An Interactive LiDAR to Camera Calibration

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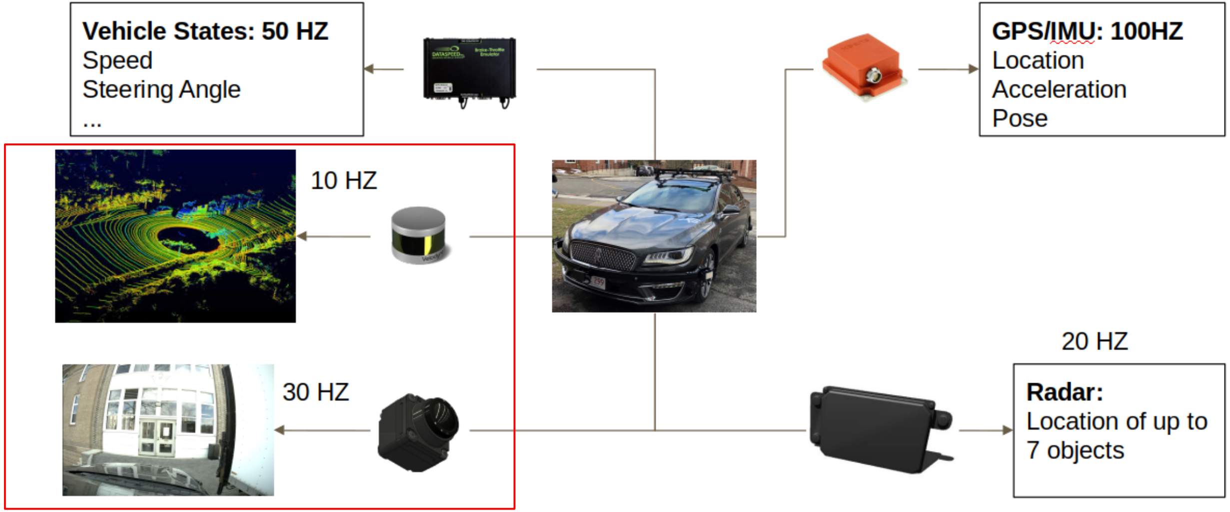
Motivation: Camera-LiDAR system in autonomous driving

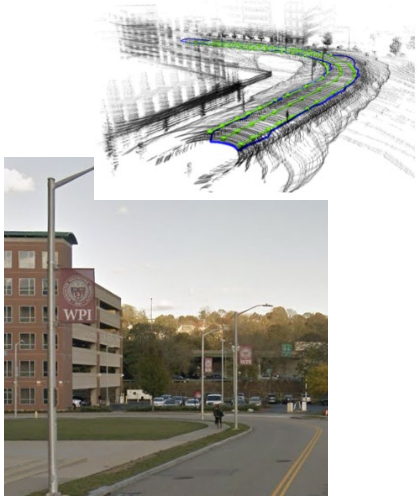
- Key part of autonomous driving sensor system



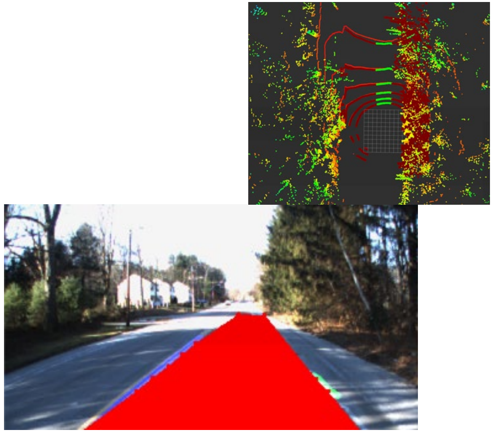
Motivation: Camera-LiDAR system in autonomous driving

- Used in many perception applications

Object Tracking



SLAM

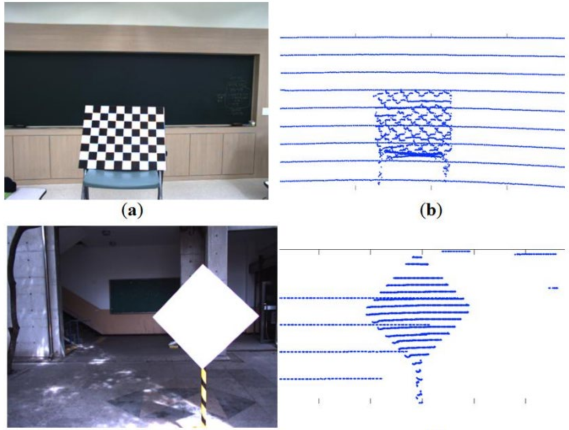


Lane Detection

Motivation

- Need of long-range: indoor -> outdoor
- Need of sparse compatible: 64 line LiDAR -> 16 line LiDAR
- Need of automation: manual adjustment -> automated optimization

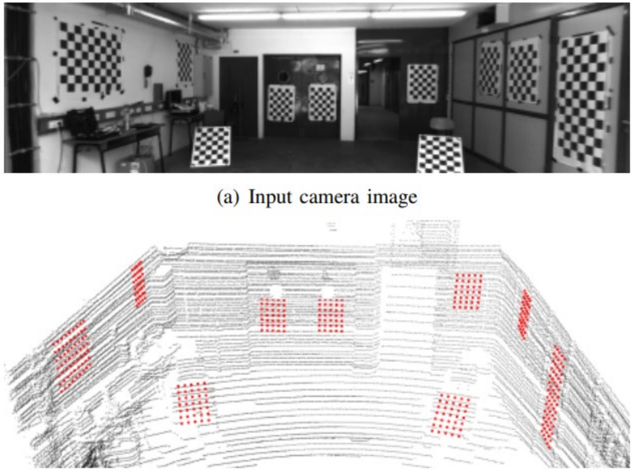
Related works: correspondence generation



(a) (b)

(c) (d)

Edge correspondence[1]



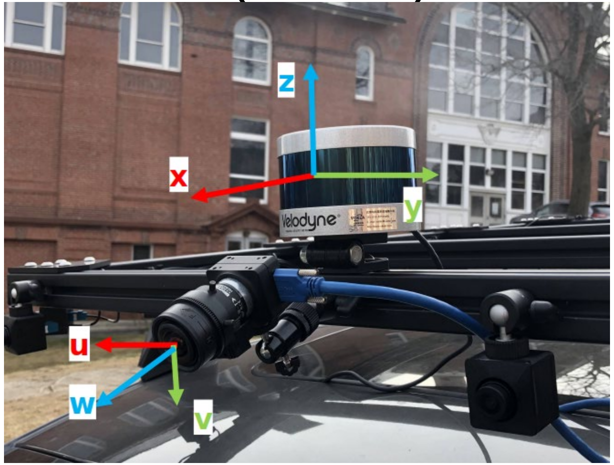
(a) Input camera image

Surface correspondence[2]

[1] Park, Yoonsu, et al. "Calibration between color camera and 3D LIDAR instruments with a polygonal planar board." Sensors 14.3 (2014): 5333-5353.
[2] Geiger, A., Moosmann, F., Car, Ö., & Schuster, B. (2012, May). Automatic camera and range sensor calibration using a single shot. In 2012 IEEE International Conference on Robotics and Automation (pp. 3936-3943). IEEE.

Method: LiDAR-Camera projection models

- Extrinsic matrix - coordinate transformation from LiDAR to Camera (6-DOF)



$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} \boldsymbol{R} & \boldsymbol{t} \\ \boldsymbol{0} & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (1)$$

$t = [u_0, v_0, w_0]^T$
(2)

$$R = R_{roll} R_{pitch} R_{yaw}$$

$$R_{roll} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos(\alpha) & -sin(\alpha) \\ 0 & sin(\alpha) & cos(\alpha) \end{bmatrix}$$

$$R_{pitch} = \begin{bmatrix} cos(\beta) & 0 & sin(\beta) \\ 0 & 1 & 0 \\ -sin(\beta) & 0 & cos(\beta) \end{bmatrix} \quad (3)$$

$$R_{yaw} = \begin{bmatrix} cos(\gamma) & -sin(\gamma) & 0 \\ sin(\gamma) & cos(\gamma) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Method: LiDAR-Camera projection models

- Intrinsic matrix - camera lens model

$$\begin{bmatrix} i \\ j \end{bmatrix} = \begin{bmatrix} f_x/w & 0 & i_0 \\ 0 & f_y/w & j_0 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}$$

Simple solution:
Pinhole Model

$$x_d = (1 + k_1 r^2 + k_2 r^4 + k_5 r^6) \begin{bmatrix} u/w \\ v/w \end{bmatrix}$$

$$dx = \begin{bmatrix} 2k_3 uv + k_4(r^2 + 2u^2) \\ k_3(r^2 + 2v^2) + 2k_4 uv \end{bmatrix}$$

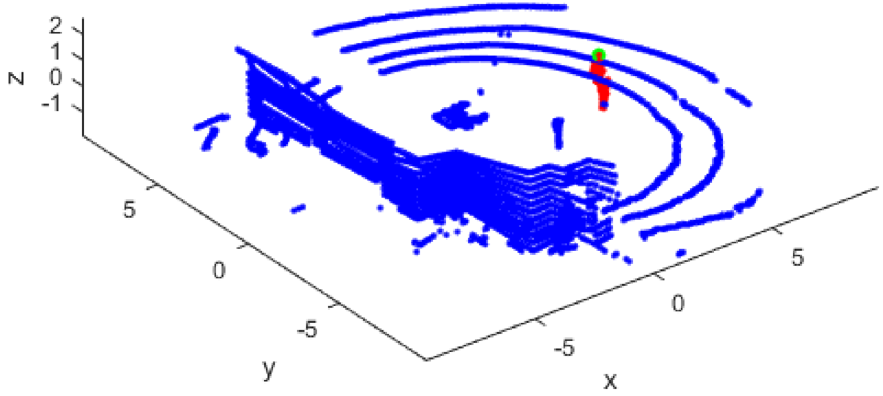
$$\begin{bmatrix} i \\ j \end{bmatrix} = \begin{bmatrix} f_x & \alpha_c \cdot f_x & i_0 \\ 0 & f_y & j_0 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}$$

Where $r = \sqrt{u^2 + v^2}$.

Full solution:
Fisheye Model

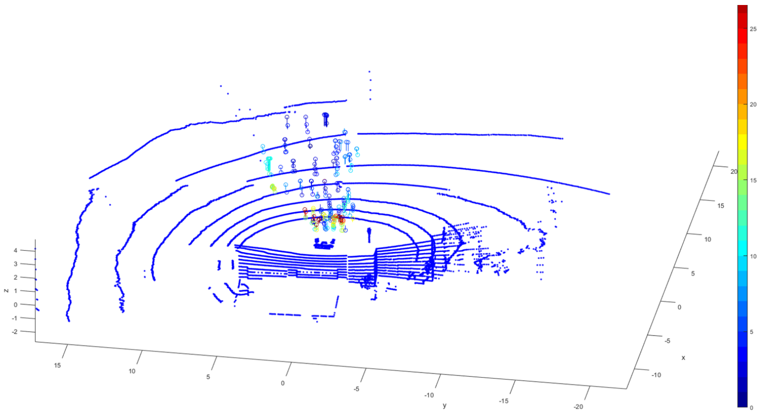
Interactive calibration toolbox

- Automatic corner point detection from LiDAR frame sequence
- Interactive corner point labeling on associated camera frames



Result validation

LiDAR-camera projection validation
on single camera frame



Projection offset visualization of all
correspondences on LiDAR frame

Application: Lane detection

- Detect lane markers on LiDAR frames and project to camera frames

Question

Thank you!
Questions?