Study on Huizhou architecture of point cloud registration based on optimized ICP algorithm

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Abstract: In view of the current point cloud registration software has high hardware requirements, heavy workload and multiple interactive definition, the source of software with better processing effect is not open, a two-step registration method based on normal vector distribution feature and coarse feature based iterative closest point (ICP) algorithm is proposed in this paper. This method combines fast point feature histogram (FPFH) algorithm, define the adjacency region of point cloud and the calculation model of the distribution of normal vectors, setting up the local coordinate system for each key point, and obtaining the transformation matrix to finish rough registration, the rough registration results of two stations are accurately registered by using the ICP algorithm. Experimental results show that, compared with the traditional ICP algorithm, the method used in this paper has obvious time and precision advantages for large amount of point clouds.

1. Introduction

In recent years, many scholars at home and abroad have done extensive research on the registration algorithm of point cloud. The point cloud registration algorithm can be divided into feature based registration and feature free registration. Feature based registration uses the geometric features of point clouds. The feature free registration is directly using the data of the point cloud itself for registration. Feature based point cloud registration is commonly use the algorithm of curve registration [1], firstly, the 3D curve must be extracted from the two stations of the target, and the curve is used as the feature to calculate transformation, the method has significant precision effect on the target with obvious characteristic curve. Higuchi K et al. [2] uses curvature registration, Building discrete grid on the point cloud, and each grid is mapped to a spherical image, and the conversion between the views is calculated by matching the spherical image, then 3D model is established from the point cloud, this method is suitable for the registration of similar spherical objects, and has good effect on regular shape. Local feature registration mainly uses local point feature descriptors to calculate local features in the neighborhood, and finds the corresponding points according to the features. Zhang Zhe et al. [3] firstly seek the neighborhood and normal distribution feature descriptors of the point cloud, establish the local space coordinates for each selected key point, and calculate the fast point feature histogram (FPFH) of the key points, then find the transformation matrix. The feature free registration is the direct registration using the original point cloud data, among them the iterative closest point algorithm (ICP) proposed by Besl [4] is typical, however, the initial requirement of the point cloud is high, and the algorithm is easy to fall into local optimum, therefore, it is suitable for point cloud with smaller data or point cloud after coarse registration. In order to speed up the corresponding search, Akca D et al. [5] propose an efficient spatial partitioning method, greatly reduce computation time.

Although there are some cloud point registration software in the market, there are also many problems such as high hardware requirements, multiple interaction definition, and not open source. Based on the existing research, this paper proposes a fast point feature histogram based registration...
method for ancient buildings, the results show that the scheme is not limited to the hardware requirements of registration software, and has a good time efficiency.

2. Point cloud preprocessing
The key to point cloud registration is to calculate the relationship between the source point and the target cloud point, obtaining the optimal transformation between two stations. In order to improve the efficiency of global point cloud registration, it is necessary to preprocessing the original point cloud before registration.

2.1. Segmentation
Cause the objects often close to its surroundings, the background and the surrounding environment are also recorded by the scanner in the form of point cloud after scanning, so it is necessary to segment the background and the environment point cloud. After segment, the point cloud data will be greatly reduced compared with the original point cloud data. Data comparison before and after segment is shown in Table 1. The object of this study is statue of Luban and huizhou ancient stage. Firstly, useing random sampling consensus (RANSAC) algorithm to segment point clouds. Figure 1 is a schematic diagram of random sample consesus algorithm.

Figure 2 and Figure 3 are statue of luban and huizhou ancient stage which was segmented.

Table 1. Comparison of the number of point clouds before and after segmented

|                  | Original point cloud one | Original point cloud two | Point cloud after segmented one | Point cloud after segmented two |
|------------------|--------------------------|--------------------------|--------------------------------|--------------------------------|
| luban statue     | 3750277                  | 4521327                  | 59507                          | 80017                          |
| ancient stage    | 2391302                  | 1067238                  | 352247                         | 554344                         |

2.2. Filtering
In the scanning process, although the sampling point is dense, the point cloud data has high accuracy, but it is also the main reason affecting the registration time. By filtering, it is very practical to improve
the speed of registration. In this paper, we use the voxel grid filter (VoxelGrid)[6] to reduce the point data. Figure 4 and Figure 5 are statue of luban and huizhou ancient stage which was filtered.

3. Registration
Point cloud registration is a process to get a complete data model of objects, by obtaining the transformation matrix, in order to transform the point cloud from different stations into the same coordinate system to form a complete point cloud.

3.1. Registration process
In this paper, we use TX5 3D scanner from trimble company for point cloud data acquisition. After obtaining the point cloud of two stations, the voxel mesh filter is firstly used for point cloud down sampling.

Before the coarse registration of point clouds, there is no initial position relationship between two point clouds. Figure 6 is the working principle of the scanner. Scanner is placed at the position A and B to scan the same object. The point cloud data P in coordinate system of O1-x1y1z1 is obtained at A, The point cloud data Q in coordinate system of O2-x2y2z2 is obtained at B, the purpose of coarse registration is to fuse the point clouds P and Q in different coordinate systems and convert them into the same coordinate system.

![Figure 6. Principle of the scanner](image)

For point gathers P and Q, Pi (X, Y, Z) ∈ P, Qi (x, y, z) ∈ Q, Pi and Qi are the coordinates of the same object in different coordinate systems, Registration is to make the point pairs (Pi, Qi) satisfy the rigid body transformation (R, T) of the two point gathers. That is

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix} =
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix} +
\begin{bmatrix}
\cos\alpha & -\sin\alpha & 0 \\
\sin\alpha & \cos\alpha & 0 \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
\cos\beta & 0 & -\sin\beta \\
0 & 1 & 0 \\
\sin\beta & 0 & \cos\beta
\end{bmatrix}
\begin{bmatrix}
1 & 0 & 0 \\
0 & \cos\gamma & -\sin\gamma \\
0 & \sin\gamma & \cos\gamma
\end{bmatrix}
\begin{bmatrix}
t_x \\
t_y \\
t_z
\end{bmatrix}
\]

(1)

In the formula, R is the rotation matrix; T is the translation matrix; α, β, γ are the rotation angles along the X, Y and Z axes respectively. Figure 7 is the registration flow chart.

3.2. FPFH algorithm
Fast point feature histogram is improved by simplifying the point feature histogram (PFH)[7], PFH algorithm does not use the surface normals and curvatures of point cloud to represent the geometric features around a point, but constructs the feature histogram based on the normal curvature of the point and its neighborhood, and looks for the corresponding points based on the feature histogram. By querying the spatial differences between the point and the neighborhood, a multidimensional...
histogram is formed to describe the K neighborhood geometric attributes of the points. In order to compute the relative deviation between two point gathers Ps, Pt and their corresponding normal ns and nt, a fixed local coordinate system is defined at one of the points, as shown in the Figure 8.

\[
U = n_s, \quad V = U \times \frac{(P_t - P_s)}{\|P_t - P_s\|}, \quad W = U \times V.
\]

Figure 8. Define a fixed local coordinate system

Figure 9. Steps of FPFH algorithm

Using the uvw coordinate system of Fig. 8, the deviations between the normal vectors nt and ns can be represented by a set of angles:

\[
\alpha = V \cdot n_t \quad (2)
\]

\[
\phi = u \cdot \frac{(P_t - P_s)}{d} \quad (3)
\]

\[
\theta = \arctan(w \cdot n_t, u \cdot n_t) \quad (4)
\]

Among them, \(d = \|P_t - P_s\|\) is the Euclidean distance between point P_t and point P_s, experiments in [8] show that this eigenvalue has no effect on the robustness of PFH algorithm and can be omitted. If there are n points in the point cloud P, the theoretical computation complexity of PFH is O(nk^2), where k is the neighborhood number of each point in P. All the three tuples \((\alpha, \phi, \theta)\) are grouped according to statistics, and the point feature histogram is obtained. However, for dense point clouds, the computation time complexity of the point feature histogram is high, and FPFH is a simplification of PFH, which can reduce the computational complexity to O(nk), while retaining most of the recognition features of PFH. The followings are the procedure:

(1) According to the formula (1) ~ (4) to calculate the three tuples \((\alpha, \phi, \theta)\) of each query point P_q and its neighborhood point, a simplified point feature histogram (SPFH) is established.

(2) The K neighborhood of each point is redefined, and the nearest point feature histogram is computed by using the adjacent SPFH value, i.e. the fast point feature histogram FPFH, such as formula (5), where \(\omega_i\) is the distance between the query point P_q and the adjacent point P_i.

\[
FPFH(P_q) = SPFH(P_q) + \frac{1}{k} \sum_{i=1}^{k} \frac{1}{\omega_i}SPFH(P_i) \quad (5)
\]

Using FPFH algorithm to coarse registration, in the target point cloud, the similar points with its histogram are searched to form a queue, and a point is randomly selected as the corresponding point in the queue. The transformation parameters and the error of point cloud registration are calculated according to the corresponding points, and the optimal transformation is selected iteratively. The steps
of the FPFH algorithm are shown in Figure 9. The registration result of the statue is shown in Figure 10, and the registration result of the ancient stage is shown in Figure 11.

4. Conclusions
This paper selects the statue and Huizhou architecture as the research object. Figure 10a and Figure 11a show the initial position before FPFH registration, Figure 10b and Figure 11b are FPFH registration results respectively, Figure 10c and Figure 11c are ICP registration results respectively. The two point clouds of the statue have 16307 and 21634 points respectively, and the two point clouds of the stage have 42132 and 75624 points respectively. The ICP registration time of the statue is 72 seconds, and the improved ICP registration time is 51 seconds by using FPFH. The ICP registration time of the ancient stage is 51 seconds, and the improved ICP registration time is 155 seconds by using FPFH. Analysis shows that if the number of points is less than twenty thousand points, the ICP registration effect can be achieved by using the FPFH registration effect. However, when the number of points is more than forty thousand points, the FPFH algorithm is not dominant either in time consuming or in the final registration accuracy. The ICP algorithm combined with FPFH algorithm has higher time efficiency compared with the traditional ICP algorithm.

This paper compares the commonly used registration algorithms in registration software, it is proved that the ICP algorithm combined with FPFH has more advantages, and shows excellent accuracy and time efficiency, the scheme used in this paper has low requirement to the system hardware and can be carried out in windows and Linux operating systems.

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