TECHNISCHE HOCHSCHULE
OSTWESTFALEN-LIPPE
UNIVERSITY OF
APPLIED SCIENCES
AND ARTS

Autonomous Vehicles

Introduction

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Content

- Basics of the technology
  - LASER and properties
  - Interferences
- Measurement
  - Transmitter and receiver
  - Measurement methods
- Data processing
- System concepts
  - Stationary Systems
  - Scanner
- Applications ...
  - in the vehicle
  - beyond

Technology basics

LIDAR ("Light Detection And Ranging")

- Optical measurement method
- Used to locate and measure in 3D space
- Consists of three components:
  - Radiation source : IR emitter
  - Receiving device : photo-receiver
  - Data processing unit
- "Time-of-Flight" method : Measurement of time between transmit and receive

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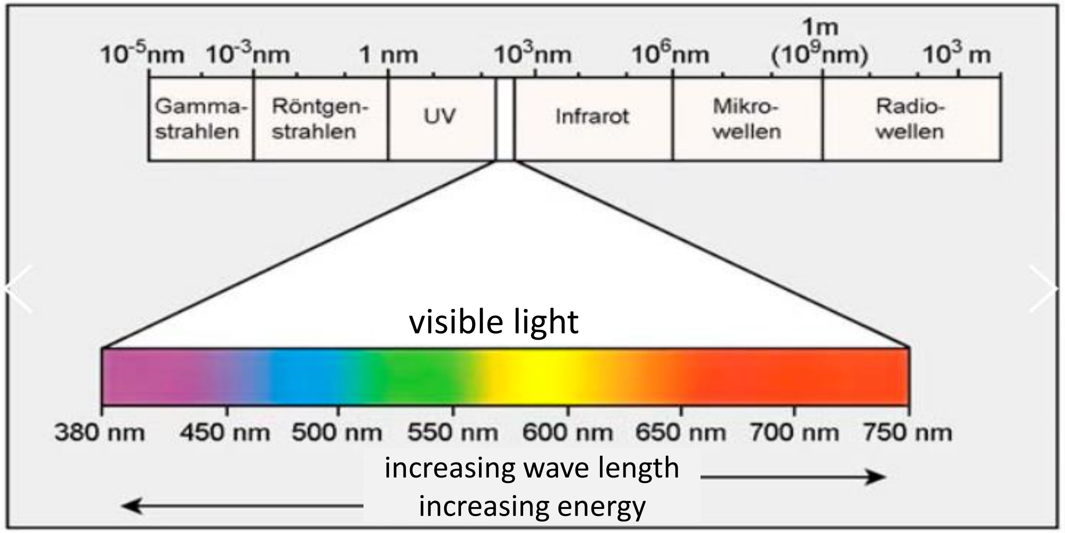
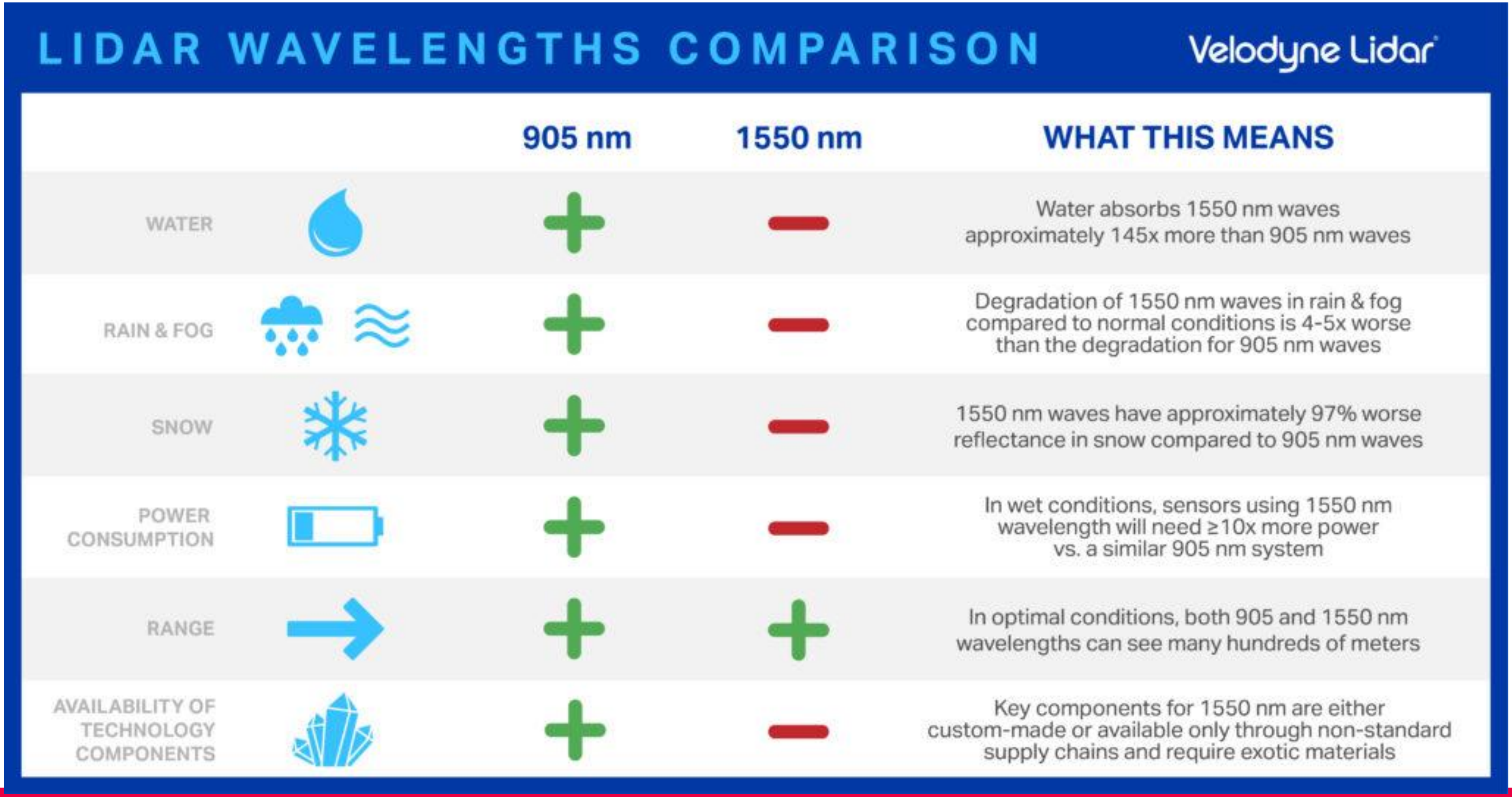
Light as an electromagnetic wave

- LIDAR systems use wavelengths from 850nm to 1µm (infrared range)
- Just outside of visible light
- Measurement of light by photodiode (PIN or avalanche diode)

- Visible range of the electromagnetic spectrum of light : 380nm - 780nm



Comparing wavelenths



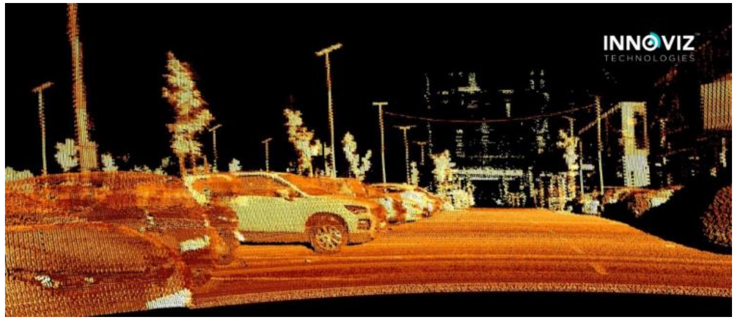
LIDAR WAVELENGTHS COMPARISON — Velodyne Lidar

	905 nm	1550 nm	WHAT THIS MEANS
WATER	+	−	Water absorbs 1550 nm waves approximately 145x more than 905 nm waves
RAIN & FOG	+	−	Degradation of 1550 nm waves in rain & fog compared to normal conditions is 4-5x worse than the degradation for 905 nm waves
SNOW	+	−	1550 nm waves have approximately 97% worse reflectance in snow compared to 905 nm waves
POWER CONSUMPTION	+	−	In wet conditions, sensors using 1550 nm wavelength will need ≥10x more power vs. a similar 905 nm system
RANGE	+	+	In optimal conditions, both 905 and 1550 nm wavelengths can see many hundreds of meters
AVAILABILITY OF TECHNOLOGY COMPONENTS	+	−	Key components for 1550 nm are either custom-made or available only through non-standard supply chains and require exotic materials

Resulting „image“

- What we get is an image of distances + the amount of reflected IR light (depends on sensor)
  - Compare: Camera - image of reflected visible light (color, brightness)

- Also called „point clouds“



Lidar point clouds (distances) visualized to show 3D structure

Image: Innoviz

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Measurement - transmitter and receiver

- Features and characteristics of current transmitters:
  - Power diodes with up to 70 W peak power.
  - Pulse duration approx. 30 ns (should be as short as possible)
  - Powerful driver stage necessary
  - High temperatures at power densities of approx. 35 GW/m^2 → noise

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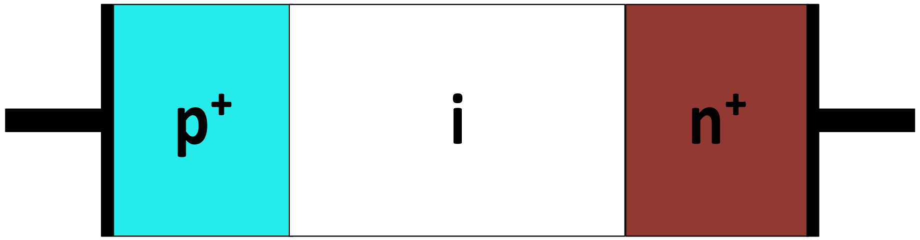
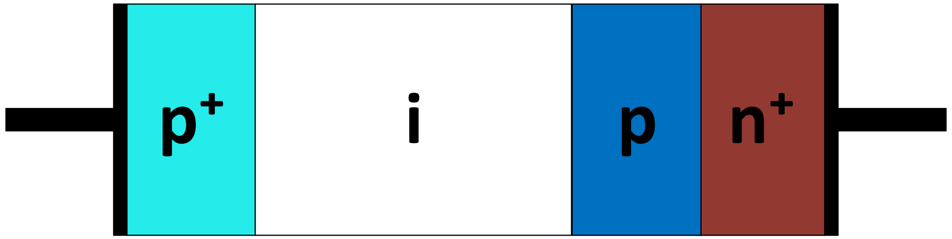
Measurement - transmitter and receiver

- PIN diode
  - Intrinsic layer (intrinsically conductive)
  - Significantly more charge carriers than PN diode
  - Lower noise
  - Good temperature stability



- Avalanche diode
  - Additional doping layer for higher field strength distribution
  - Impact ionization leads to avalanche-like current flow
  - Very sensitive
  - Single photons countable
  - Tend to noise
  - Poor temperature stability



Measurement - transmitter and receiver

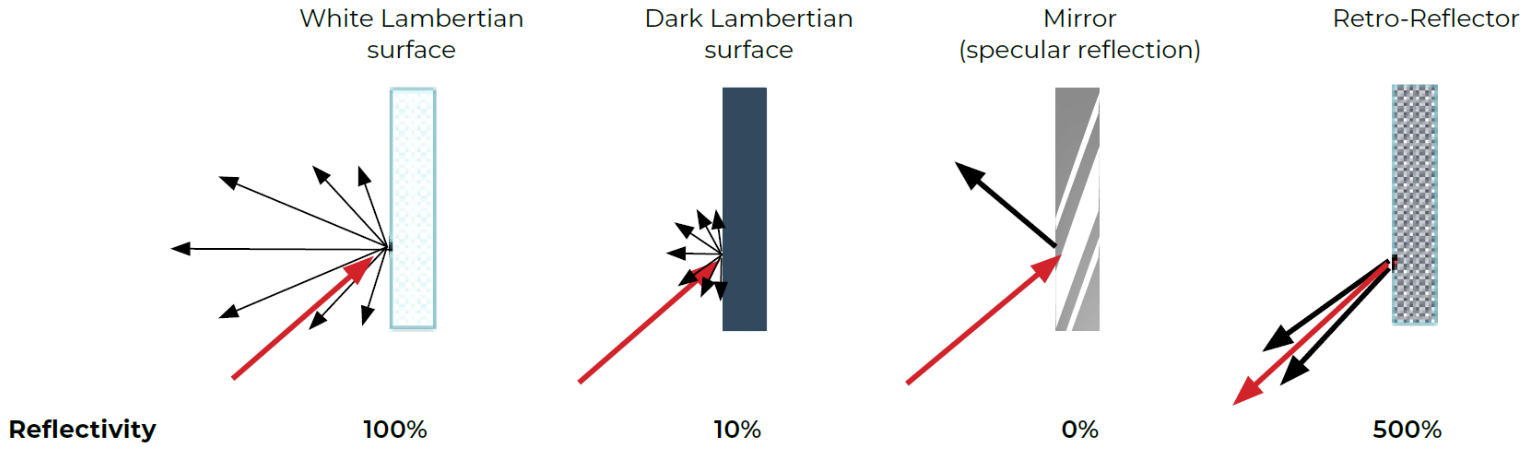
- The receiver also has an optical system that focuses the incoming pulses.
  - Quality and aperture of the optics are important for sensitivity

- Peak values for sensitivity are between -40 dBm and -50 dBm at a wavelength of 850 nm

- Measurement frequencies of up to 100 MHz

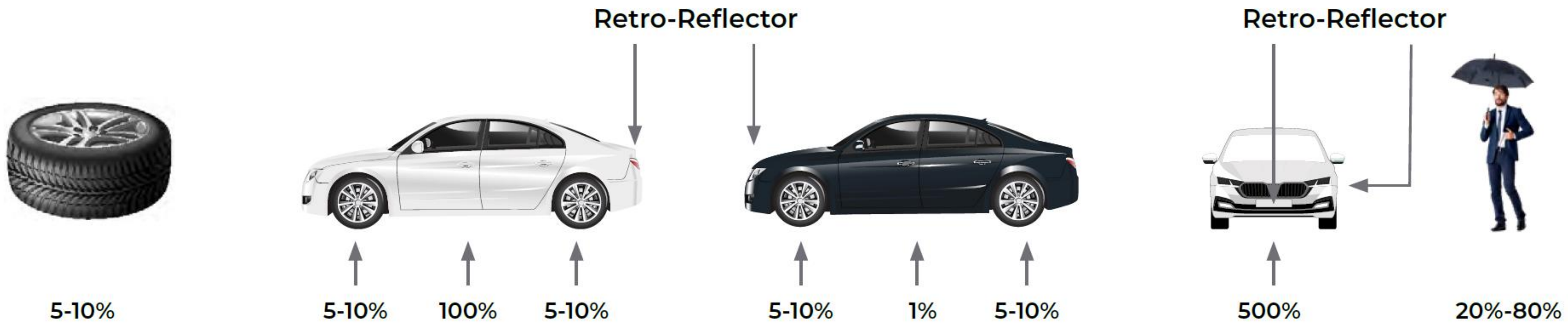
Reflectivity

- 100% reflectivity defined by an white lambertian surface
  - All light scatters back in lambertian manner
  - No absorption
  - Same intensity seen from any angle



Reflectivity

- Real world objects typically consist of multiple surfaces
  - Portions of the object become visible while others still might be invisible
    - Color
    - Material
    - Shape
    - Structure



Measurement - Measurement method

- Timing
  - "Time-of-flight" method: $r = \frac{c_0 \cdot t_{of}}{2}$
  - Range in clear visibility are several hundred meters
- Phase modulation
  - Determining the phase of the received signal and comparing it to the transmitted signal.
  - Phase change proportional to distance
  - Technically more accurate to determine than elapsed time
  - Negative: Atmospheric disturbances have a stronger influence
  - Range up to 150 meters
- Frequency modulation
  - Evaluate frequency shift due to Doppler effect
  - This is proportional to the speed difference between transmitter & receiver
  - Very complex at optical frequencies

Velocity measurement

- Since doppler difficult to use for optical frequencies

→ Differentiation: $v = \dot{r} = \frac{r_2 - r_1}{t_2 - t_1}$; $a = \dot{v} = \frac{v_2 - v_1}{t_2 - t_1}$

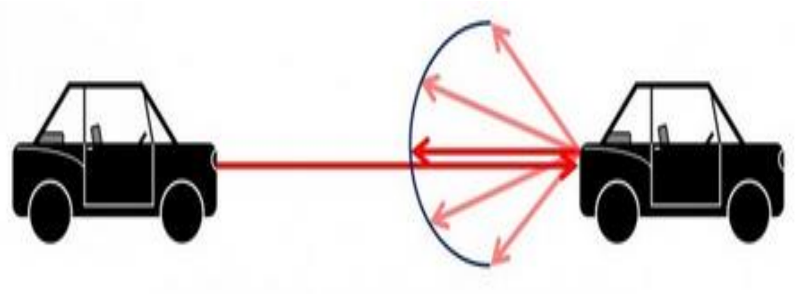
- Calculation of velocity sufficiently accurate
- Calculation of acceleration problematic (error propagation).
- Kalmann filters are used
  - Predictions are compared with measurement to provide stable results

Problems

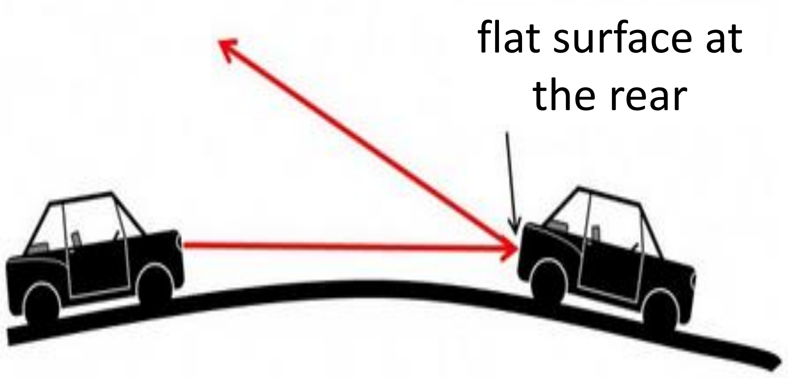
- Diffuse reflection: The backscattering is spherical in a 180°degree, only small portion of the emitted light is received

- Total reflection : The object is invisible to the receiver

- Attenuation of the atmosphere



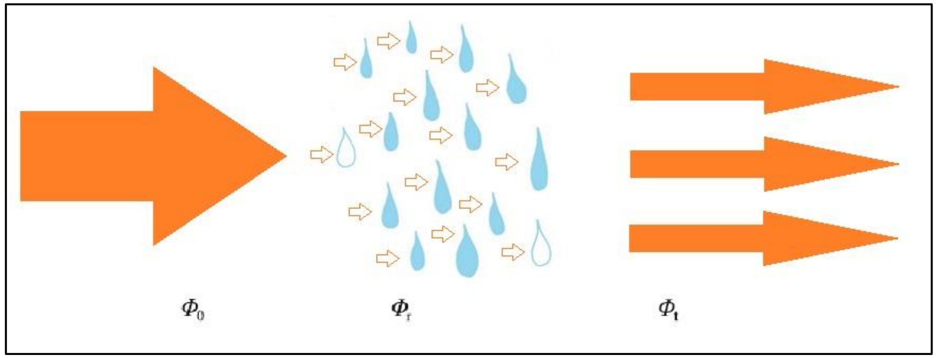
Diffuse reflection

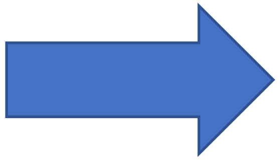


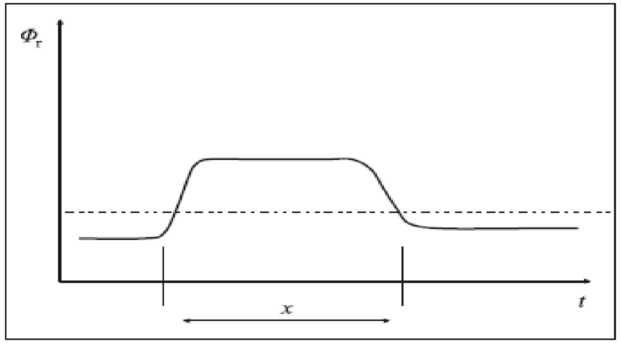
Total reflection

Disturbances due to environmental influences

- Environment and atmosphere (fog, rain, ...)
- Transmitted pulses are reflected and absorbed
- Power of a beam over a distance: $\Phi_0 = \Phi_r + \Phi_a + \Phi_t$
- Pulse response of such interference lower, therefore can be detected and filtered
- Solar radiation and other light sources cause a constant power component







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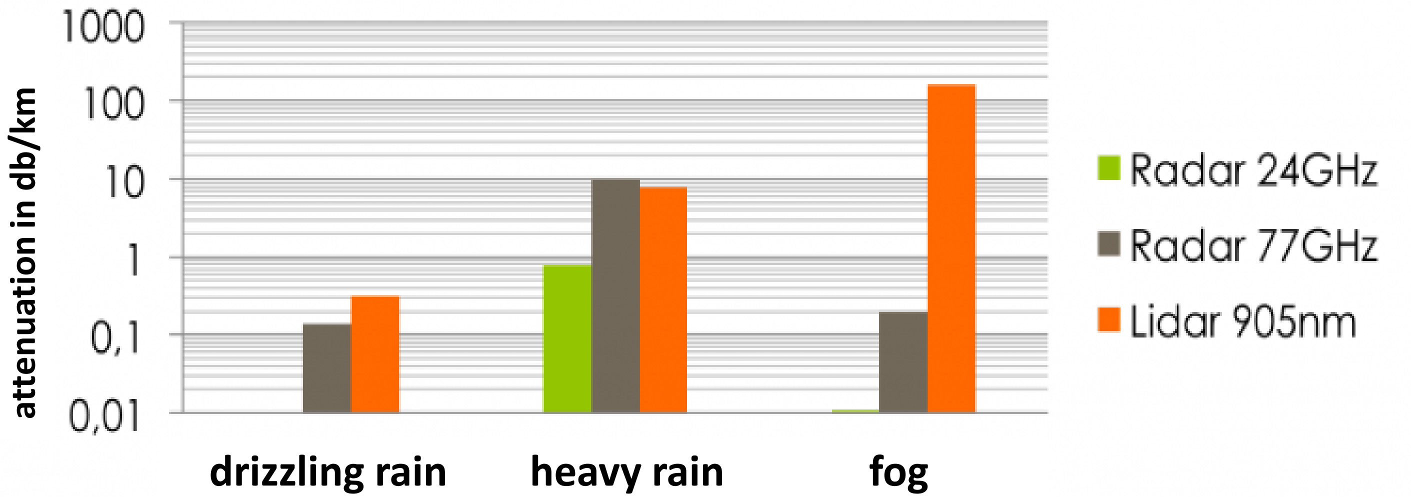
Disturbances due to environmental influences

- Reflection of individual pulses on the water droplets in the air
- Weather-dependent attenuation of the signals



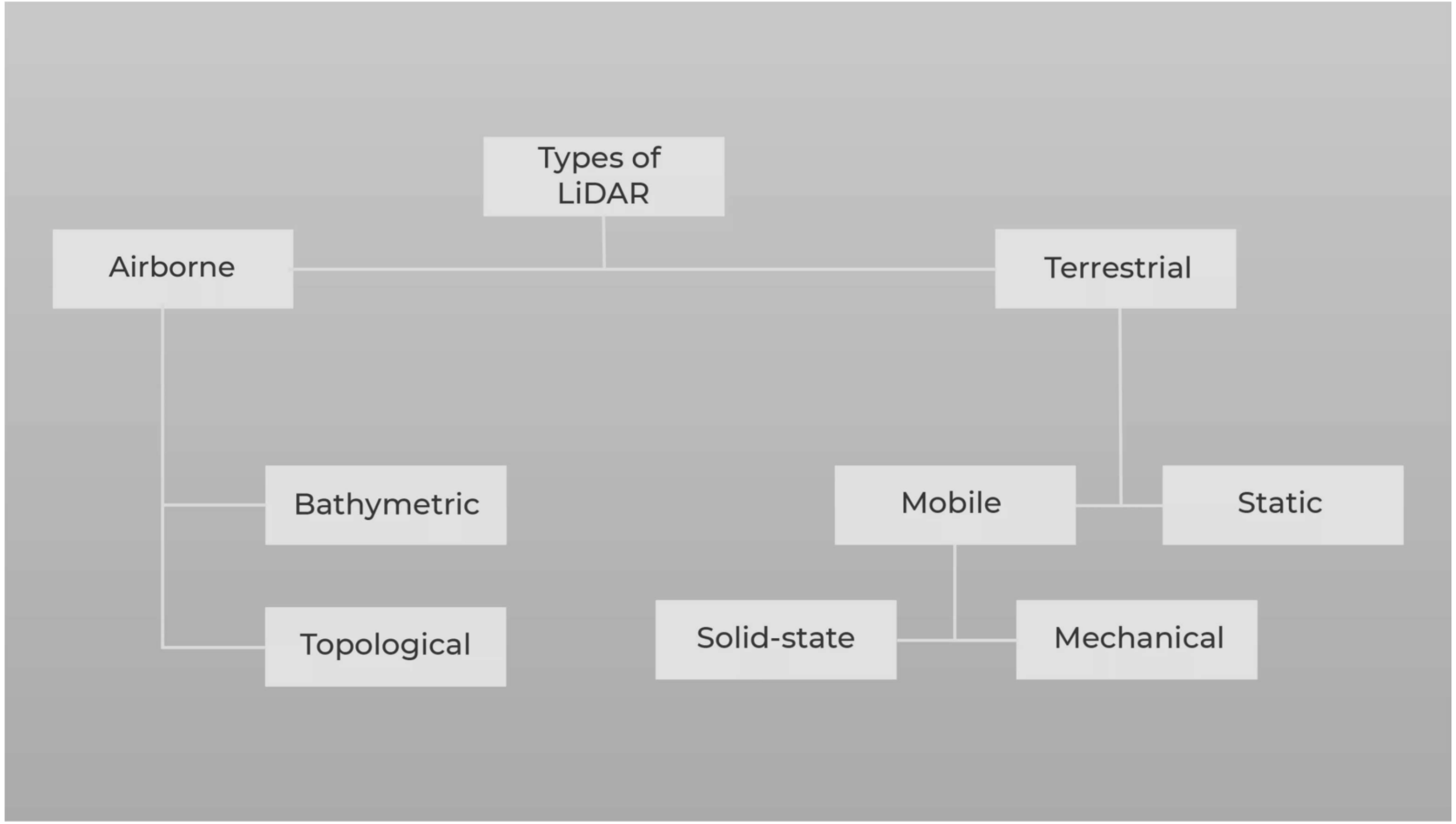
Basics of the technology - Interference

- Some parameters which cannot be influenced:
  - Size of the target object
  - Reflectance
  - Transmission of the prevailing atmosphere

- Parameters which can be influenced:
  - Intensity of the light pulse
  - Sensitivity of the receiver

- Limitations:
  - Eye safety must be guaranteed
  - Reflection angle strongly influences the reception performance

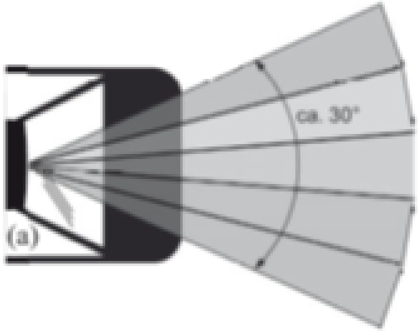
Types of Lidar



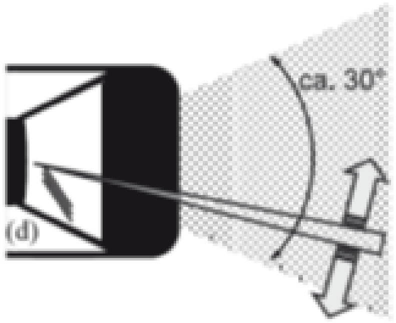
System concepts - stationary systems

- Relatively stationary systems which are permanently installed on the vehicle.

- A larger area can be scanned by 2 types of stationary systems:



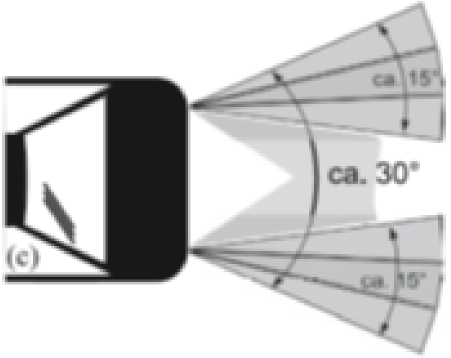
  - Multibeam
    - Several lasers cover in parallel many individual angular sections



  - Sweep
    - Laser is moved in one area and thus this area is scanned

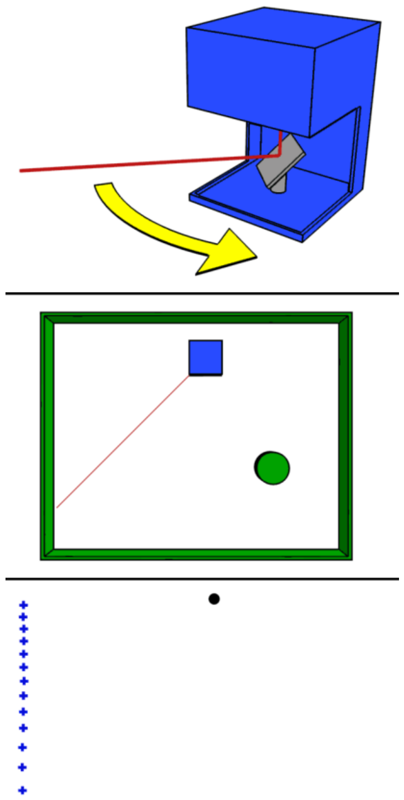
System concepts - stationary systems

- Mixed forms: small number of lasers, which are pivoted at a small angle.
- Pivoting is done with the help of movable mirrors or variable optics
  - MEMS micro mirrors



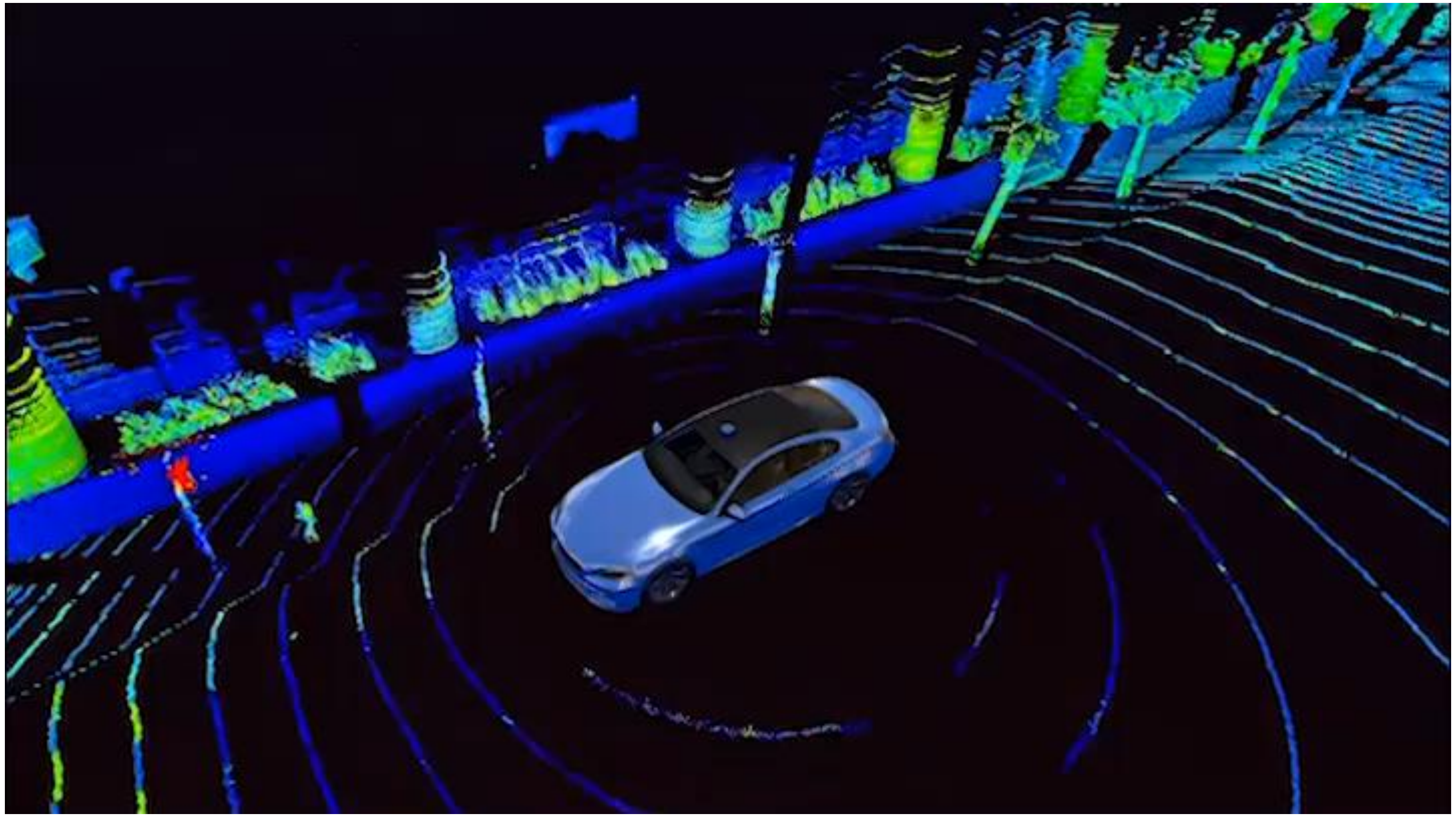
System concepts - Scanner

- Rotating scanners that allow 360° scanning (e.g. the HDL-64E).
  - The speed must be low enough and the optics must provide sufficient surface area
- One or more measuring units
- Enormous amounts of data, which require complex analysis
  - Especially important for autonomous driving



Images: Velodyne, Waymo, wikipedia

360° scanner video



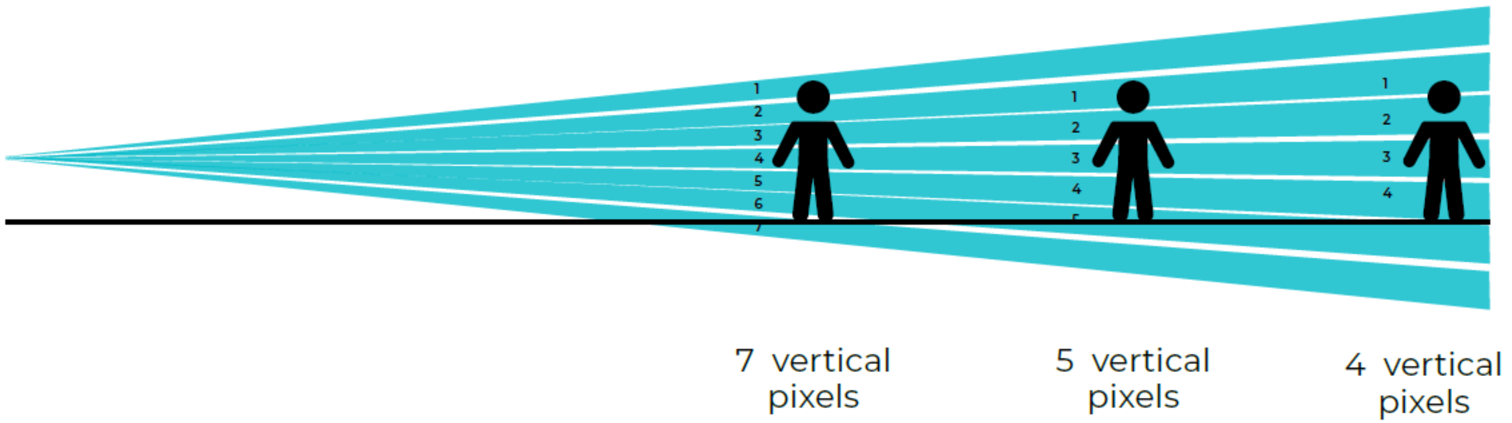
Velodyne Lidar

- https:/[redacted]

Resolution

- In spherical coordinates vertical and horizontal resolution is constant (e.g. 0.1°)

- In cartesian coordinates resolution is not constant, but decreases with increasing distance



Resolution

- Detection of small objects
  - Longe range detection requires high resolution
    - res = 0.05° at 150m distance ➔ 13 cm per pixel

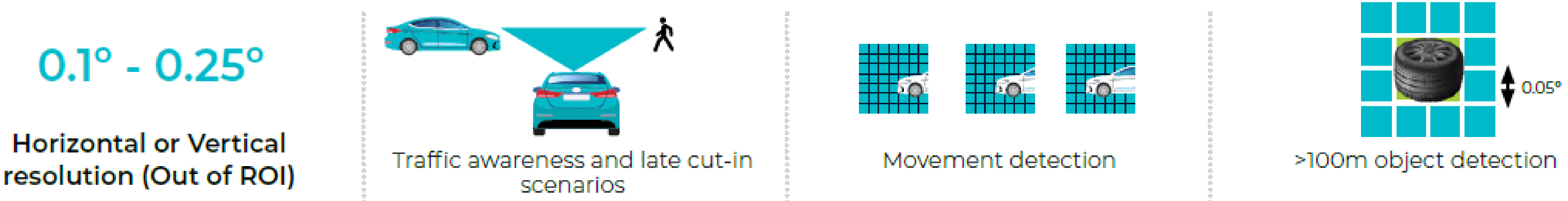


Image: Innoviz

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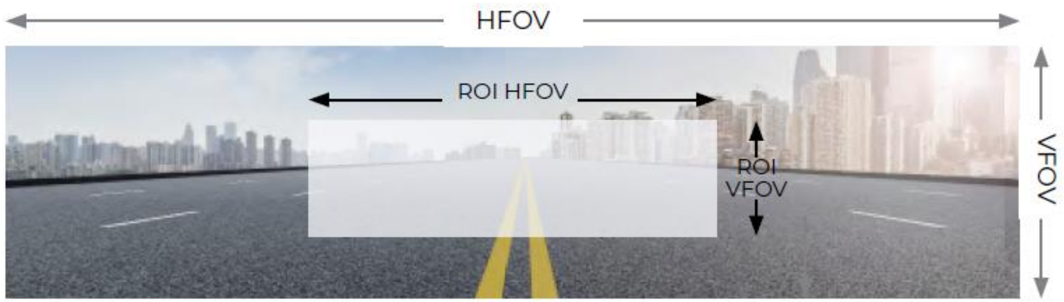
High resolution ROI

- High resolution needed in specific regions of interest (ROI)
  - Center of the field of view (FOV)



Horizontal shift of the ROI

- Range is increased by dynamically focusing laser energy within the ROI, while reducing energy provided to regions outside the ROI.
- Regions of interest can be configured independently and can be located anywhere in the FOV.

Image: Innoviz

Pros and Cons

Advantages

- High accuracy in 4 dimensions
  - 3D position + speed
- Exact contours of objects
- High resolution
- Light independent

Disadvantages

- Laser scanner still have large design
- Mechanically moving parts

→ MEMS systems to be preferred

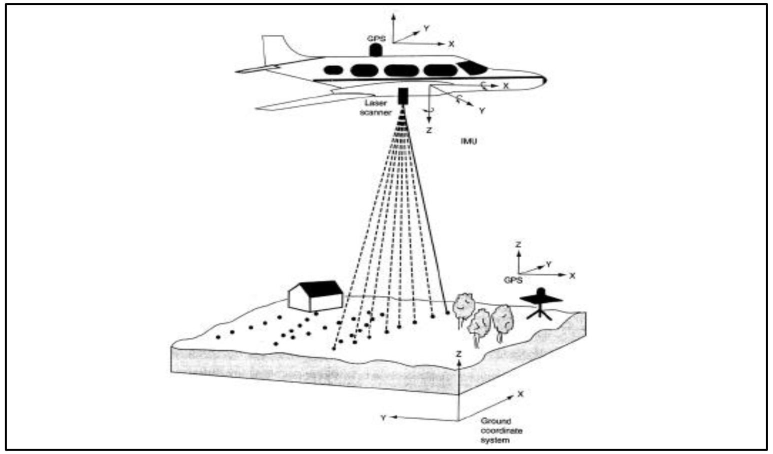
- Optical systems difficult to integrate
- Prone to dirt

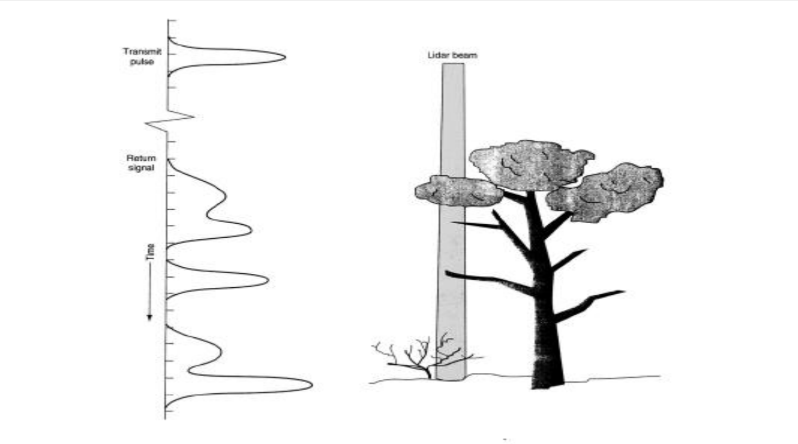
Vehicle applications

- Use in a vehicle for distance measurement (e.g. ACC)
  - Directional sensors that use pulses to measure the distance to the vehicle ahead
  - Placement of the sensors is not important, anywhere in the front possible
    - But: in a visible area
- Suitable filters can be used to inform the driver if the sensor is dirty
  - Advantage: no detailed image (like that of a camera) necessary
- Visibility measurement with the help of the specific absorption coefficient is possible
  - Warning of the driver in case of fog or automatic control of the headlights is possible
- Day/night detection

Further applications

- LIDAR systems in aircraft for mapping and surveying
- With the help of GPS and IMU data, entire areas are scanned
- Specific reflectance of an object can be evaluated to determine the exact height and shape of the object





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Further videos

- [Innoviz Webinar: LiDAR vs Camera (with Mati Shani & Dr. Raja Giryes) – YouTube]
- [Innoviz discusses LiDAR for Autonomous Driving with MIT Students - YouTube]