Automotive Sensors

LiDAR

Automotive Intelligence Lab.

HANYANG UNIVERSITY

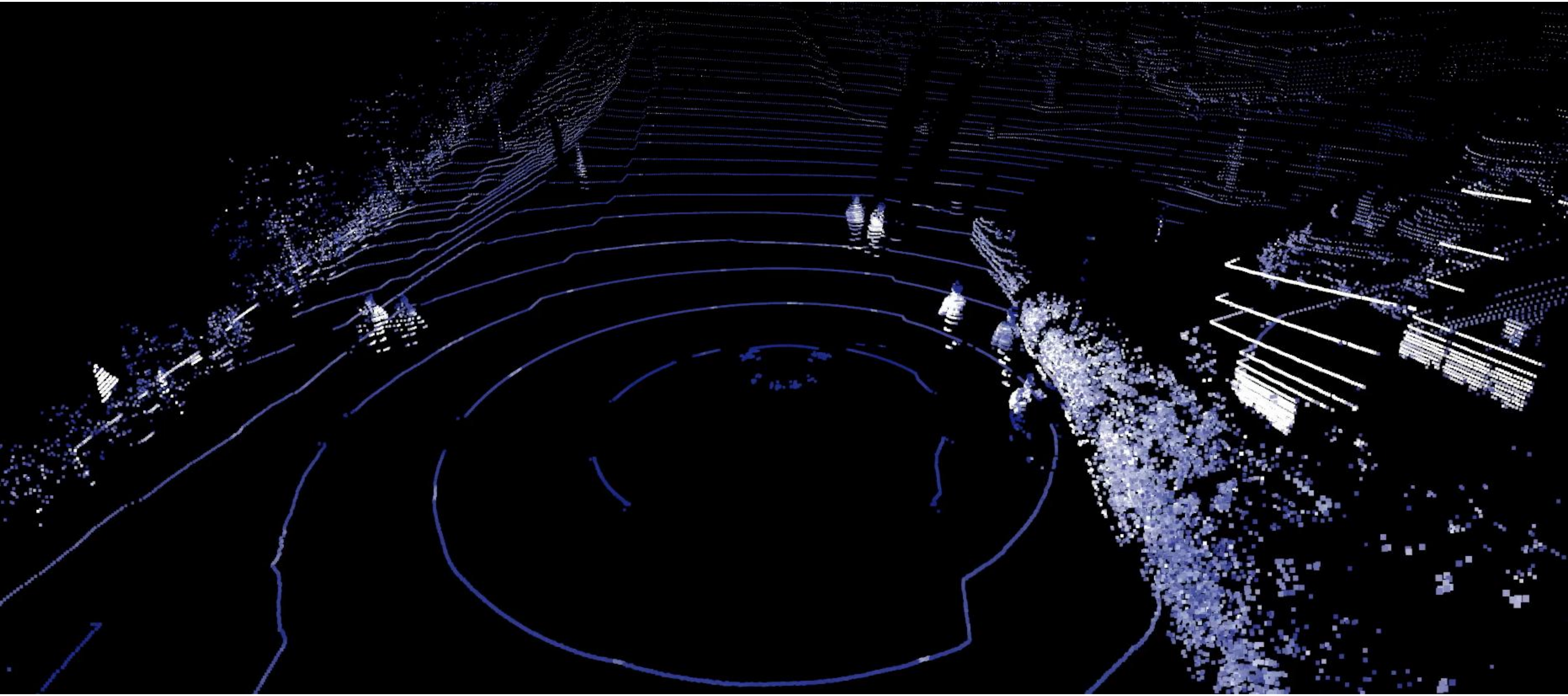
AI LAB Automotive Intelligence

Contents

- Principle of LiDAR
- LiDAR based perception system

Principle of LiDAR

LiDAR (Light Detection And Ranging)



LiDARs on Autonomous Cars

Classification Criteria of LiDAR sensors

ㄴ 회전방식 스캔

Distance measurement

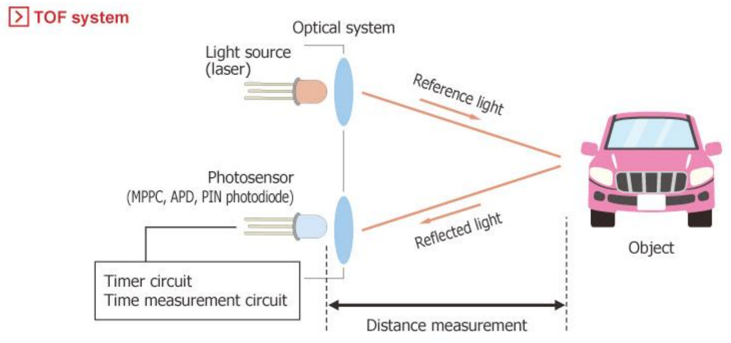
3D Beam-scanning technology

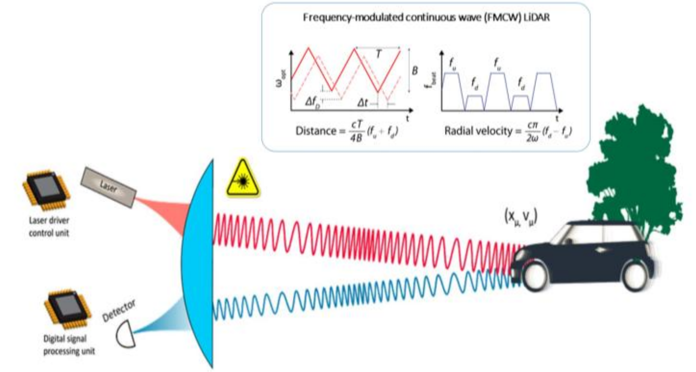
Wavelength of light

1. Distance measurement

LiDAR

- Direct Detection
  - ToF
- Indirect Detection
  - FMCW
  - AMCW
  - Etc.
    - Trigonometry
    - Phase



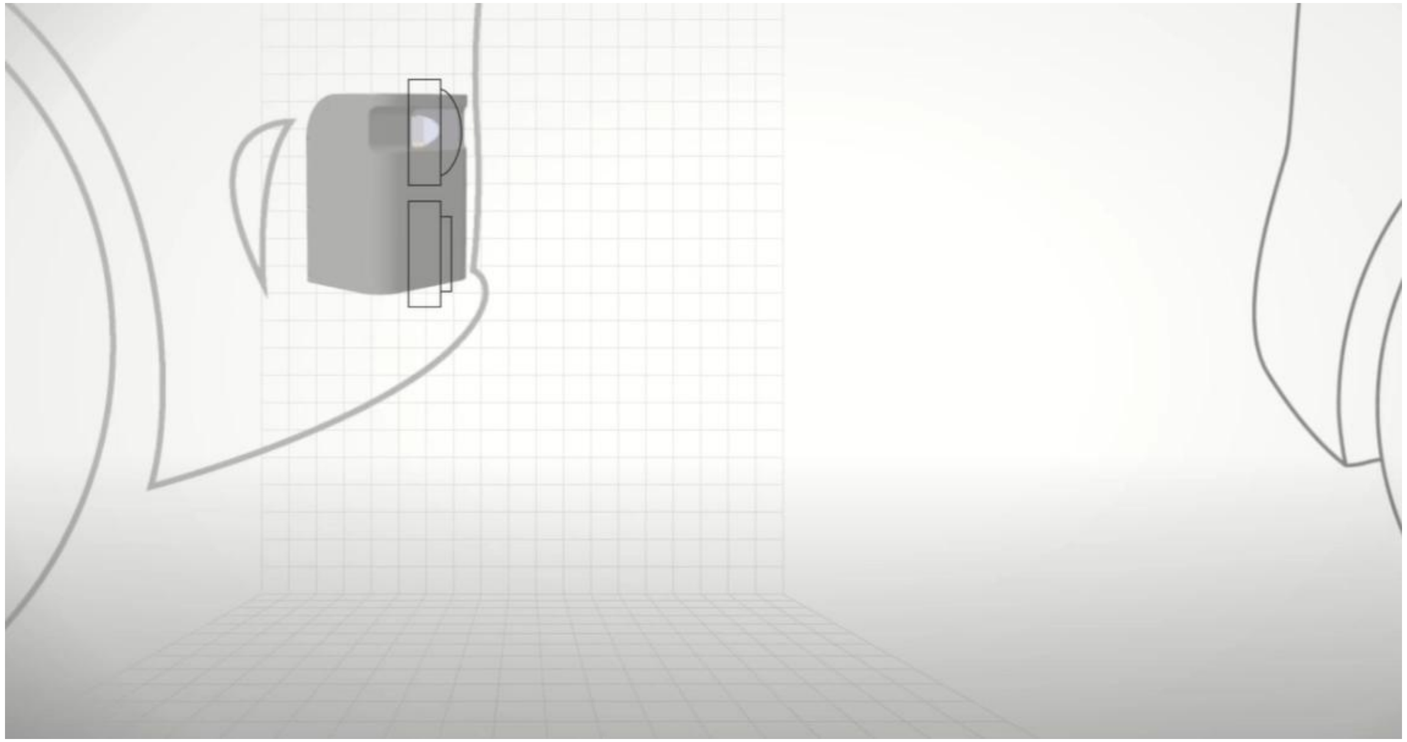


- ToF: Time of Flight
- FMCW: Frequency Modulation Continuous Wave
- AMCW: Amplitude Modulation Continuous Wave

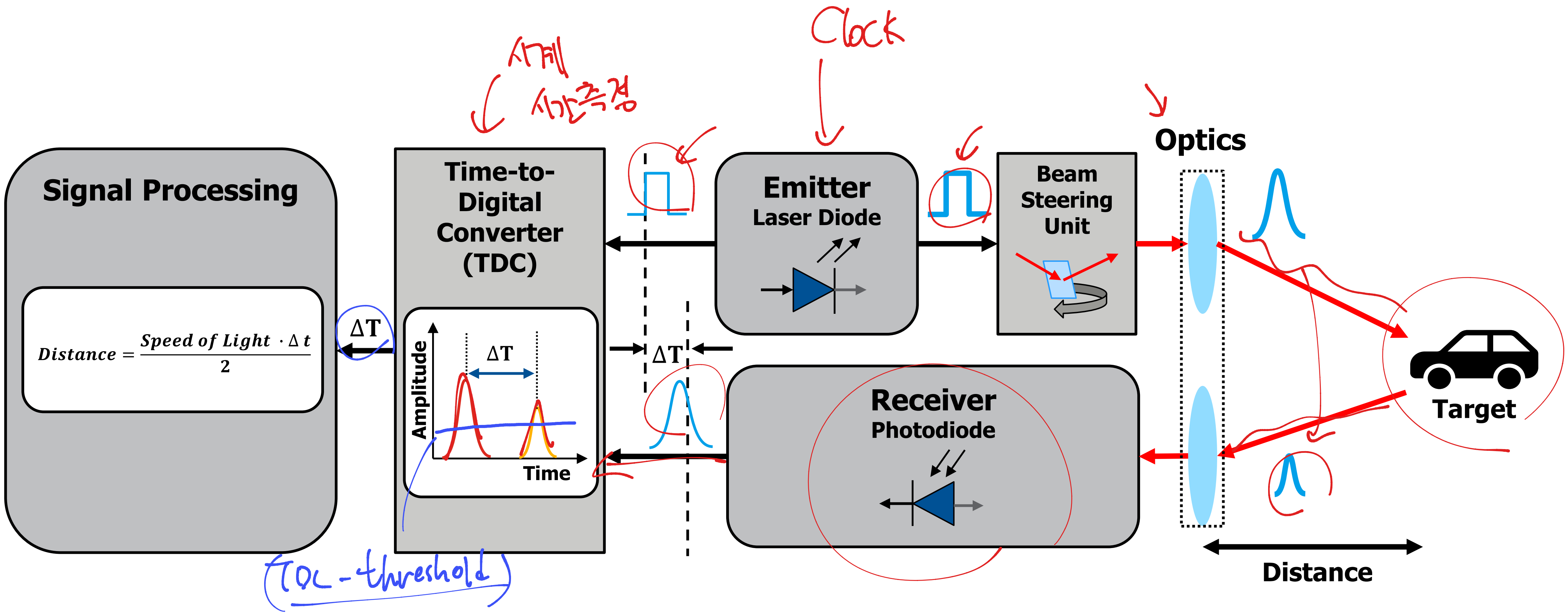
ToF (Time of Flight)

Time of Flight (ToF)

- Emitting a laser pulse on a surface
- Catching the echo pulse to the LiDAR pulse source with sensors
- Measuring the time laser travelled using TDC (time to digital converter) threshold
- $\text{Distance} = \dfrac{\text{Speed of light} \times \text{Time elapsed}}{2}$



LIDAR structure



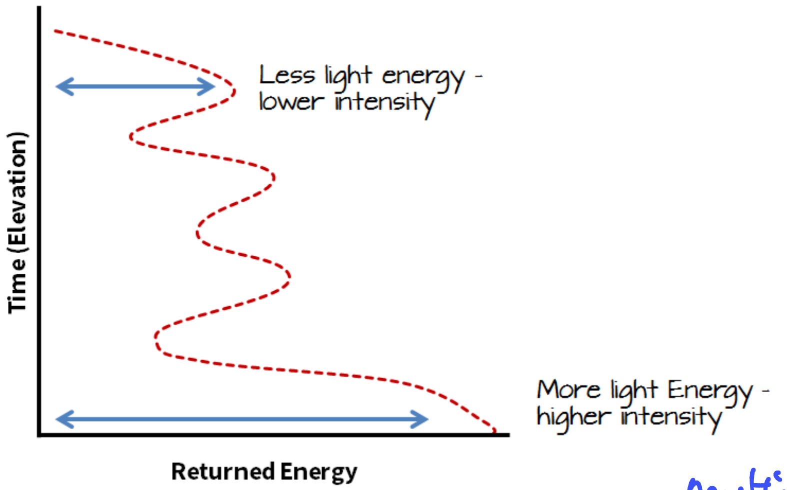
Reflectivity and Intensity (반사강도)

Reflectivity

- The strength of the reflectivity varies with the composition of the surface object reflecting the return.
- $\boxed{\text{reflectivity} = \alpha \cdot \text{intensity} \cdot \text{range}^2,\ (\alpha \text{ is constant})}$ → $\text{intensity} = \dfrac{\text{reflectivity}}{\alpha \cdot \text{range}^2}$

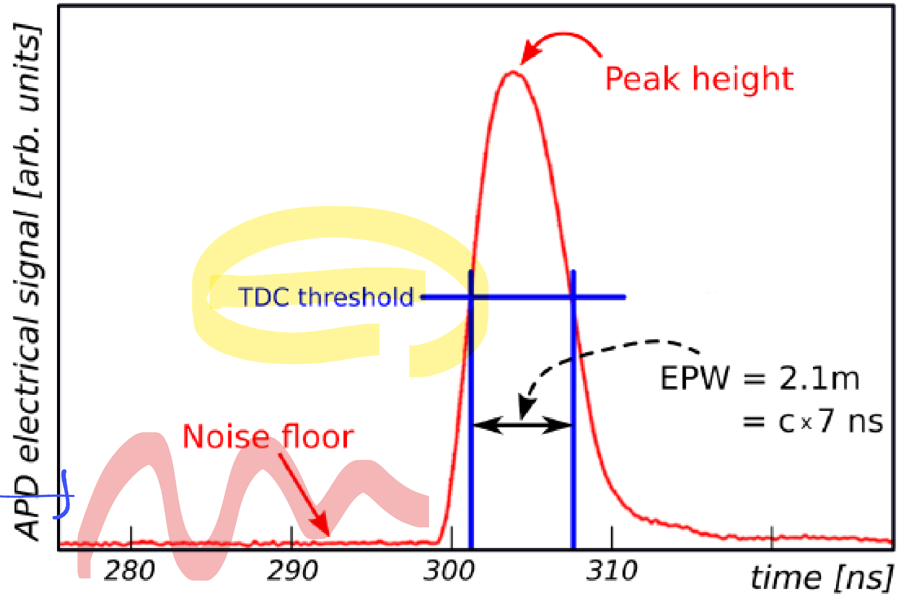
Intensity

- Measurement collected for every point of the return strength of the laser pulse.
- Based in part on the reflectivity of the object hit by the laser pulse.



민감하면 노이즈↑

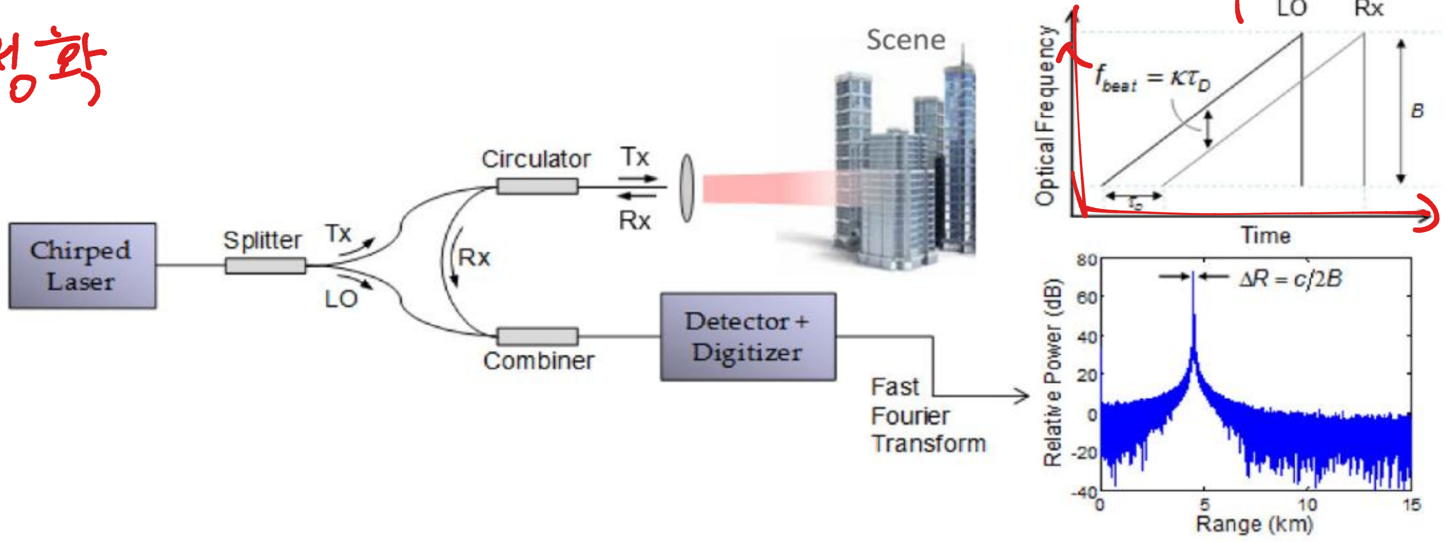
multipass, 다의광



FMCW (Frequency-Modulated Continuous Wave)

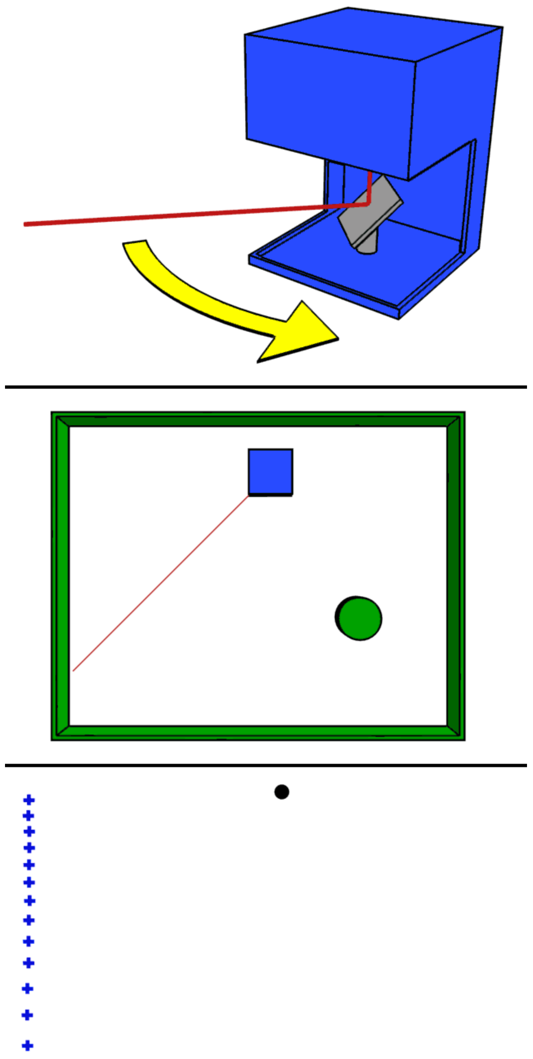
- **FMCW lidar sends out a constant stream of light ("continuous-wave") and changes the frequency of that light at regular intervals ("frequency-modulated").**
  - This allows us to both determine the location of objects and precisely measure their velocity using the Doppler effect.
- **Due to coherent detection, FMCW technology can achieve**
  - high resolution without requiring fast electronics or high optical power,
  - immune to direct sun light and interference from other LiDAR transmitters.

비쌈. but 정확

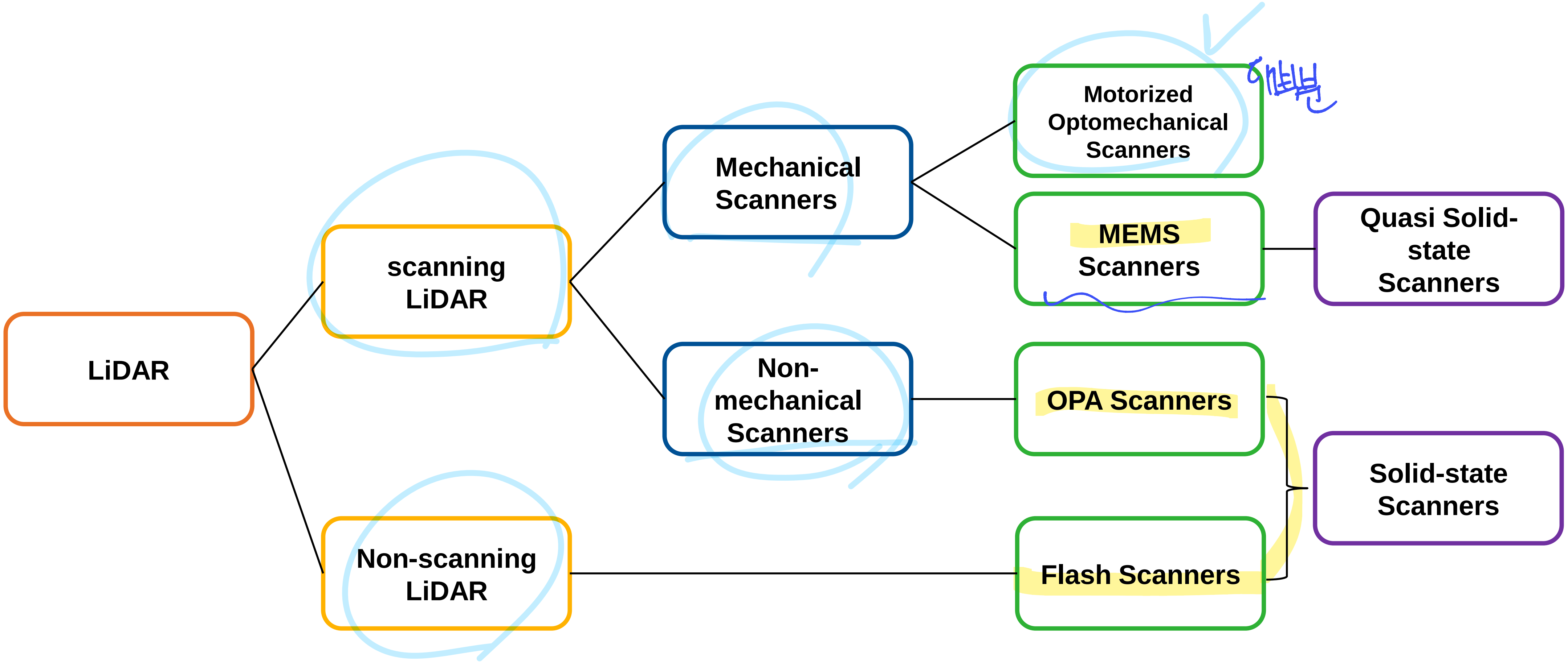


FMCW (Frequency-Modulated Continuous Wave)

2. 3D Beam-scanning technology



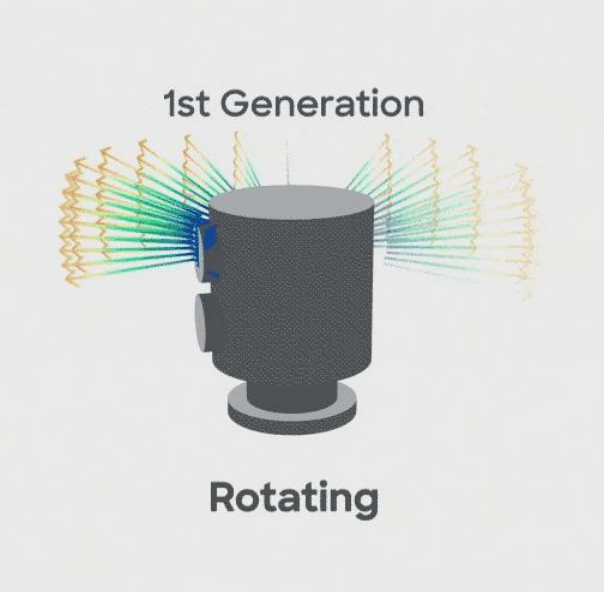
2. 3D Beam-scanning technology

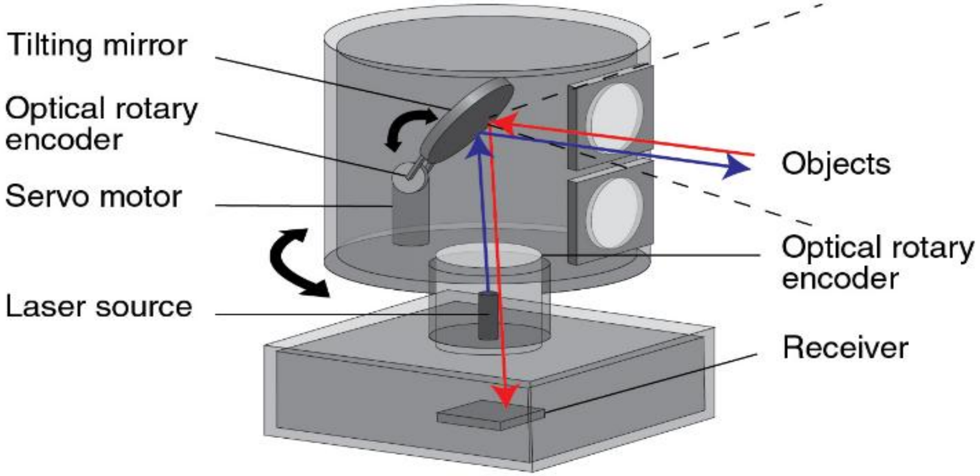


Mechanical LiDAR

Mechanical(Motorized) LiDARs

- Motorized optomechanical scanners are the most common type of LiDAR Scanners.
- Motorized LiDAR rotates multiple channels of transmitters and receivers by a motor.
- These kind of LiDARs are not power-efficient and are vulnerable to mechanical shock and wear.
- Their vertical resolution is fixed and dependent on the number of transmitter and receiver channels, so a high vertical resolution is always at the price of high cost.





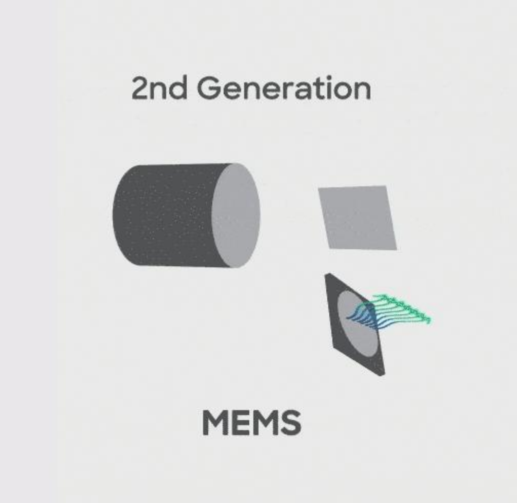
Mechanical LiDAR

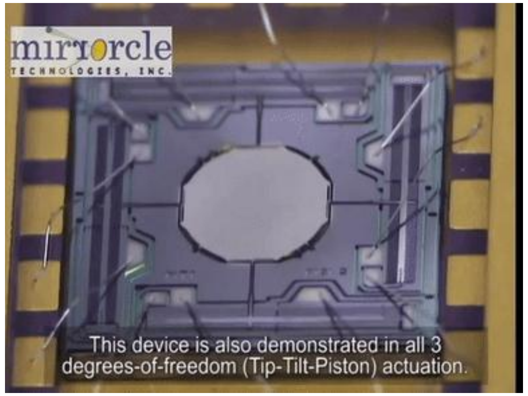
LiDAR Beam captured by IR Camera

MEMS (Micro-Electro-Mechanical Systems) LiDAR

- Superior in terms of size, scanning speed, and cost.
- Tilting tiny mirrors to precisely steer the laser beam.

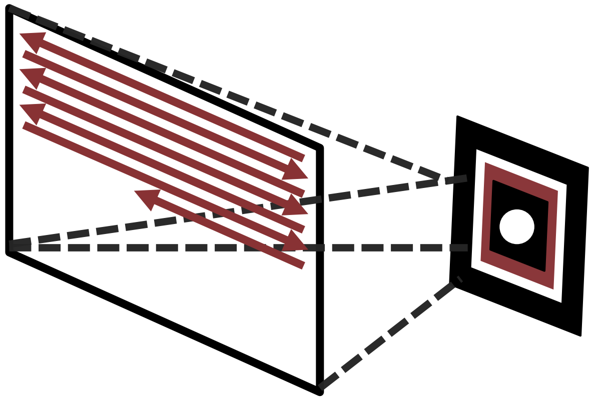
Dence Good





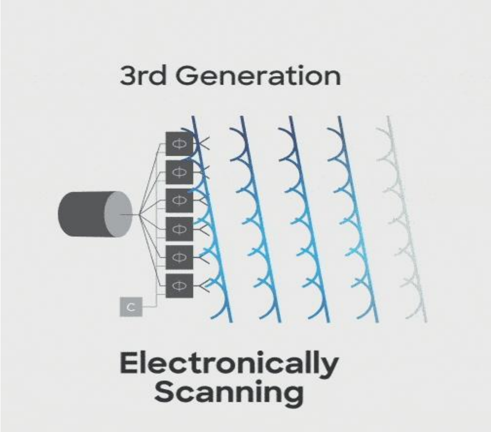
내구성 취약.

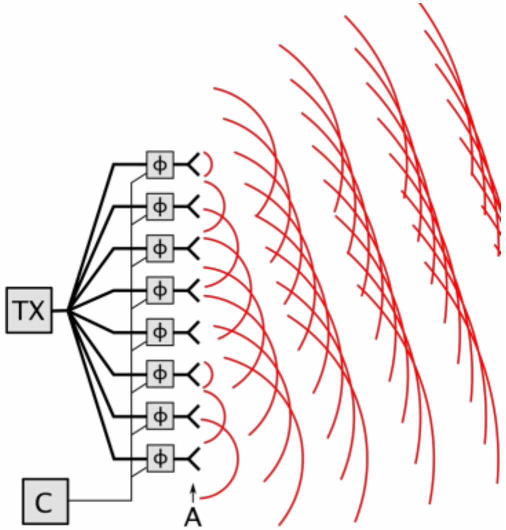
MEMS 3D Scan

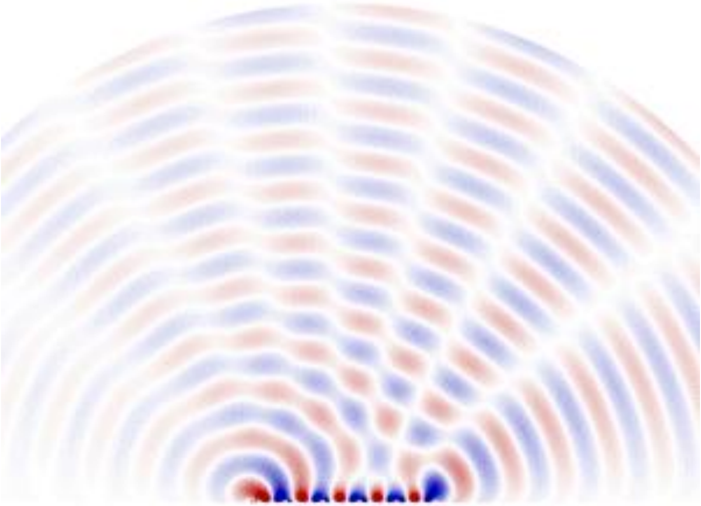


OPA LiDAR

- Superior in terms of stabilization, size, cost and reliability.
- Steering the laser beam by adjusting the phase of the light emitted, without moving parts.

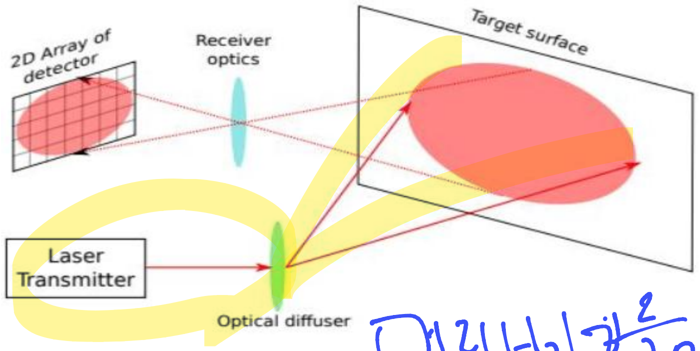






Flash LiDAR

- Superior in terms of vibrations resistant, scanning speed, size, and price.
- Like flash camera, capturing the entire scene quickly in single flash.
- High laser power is needed to illuminate the entire scene and detect at a distance.



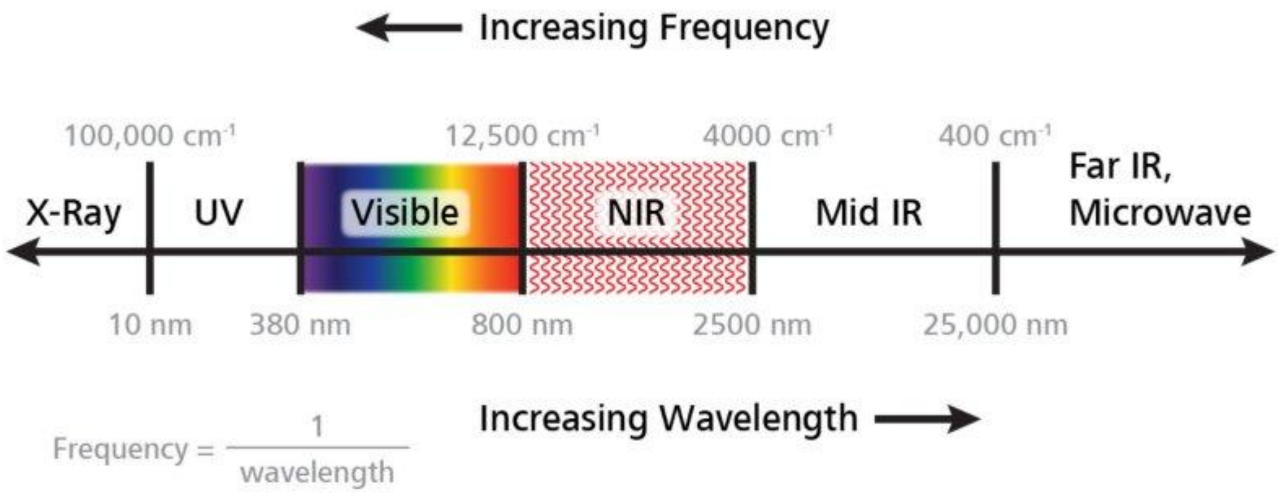
멀리보기 힘듦

3. Wavelength of Light

The types of wavelengths and laser types used in laser beams are as follows:

- Spectrum range: Near-InfraRed(NIR)
  - 850nm
    - Ouster
  - 905nm
    - Velodyne
  - 1550nm
    - Luminar

가격 쌈



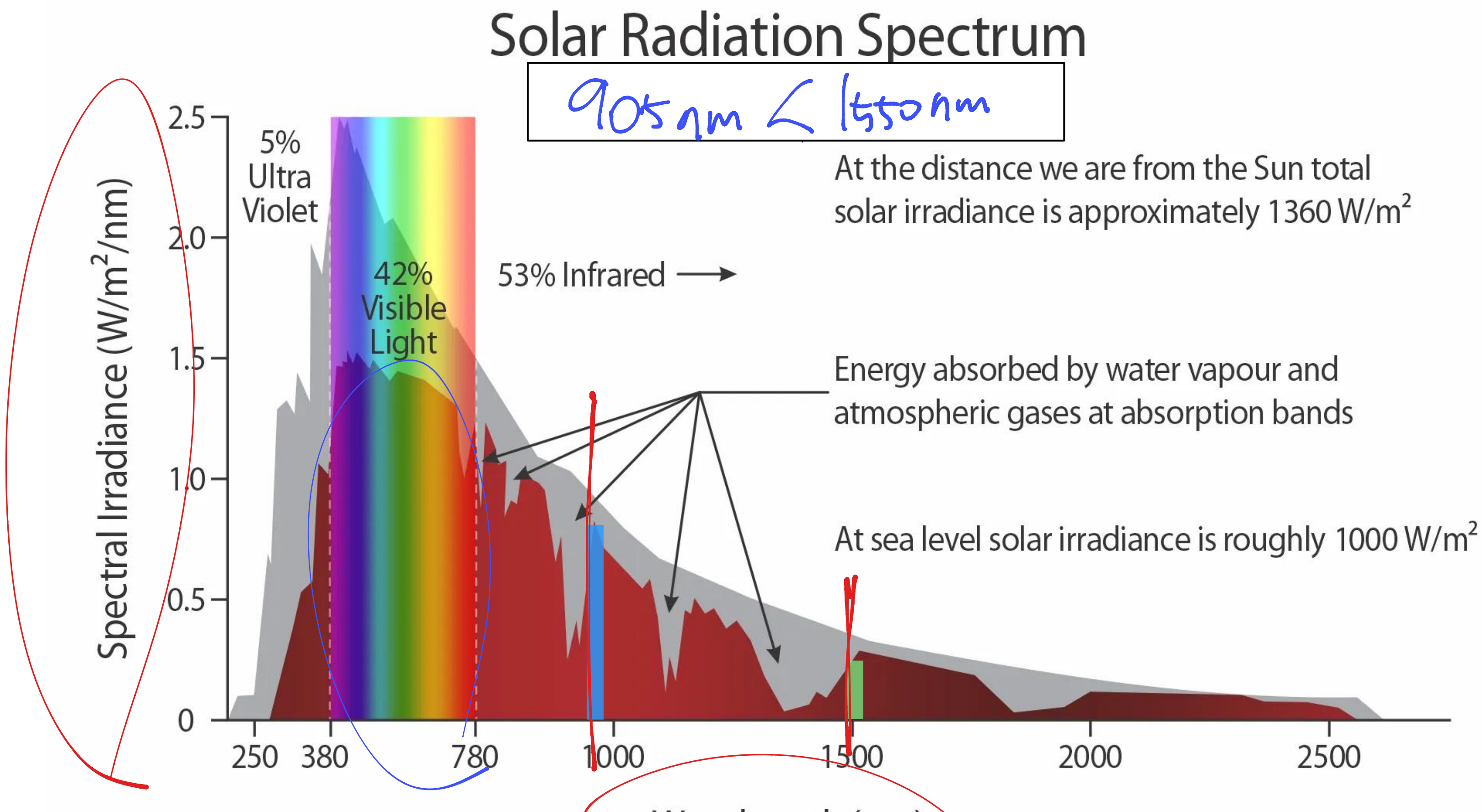
850nm LiDAR Ouster

905nm LiDAR Velodyne

1550nm LiDAR Luminar

Wavelength

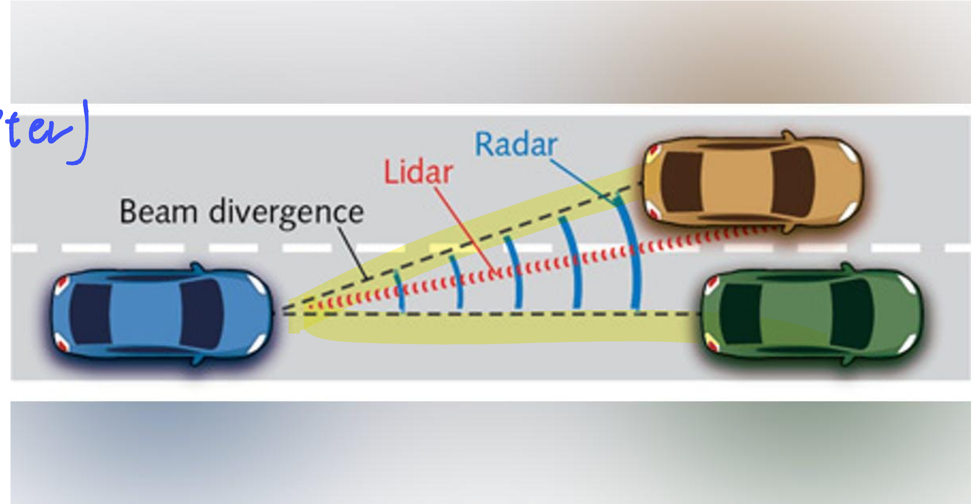
- **Comparison of frequently used wavelengths of 905 nm with higher power of 1550 nm.**
  - *Background noise*
  - 905nm has 3 times more background noise then 1550nm



Beam Divergence

Beam divergence:

- $\boxed{\sin\theta \approx 1.22 \frac{\lambda}{D} \quad (\lambda: \text{wavelength},\ D: \text{Beam diameter})}$
- $\boxed{\theta \approx 1.22 \frac{\lambda}{D}}$
- The longer the wavelength, the more beam spreads



Comparison with RADAR

- Wavelength of LiDAR and 77GHz mm Wave
  - LiDAR: $905nm, 1550nm$
  - 77GHz: $4mm$
- Radar has 4,000 times more beam divergence than LiDAR
- Sensors using electromagnetic waves make it as difficult to obtain images with high resolution as LiDAR.

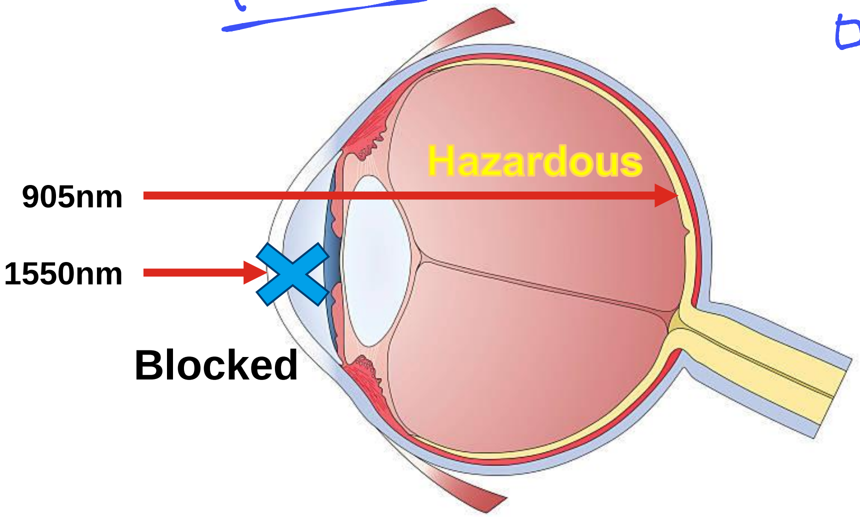
MPE (Maximum Permissible Exposure)

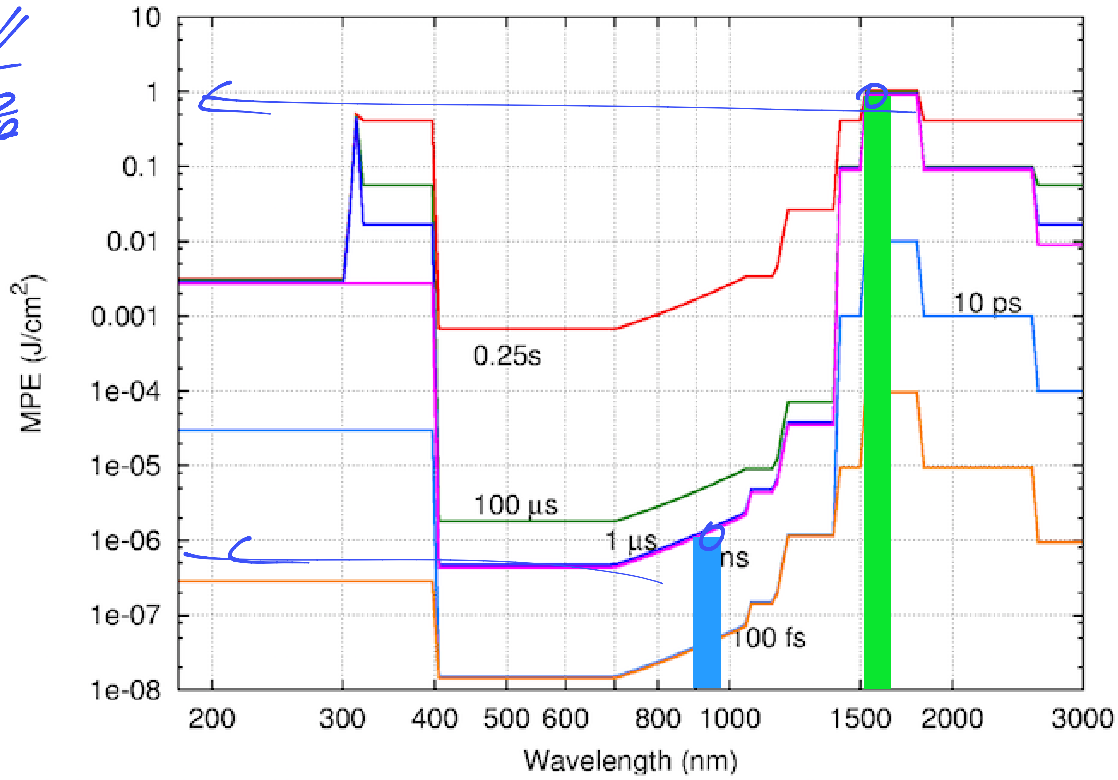
- High-power laser pulse can increase detection distance.
- Laser pulse should satisfy Eye safety (Maximum Permissible Exposure: MPE)!
- 1550nm laser source can be 1,000,000 times safer then 905nm.

Future

$\boxed{905\,nm < 1550\,nm}$

멀리볼수있음

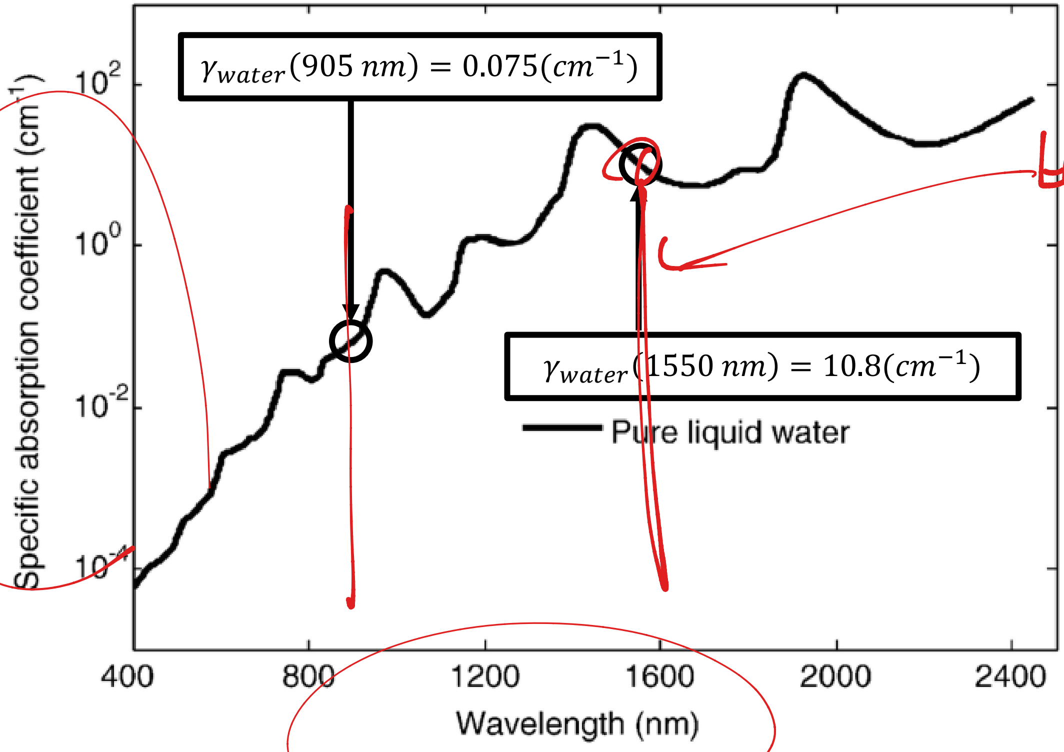




Water Extinction Effect

- **Phenomenon where water absorbs and scatters light, reducing the intensity of light.**
  - It occurs in the case of rain or on wet road surfaces.
- **1550nm has 140 times more extinction then 905nm.**

905nm → 1550nm

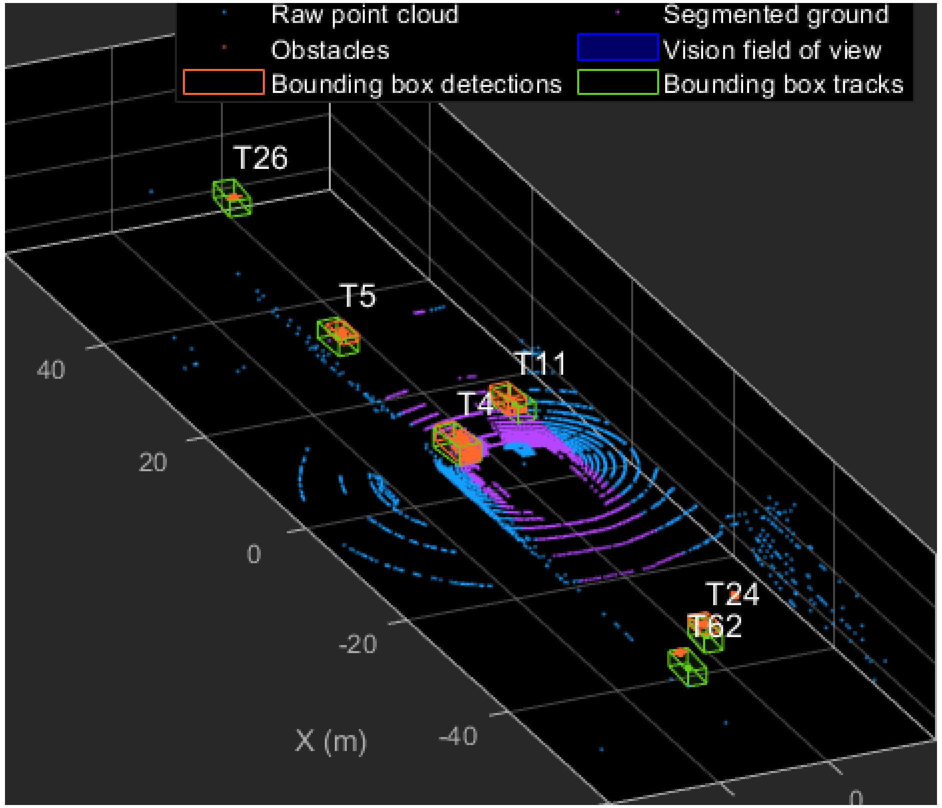


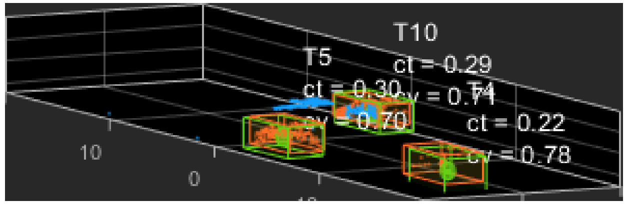
비올때 흡수 많이됨

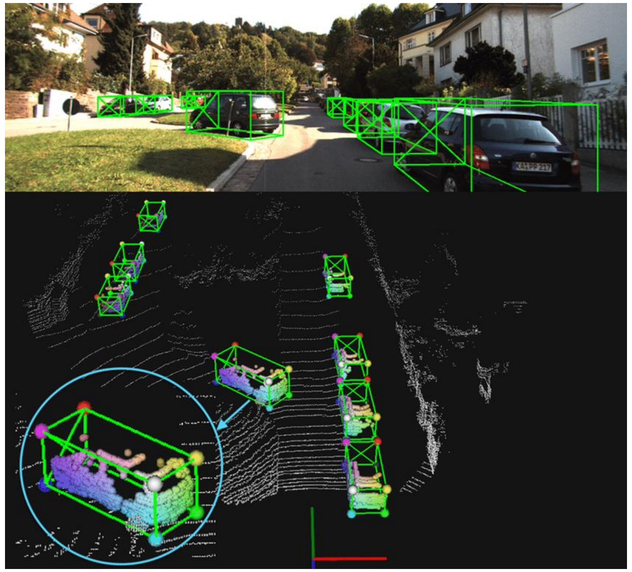
LiDAR based perception system

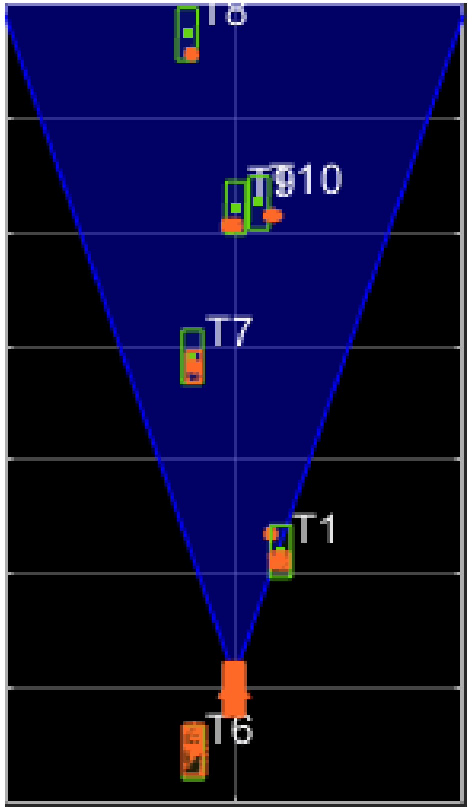
3D Object Detection

- **Recognizing the position, orientation, size information of an object for a class of interest for a point cloud.**
- **Two approaches to detecting 3D objects using LiDAR**
  - **Traditional (rule-based)** methods and **machine learning** methods.







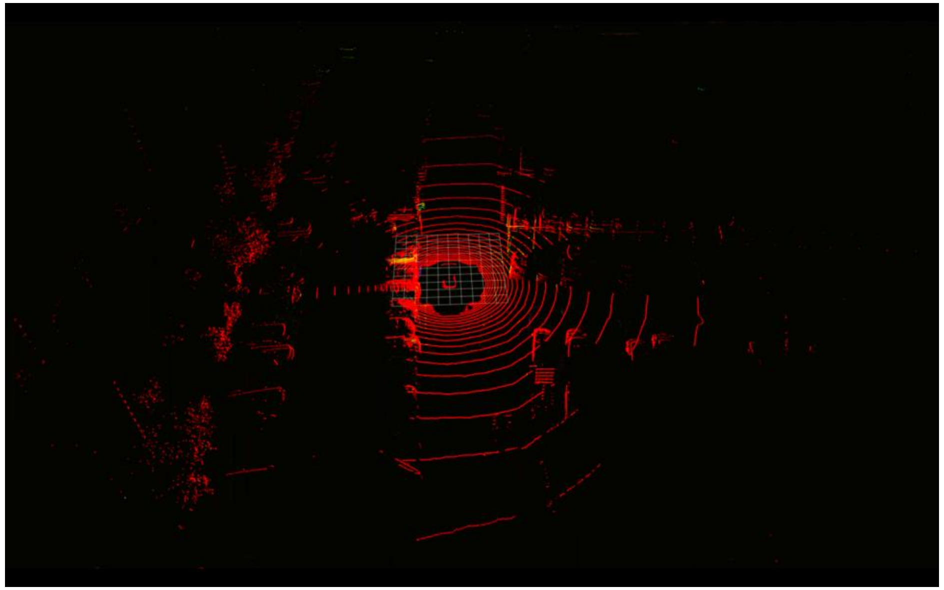


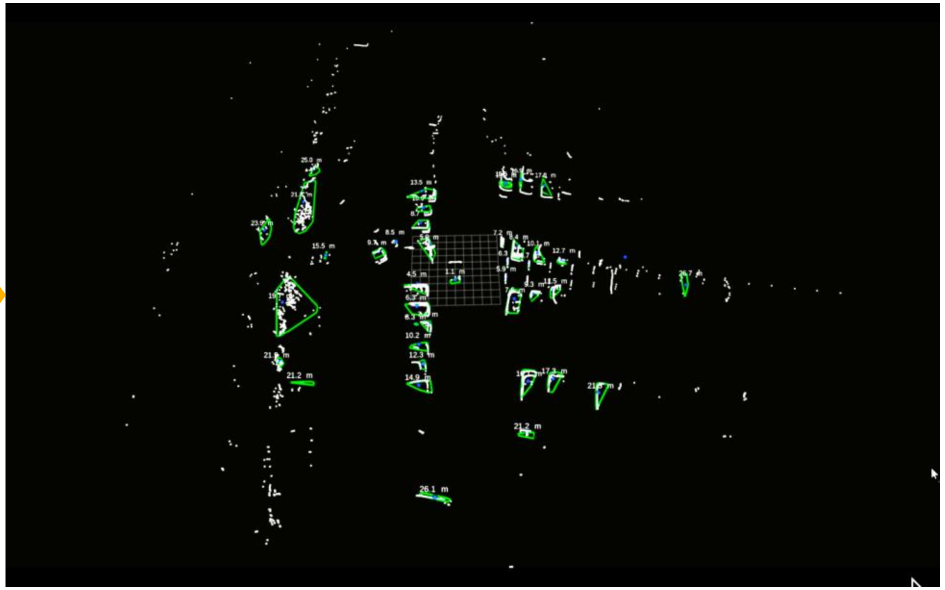
3D Object Detection - Traditional Method

Pipeline

- **Preprocessing**: processing raw point cloud data to remove noise and extract useful information.
- **Ground Removal**: eliminate unnecessary points on the ground.
- **Clustering**: cluster points and detect objects.
- **Bounding Box Fitting**: fitting bounding boxes around detected objects.

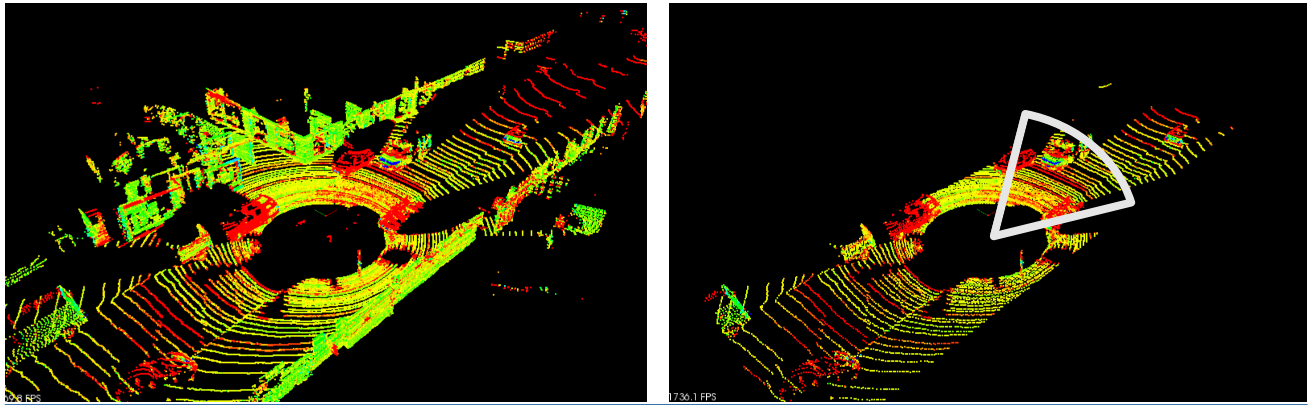
1) Preprocessing → 2) Ground Removal → 3) Clustering → 4) Bounding Box Fitting



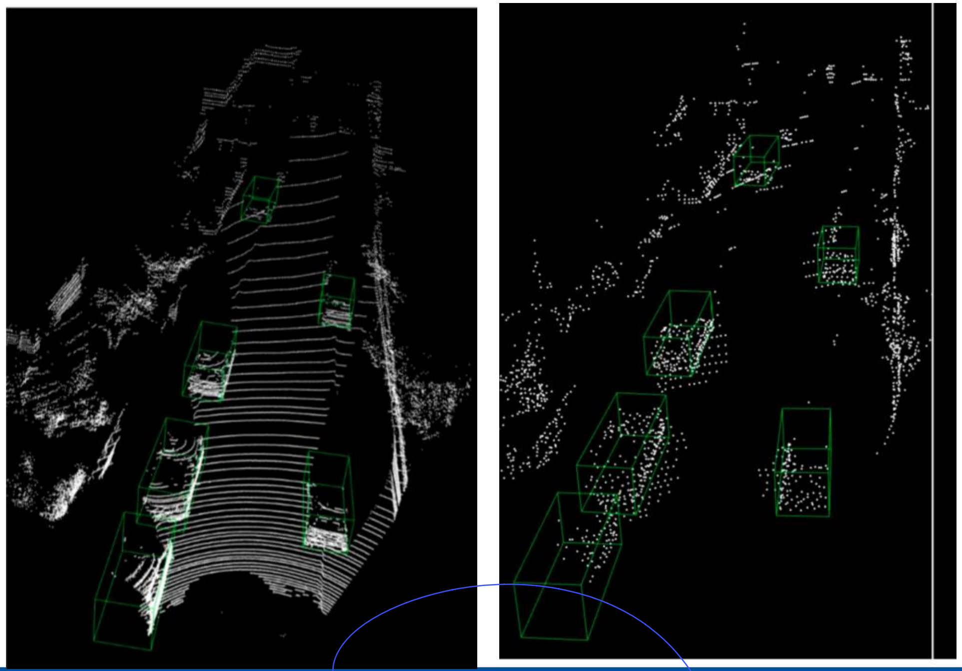


Traditional Method – Preprocessing

- **Processing raw point cloud data collected from LiDAR to remove noise and extract useful information.**
- **Performing to make the data more suitable for subsequent analysis or application.**
  - Setting ROI(Region Of Interest), Downsampling to reduce the amount of point cloud data computation is also a process of preprocessing



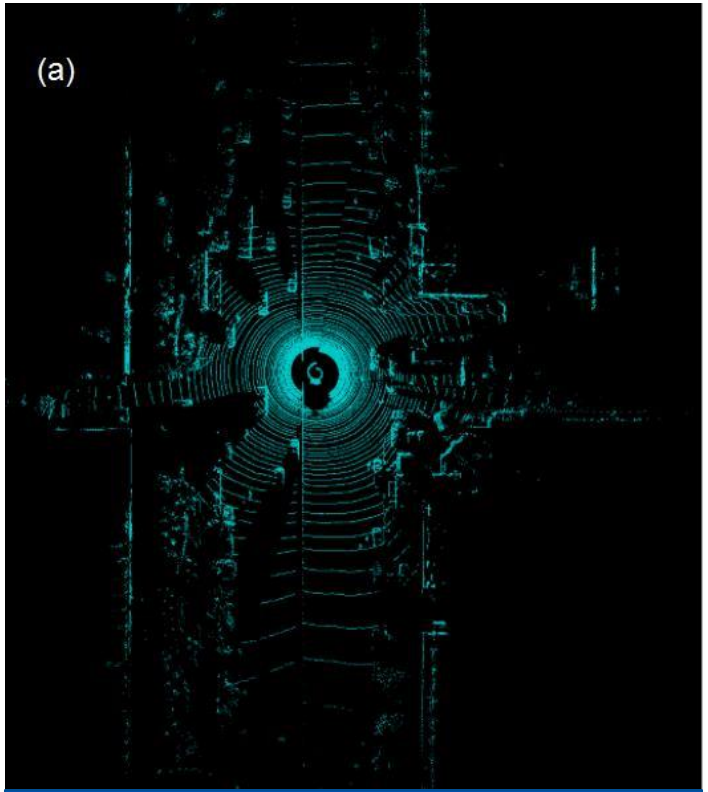
Setting ROI (Region Of Interest)



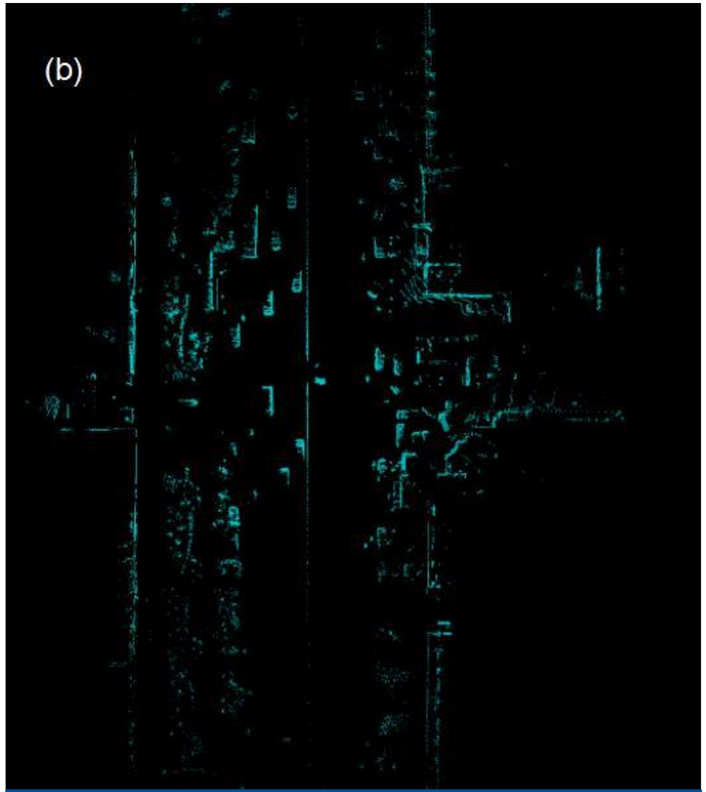
DownSampling

Traditional Approach – Ground Extraction

- **Identifying and removing ground points from the collected point cloud.**
- **It is needed to detect and analyze non-ground objects such as vehicles, pedestrians, and buildings within a 3D environment.**
  - RANSAC(Random Sample Consensus), Height-based thresholding etc..



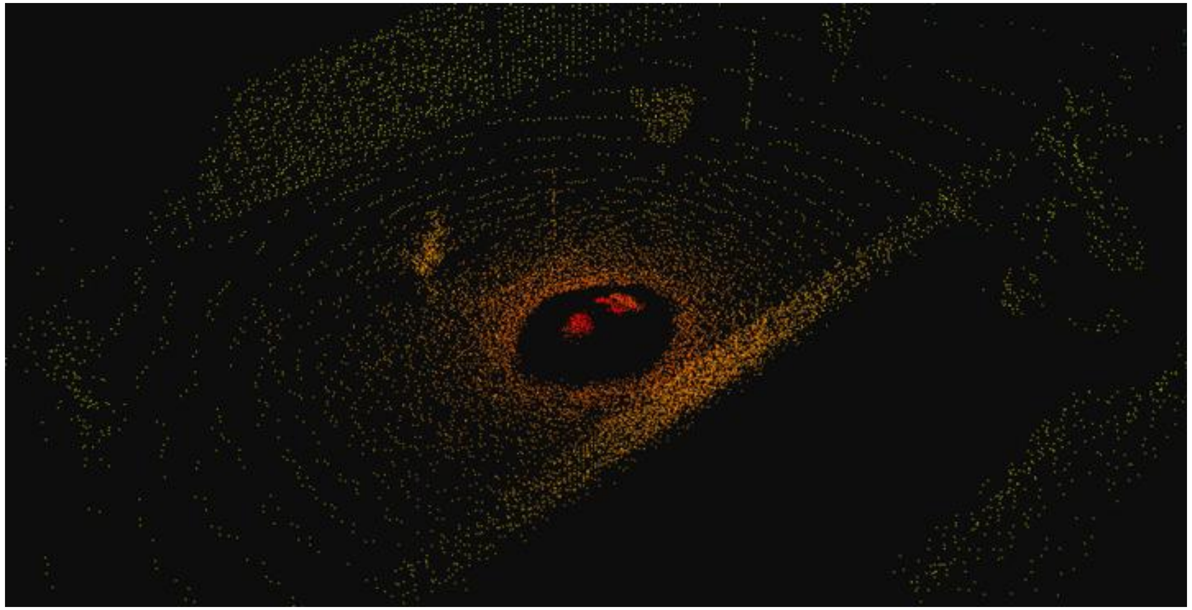
LiDAR Point Cloud Data

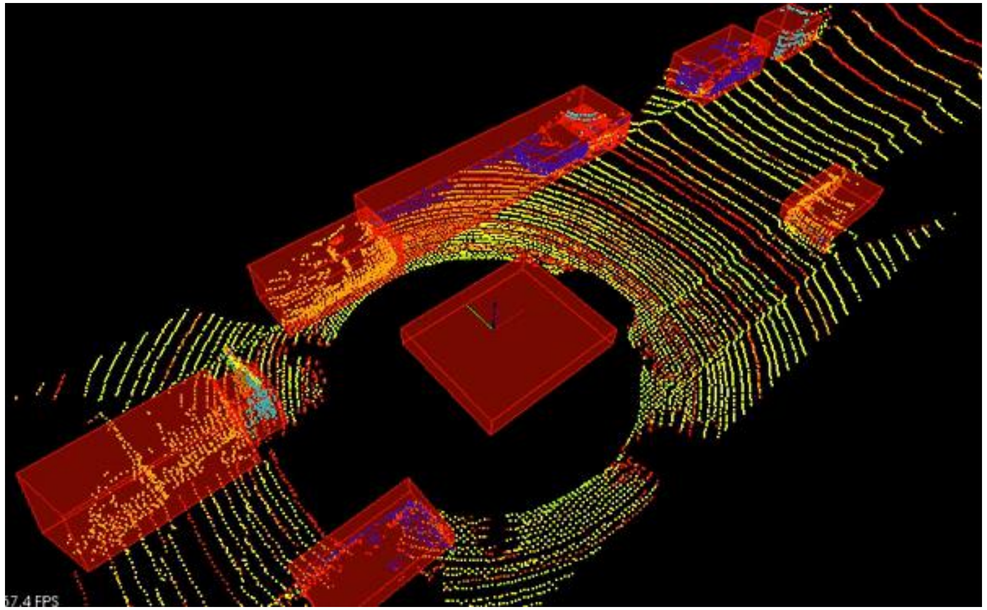


Ground removed Point Cloud

3D Object Detection – Clustering

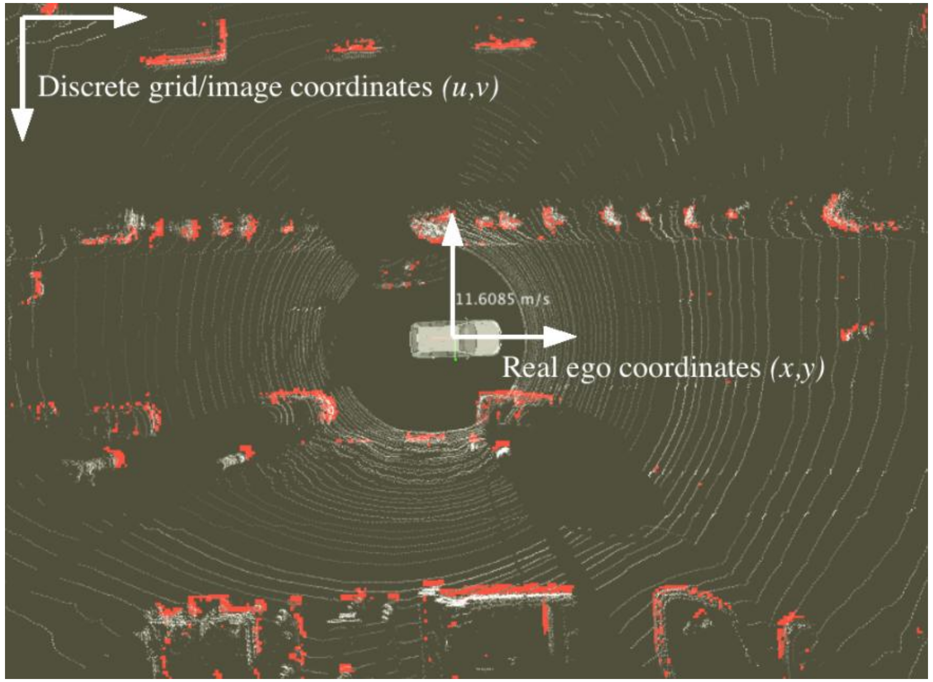
- The definition of clustering refers to the process of dividing objects into several subgroups given objects.
- Among the traditional clustering methods, the most widely used method is clustering based on the Euclidean distance.
- Classifies points with close Euclidean Distance into one point cluster, and detects objects based on the cluster.

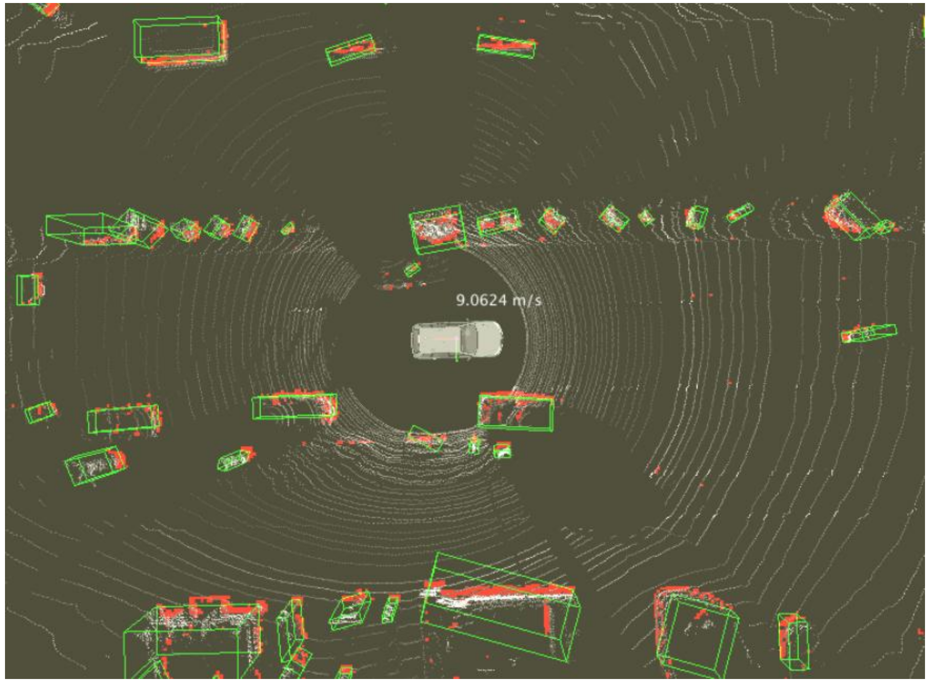




Traditional Method – Bounding Box Fitting

- Wrapping bounding boxes on clustered objects.
- Using to indicate the location, size, and orientation of an object and provides structural information needed to more easily identify and track the object.

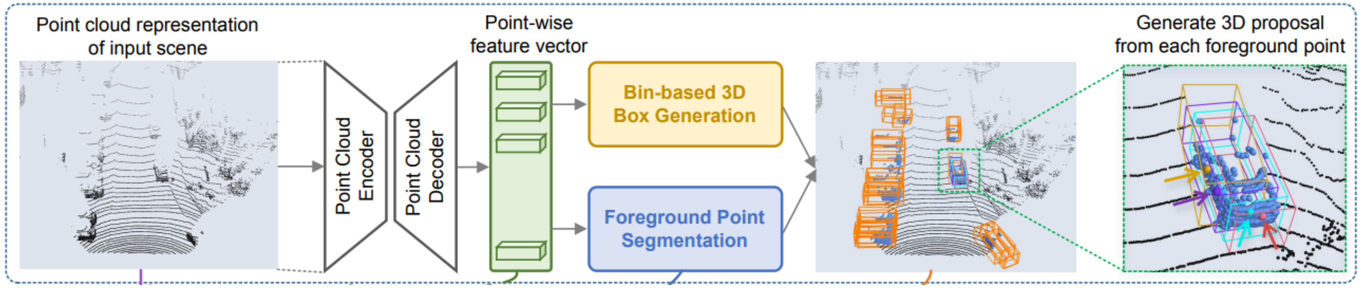




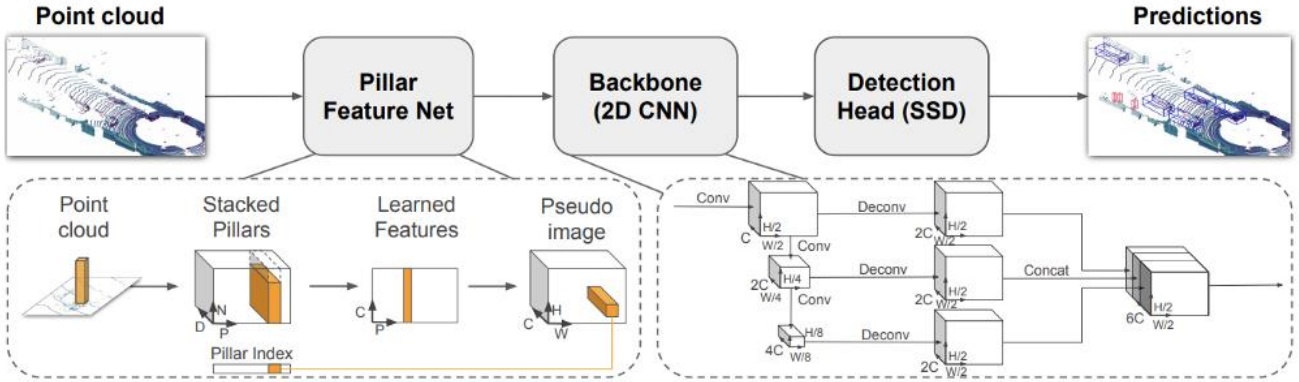
3D Object Detection – Machine Learning Method

3D objects can be predicted with several machine learning techniques

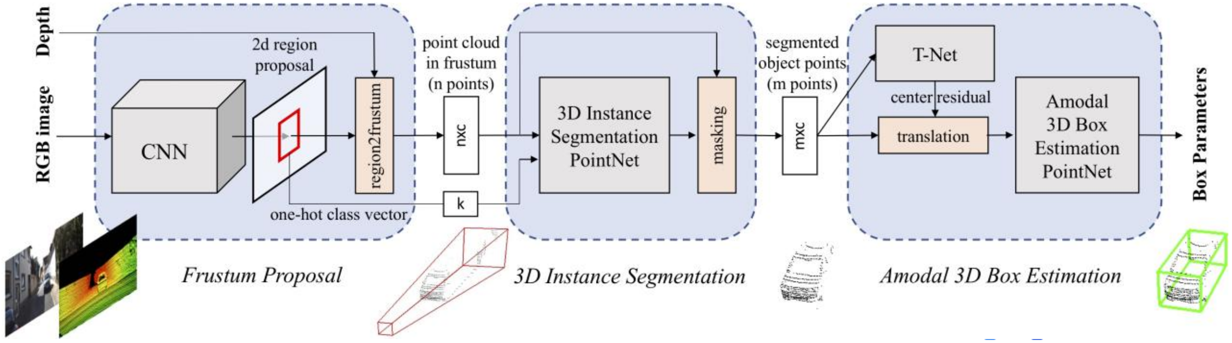
- Point-based
  - Point clouds are fed directly into the network, reducing loss of information



- Voxel-based
  - Voxels(Volume + Pixel) are used to reduce the amount of information in the point cloud

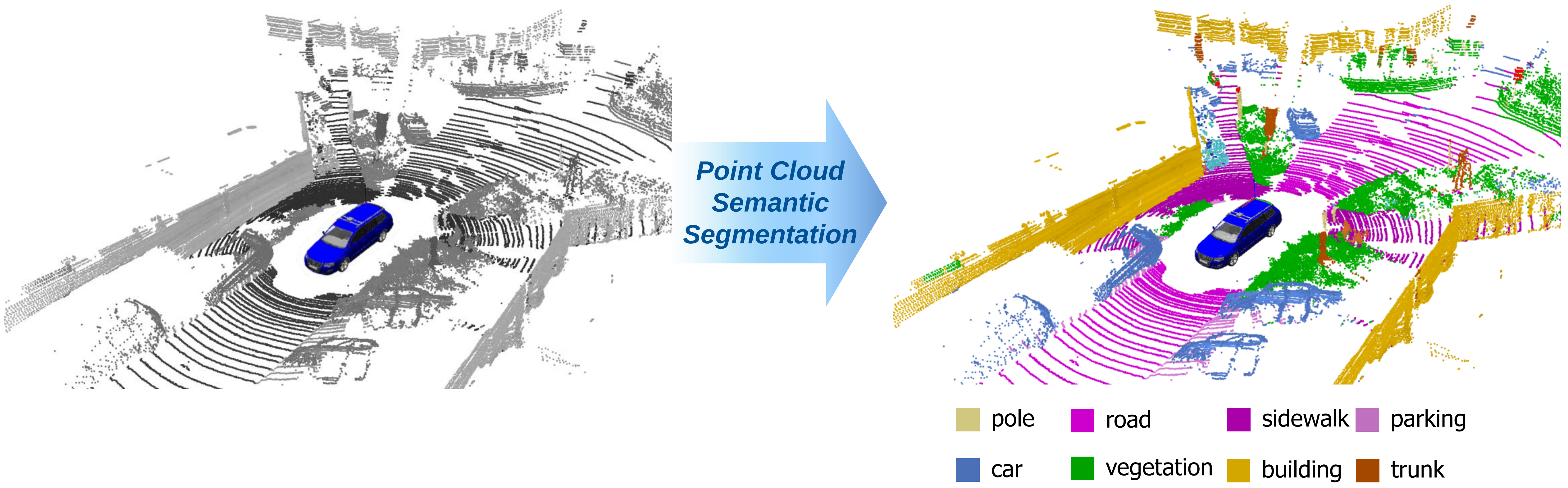


- Projection-based
  - Represent point clouds data as 2D views from different directions



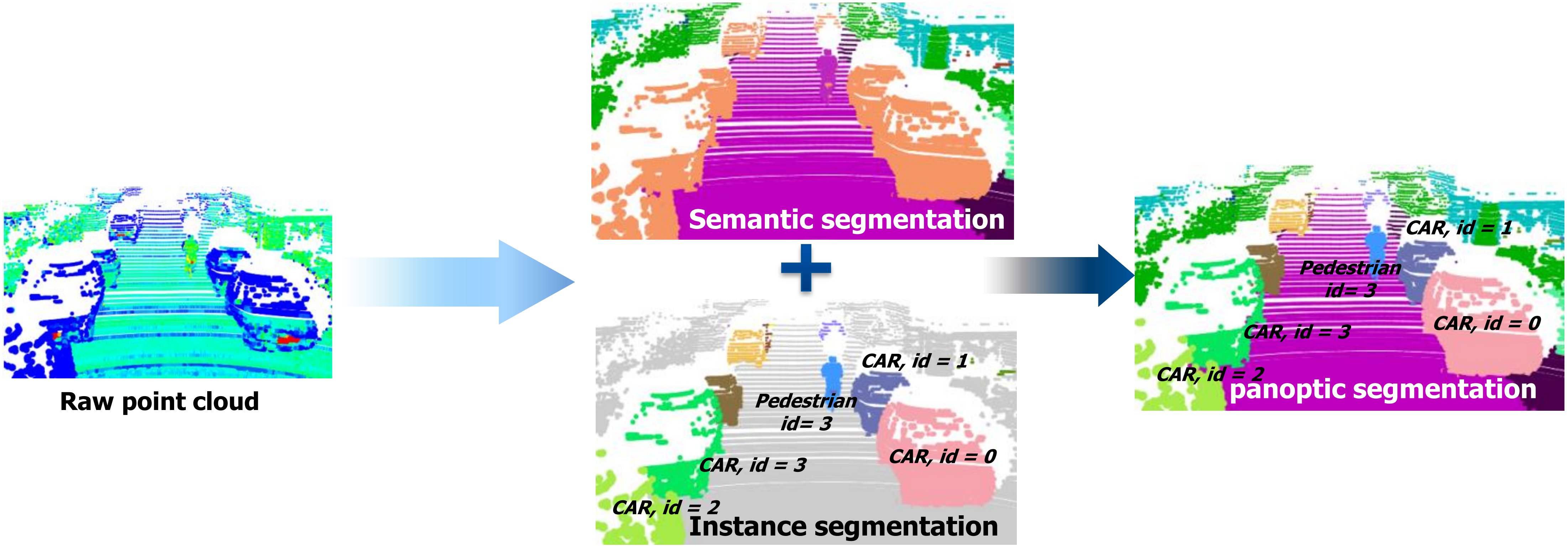
Point cloud semantic segmentation

- **Point Cloud Semantic Segmentation aims to assign class labels for each point.**
  - Since it is point-wise classification, It helps better understand the surrounding environment.
  - Both dynamic and static objects can be classified. (cars, roads, vegetation, etc.)



Panoptic segmentation

- **Panoptic segmentation**
  - Semantic segmentation + Instance segmentation
    - Semantic segmentation: Predict **every point** of input into each **class (No individual id for objects)**
    - Instance segmentation: Predict on points for the **class of interest (With individual id for objects)**
  - Panoptic segmentation: **Classification of all points** and **individual IDs for interest classes**



LiDAR SLAM

- **SLAM (S**imultaneous **L**ocalization **A**nd **M**apping**)**
  - Technological mapping method that allows robots and other autonomous vehicles to **build a map and localize** itself on that map at the **same time.**

LIO-SAM implemented by AILAB

Velodyne 16ch LiDAR with barebone comupter

THANK YOU
FOR YOUR ATTENTION