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Performance evaluation of LiDAR-based position measurement system

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Abstract
Application of laser-based measurement systems such as LiDARs are becoming more common in a wide range of application areas. Many of these applications are sensitive on the performance of the positioning measurements LiDARs. The main objective of this paper is to describe a methodology for performance evaluation of LiDAR-based position measurement system. The proposed approach, based on carried out experimentation, can generally be applicable for LiDAR evaluation for large-scale position measurements. The methodology was developed for the characterization of volumetric error of positioning measurements in a three-dimensional Cartesian coordinate system with the utilization of an external laser tracker. The methodology requires a measurement artifact with a spherical geometry which is inspected from various distances with the LiDAR. The laser tracker measurements are used for validation and verification purposes. This paper presents a case study with the implementation of the proposed methodology for a selected commercially available LiDAR system. Positioning error identification is essential for performance evaluation, the measurement shown in the paper outlines the performance of the selected LiDAR system.

LiDAR, performance evaluation, large-scale metrology, position measurement

1. Introduction

Due to the recent developments in the field, LiDAR technology is gaining more ground in civil engineering, transportation and in many areas of industrial applications. More sustainable cities and safer transport can be supported with 3D scanning that can deliver results quickly. In industrial applications, rugged, reliable and affordable high-resolution LiDAR sensors enable safer and faster automation in the area of mining, agricultural, forestry and so to climate change mitigation, construction and logistics industries [1]. For these applications adequate measurement accuracy based on LiDAR reading is crucial. The main goal of this paper is to develop and demonstrate a methodology to evaluate the positioning performance capabilities of an industrial-grade high resolution LiDAR system.

2. Methodology for performance evaluation

The following section presents a methodology for evaluating the performance of a LiDAR-based position measurement system and its results. In previous research by Lambert et al. [2] has been implemented about performance analysis of LiDARs for automated driving systems, in comparison, this paper concentrates more on the methodology evaluating the short and middle-range positioning capabilities of a LiDAR system. The capabilities of a commercially available low-cost, high-resolution 32-channel LiDAR sensor are investigated in this study by using a Leica AT901 laser tracker as a reference measurement system and a spherical reference object. The radius of the reference object was measured by a coordinate measuring machine (CMM). The surface of the artifact was covered with a thin layer of paint with low reflectivity.
The methodology is realized in a measurement arrangement, where the LiDAR was tilted to different orientations at different distances, in order to explore potential performance inhomogeneities in the near and middle operational range. After the initial arrangement (see Figure 1), first the position and the radius of the measurement artifact was measured by using the laser tracker and Spherically Mounted Retroreflector (SMR) Ball Probes. Only one two-dimensional slice of the operational range of the LiDAR was investigated. This step was based on the assumption that the scanning is performed with the same characteristics in all slices of the cylindrical operational range of the LiDAR. Two conditions were changed in the measurement arrangement during the implementation of the methodology. The first was the distance of the LiDAR from the measurement reference object and the second was the tilting angle of the LiDAR [3], with which the measurement accuracy of the middle and peripheral region was studied. In all positions and orientations, a point cloud was measured with the LiDAR. Data capturing was performed for 10 seconds at a horizontal resolution of 2048 points with 10 Hz sampling on 32 channels.

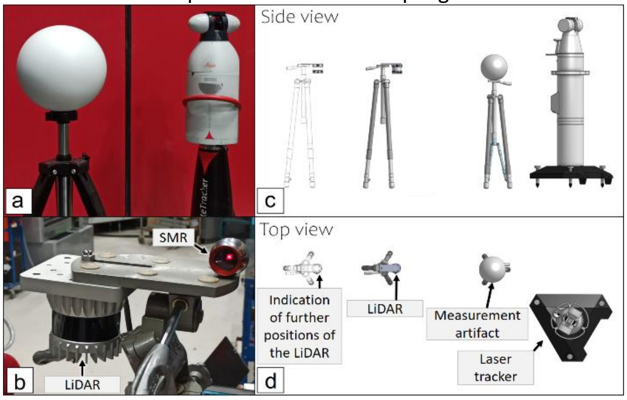

Figure 1. a) The spherical reference object and the Leica AT901 laser tracker b) A commercially available LiDAR mounted on the tilting console with the SMR c) Side view of the measurement arrangement d) Top view of the measurement arrangement

All measuring poses of the LiDAR was recorded with the Leica laser tracker using SMR points in the reference coordinate system. Measurements were made by tilting the LiDAR into the middle and side ranges at a total of 6 different distances. In each step, the actual pose of the LiDAR was determined based on the 3 points recorded on the LiDAR's tilting console using the SMR (as can be seen in Figure 1.). After capturing the measurement data, the agreement between the laser tracker and the LiDAR was evaluated along 3 main aspects: i) the radius of the spherical artifact measured from different distances, ii) the distance between the LiDAR and the measurement artifact, and iii) the position measured in the (local) LiDAR coordinate system compared to the values measured by laser tracker in the global coordinate system.

2.1. Data analysis

In order to quantify the aforementioned three evaluation aspects, the measurement data had to be analyzed. To determine the radius and the center point of the measurement artifact, a point cloud was recorded by moving the SMR along the surface of the spherical reference object for each condition in the measurement arrangement. The resulting point cloud data set in each case was spherically fitted using the method of least squares. The radius and center point are determined from the recorded points by minimizing the following equation: [4]

$$\sum((x-x_c)^2+(y-y_c)^2+(z-z_c)^2-r^2)^2$$

Where x, y, z are the collected data points, x_c, y_c, z_c are the coordinates of the sphere's center, and r is the radius. The center of LiDAR was determined relative to the 3 points. By default, the LiDAR recorded much bigger area than what was necessary for the test. Therefore the point cloud was preprocessed to filter out the surrounding area and only contains the points measured on the measurement artifact surface. In the case of longer distances from where only one channel reached the measurement artifact, and there were not enough points available for a spherical fit, a circle was fitted in the plane of the measured points.

3. Results

The distance, the number of channels or lines, and the relationship between the measured points to the artifact are shown in Figure 2.

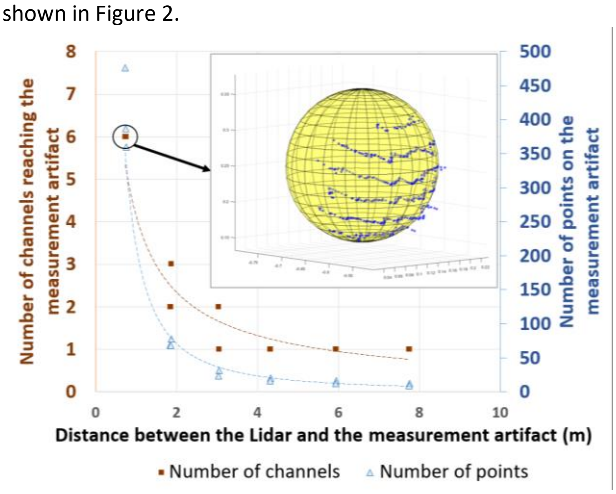

Figure 2. The relation between distance and the number of measured points and number of used channels

The determinability of the radius is highly correlated with the distance, as fewer channels and thus fewer points reach the measurement artifact from a longer distance. It can be seen that from the points collected on a single channel, the determination of the center point during the circle fitting already results in significant method uncertainty. This emphasizes the need to increase the number of channels for applications requiring dimensional measurements of objects in the middle operational range. In the second aspect, where the accuracy of the relative distance measurement was examined, it can be concluded that the independent distance measurement of the LiDAR carries a lower total measurement uncertainty. This is only partially due to the smaller sensitivity on the method uncertainty related to the fitting, and more related to the position measurement for each sampled point on the surface of the artifact. During the third evaluation aspect, when the determination of the position was also evaluated in addition to the distance, it can be seen that the uncertainty of the position measurement also increases in proportion to the distance. The results of the three aspects are presented in Table 1.

Table 1 Summary of measurement errors in case of different test conditions

Range of the field of view	Distance measured by the laser tracker (mm)	Distance error measured by the LiDAR (%)	Position error vector length (mm)	Radius measured by the LiDAR (mm)	Radius error measured by the LiDAR (%)	Number of sample points
Upper	734.88	-4.20	31.00	100	-8.2	476
Lower	751.94	-4.69	56.98	93	-16.0	360
Middle	744.83	-3.33	31.47	108	-0.8	387
Upper	1846.50	-1.82	70.06	98	-10.8	69
Lower	1867.50	+0.42	91.88	106	-1.9	78
Middle	1854.70	-0.85	22.35	99	-9.5	68
Lower	3056.70	-1.92	176.29	106	-2.0	31
Middle	3041.20	-0.15	12.51	114	+5.0	23
Lower	4332.80	-0.84	210.45	88	-22.8	20
Middle	4316.10	-2.92	139.93	104	-4.5	16
Lower	5954.20	-0.62	290.89	105	-2.8	16
Middle	5938.80	-0.27	27.25	109	+0.7	12
Lower	7758.70	-0.28	363.05	102	-6.5	12
Middle	7744.60	-3.31	258.94	170	+36.3	9

4. Summary, Conclusion

The presented methodology can provide a basis for assessing the position measurement accuracy of LiDAR devices and explore performance inhomogeneities based on relative distances and orientations in the operational range of any LiDAR system. The methodology was implemented on a commercially available LiDAR.

The method can be further developed using a larger measurement artifact to capture more points from a greater distance. This study does not cover the examination of the fit goodness of the LiDAR coordinate system as only one reference object was used, which does not give enough points to examine the fit of coordinate systems properly. This requires additional objects placed at different points simultaneously in the operational space.

References

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