Extrinsic Calibration Algorithm between a Stereo Visual System and 3D LiDAR

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Introduction

Background:

3D LiDAR (light detection and ranging) can produce 3D point cloud which measures the distance of world points. A **stereo visual system** has two cameras that can also give the perception of 3D depth.These sensors are used for autonomous driving and other applications frequently.

Objective:

The goal is to develop an **extrinsic calibration** algorithm to get rigid transformation parameters (rotation and translation) between a **stereo visual system** and **3D LiDAR.**.

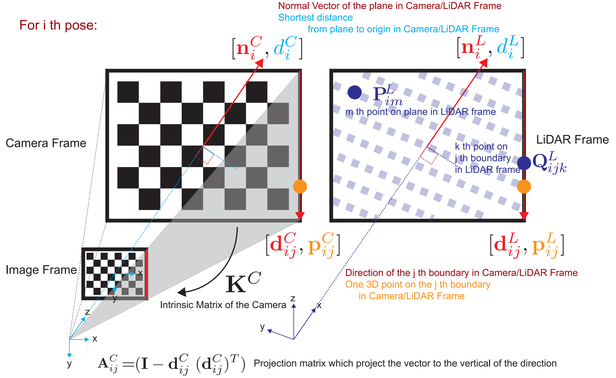
Highlight:

We use **checkerboard** as a common calibration target to do **intrinsic calibration** of the camera and extrinsic calibration of the system at the same time.

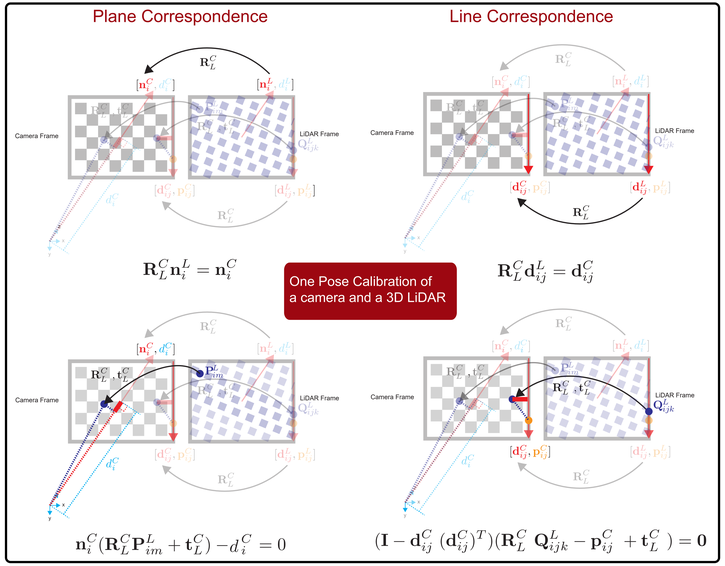
We use **line and plane correspondences** [1] to do the extrinsic calibration between the stereo visual system and 3D LiDAR with **one pose**.

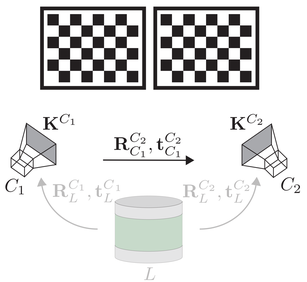
We use **non-linear optimization** to refine the result by utilizing **stereo constraint** and **LiDAR disparity constraint** with multiple poses.

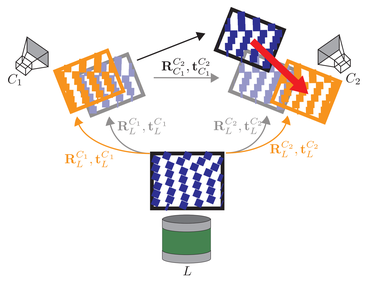
Notation



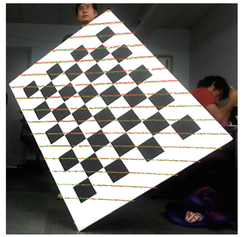
Methodology



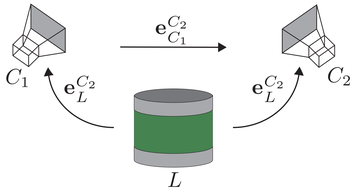




Rigid Vs Similarity Transformation



Non-linear optimization



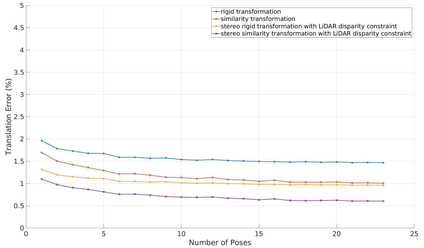
$$\mathbf{e}_{\mathbf{C_1}}^{\mathbf{C_2}} = \sum_{i=1}^{N} \frac{1}{N_i} \sum_{m=1}^{N_i} \|\mathbf{R}_{C_1}^{C_2}(\mathbf{R}_L^{C_1}\mathbf{P}_{im}^L + \mathbf{t}_L^{C_1}) + \mathbf{t}_{C_1}^{C_2} - (\mathbf{R}_L^{C_2}\mathbf{P}_{im}^L + \mathbf{t}_L^{C_2})\|^2$$

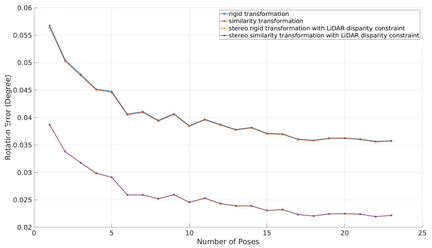
$$\mathbf{e}_{\mathbf{L}}^{\mathbf{C_1}} = \sum_{i=1}^{N} \frac{1}{N_i} \|\mathbf{n}_i^{C_1}(\mathbf{R}_L^{C_1}\mathbf{P}_{im}^L + \mathbf{t}_L^{C_1}) - d_i^{C_1}\|^2 + \sum_{i=1}^{N} \sum_{j=1}^{4} \frac{1}{K_{ij}} \sum_{k=1}^{K_{ij}} \|\mathbf{A}_{ij}^{C_1}(\mathbf{R}_L^{C_1}\mathbf{Q}_{ijk}^L - \mathbf{p}_{ij}^{C_1} + \mathbf{t}_L^{C_1})\|^2$$

$$\mathbf{e}_{\mathbf{L}}^{\mathbf{C_2}} = \sum_{i=1}^{N} \frac{1}{N_i} \|\mathbf{n}_i^{C_2}(\mathbf{R}_L^{C_2}\mathbf{P}_{im}^L + \mathbf{t}_L^{C_2}) - d_i^{C_2}\|^2 + \sum_{i=1}^{N} \sum_{j=1}^{4} \frac{1}{K_{ij}} \sum_{k=1}^{K_{ij}} \|\mathbf{A}_{ij}^{C_2}(\mathbf{R}_L^{C_2}\mathbf{Q}_{ijk}^L - \mathbf{p}_{ij}^{C_2} + \mathbf{t}_L^{C_2})\|^2$$

$$(\mathbf{R}_L^{C_1}, \mathbf{R}_L^{C_2}, \mathbf{t}_L^{C_1}, \mathbf{t}_L^{C_2}) = \underset{\mathbf{R}_L^{C_1}, \mathbf{R}_L^{C_2}, \mathbf{t}_L^{C_1}, \mathbf{t}_L^{C_2}}{\arg\min} \mathbf{e}_{\mathbf{L}}^{\mathbf{C_1}} + \mathbf{e}_{\mathbf{L}}^{\mathbf{C_2}} + \mathbf{e}_{\mathbf{C_2}}^{\mathbf{C_1}}$$

Results





Conclusion and Future Work

Using line and plane correspondences, we can use fewer (even one) poses to get more accurate result. Using LiDAR disparity constraint and stereo constraint, we can improve results with multiple poses significantly. We implemented a calibration toolbox in C++ with high efficiency and accuracy.We will extend the calibration framework to multi-sensor calibration problem including intrinsic and extrinsic calibration, a calibration toolbox will be released.

References

[1] L. Zhou, Z. Li, and M. Kaess, "Automatic extrinsic calibration of a camera and a 3d lidar using line and plane correspondences," in Intelligent Robots and Systems, 2018. IROS 2018. IEEE/RSJ International Conference on. IEEE, 2018
[2] R. Unnikrishnan and M. Hebert, "Fast extrinsic calibration of a laser rangefinder to a camera," 2005.

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