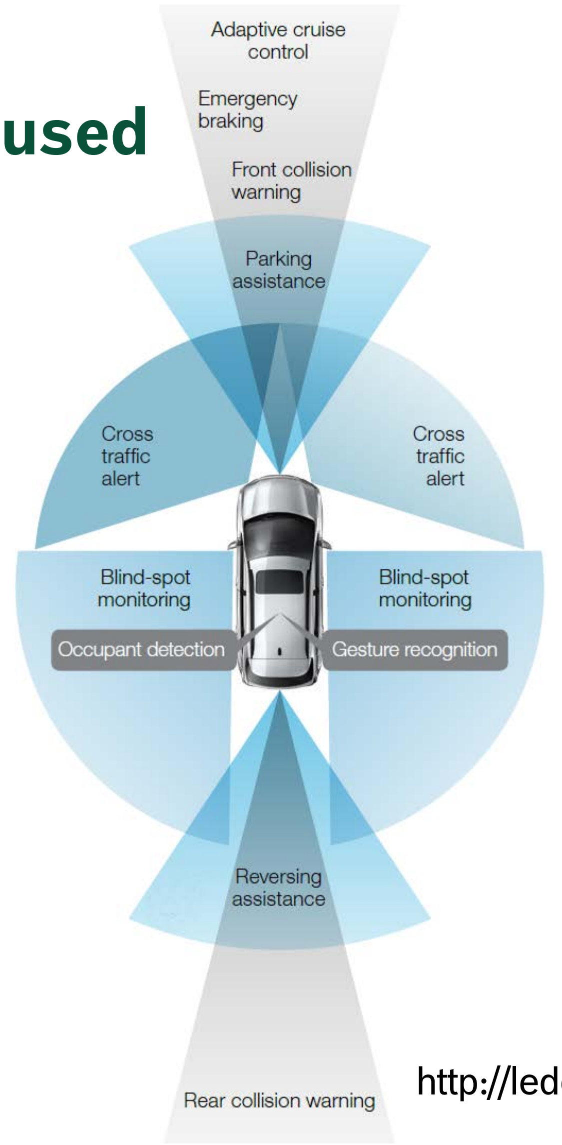


https://www.ibeo-as.com

Lidar Sensors

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

RBRO/ESA2 | 15.10.2018

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THANK YOU FOR YOUR ATTENTION!