Basic Experiment of LIDAR Sensor Measurement Directional Instability for Moving and Vibrating Object

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Abstract—In this paper, a basic study on directional instability of measured data in a vehicle equipped with a LIDAR sensor. To realize autonomous car control without human, it is important to estimate the correct current position and it would be measured by LIDAR device generally. The difficulty in the process is the angle estimation. In rotational motion, all points in the point cloud data shift to different distances and directions, making the estimation unstable.

We improved ICP to remove the instability of angle estimation. One is the two-sided search method, which improves the way points correspond in ICP. The other one is to convert the shape data (point cloud data) to the r-θ coordinate system so that the point cloud can easily obtain the best correspondence. We conducted estimation using point cloud data that imitate a road with fences placed on both sides. As a result, the range of accuracy within 0.1 degrees of the estimation error for the two-sided search method was 0.63 times larger than that for ICP. Similarly, in the case of ICP in the r-θ coordinate system, the result was 1.76 times larger. An analysis of the evaluation function E revealed the reason why the two-sided search method did not estimate well. It was because each point prevented the selection of the correct correspondence.

These results indicate that ease of response is important in self-location estimation. However, the r-θ coordinate system is not suitable for estimating movement, we would like to improve it so that it can be used in all situations.

Keywords—ICP, LIDAR, self position estimation

I. INTRODUCTION

In this paper, a basic study on directional instability of measured data in a vehicle equipped with a LIDAR sensor. Government and companies cooperate each other and the technology development of automatic driving is progressing actively for the aim of practical application by 2020[1,2,3]. To realize autonomous car control without human, the correct current position estimation (localization) is an important factor, and it would be measured by LIDAR device generally[4,5,6]. LIDAR (Light Detection and Ranging) is used as an important device for recognizing surrounding environment like human

the farther away from the center of rotation, the easier it is for errors to be included. As Fig. 1, basically, the estimation of the rotation angle (B) is a difficult calculation than the x-y positional estimation (A).

Fig. 1. The point cloud data when it is rotated. Comparing with the positional estimation of x-y (a), when the rotation angle changes, the farther away from the center of rotation, the more easily to include the error (b).

Fig. 2. Difficulty of rotation angle estimation process by using ICP algorithm.
In previous study, the localization methods which are robust against the influence of sensor noise and past estimation errors by using the improved scan matching techniques and a probability estimation that take into account the errors have been proposed and developed[7,8,9,10]. In those studies, the LIDAR sensor output's disturbance have been treated as uniform "noise", and it have not been taken into account the factor of movement direction of the sensor itself for example.

The aim of this study is firstly to measure the dependency of the target object movement direction by the rotation angle \( \theta \) estimation calculated by ICP (Iterative Closest Point) algorithm. The reason of using the rotation angle \( \theta \) as the evaluation function is that the variable with the large influence on the accuracy of self position estimation is the rotation angle \( \theta \)[10,11,12].

Our approach to this problem is summarized in Fig. 2. If we use the ICP method only (Fig. 2a), the phenomenon that corresponding points are concentrated on one point occurs in most cases. To avoid the concentration, we generally adopt a method that does not use the corresponding points once used. However, not using the points once used, an order problem occurs in the calculation of candidate points (Fig. 2b, red colored number 1,2,3...). Since not using the points once used, the starting point of the candidate points affects the localization result as a result. In our approach, in order to enable the search of highly valid candidate points, we have a developed a method to improve the accuracy by calculating the corresponding points not only one direction but also from the opposite direction (Fig. 2c, the red colored number 1,2,3...), and we named this method "two-sided search method.

In addition to this, we focused on the ease of correspondence of the points. Fig. 3 shows the conversion of point cloud data expressed in the x-y coordinate system to the r-\( \theta \) coordinate system. The vertical axis is distance from the center and the horizontal axis is the initial angle \( \theta \). Using point cloud data converted to the r-\( \theta \) coordinate system for ICP enables easier and more accurate angle estimation.

\[ E(R, T) = \sum_{i=1}^{m} | \tilde{a}_i - (R(\theta)\tilde{a}_i + T)|^2 \]  
\[ R(\theta) = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \]  

where \( \tilde{a}_i \) is the previous measured point set represented as (x,y) coordinates, and \( \tilde{a}_i \) is the present measured point data set. \( R \) means the rotation matrix. The rotation angle \( \theta \) was estimating by minimize the evaluation function E by simple Euler method.

Basically, the order of \( \tilde{a}_i \) are defined by the rotation direction of LIDAR, such as right or left. In our process, the matching order i is 1,2,3... in forward order, on the other hand, m, m-1, m-2, ... in reverse order if the maximum point number is m. The two-sided search method estimates in forward and reverse order, respectively, with no duplication of the correspondence points.

Fig. 4 is a simulation of the measurement of point cloud data. It shows a road with fences on both sides, and the blue circle in the center represents the LIDAR-equipped robot. The robot detects the wall as points by irradiating rays of light around it and obtains point cloud data as shown in Fig. 5. The red point cloud data is the original data, and the green point
cloud is a plot of the original data rotated by $\theta$. We conducted an estimation experiment using it. As experimental condition, we used:

1) Simple ICP matching allowing duplication of the correspondence points.
2) ICP with the order (1,2,3...) and (m,m-1,m-2...), respectively, not using the points once used, and adopt the one with the better result.
3) Replace the point cloud data in the $r$-$\theta$ coordinate system and use a simple ICP to estimate the rotation angle.

Change the initial value of rotation angle $\theta$ from -180 deg to 180 deg at 0.1 deg intervals. The angular resolution of LIDAR is 1 deg intervals. Each point contains 1% noise for the distance $r$ from the center. Measure the estimation error of rotation angle and the value of the evaluation function $E$ when the theta is changed.

IV. RESULT

A. Angle Estimation with ICP

The results are shown in Fig. 6. In Fig. 6 (a), horizontal axis shows the initial rotation angle (green in Fig. 4), vertical axis is the estimation angle difference from the original position. If the values on the vertical axis converge to 0deg, then the estimation is correct. This shows that the correctly estimated range was -51deg to 51deg. Compared with Fig. 6(b), $E$ took a minimum value when the initial rotation angle $\theta$ was 0deg and 180deg, and became hollow in the range of 52deg to 125deg.

B. Angle Estimation with Two-Sided Search Method

The results are shown in Fig. 7. The correctly estimated range was -32deg to 32deg. In Fig. 7(b), the graph has a hollow shape at around 90deg, as in ICP. However, unlike ICP, the waveform is unstable. The two-tailed search method did not achieve the expected results. Fig. 7(b) shows that the waveform of $E$ is disturbed, and the estimation ends at the hollows caused by this. Observing the estimation, the two-sided search method tends to shift the correspondence of multiple points at the same time, which cause of the waveform disturbance.
C. Angle Estimation with ICP in r-θ Coordinates

The results are shown in Fig. 8. The range of correct estimation was -90deg to 90deg, which was the best performance among the experiments conducted. The shape of the E waveform was nearly a triangle, with maximum values exactly at 90deg and -90deg. ICP estimates E with a simple linear distance, but when estimated in the r-θ coordinate system, the corresponding line draws a curvilinear trajectory in the x-y coordinate system. In other words, the distance what point traveled can be calculated. Therefore, it is thought that it is possible to detect that the distance traveled at 90deg is larger than that at 52deg.

![Fig. 8. Results of angle estimation by ICP in the r-θ coordinate system.](image)

D. Conclusion

In this paper, a basic study on directional instability of measured data in a vehicle equipped with a LIDAR sensor. In some cases, the two-sided search method give better results than ICP, but basically, ICP give better results when the number of points was sufficiently large. These results indicate that ease of correspondence is more important than correct correspondence. In the future, we will adopt parallel translation estimation and conduct experiments including actual measurement data.

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