DEVELOPING A METHOD FOR ROBUST CO-REGISTRATION OF POINT CLOUDS OF CURVED SURFACE IN CURVED ROAD

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ABSTRACT : In this paper, we present a method that achieves accurate and robust co-registration of multi-temporal point cloud data of curved surface. One of the most popular methods for the purpose is Iterative Closest Point (ICP) algorithm. Although the ICP achieves accurate co-registration with good initial parameters, it creates a low accuracy of results in case there are some occlusions or large initial gaps. In this paper, we improved the method we previously proposed for implementing a robust co-registration even in the areas that have curved surface objects. The proposed method estimates the local and relatively global normals of point clouds. Then, by comparing the histograms of two point clouds, relative rotation angles are estimated. At this stage, a rough co-registration is completed. Finally, the ICP method is implemented and consequently, the accurate co-registration is achieved. In the experiment, we used terrestrial light detection and ranging (LiDAR) and measured the point clouds with curved walls. The proposed method generated acceptable root mean square error (RMSE), and it was demonstrated that the proposed method is applicable to various types of urban areas. Consequently, it is concluded that the proposed method is capable of automatic and efficient for investigating road condition via co-registration of temporal point clouds.

1. INTRODUCTION

It has passed over 50 years since public infrastructures constructed in high economic growth period in Japan, and they need periodical investigation for maintenance. Above all, road is one of the most important infrastructures in terms of number and function. In reality, it is not practical to frequently investigate the condition of all the roads due to the limited time and cost. On the other hand, mobile mapping system (MMS) became more and more popular these years. MMS can obtain huge amount of point clouds of roads and around within a short time. If co-registration of multi-temporal point clouds in the same area measured by MMS is successful, it becomes possible to detect the deformations such as ruts or cracks on the roads by measuring the difference of road surface height. Therefore, MMS is capable of specifying the area that needs maintenance.

The Iterative closest point (ICP) algorithm is probably the most popular among methods of co-registration. The ICP is a method that converts Point Cloud 1 (PC1) iteratively to minimize the sum of squares of distances between two corresponding points, that is determined by searching the closest point of Point Cloud 2 (PC2) for each point of PC1. The ICP algorithm achieves co-registration with high accuracy in case of a good initial condition. On the other hand, it is clear that the ICP has some weaknesses that it needs to be set initial parameters of conversion matrix, and that its accuracy decreases extraordinary in case there are some lacks of points or large initial gaps.

Our research group has studied co-registration of point clouds for a long time, and has achieved accurate co-registration of point clouds using vertical planes (Susaki and Deguchi, 2016). However, in their study, two certain assumptions of the directions of walls are necessary. One is that walls are perpendicular to the ground surface, and the other is that the normals of walls exist only along two dominant directions intersecting perpendicularly. With their assumptions, co-registration can't be achieved in case of areas with curved road or walls that have curved surface. Considering their problem, in this paper, we propose an algorithm to achieve accurate co-registration in the area with walls of curved surface, referring to their method. First, the similar way of them, rough co-registration is attained by using both global and local normals of ground and wall points. Second, precise co-registration is achieved by the ICP method after extracting common area of two point clouds.

In this paper, Chapter 2 explains the way of co-registration of point clouds in the curved surface, and used data are in Chapter 3. Chapter 4 shows the results and its considerations, and lastly, conclusions and future works are shown in Chapter 5.

2. PROPOSED ALGORITHM

The flowchart of the proposed method is shown in Figure 1. It is divided into two stages. In the first stage, correction of direction and position is roughly accomplished by using the local and relatively global normal vectors of planes. After that, in the second stage, the more accurate co-registration is achieved by applying the ICP algorithm.

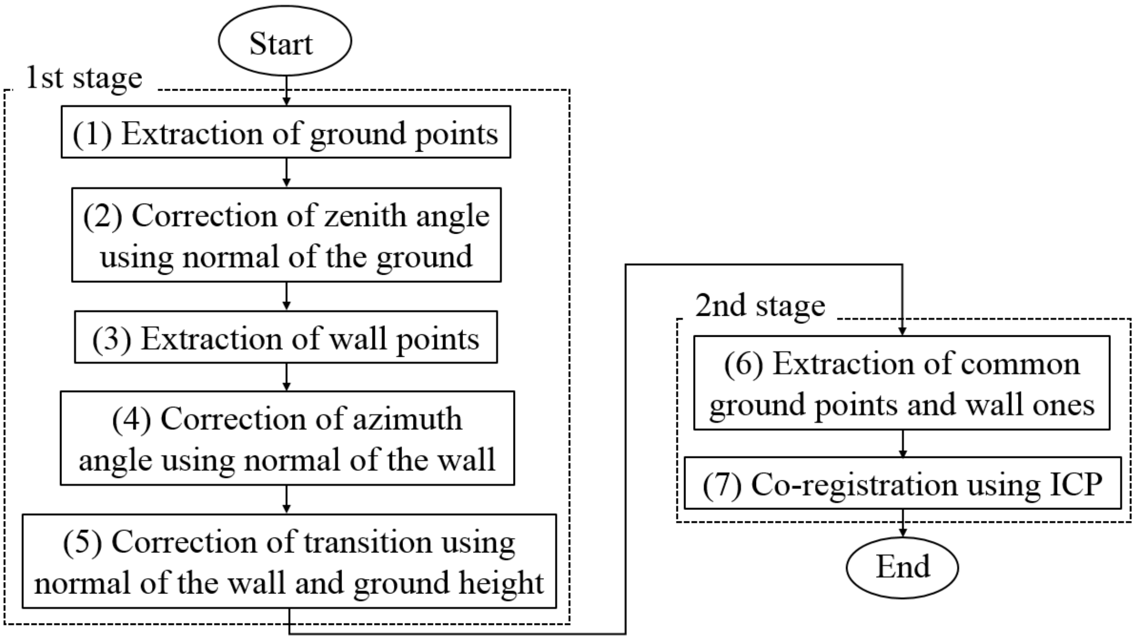

Figure 1 Flowchart of the proposed algorithm

First, extraction of ground points is accomplished in order to correct zenith angle. The whole point clouds are divided into voxels, and Root Mean Square Error (RMSE) for estimating plane is calculated in each voxel. The largest plane area is extracted as ground surface by applying region growing method to voxels that are considered to be plane. Then, the normal vector of the ground is estimated, and rotation angle α, that transfers the normal of the ground to positive direction of the z axis, is estimated and applied to both PC1 and PC2 to correct zenith angle (Figure 2). Next, only PC1 is corrected its azimuth angle (Figure 3). In Figure 3, PC1 is shown as broken lines, and PC2 is shown as solid lines.

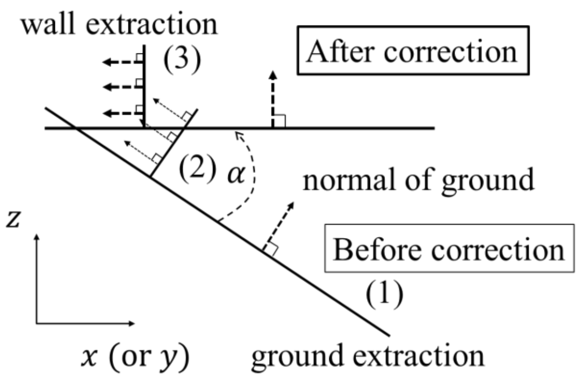

Figure 2 Correction of zenith rotation

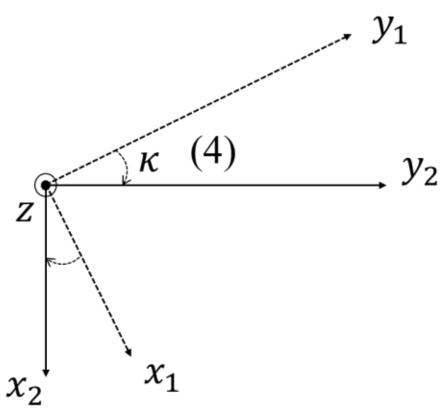

Figure 3 Correction of azimuth rotation

Points in the voxels that have zenith angle of normals around 90º are extracted as wall points, from voxels that are considered to be plane, but not to be the ground. “Around 90º” aims at extracting all wall points considering the case that ground or wall points have some slopes. Wall points estimated by this process can be regarded as 2-dimentional point clouds by observing from the positive direction of the z axis. Accordingly, walls with curved surface are considered to be curved lines. Then, reference points are set at regular intervals on this curved line, and a histogram is produced by calculating directional angles from each reference point to another ones. These processes except azimuth angle correction are applied to both two point clouds. κ, a rotation angle around the z axis, is estimated by minimizing the sum of squares of errors of these two histograms of PC1 and PC2 (Figure 4). The equation is shown in (1), where $P_1(\theta)$ denotes the probability of normals of walls in PC1, and $P_2(\theta)$ denotes that in PC2.

$$\kappa = argmin\ f(x)$$
$$f(x) = \sum_{\theta=0}^{2\pi} \{P_2(\theta) - P_1(\theta - x)\}^2 \tag{1}$$

Applying κ to only PC1, the rotation angle around the z axis of two point clouds is roughly corrected. In addition, directional angles of normal vectors on the reference points of walls are calculated both in PC2 and in rotated PC1. Figure 5 is produced by plotting these directional angles and coordinates of x (or y) of reference points. Then, tx and ty, that are x and y component of parallel transition terms, are estimated by minimizing the sum of squares of errors (2). In equation (2), $S_j(i)$ describes the slope of normal when x coordinate is i in point cloud j. ty is also calculated in the same way. Red shows PC1, that will be transferred, and green shows PC2 in both Figure 4 and Figure 5. Lastly, in reference to the parallel transition along the z axis, the same process as Susaki and Deguchi's is applied. Ground points of both PC1 and PC2 are divided into grids, and the difference of heights is calculated in each grid to estimate tz, the z component of parallel transition terms. These parallel transition terms are only applied to PC1. This is the end of the first stage.

$$tx = argmin\ g(x)$$
$$g(x) = \sum \{S_2(i) - S_1(i - x)\}^2 \tag{2}$$

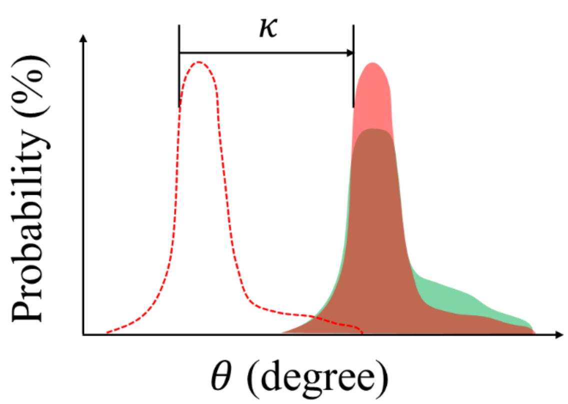

Figure 4 Determination of rotation angle around z axis κ

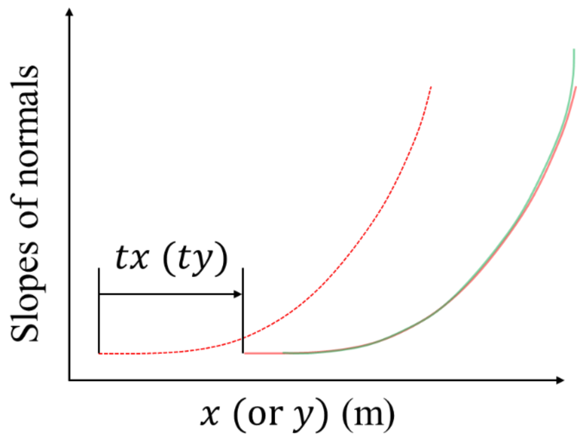

Figure 5 Determination of parallel transition terms of x (y)

Next, in the second stage, accurate co-registration is achieved. The common area of only ground and wall points of two point clouds are determined. Considering the time for calculation, point clouds are sampled the same way as preprocess. Then, the ICP algorithm in a Point-to-Plane mode is applied to sampled point clouds, and co-registration of proposed method is completed.

3. DATA USED

We selected curved road in Katsurazaka area, Nishikyo-ku, Kyoto city, as our study area so that we verify the availability of proposed method for co-registration using curved surface (Figure 6). In this area, about 80 m long wall with a little rough curved surface is available. The proposed method does not need the assumptions of Susaki and Deguchi's about the directions of walls, because there are vertical planes with normals of several directions. In addition, road has about three-degree gradient in this area.

We did measurement using Riegl VZ-400, a terrestrial Light Detection And Ranging (LiDAR) in the afternoon of June 8, 2017. The measurement range was from 30º to 130º of zenith angle and 360º of azimuth angle. The interval angle for the measurement was set to 0.04º for both zenith and azimuth angle. In the measurement, the LiDAR was set up at different two points. Cylindrical reflectors with a diameter of 5 cm and height of 5 cm were also set. Central coordinates of these reflectors could be obtained with high accuracy using the LiDAR. The proposed method was assessed its accuracy by RMSE, using coordinates of 11 reflectors.

The number of points measured by the LiDAR was more than ten millions. Appling this algorithm to this number of points is not practical due to long time for calculation, in spite of the accuracy. In addition, the density of points changes depending on the distance to the LiDAR. The point clouds were sampled so that calculation time is shortened and the density of points is enhanced its uniformity (Table 1). The way of sampling is that whole point clouds are divided into voxels of 3 cm in each side, and point clouds are reconstructed by the center of points in all voxels. Additionally, only PC1 was given an initial transition artificially in order to examine an availability of the proposed method. In this study, rotation angles were set to be 30º along the x, y, and z axes, and parallel transition terms were set to be 10 m along the x, y, and z axes (Figure 7).

Table 1 The number of points used before and after preprocess

State	Point cloud 1	Point cloud 2
Before preprocess	13,991,049	14,824,225
After preprocess	2,929,091	3,019,883

Figure 6 Study area

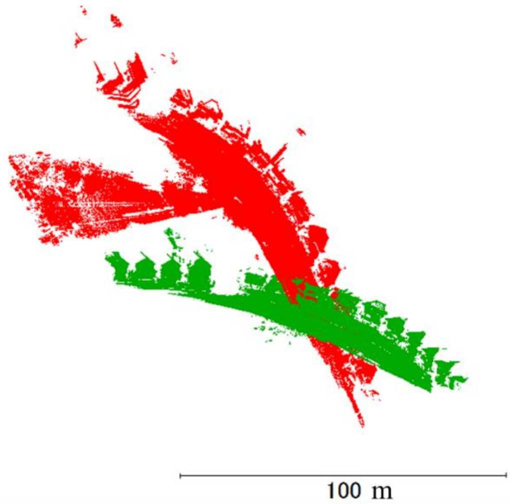

Figure 7 Point clouds after preprocess, red shows point cloud 1 and green shows point cloud 2

4. RESULTS AND DISCUSSIONS

First, ground points were extracted from both PC1 and PC2. In the calculation of the RMSE for estimating plane, the voxel size was set to be 0.5 m in each side and the maximum RMSE was set to be 0.02 m. Then, ground points were corrected to be horizontal using the normal vector of the ground. Next, the range of zenith angle of normals of planes for extracting walls was set to be 70º to 110º. Accordingly, wall points were extracted from voxels that were plane but not the ground, and had a certain zenith angle. Figure 8 shows all walls observed from the positive direction of the z axis. According to Figure 8, walls of houses and walls with curved surface were successfully extracted. Next, a histogram of correction of azimuth angle κ was created using the largest and most continuous wall (Figure 9). In Figure 9, the horizontal axis shows directional angles calculated from one reference point to another, and the vertical axis shows the probability of each directional angle. In creating histogram, the reference points were set at a certain interval of 1 m from end to end in order, probabilities of normals of walls were counted in every 0.1°, and κ was calculated also in every 0.1° in equation (1). Then, parallel transition was corrected along the x, y, and z axes in order. The component of parallel transition terms tx was estimated using the distribution of local normals of reference points on azimuth corrected wall and coordinates of x on these points. Parallel transition along the y axis was also estimated in the same way. These estimations are shown in Figure 10. Estimation of parallel transition for the z axis was calculated using Susaki and Deguchi's method, and processes of the first stage were completed. The RMSE of the first stage is shown in Table 2. This shows RMSEs by way of "average $\pm$ standard deviation" of five trials. According to Table 2, rough co-registration of RMSEs less than 1 m was achieved in the first stage.

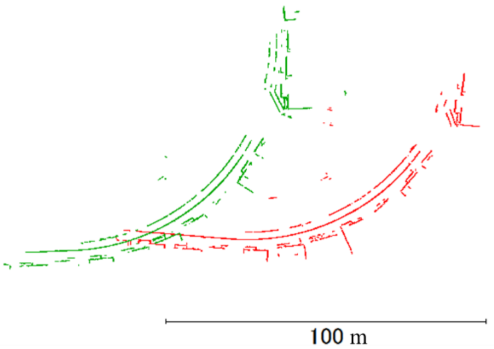

Figure 8 Wall points observed by positive direction of the z axis.

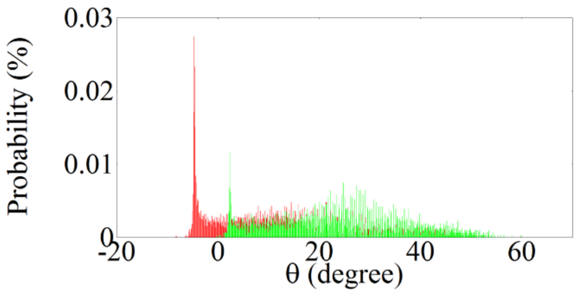

Figure 9 Histogram of correction of azimuth angle

In the second stage, the ICP algorithm in a Point-to-Plane mode was applied to the common area extracted from ground and wall points of both PC1 and PC2. Figure 11 shows the condition of point clouds after the second stage. RMSEs were also shown in Table 2. The accurate co-registration of RMSEs less than 10 mm was successfully achieved in the second stage. For your reference, RMSEs calculated before preprocess were also shown in the same table.

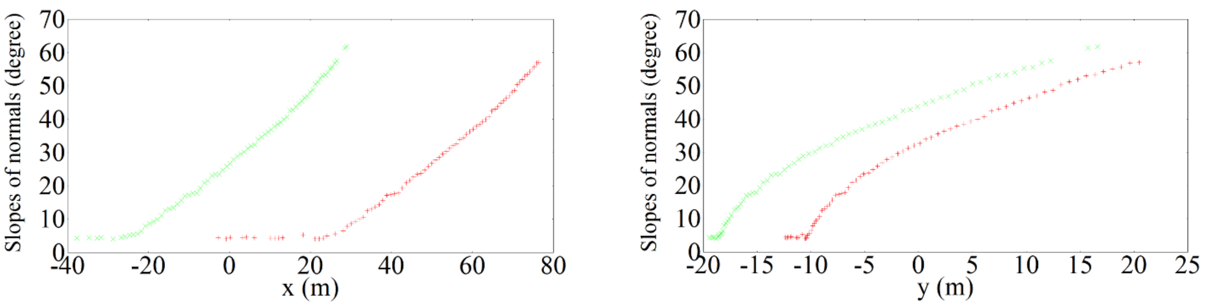

Figure 10 Calculation for parallel transition terms, left shows x and right shows y.

Table 2. Accuracy assessment

Status	RMSE (mm)	Component		
		x	y	z
Before process	56,756.02	24,905.29	31,449.90	40,148.18
After 1st stage	369.43±282.38	276.71±328.62	112.57±45.51	142.73±57.18
After 2nd stage	7.28±1.43	4.10±1.22	5.65±0.98	1.90±0.56

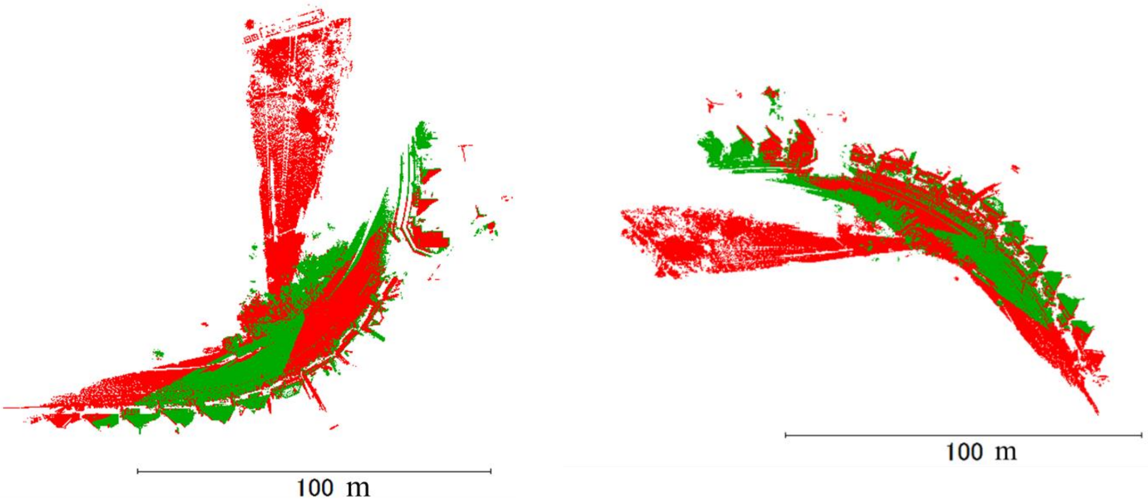

Figure 11 Point clouds after applying proposed algorithm

5. CONCLUSIONS

In this paper, we presented an algorithm that achieved accurate co-registration even though in the areas that have curved surface objects. In the first stage, co-registration was roughly achieved with RMSEs less than 1 m. Additionally, in the second stage, accurate co-registration was succeeded with RMSEs less than 10 mm using the ICP method in a Point-to-Plane mode. The proposed method was proved to achieve accurate co-registration without assumptions of directions of walls, and even in the case that two point clouds have large initial gaps. The final distance of this study is to help the maintenance of road by detecting the deformations such as ruts and cracks after applying the proposed method to multi-temporal point clouds of roads obtained by MMS. Thus, it is left as future work to verify the availability of this method to detect deformations when applied to the areas that have some deformations. In addition, to examine the proposed method in other areas that have curved surfaces and without it, to verify whether this method can achieve co-registration in case there are some pedestrians or parked vehicles, and to examine if this method is available to point clouds obtained by MMS, are also important problems for near future.

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