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Comparison of NDT and ICP Method's point cloud registration performance

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ABSTRACT

The point cloud registration approaches are the key problem for three-dimensional reconstruction in reverse engineering, computer vision, cultural heritage and other fields. The Iterative Closest Point (ICP) is widely used in registering of point clouds in various fields of application. Furthermore, the performance of the Normal Distribution Transform (NDT) method directly depends on the selected cube cell size for the data. Choosing the optimum cell size is a challenging problem and there is no proved way for all cases. However, NDT has several advantages over ICP for data storage and speed. The main purpose of the study is to investigate the performance of NDT and ICP algorithms on point cloud registration. For this purpose, a sample dataset was used for comparative assessment. In the study, the fine registration analysis carried out for two different initial distances between point clouds as 10 cm and 5 cm. According to the results, NDT algorithm produced slightly lower root mean square error (RMSE) value for 10 cm initial alignment distances than ICP method while the ICP method produce lower RMSE value for 5 cm initial alignment distance. However, the calculated mean distances between the point clouds after registration demonstrate that the NDT method provides better results than the ICP method for this test data.

1. INTRODUCTION

Point clouds produced by Lidar (Light Detection and Ranging) or photogrammetric measurement methods are used in many 3D modeling studies. However, the point cloud registration approaches are essential steps in the integration of multi-platforms data (Cheng et al., 2018).

A registration process consists of two main steps: initial alignment (Initial registration) and fine registration (Yoshimura et al., 2016). Registration steps are for producing of 3D absolute modeling. So many scans of the object are required and these scans need to be registered for accurate modeling. However, fine registration starts after the coarse initial registration to achieve more accurate registration of the point clouds (Fangning and A. Habib, 2016). A fine registration procedure can be segmented into four sections and the most important part is a successfully performed initial registration (Fangning and A.Habib, 2016). Second step is the selecting of corresponding points, third is the estimation of transformation parameters between point clouds and last step is RMSE calculation according to threshold or given iteration number. The most widely used registration point cloud algorithm is the iterative closest point (ICP) that was first proposed by (Besl & McKay, 1992). It searches for the optimal matching of two point clouds by constantly searching for the optimal rigid body transformation matrix. However, if the initial position of point cloud data set varies greatly, ICP algorithm can fall into the local optimal solution. A new point cloud registration algorithm based on the NDT method can be used for special cases (Biber & Straßer, 2003; Magnusson, 2009).

In this study, ICP and NDT algorithms were analyzed in terms of RMSE and, the "cloud to cloud" mean distances after registration was compared. Also, Sample point cloud data in Matlab environment was used to compare the two fine registration algorithm.

2. METHOD

Iterative Closest Point (ICP) algorithms and its variants are often used for the fine registration (Besl & McKay, 1992). However, another preferred method for the registration problem is the 3D least squares surface matching (Gruen & Akca, 2005). The method depends on Least Squares 2D image matching. Magnusson et al. 2009

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used NDT to register 3D point clouds. The advantage of this method is that it does not need to find the corresponding point, because it uses a set of Gaussian distribution to describe the point cloud.

2.1. ICP

ICP technique has many variations in point cloud studies. But, in the description of the main algorithm (Besl & McKay, 1992), a "data" shape P is registered to be in best alignment with a "model" shape X .(Besl & McKay, 1992)

The distance "E" between a single data point $\vec{p}$ and model point $\vec{x}$, belongs to point cloud model X, is shown as below (Equation 1) :

$$E(\vec{p}, X) = \min_{\vec{x}\in X} = \|\vec{x} - \vec{p}\| \quad (1)$$

The closest point in X that yields the minimum distance is represented. After calculating the closest point, the nearest points are calculated for each point in P according to the corresponding point Y. The least squares registration is computed with Q operator as described below (Equation 2):

$$(\vec{q}, E) = Q(P, Y) \quad (2)$$

The positions of the aligned point set are updated by applying the registration vector to the point set P. The iteration is initialized by adjusting P_0 = P. The registration vectors are defined according to the initial points P_0 so that the final registration represents the 3D absolute transformation.(Besl & McKay, 1992)

The algorithm proceeds as follows:

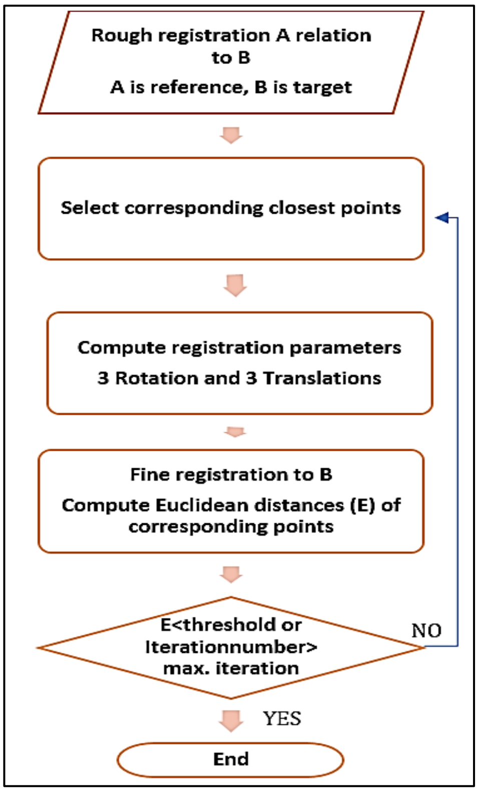

Figure 1. ICP algorithm process steps

When the RMSE change falls below a predetermined threshold ("t">0), it ends the iteration to indicate the desired sensitivity of the recording: $E_k - E_{k+1} <$ "t". (Figure 1)(Besl & McKay, 1992)

2.2. NDT

The three-dimensional point cloud model is divided into cube cells with equal shape and size in NDT approach. Each cell contains at least six point cloud data and the distribution of point clouds for each cell estimated by normal distribution method by following equation (Magnusson, Nuchter, Lorken, Lilienthal, & Hertzberg, 2009).

$$P(x) = -\frac{1}{c}\exp\left[-\frac{(x-q)^T C^{-1}(x-q)}{2}\right] \quad (3)$$

Once the two point clouds to be matched are obtained, the first transformation matrix T is calculated using the odometer reading method, and then the data in the target point cloud can be converted into the reference point cloud by rotating the transformation matrix T (Equation 4). The probability distribution of each point to be matched is evaluated as the fraction value of each coordinate transformation parameter T by following formula.

$$s(p) = \sum_{i=1}^{n} \exp\left[-\frac{(x_i - q_i)^T C^{-1}(x_i - q_i)}{2}\right] \quad (4)$$

Where c is a constant and is determined by requiring that the probability mass of p equals one within the space spanned by a cell, x represents the point in the cube cell, q is the mean vector of points in the cube cell and C represents the covariance matrix of points (Equation 3&4).

3. RESULTS

In the case study, in order to evaluate the registration accuracy, two different initial alignment distances between point clouds as 10 cm and 5 cm were determined. The sample dataset in Matlab software was used in the study and the dataset was given in Figure 2. The performance of the algorithms was evaluated in terms of point to point cloud distances for two different initial distances. Moreover, the RMSE values of the registration process was also evaluated in order to determine the performance of both algorithms.

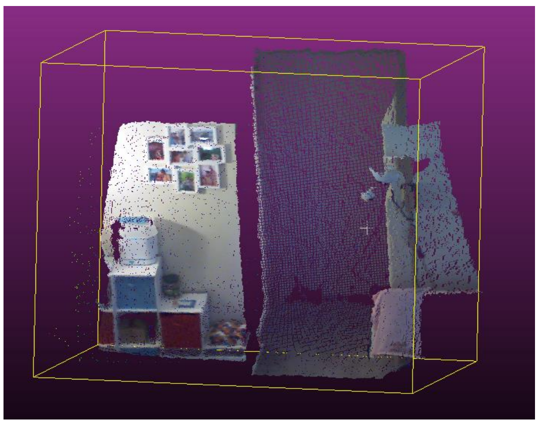

Figure 2. Living Room Point Cloud in Matlab

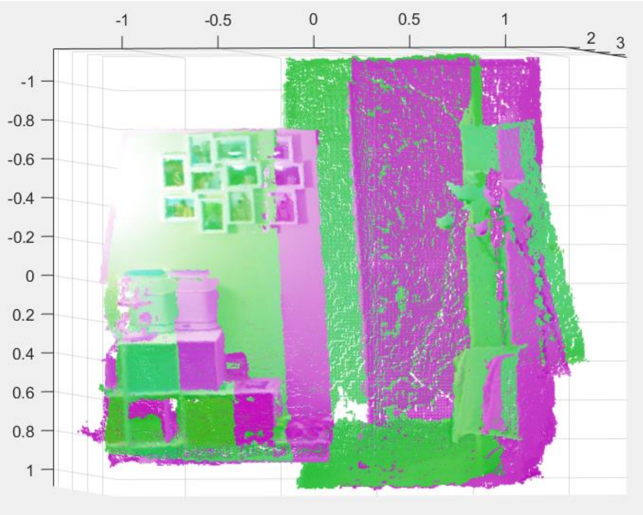

Figure 3. The point cloud of the living room1 and the living room 2 with 10 cm initial alignment in Matlab.

Figure 3 shows point cloud data aligned with 10 cm. The point clouds aligned with 5 cm are not much visually different in the Matlab environment, so the differences of only 10 cm are shown.

Two different initial alignment distances as about 10 cm and 5 cm were determined and they have been registered with the ICP and NDT methods. Two different comparisons were made in terms of RMSE values of fine registration and mean distance differences between two different surfaces as a result of registration. The mean distance differences between two different point clouds were made with the Cloud Compare Software (Figure 4 & 5). In the ICP method, while the RMSE is 0.0677 m and the mean distance is 0.0480 m for 10 cm alignment, the RMSE is 0.0519 m and the mean distance is 0.033 m for the 5 cm alignment (Figure 4, and Table 1).

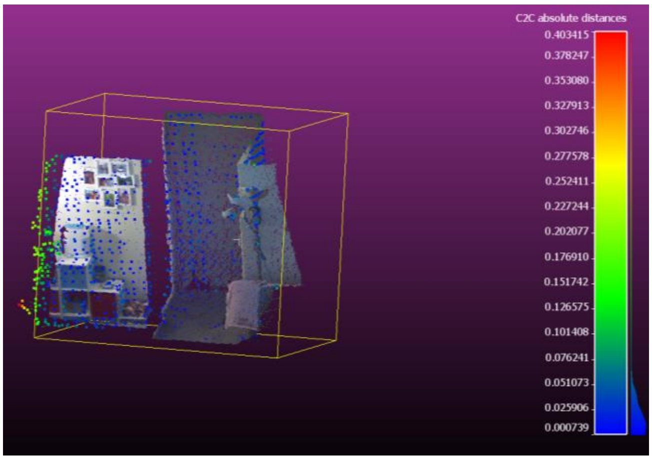

Figure 4: The mean surface differences after ICP registration

In the NDT method, while, the RMSE is 0.0625 m and the mean distance is 0.0365 m for 10 cm alignment, the RMSE is 0.0531 m and the mean distance is 0.0273 m for the 5 cm alignment (Figure 5 and Table 1).

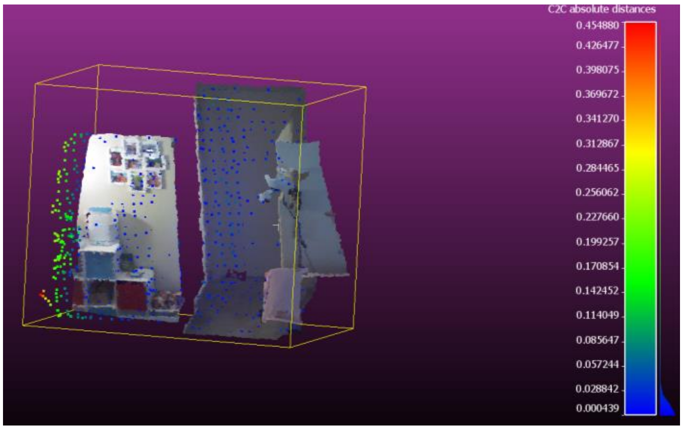

Figure 5. The mean surface differences after NDT registration

According to the results, NDT algorithm produced slightly lower root mean square errors for 10 cm initial alignment distances than ICP method while the ICP method produce lower RMSE values for 5 cm initial alignment distance. Briefly, if the initial alignment is given properly, ICP is better results as RMSE values. However, the mean distances between point clouds after registration was calculated by cloud to cloud compare demonstrate that the NDT method provides better results than ICP method for this data. But, the results are very close to the ICP.

Table 1. RMS values and C2C mean distance/standard deviation

Statistics	ICP(10 cm)	ICP(5 cm)	NDT(10 cm)	NDT (5 cm)
RMS (m)	0.0677	0.0519	0.0625	0.0531
C2C (m)	0.0480	0.0333	0.0365	0.0273

4. DISCUSSION

In this study, ICP and NDT registration algorithms were compared and sample point cloud data in Matlab environment was used to compare the two registration algorithm. The result shows that NDT and ICP make correct matches if the initial alignment is given properly. ICP differs from the NDT in terms of the approaches that use point to point transformation. Since NDT has advantages in terms of speed and data storage over ICP due to its algorithm that uses voxels, it can be used for cases such as robotic or autonomous driving applications that needs to be faster (Magnusson, M, 2009). In overall assessment, NDT produced slightly better results than ICP for the datasets which has initially aligned as 10 cm. For 5 cm initially aligned data, the ICP's RMSE value obtained lower than the NDT method. It can be gathered from the results that if the initial alignment is given correctly, ICP will give better results as RMSE values. According to the analysis based on cloud to cloud distances, NDT method provides better results for both initial distances than the ICP method. According to the results obtained from the study, both methods can be used for fine registration.

5. CONCLUSION

ICP can always reach the correct match, if the initial alignment is given properly. On the other hand, NDT has advantages over ICP in terms of data storage and speed. Therefore, it can be said that each of these methods has both advantages and disadvantages and one unique registration technique cannot recommendable. The success of the registration methods is differs according to the structure and density of the point cloud and especially depend on the initial alignment. So the methods that to be used should be determined by experience in this field.

In the future, these methods will be compared with larger and different data-sets and the accuracy of these methods will be evaluated.

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