

AN ACCURATE REGISTRATION METHOD BASED ON POINT CLOUDS AND REDUNDANCY ELIMINATION OF LIDAR DATA

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ABSTRACT:

A new method for accurate registration and redundancy elimination on point clouds is presented in this paper. Firstly, the accurate registration arithmetic which based on Iterative Closest Point (ICP) algorithm and feature registration method provides an accurate way in the process of registering. And the redundant data in the point cloud after registering can also be deleted efficiently with an algorithm considering the weight value of each corresponding point. Furthermore, a 3D application system is developed in VC++6.0 and OpenGL 3D graphic library. Thus, those problems in registration and redundancy elimination of point clouds can be solved efficiently in this system.

1. INTRODUCTION

With the development of the modern surveying technology, the 3D laser scanning technology has been a hot destination of research in this field. Millions of spatial points can be obtained within a second as the result of the improvement of accuracy and velocity (Yanmin Wang, 2007). However, large number of points becomes redundancy after the registration among some stations. It has caused a lot of problems in the process of storage、translating、displaying and so on. More over, the precision of the data analyzing and the quality of the surface reconstruction can also be impacted by the mass redundancy data. However, the existing algorithms in some correlative software have many problems in the data processing. For example, when the number of constraints is limited, or some of constraints were moved a short distance without our notice or something else happened in the process of scanning, the veracity of registration can not be ensured. At the same time, many points are redundant after registration. But whether this part of points should be deleted or which part of points are more accurate, there will cause a lot of error because of factitious factors. So a further accurate registration followed by redundancy elimination after the primary registration should be actualized as soon as possible.

2. RESEARCH ON REGISTRATION

2.1 Research on existing algorithms of Registration

Registration plays an important part in 3D model acquisition and object recognition. If we want to obtain a whole model of an object, this object should be scanned by the laser scanner from many view point. The data from each scan station has its own coordinate system.

$$\begin{Bmatrix} x_p^1 \\ y_p^1 \\ z_p^1 \end{Bmatrix} = R \begin{Bmatrix} x_p^2 \\ y_p^2 \\ z_p^2 \end{Bmatrix} + T \quad (1)$$

In equation (1), x^1, y^1, z^1 are the values of 3D coordinate of one point in the first scan station. x^2, y^2, z^2 are the values of 3D coordinate of one point in the second scan station. R is the rotation matrix and T is the translation vector.

After registration, those data in different coordinate systems can be transformed into a common coordinate system. So the most important problem is get the rotation matrix R and translation vector T accurately.

There are two main methods on data registration nowadays. A popular method for aligning two point clouds is the Iterative Closest Point (ICP) algorithm (BESL.P.J, 1992). This algorithm starts with two point clouds and an estimate of the aligning rigid body transform. It then iteratively refines the transform by alternating the steps of choosing corresponding points across the point clouds, and finding the best rotation and translation parameters that minimizes an error metric based on the distance between the corresponding points. The methods for searching closest points contain point to point searching method、point to plane searching method、point to projection searching method and so on.

The other method is registering with features. This algorithm is based on features in the original data or the features which are reconstructed into geometries from the original points. These features can be points、spheres、planes and cylinders.

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In order to register accurately and efficiently, the process of registration is divided into two steps, primary registering and accurate registering.

2.2 Primary Registering

The first step is the primary registering with the geometry feature constraints. Signal points can be used as constraints in registering. We can also fit the spheres, planes and cylinders from the point cloud. Parameters in those geometries can be used as constraints in registering.

In order to simplifying the calculating process, yant symmetric matrix M is used to construct rotation matrix.

$$M = \begin{bmatrix} 0 & -c & -b \\ c & 0 & -a \\ b & a & 0 \end{bmatrix} \quad (2)$$

$$R = (I - M)^{-1}(I + M) \quad (3)$$

Because matrix M can be easily proved to be orthogonal matrix, the rotation matrix R can be presented with a, b and c.

$$R = \frac{1}{\Delta} \begin{bmatrix} 1+a^2-b^2-c^2 & -2c-2ab & -2b+2ac \\ 2c-2ab & 1-a^2+b^2-c^2 & -2a-2bc \\ 2b+2ac & 2a-2bc & 1-a^2-b^2+c^2 \end{bmatrix} \quad (4)$$

If

$$\begin{aligned} X &= (x, y, z)^T, \\ X' &= (x', y', z')^T, \\ T &= (\Delta X, \Delta Y, \Delta Z)^T \end{aligned}$$

The transformation equation is:

$$X' = T + \lambda TX \quad (\lambda = 1) \quad (5)$$

If $X = (a, b, c)^T$, after deduction, we can get:

$$X = (A^T A)^{-1} A^T L \quad (6)$$

where
$$A = \begin{bmatrix} 0 & -z - \lambda z' & -y - \lambda y' \\ -z - \lambda z' & 0 & x + \lambda x' \\ y + \lambda y' & x + \lambda x' & 0 \end{bmatrix}$$

$$L = (x'-x \quad y'-y \quad z'-z)^T$$

So the rotation matrix R can be obtained. At the same time, the translation vector T is given by:

$$T = X' - \lambda RX \quad (7)$$

2.3 Accurate Registering

After primary registering, the data in different stations are transformed from independent coordinate systems into a unified coordinate system on the whole. The accurate registration is based on ICP algorithms and registering with features algorithm. In this process, directly searching method which uses the basic spatial cubes with optimal step size is put forward in order to make it efficient for searching the corresponding points in the 3D space to gain the relative parameters accurately. At the same time, the coordinates of each original station are considered. The aim is to get a weight value for the parameters of each point, and to ensure the precision of registration and the high accuracy of the data after redundancy eliminating and merging. The process of accurate registration is shown in the Figure 1.

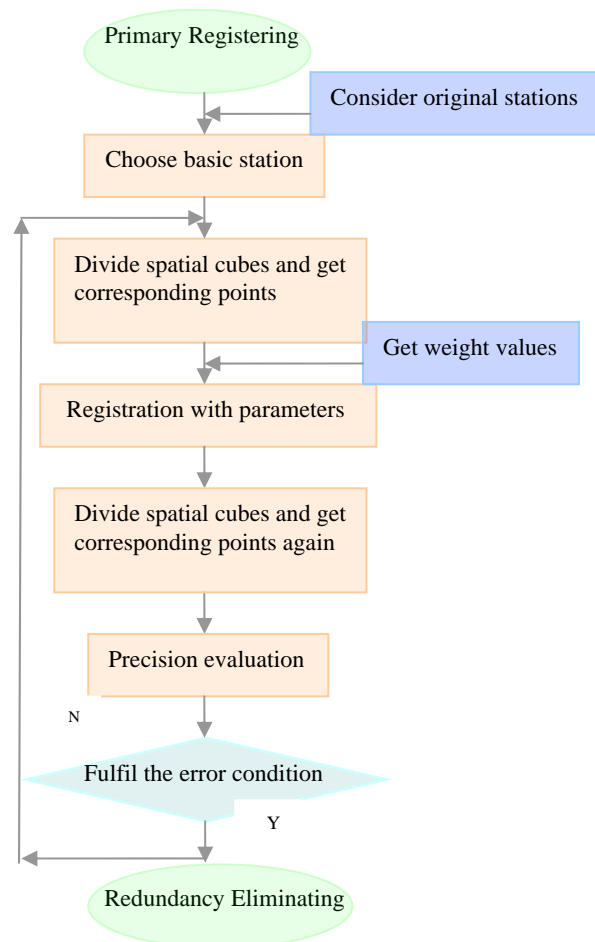


Figure 1 Flow Chart of Accurate Registration

The research results of this part mainly include three aspects as follows:

1. Selecting the optimal side length of the spatial cubes.

The side length of the basic spatial cube is decided according to resolution of the points cloud. Different resolutions of points cloud are applied in the experiments. Firstly, get the maximal

value and the minimal value in the direction of X、Y and Z, and the number of cubes is decided by equations(8).

$$\begin{cases} m = INT\left(\frac{X_{max} - X_{min}}{t}\right) + 1 \\ n = INT\left(\frac{Y_{max} - Y_{min}}{t}\right) + 1 \\ l = INT\left(\frac{Z_{max} - Z_{min}}{t}\right) + 1 \end{cases} \quad (8)$$

where m, n, l = numbers of cubes in directions of X,Y,Z. And choose a t as the side length of the special cube. Finally, a relation between the side length and the resolution is gained through comparison and analysis by Figure 2 and Figure 3.

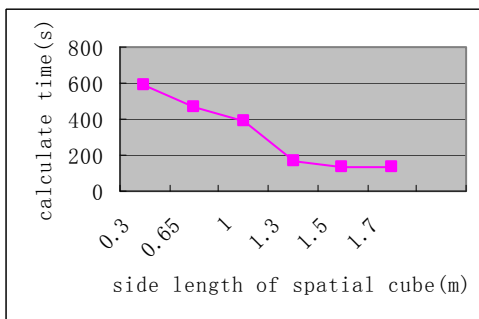


Figure 2 Side Length and Calculate Time

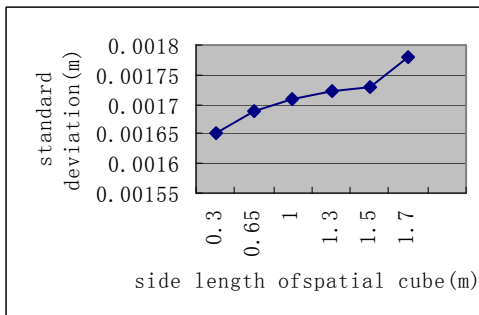


Figure 3 Side Length and Std

The optimal side length should be in the range of 20 times to 25 times of the resolution, and this value can be confirmed to make it possible to obtain the accurate parameters for registration with the minimal error、the least iterative times and the shortest period.

2. Searching the corresponding points.

Calculate the distances between each point and the geometry center point in one basic spatial cube of one station, choose the nearest point P, and in the corresponding cube of the other state, find a point Q that the distance between P and Q is the shortest. Points P and Q are a pair of corresponding points. All the

corresponding points among these stations can be selected quickly and accurately with this method. Furthermore, the errors brought forth by the data which are not exact integrity in each basic cube are decrease.

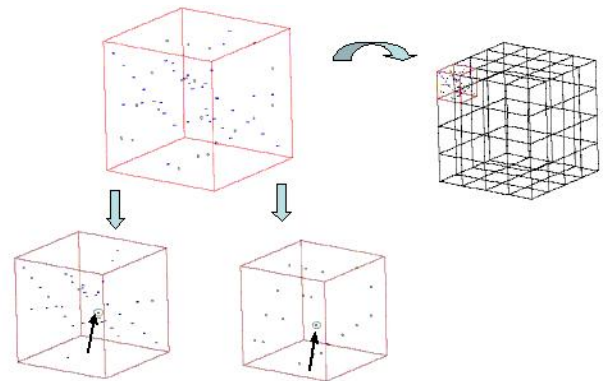


Figure 4 Search the Corresponding Points

3. Registration with weight values

The distance between the original station and a point in this station is very important. Because the point valid or not is directly impacted by this distance. So weight value which is decided by that distance of each pair of corresponding points is considered when calculating the parameters for registration. Thereby each point which belongs to different cubes in different stations can be registered with the optimal parameters.

If there are n pairs of corresponding points, the distance between this point and its original scan station is l .

$S = \sum_{i=1}^n l_i$, and the weight value of this point $P_i P_i = S - l_i / S$. So

the weight value matrix P can be defined as equation (9).

$$P = \begin{bmatrix} p_{11} & 0 & 0 & 0 \\ 0 & p_{22} & 0 & 0 \\ 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & p_{nn} \end{bmatrix} \quad (9)$$

The functional model of indirect adjustment can be expressed as follows equations:

$$\begin{aligned} \Delta &= B\tilde{X} - l \\ D &= \sigma_0^2 Q = \sigma_0^2 P^{-1} \end{aligned} \quad (10)$$

Because:

$$V = B\hat{x} - l \quad (11)$$

Then we can get:

$$\hat{x} = (B^T PB)^{-1} B^T Pl \quad (12)$$

where:

$$B = \begin{bmatrix} 0 & -z - \lambda z' & -y - \lambda y' \\ -z - \lambda z' & 0 & x + \lambda x' \\ y + \lambda y' & x + \lambda x' & 0 \end{bmatrix} (\lambda = 1)$$

$$l = (x' - x \quad y' - y \quad z' - z)^T$$

So the solution of equation (11) $X = (a, b, c)^T$ can be obtained from the above equations.

3. REDUNDANCY ELIMINATION

After the accurate registration, large numbers of points are overlapped at the same place. So in each cube, choose the data of one station that the distance between the point and its own original scan-station is the shortest. At the same time, if the first part of data is not integrated, the partial data of another station which is secondly nearest to its own original scan-station are used to fulfil the hole in this cube. The other points in this cube are eliminated. Thus, the data which are remained at last are ensured to be valid and non-redundancy by means of this method.

4. EXPERIMENTAL RESULT

According to the related researches, a 3D application system is developed in VC++6.0 and OpenGL 3D graphic library to validate the feasibility and the accuracy of the algorithms. The point clouds obtained by Leica HDS4500, Leica HDS3000 and Leica HDS6000 are used in the experiments. Take two stations of data dng1 and dng2 obtained from Leica HDS4500 for example.

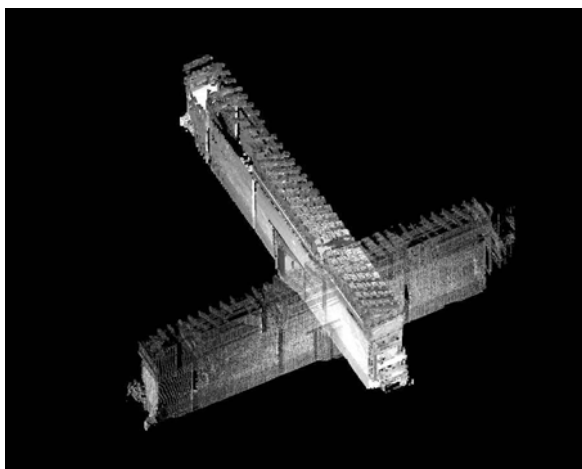


Figure 5 Data before Primary Registration

Data from two stations are in different coordinate systems before primary registration (see figure 5). And they are transformed into a uniform coordinate system basically after primary registration. However, two parts of data are layered, and the average error is 0.008m after primary registration. This kind of data can not be merged together and used directly. This is shown in figure 6.

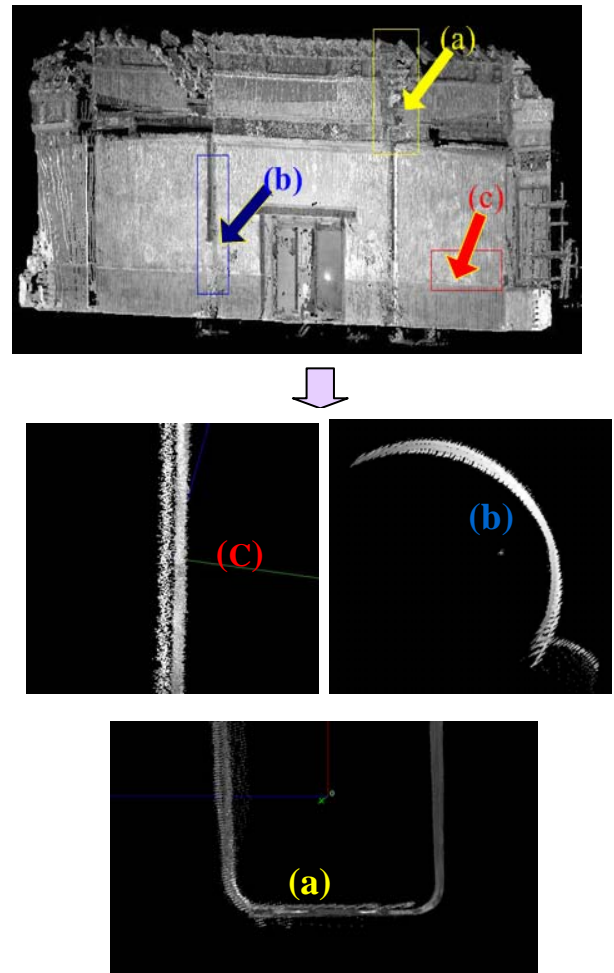
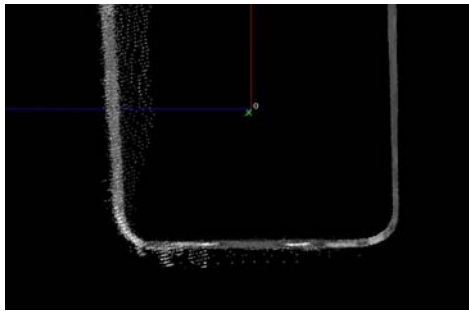


Figure6 Data after Primary Registration

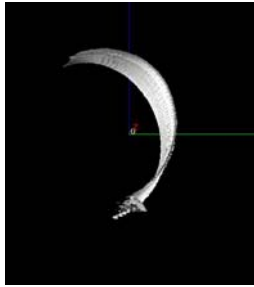
- (a) Data of girder layered
- (b) Data of pillar layered
- (c) Data of wall layered

In the accurate registration, choose 1.5m as the side length of cube. After 7 times iterative calculations in 130.65s, two parts of data are registered very well. The average error is 0.00172m, and the standard deviation is 0.00194m. Layered data from different scan stations are registered with very little error, and they are not layered any more (see Figure 7).

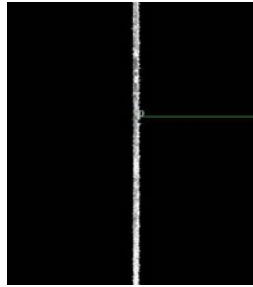
Before registration, each station contains 1220780 points and 1222458 points respectively. After two steps of registration and spending 7.88s in redundancy elimination, there are only 1578349 points when they are merged together. The data are reduced 35.4%. Thus, not only are the redundant data eliminated efficiently, but also the texture of point cloud are much clearer.



(a)



(b)



(c)

Figure 7 Data after Accurate Registration

- (a) Data of girder without layered
- (b) Data of pillar without layered
- (c) Data of wall without layered

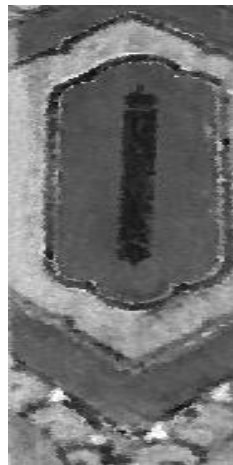


Figure 8 Data before Redundancy Elimination and after Redundancy Elimination

5. CONCLUSIONS

To conclude, accurate registration and redundancy elimination for point clouds is the first step in the data processing of 3D Laser Scanning. The accuracy and the efficiency of the 3D modelling、 surface reconstruction and data analyzing is directly decided by this step. By using this algorithms proposed above, the relative valid points in each station are remained. The maximum accuracy of the original data is kept, and the redundant data are eliminated. It provides ideal data for the following work of the data processing of 3D Laser Scanning.

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