Why sensor fusion?

Range > 200m

Usually no Lidar points at all.

Radar detection is OK.

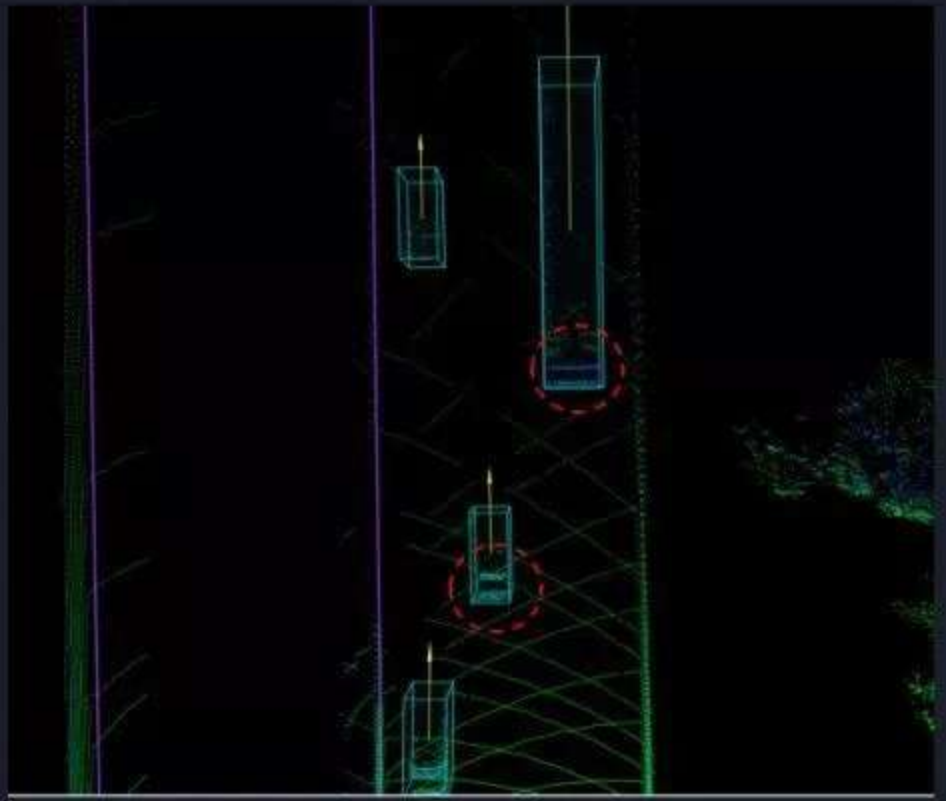
Camera detection is still stable by using long lens camera.

Ego motion

Vehicle's ego motion is usually not hard to compensate given accurate localization results.

Motion from others

Fast moving object may be scanned twice by multiple Lidars or even the same Lidar with in one Point Cloud.

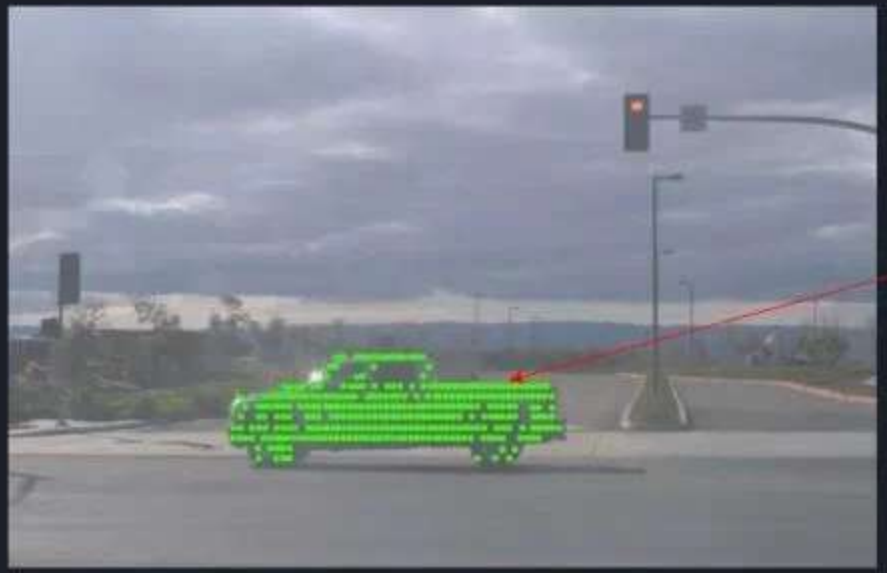


Time synchronization

Using an universal timestamp (GPS time) for all sensors' data.

Time synchronization

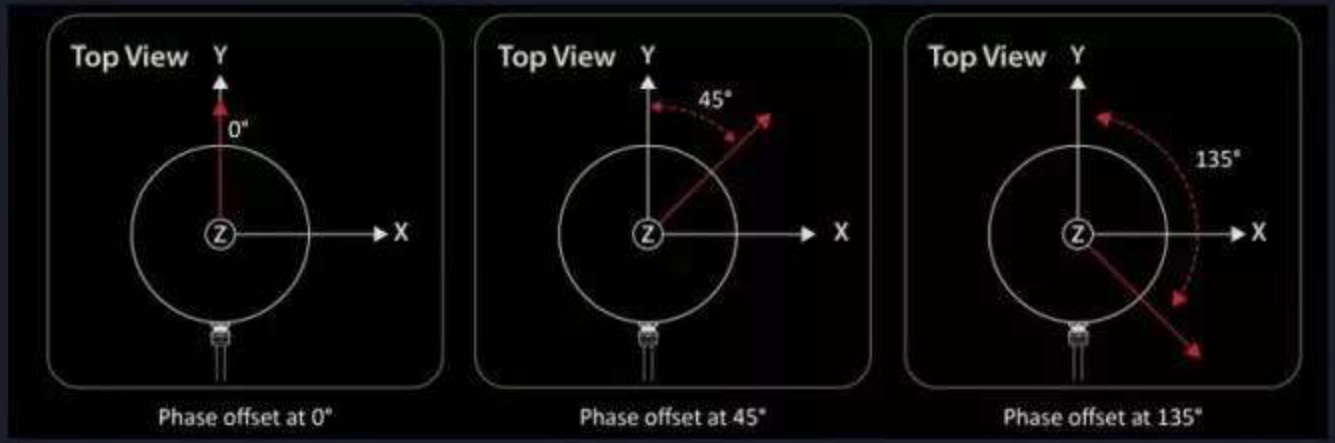
Using one sensor as the master to trigger slave sensors.



Lidar obstacle and camera obstacle are matched perfectly for a 50+ mph running truck.

Time synchronization

Lidar Phase Lock: The red arrows shown in figure below indicate the firing direction of the sensor's laser at the moment it receives the rising edge of the PPS signal.

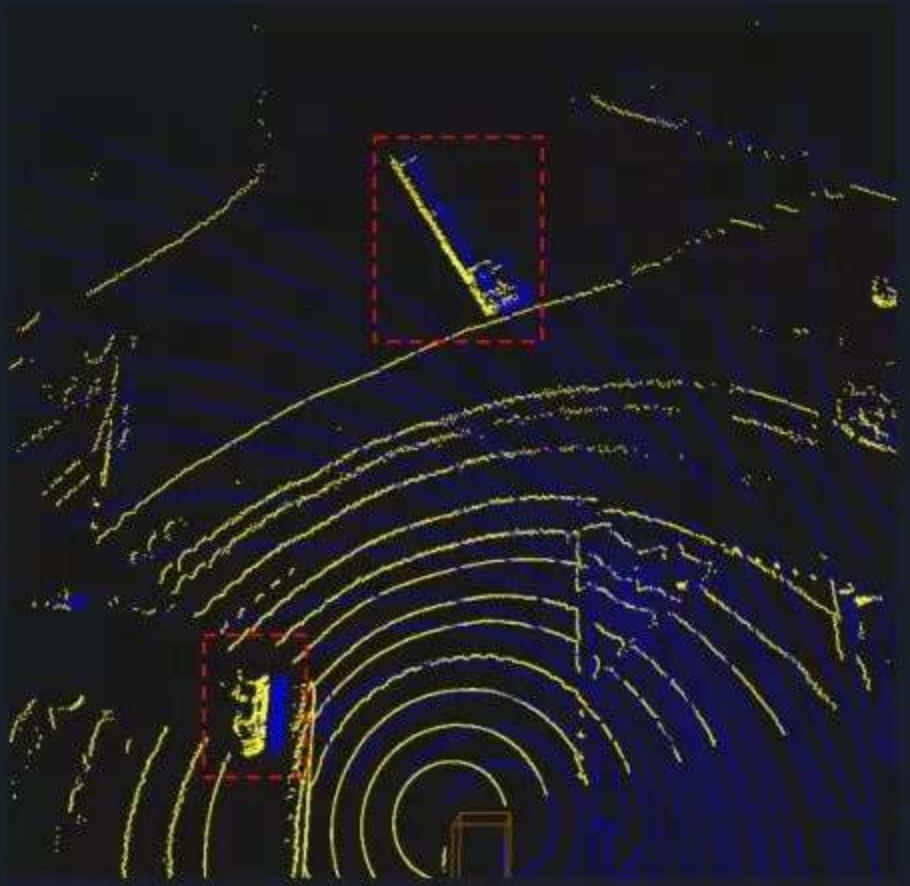


** *VLP-32c User Manual*

Sensor Calibration

Find the Rigid body transform (Rotation and Translation) between two sensors.

Multi-Lidar Calibration



Multi-Lidar Calibration

Iterative Closest Point (ICP)

Given two point sets:

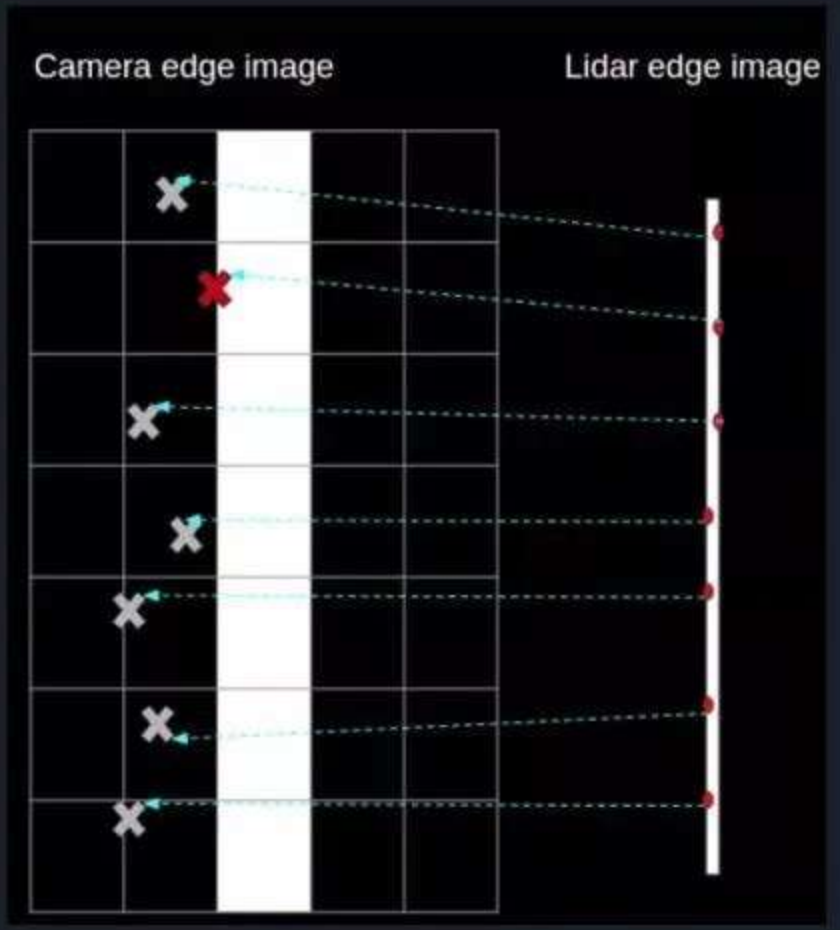
$$source : \{x_1, x_2, x_3, \ldots\}$$
$$target : \{y_1, y_2, y_3, \ldots\}$$

Find translation T and rotation R that minimizes the sum of the squared error, defined as:

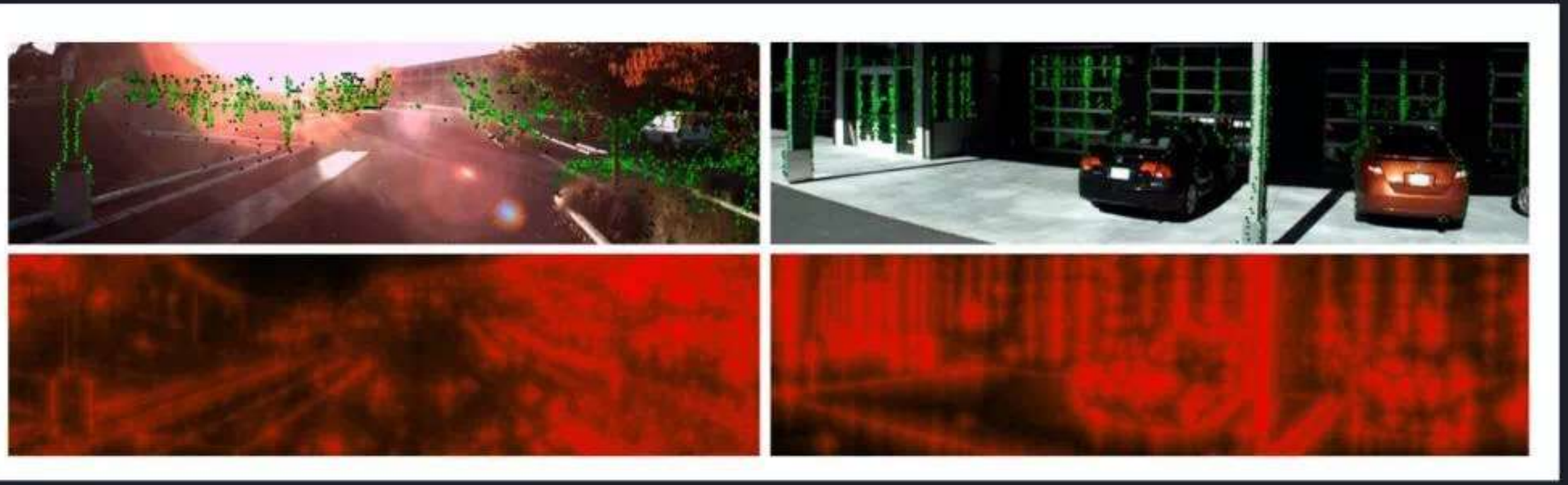
$$\frac{1}{N_c} \sum_{i=1}^{N_c} \|y_i - Rx_i - T\|^2$$

Camera Lidar Calibration

$$K * [R|T]^{camera}_{lidar} * P_{lidar}$$



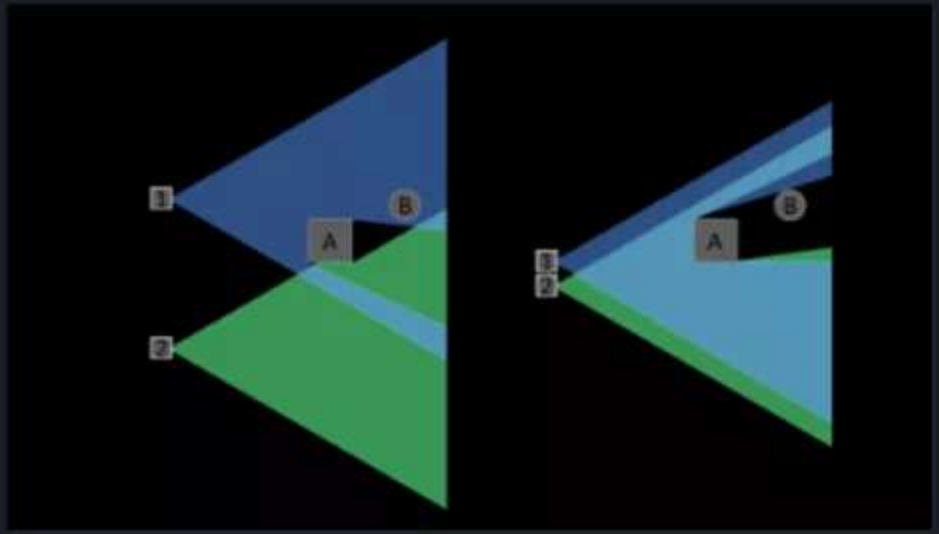
Camera Lidar Calibration



**Reference: Jesse Levinson, Sebastian Thrun. Automatic Online Calibration of Cameras and Lasers.

Sensor FoVs

The object detected by one sensor cannot be observed by the other one. Which one should we trust ?



** Reference: https://autonomous-driving.org/2019/01/25/positioning-sensors-for-autonomous-vehicles

Camera Lidar Fusion

Method 1:

Project 3D Lidar points onto image by using camera intrinsic, camera to lidar Extrinsic.

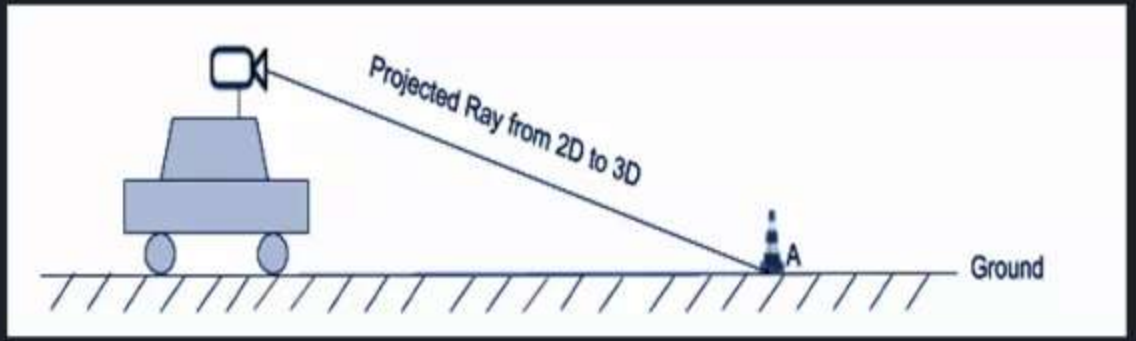
$$K * [R|T]_{lidar}^{camera} * P_{lidar}$$

NOTE, different FoVs matters!

Camera Lidar Fusion

Method 2:

Directly calculate the 2D object position in 3D by making a bunch of assumptions.

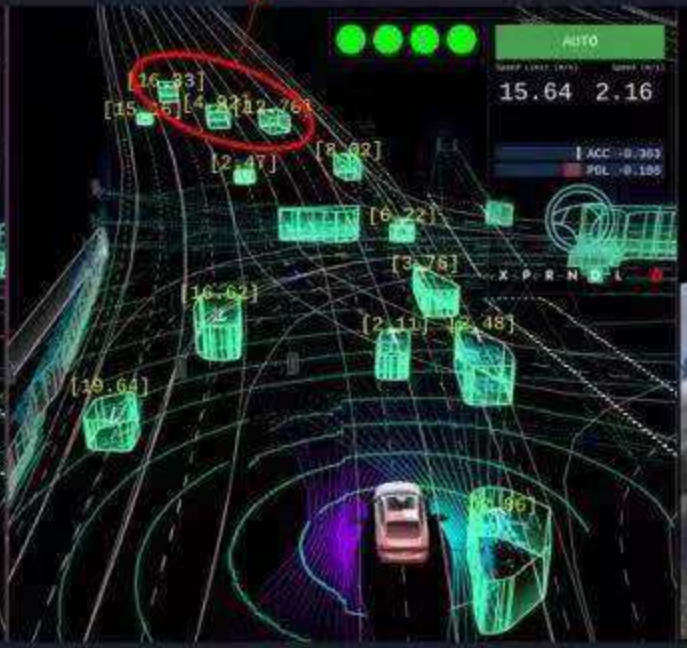


NOTE, assumptions can be wrong!

Radar Lidar Fusion

Three more cars are detected

(W/O Radar Fusion)



(With Radar Fusion)

(Camera View)