Calibration of 2D LiDAR sensors using cylindrical target

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Introduction

2D LiDARs are widely used in robotics and self-driving systems due to their affordability and accurate distance measurements. When mounted on moving platforms, 2D LiDARs can *approximate 3D scenes* and gather *dense point clouds*, especially when multiple sensors are used. Proper extrinsic calibration of these sensors, however, is critical for accuracy.

During 2D LiDAR – 2D LiDAR calibration we are interested in finding the *rotation* and *translation* between the sensors. Current methods rely on either (i) perpendicular planar surfaces or (ii) sensor fusion with other devices like cameras.

Our Contribution: We propose an alternative *calibration method using cylinders* as the sole target. The elliptical view of the cylinder from the 2D LiDAR can yield the necessary 3D information to perform an accurate calibration.

Calibration method

We capture the cylinder in both sensor's field of view, which will appear as ellipses. From the ellipse parameters, the 3D axis of the cylinder can be calculated. Given at least *three measurements of cylinders* in different orientations, the rotation between the sensors can be calculated.

The 2D nature of the sensors introduces an ambiguity when trying to calculate a 3D rotation as two different cylinders can have the same elliptical view. The ambiguity is solved by reducing the possible rotations to *four candidates (see Figure 3.)*, after which a manual selection is needed.

Once the rotation is known, the translation can be estimated by aligning the cylinder axes with the ellipse centers from both sensors; there exists a least-squares optimal solution.

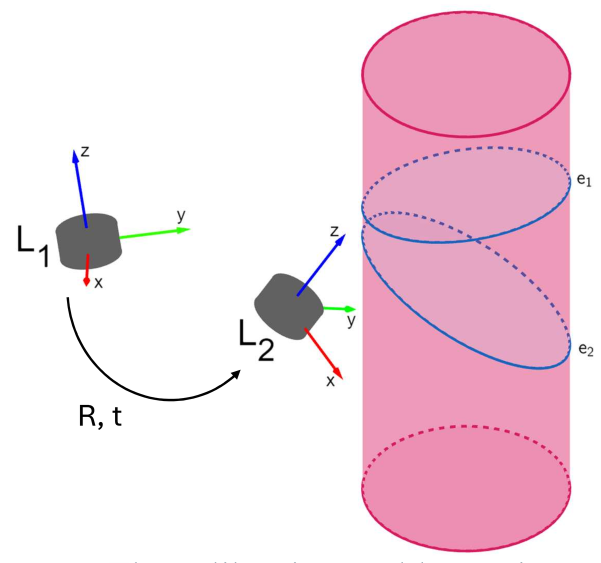


Figure 1. The calibration problem using a cylinder. We are interested in finding the rotation ***R*** and translation ***t*** between the two LiDARs.

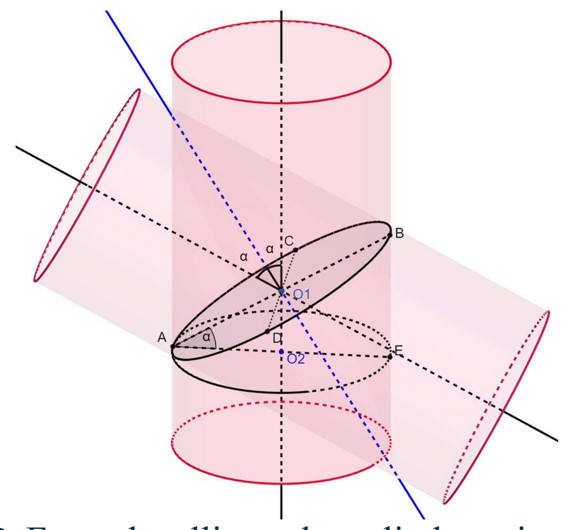


Figure 2. From the ellipse, the cylinder axis can be given, however two cylinders are possible for a given ellipse, which introduces ambiguity.

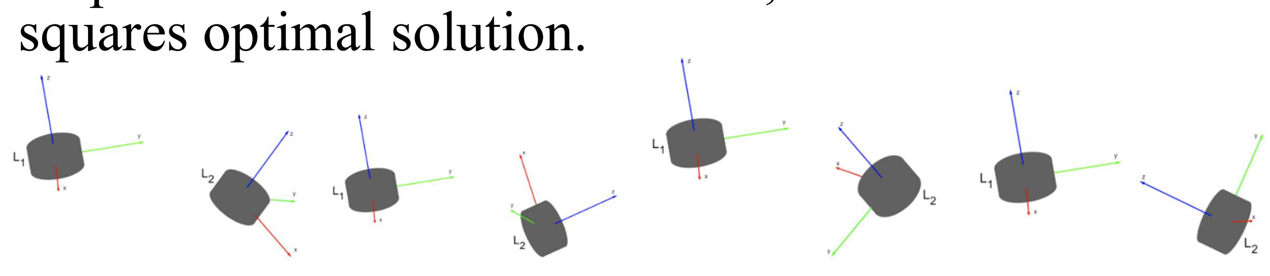


Figure 3. Example of ambiguous solutions of the calibration.

Target cylinder

The quality of the calibration relies heavily on the accuracy of the ellipse fitting. When a solid cylinder is used, only a short arc from the ellipse is visible, which greatly reduces the accuracy. We propose three solutions to this problem by finding a suitable target cylinder:

(i) when *double-returns* are available *on the LiDAR*, a cylinder made from a transparent material can be used, thus getting measurements from the back of the cylinder as well, greatly improving the ellipse fitting accuracy
(ii) when double-returns are not available, a *semireticulate cylinder surface* can be used to measure points from both the back and front of the cylinder (*see Figure 4.*)
(iii) getting the *sensor setup inside a solid cylinder* is the best solution, as we can gather points from almost the whole circumference of the ellipse (*see Figure 5.*)

Figure 4.

Figure 5.

Results

We tested the proposed calibration method on *simulated data* as well as on a *real setup of two RPLiDAR A1M8 sensors*. The real-world results are compared with [1] and [2] on the same setup. The simulated data was generated with multiple levels of noise, at each noise level 21 randomized sensors setups were calibrated.

The error analysis on simulated data can be seen on *Figure 5.*, while *Table 1.* and *Figure 7.* demonstrate real-world comparative-quantitative evaluation. The factory parameters and the CAD measurements of the 3D printed mount (*see Figure 6.*) provide the baseline for comparison.

The proposed method gives accurate results that out-perform the rival algorithms and provides an alternative and reliable way to calibrate 2D LiDARs when no other sensors are available.

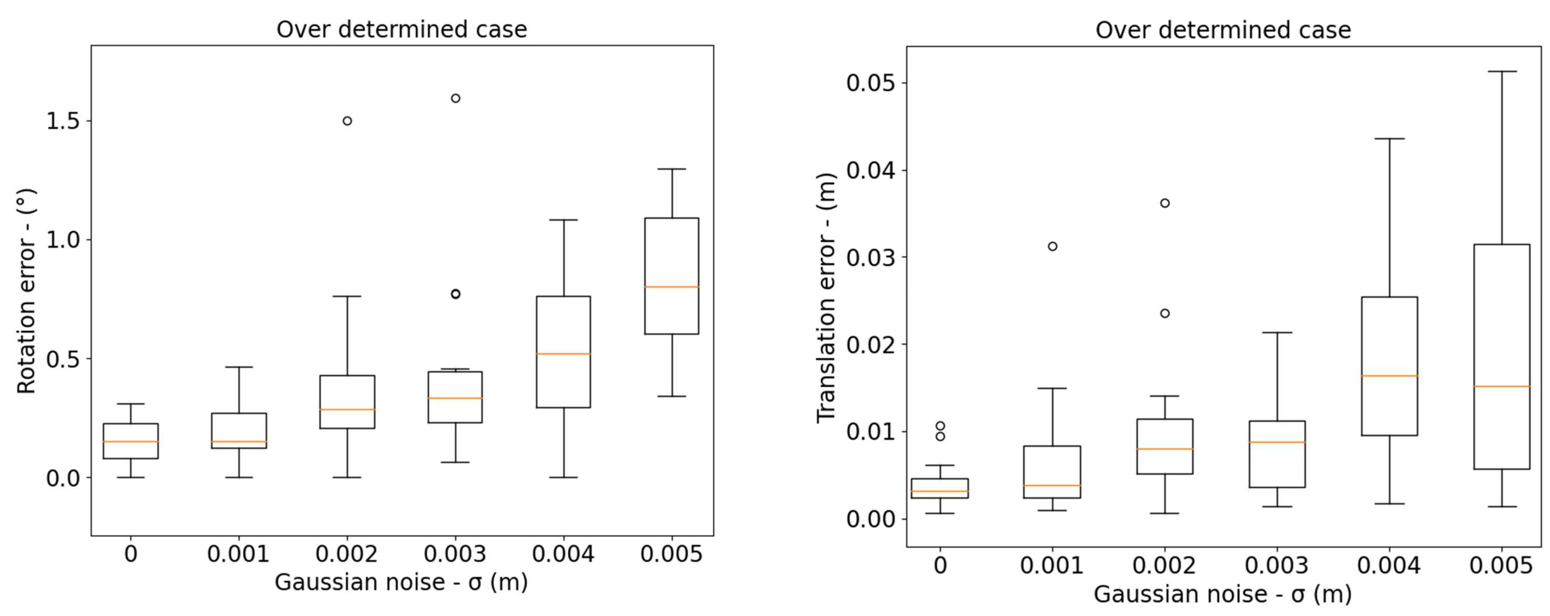


Figure 5. Rotation and translation error of the proposed algorithm on the simulated data with various levels of noise.

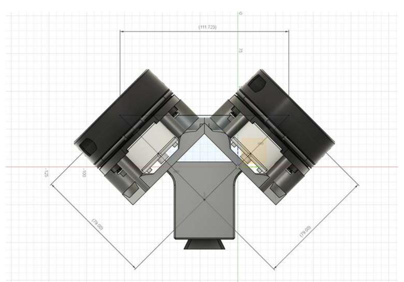
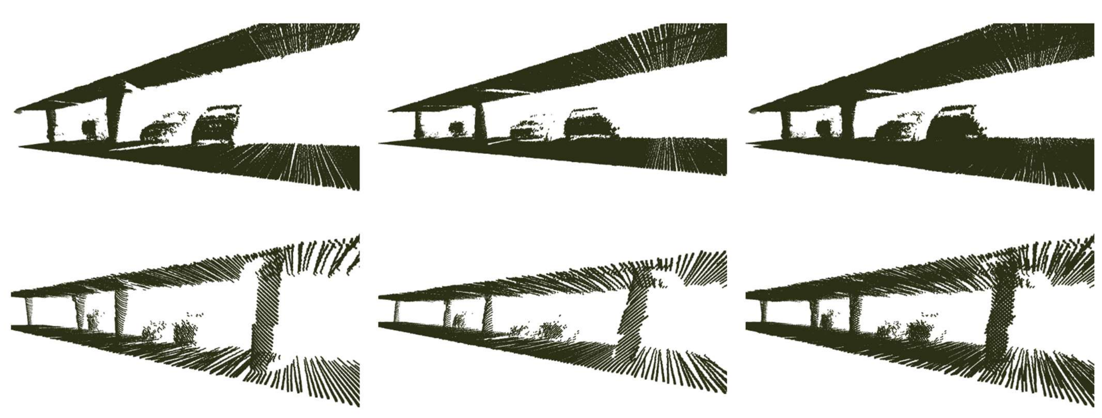


Figure 6.

Calibration results	Rotation error (○)		Translation error (m)
	Min. case	*Over-det. case*	*Over-det. case*
3D printed cylinder (proposed method)	5.3305	4.9234	0.0282
Concrete tube (proposed method)	**3.2252**	**2.8708**	**0.0066**
Choi et al.[1]	5.4517		0.1165
Zhang and Pless[2]	10.91		0.1060

Table 1. Results of the calibration on the real sensor setup. Our method achieves the best results when the sensor setup is put inside a cylinder.



(a) First LiDAR (b) Second LiDAR (c) Both

Figure 7. 3D reconstructions of a garage, containing cylindrical pillars and parking cars. The 2D LiDARs are calibrated by the proposed calibration method.

References

[1] Dong-Geol Choi, Yunsu Bok, Jun-Sik Kim, and In So Kweon. Extrinsic calibration of2-d lidars using two orthogonal planes. *IEEE Transactions on Robotics*, 32(1):83–98,2016. doi: 10.1109/TRO.2015.2502860.

[2] Qilong Zhang and Robert Pless. Extrinsic calibration of a camera and laser rangefinder (improves camera calibration). In 2004 *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), volume 3*, pages 2301 – 2306, 2004.