LiDAR Extrinsic Calibration using a Cubic Target

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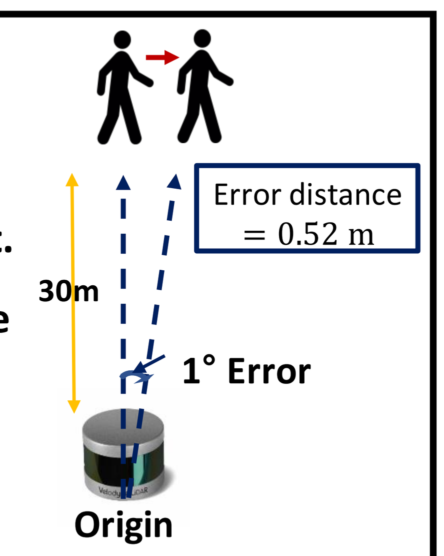
I. Introduction

- **Background**

  When LiDAR is assembled on Automobile, misalignment can occur

  For Safety and Accurate mapping, need to inspect LiDAR alignment.

  At a distance of 30m with an alignment error of 1 degree, a distance error of 0.52m is shown.

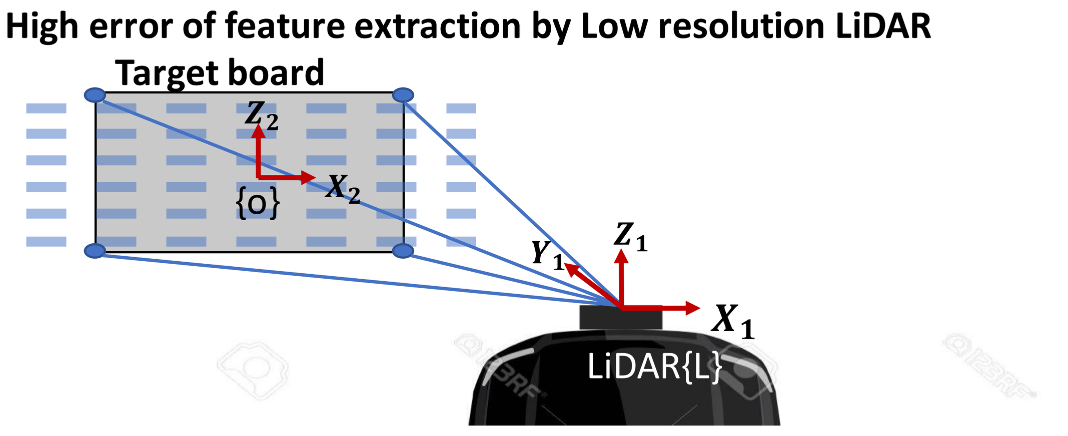


- **Previous Method**

  Single Planar Target based

  : Extract Feature Points (corners or edges) of Target and Calibrate

  : Limitation - High error of feature extraction by Low resolution LiDAR



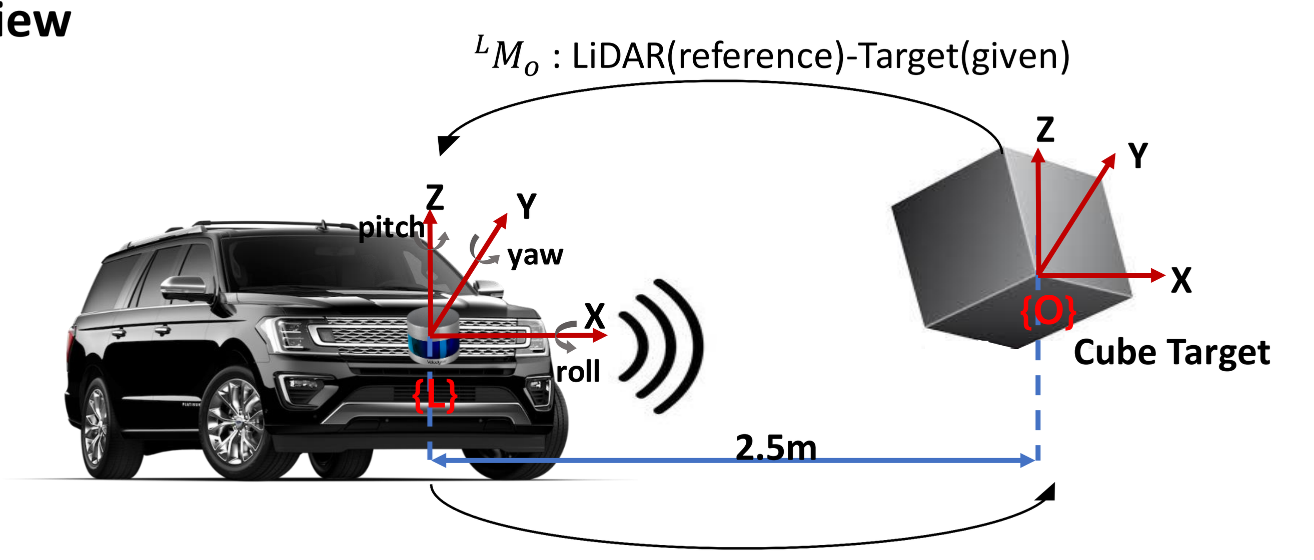
→ For accurate measurement, Use plane model instead of Features extraction

→ Use 3-planes of a Cubic Target for calibration

- **Problem Statement**
  - Design LiDAR extrinsic calibration using a cubic target
  - Evaluate alignment Precision with Simulation and Experiment

II. Algorithm

- **Overview**



- **Estimation orthogonal normal vectors**

Flow Chart

LiDAR scans cubic target
↓
Estimation of plane model with RANSAC
↓
Outlier Removal
↓
L1, L2 and L3 planes are extracted

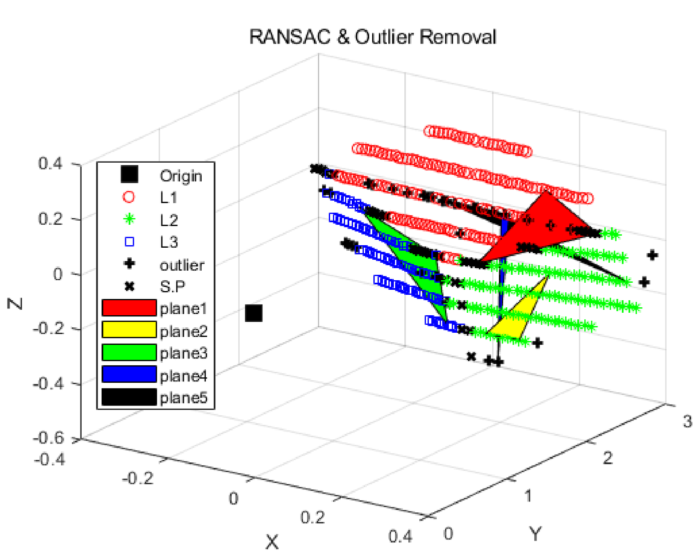


Fig1. Outlier Removal

- **Extract vertex points from intersection of 3-planes**

Flow Chart

Initial estimation of normal vector (each plane)
↓
Get errors for orthogonality of 3 vectors
↓
Estimate new planes by using Levenberg-Marquardt Algorithm until error <ε
↓
Extract 7 vertex from cubic
↓
Alignment estimation

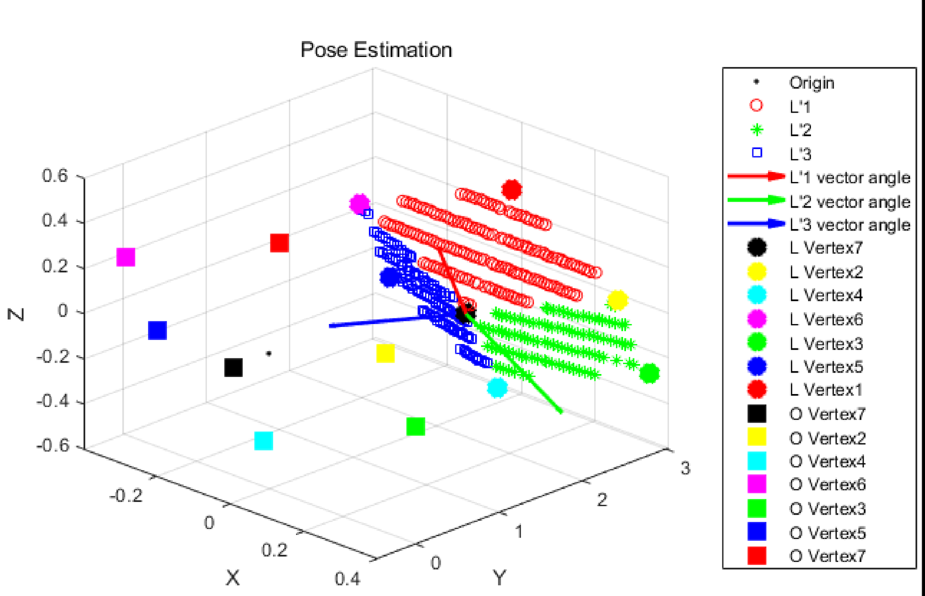


Fig2. Pose Estimation

- **Estimate new orthogonal plane**
  - L_1, L_2, L_3 estimated from RANSAC is not complete orthogonal planes, because of randomness of RANSAC.
  - To get complete orthogonal planes, Levenberg-Marquardt method is used to Optimizations.

- **Alignment estimation from Transformation matrix error**

$$^{O}P = [{}^{O}_{L}R \,|\, {}^{O}_{L}T]\,{}^{L}P \qquad {}^{L}P : \text{ Estimated 7 vertexes}$$

$$^{O}_{L}R = R_z(\phi)R_y(\theta)R_x(\psi) = \begin{bmatrix} \cos(\phi) & -\sin(\phi) & 0 \\ \sin(\phi) & cos(\phi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) \\ 0 & 1 & 0 \\ -\sin(\theta) & 0 & cos(\theta) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\psi) & -\sin(\psi) \\ 0 & \sin(\psi) & \cos(\psi) \end{bmatrix}$$

$$^{O}_{L}T = [\Delta X, \Delta Y, \Delta Z]^T$$

- **Non-linear Optimizations with Levenberg-Marquardt method.**
  - Cost function $F(\beta) = \frac{1}{2}\sum \left\| {}^{O}P - [{}^{O}_{L}R \,|\, {}^{O}_{L}T]\,{}^{L}P \right\|,\ \beta = (\phi, \theta, \psi, \Delta x, \Delta y, \Delta z)$
  - β^∗≡$argminF$(β)= β− η(J^T J+λdiag(J))^(−1) J^T F(β)
  - β^∗ is the optimal variables , J is the Jacobian matrix for cost function F, η=0.02, λ=0.3

III. Simulation

- **Simulation Environment**

  LiDAR data: from Blensor Simulator, VLP-32 model

  Cubic target: 0.5x0.5x0.5, @ 2.5m

  Initial pose: 0deg alignment offset

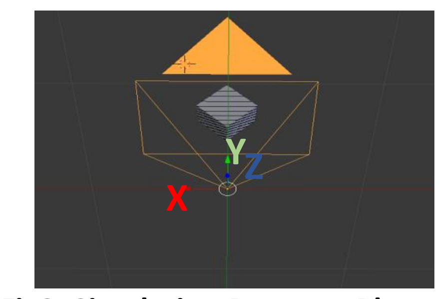


Fig3. Simulation Program Blensor

Test 1 : Translation(X axis) offset error test

- Range : $-30mm \sim 30mm$ @$5mm$ Step

Test2: Yaw rotation (Z axis) error test

- Range : $-3° \sim 3°$ @0.5° Step

Fig4. VLP-32 Velodyne Puck

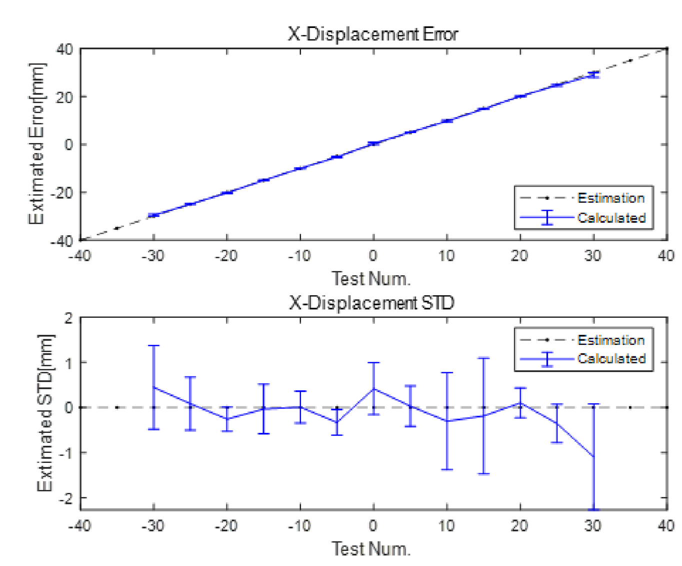


Fig5. Simulation Translation Result

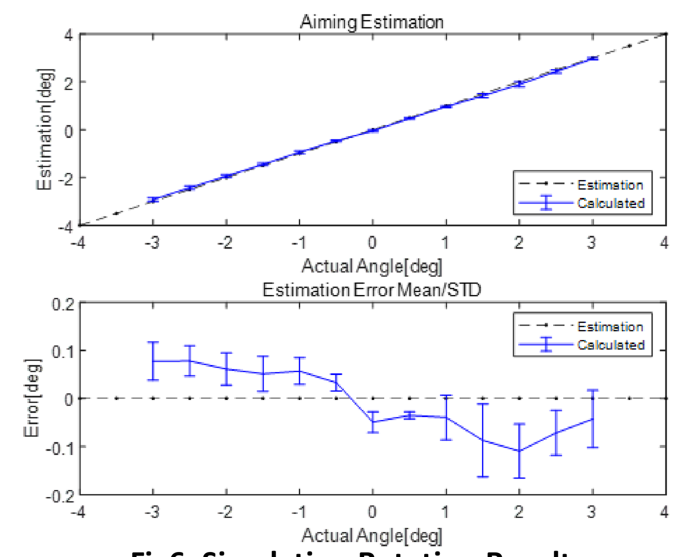


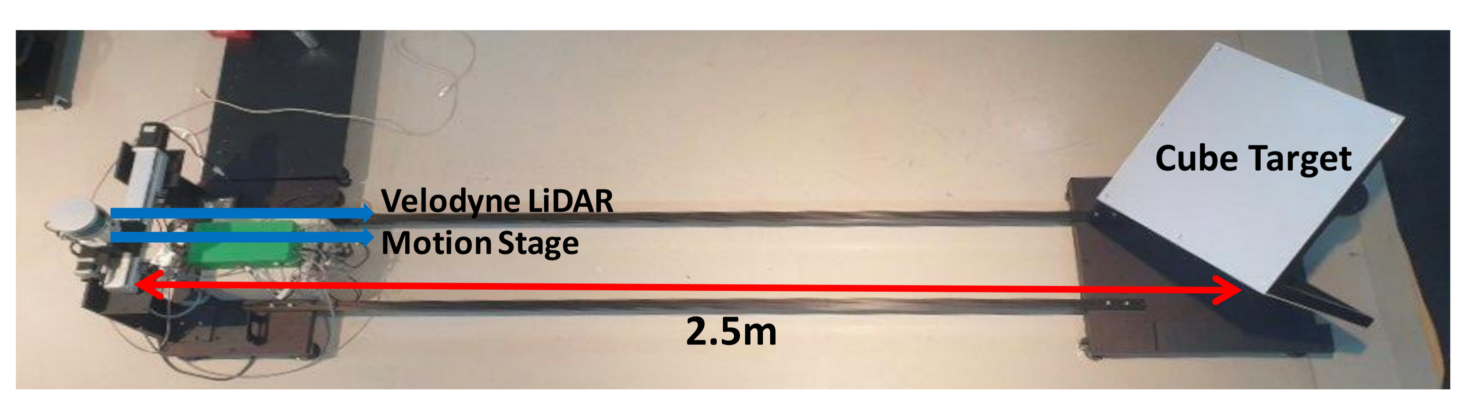
Fig6. Simulation Rotation Result

- Added white Gaussian noise to the simulation data.
- The algorithm is valid as the error falls within the allowable range.

IV. Experiment

- **Experiment Environment**

  LiDAR data: VLP-16 model



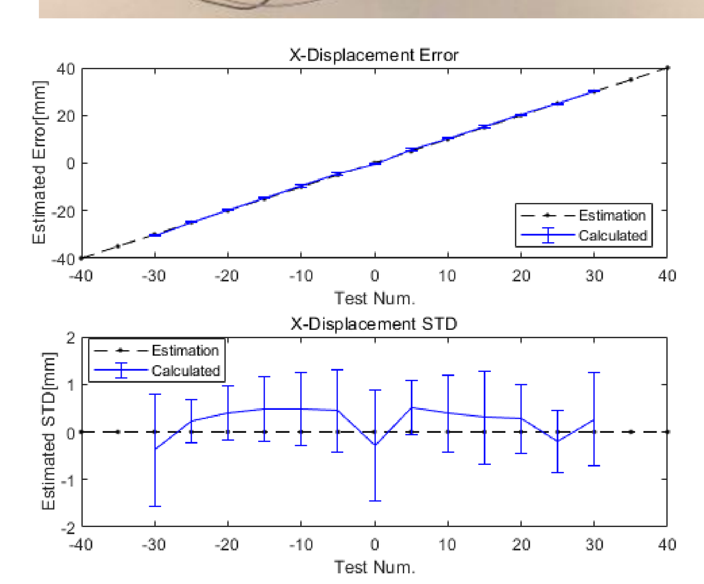


Fig7. LiDAR Translation Result

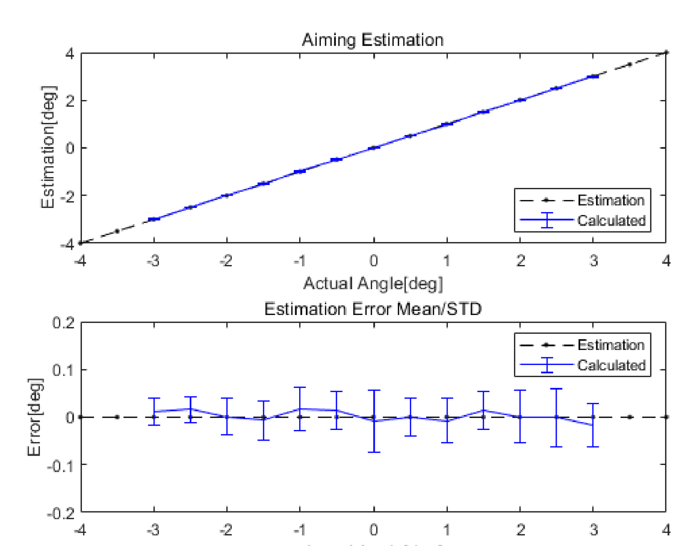


Fig8. LiDAR Rotation Result

Error	X-error		Yaw-error	
	Accuracy	Precision	Accuracy	Precision
Simulation	-0.11 mm	0.63 mm	-0.01°	0.03°
EXP	0.22mm	0.80mm	0.002°	0.044°

Table1. Analysis of Result

- Experiment and simulation have similar error order
- X translation accuracy within 0.22mm, Yaw alignment error accuracy within 0.002deg.
- Even with low resolution LiDAR, algorithm has a high performance.
- Higher than previous method of single plane based.

IV. Conclusion

- Proposed extrinsic calibration has performance of X-trans 0.80mm, Yaw 0.044deg of precision.
- Need to test other translation, rotation alignment errors.
- Improvement of algorithm to find accurate orthogonal planes. Also need to improve target design.
- Application of machine learning and a camera can be considered.