INTEGRATED REGISTRATION OF RANGE IMAGES FROM TERRESTRIAL LIDAR

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ABSTRACT:

There are generally two kinds of LIDAR, airborne and terrestrial. Terrestrial LIDAR is outstanding for its high accuracy, hyper speed and high density. A single range image of terrestrial LIDAR usually could not cover the whole object due to its multi aspects. The range images from different aspects of object can be registered into a unified point cloud model of object. The accuracy of resulted point cloud model is affected by registration accuracy directly. There are two kinds of registration. One is based on range images and another on extracted features. The former computes the distance errors of overlap part to align the range images. The other uses some frameworks or abstracted features as constraints to register the range images into a unified coordinate system. The combination of two methods can also make good results.For the methods above, neighbor range images are registered one by one. This procedure will evoke error accumulation. To solve the problem, an integrated registration method is put forward in this paper. All range images are registered and transformed to a unified coordinate system simultaneously. Parameter adjustment method is used in the new arithmetic. The spatial transformation parameters and constraint parameters are regarded as unknowns to be solved simultaneously. Integrated algorithm is actually a least square adjustment method, which assures the error distribution more rational.Point, line and plane are three feature types used as registration constraints in this paper. The point used for registration is called tic. The center point of circle or of sphere, the intersection point of two spatial lines or of three spatial planes are all points can be used for registration. Spatial transformation equation is always used as constraint of tic. Tics are the main constraints in range image registration. Line features and plane features are important registration constraints. If there are blunders in the range images, parameters of each range image will be polluted with them. Blunders are removed with comprehensive error analysis, which makes the algorithm more robust.
The procedure of integrated registration can be divided into three steps: feature extract, one by one image registration and integrated registration. Feature extract procedure is to extract point, line and/or plane features from range images. The parameters of extracted feature are obtained and can be regarded as observations in constraint equation. One by one image registration is to roughly register the involved range images and get approximates of unknowns. Integrated registration is to solve all unknowns of constraints with least square adjustment method. Blunders are removed at first and second steps.The new algorithm is realized into software. The data of the Gate of Supreme Harmony in Forbidden City are registered with the new method. The precisions from old method and new method are compared. The result proves that error accumulation is efficiently prevented. The precision is distinctly improved.

1. INTRODUCTION

LIDAR has been widely used since 60s last century for its single and high density in twenty century. Now there is an increasing interest in modeling and measuring real objects with Terrestrial LIDAR. It is traditionally used in industry measuring such as reconstruction of 3D surface of components and die. With the development of hardware and its combination with surveying, it could now be applied in the construction of digital city model, precise deformation of Large-Scale Projects, disaster assessment and survey of deposits etc [12][14]. To meet the applications above, Terrestrial LIDAR technology must be with modern survey to unify the data. There are many problems in handling data, such as noise reducing, compress and simplify of Mass data, Feature Extraction, real time operating of data and display, all of these need to be solved urgently.

The process of Terrestrial LIDAR technology includes a series of processes from data acquiring, data processing to output of results. Registration is the first step of data processing, as for spatial objects, it is usually cannot be covered by one view, thus different angles and position of views are necessary to get a complete data. The raw data of LIDAR are many separate range images with their own coordinate system. The precision of registration make great affections on the quality and precision of the following data products.

The registration of Range images means to translate all the individual range images into a unified coordinate system. There are two kinds of registration. One is based on range images and another on extracted features. The former is Iterative Closest Point (ICP) algorithm, it was first proposed by Besl and McKay [3]. It basically uses the data of range images directly to compute a minimum square distance of corresponding points. The ICP algorithm has been improved by many researchers [4][5][6][8]. Some use the color information to search corresponding point pairs [1]. The Feature-based algorithm uses control Network and corresponding features extracted from range images. There are generally three types feature include: points, lines and surfaces. Planar features are used in registration in some papers [9]. Registration based on features is smarter and easily combined. The combination of two kinds of registration is matured in a lot of software; Leica's Cyclon is one of them.

For the methods above, neighbor range images are registered one by one. This procedure will evoke error accumulation. To solve the problem, an integrated registration method is proposed in this paper. Integrated Registration of multi-stations of range images means to transform all of ranges images registered into a unified coordinate system simultaneously according to the control network and the constraints between the each station. Firstly, corresponding features of each neighbored stations are extracted, then parameter adjustment is used, which takes all constraints as observation and spatial transform parameters and part of unknown constraints as unsolved target to make an uniform adjustment and a unbiased estimated weight function is used to affirm the adjustment more robust, finally all the range images are transformed into a unified coordinate system with the solved parameters once a time. Thus Integrated Registration is more rigid mathematically.

2. INTEGRATED REGISTRATION OF MULTI-STATIONS

A station is all the range images and control data the Laser scanner acquired in a fixed position, thus the data could be taken as one range images in registration and station is the unit of registration practically. A corresponding feature is called a constraint usually.

2.1 Theory and preparation

As we discussed above, Integrated Registration is actually a parameter adjustment process, a precise control network is necessary to control the registration of stations. The coordinate system of control network is selected according to the requirement of projects, such as geodetic coordinate system, architecture coordinate system or local coordinate system etc. Denmark algorithm, which is an unbiased estimate weight value function, is used in adjustment to make the algorithm more robust to gross errors. The control network is the reference stations of integrated registration. The following work is searching for corresponding features and getting them labeled. As we discussed above, there are generally three types of features, for point feature, is usually acquired by scanner directly or extracted by fitting the corner and the centers of regular geometrics. The linear feature is boundary or axis of linear objects. Surface features are fit with local corresponding surfaces of objects.

For each stations involved in the integrated registration, there must be enough constraints to finish the integrated registration.

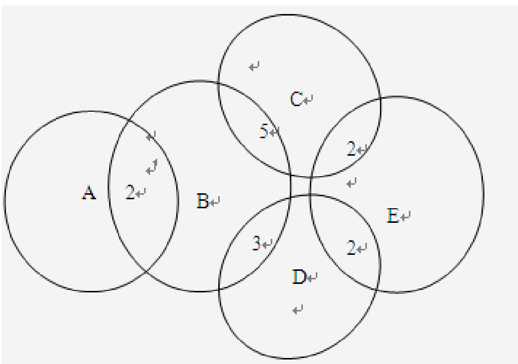

Fig 1 the Constraints among Range Images

There are generally seven parameters each station to make a spatial transformation. Each station of range images is the real shape of world, thus we assume the scale factor of station is 1. Then, assume the point constraints participate is n, direction constraints is m, then there number have been at least satisfy: $m+n \geq 3$ to realize the transformation. When there are redundant constraints, adjustment could be made to improve the precision of registration.

There are two kinds of relationship among the stations in registration; the constraints may be one - one or one - multi. Figure 1 is schematic diagram of relationship among stations, ABCED are five station of range images, when the registration is based on station B, C and D could be registered directly, A can't be registered to the station B due to its less corresponding constraints, Station E is an exceptional, it has to register to the combination of BCD.

2.2 Error Model

Traditionally the linearization of rotate matrix R is complex and huge calculated amount, in this paper we use Rodrigue matrix, an ant symmetric matrix to construct rotate matrix R for its orthogonal matrix.

Assume that

$$M=\begin{bmatrix} 0 & -c & -b \\ c & 0 & -a \\ b & a & 0 \end{bmatrix} \qquad (1)$$

a, b, c are rotate parameters, the rotate matrix R could be built as follow:

$$R=(I-M)^{-1}(I+M) \qquad (2)$$

I is unit matrix in equation (2). The calculated amount and complexity of error equations could be simplified greatly.

2.2.1 Point Error equation. For arbitrary point constraints X_0, X , there is a transformation as follow:

$$X = RX_0 + S \qquad (3)$$

From equation (1), (2), (3) we get the point error equation as follow:

$$V = Ax + Bt - l \qquad (4)$$

In equation (4):

$$x = [dS_x \quad dS_y \quad dS_z \quad da \quad db \quad dc]^T$$
$$t = dX$$
$$V = dX_0$$

A, B are linearization factor and l is residual term.

2.2.2 Plane Error equation. For one planar constraint P, P_0, there are two kinds of observations, normal vector F_p, F_{p0} and arbitrary point X_c, X_{c0}.

For normal vector, there is relationship as follow:

$$F_p = RF_{p0} \quad (5)$$

With equation (1), (2), (5) , we get the error equation:

$$V_p = A_p x + B_p t_p - l_p \quad (6)$$

In equation (6):

$$x = (0 \quad 0 \quad 0 \quad da \quad db \quad dc)^T$$
$$t_p = dF_p$$
$$V_p = dF_{p0}$$

A_p, B_p are linearization factor , l_p is residual term.

For arbitrary point X_c, X_{c0}, $X'_{c0} = RX_{c0} + S$ then,

$$F_p \bullet X'_{c0} - F_p \bullet X_c = 0 \quad (7)$$

With equation (3) (7), we get the another error equation:

$$V'_p = F_p \bullet x - l'_p \quad (8)$$

In equation (8):

$$x = [dS_x \quad dS_y \quad dS_z \quad 0 \quad 0 \quad 0]^T$$

l'_p is residual term.

2.2.3 Linear Error equation. For linear constraint L, L_0, there are two kinds of observations either, axis vector F_l, F_{l0} and arbitrary point X_l, X_{l0}. The error equation of axis vector is the same as normal vector of planar constraint. Assume F is the orthogonal vector of F_l, F_{l0}, $X'_{l0} = RX_{l0} + S$, Then we get the following equation:

$$V_l = F \bullet X'_{l0} - l_l \quad (9)$$

The error equation is:

$$V'_l = F \bullet x - l'_l \quad (10)$$

In equation (10):

$$x = [dS_x \quad dS_y \quad dS_z \quad 0 \quad 0 \quad 0]^T$$

l'_l is residual term.

Combined three types of error equations above, we can get a comprehensive error equation and get normal equation as follow:

$$\begin{bmatrix} A^T PA & A^T PB \\ B^T PA & B^T PB \end{bmatrix} \begin{bmatrix} x \\ t \end{bmatrix} - \begin{bmatrix} A^T Pl \\ B^T Pl \end{bmatrix} = 0 \quad (11)$$

When there are N range images, M control points, P plane constraints, Q cylinder constraints, the matrix of error equation is:

A: $(3M + 4P + 4Q) \times 6N$ B: $(3M + 4P + 4Q) \times 3(M + P + Q)$

Then transformation parameters can be solved by the normal equations.

2.3 Random Model

Gross errors are inevitable for integrated registrations, thus Random Model is an effective method to detect it and make the adjustment more robust.

In this paper, Posterior Variance is used as weight function to control [15].

$$L_{pvs} = \begin{cases} 1 & \text{when } \sqrt{T_i} \le K \\ 1/T_i & \text{when } \sqrt{T_i} \succ K \end{cases} \quad (12)$$

In equation (12), $T_i = \frac{v_i^2}{\hat{\sigma}_0^2 r_i}$, $K = F_{a,1,r_i}$, a F distribution whose degree of freedom is 1 and center is r_i.

2.4 Integrated Registration

The inertial process of integrated registration includes: control file acquiring, data acquiring and procedures and output of result. The flowchart of integrated registration is as follow.

The inertial value is of great importance in the process of parameter adjustment, an ideal inertial value may reduce the iteration effectively and get a precise result; however improper inertial value may lead to a divergence equation.

The observation values of parameters is the constraints in the station, thus the inertial values could be solved by pairwise registration. Due to the diversity of relationship between stations, a virtual station is assumed to make the integrated registration, when a reference station is established, its constraints is added to the virtual station and the following stations are registered one by one with the virtual station, the new constraints is added to the virtual station after each registration until all of the station is registered, thus the virtual station includes all of the inertial values of constraints.

When all the parameters are solved, check the mean square error of integrated registration and make sure it is with the tolerance; else posterior variance is used to reconstruct weight function to do iterations. After all the parameters are solved, then transforming all of stations to form an integrated model.

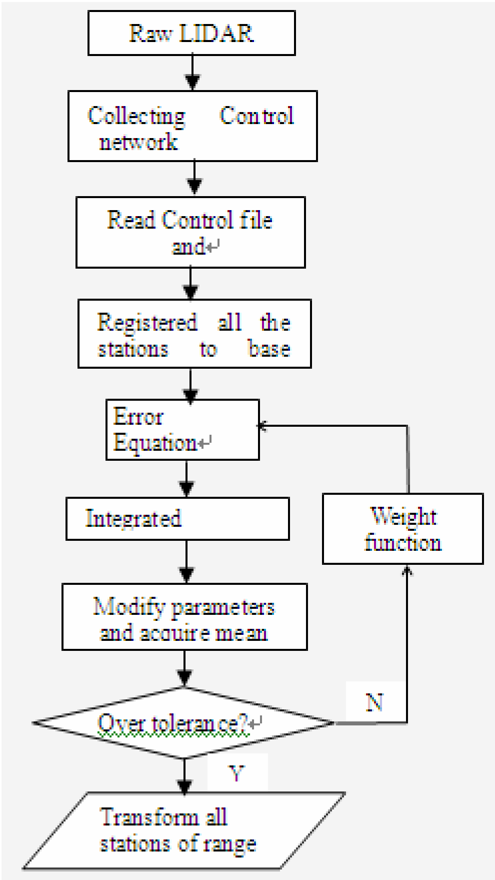

Fig 2 Procedures on Integrated Registration of Multi Station of range images

3. EXPERIMENT CONTRAST

3.1 The Gate of Supreme Harmony

The Forbidden City is an important historical cultural heritage; it is now being repaired to keep its integrity. The Gate of Supreme Harmony is one of ancient architecture being repaired. The building is symmetric and separated by ceiling, which covers the framework above, thus a control network is necessary to get a full data of the building.

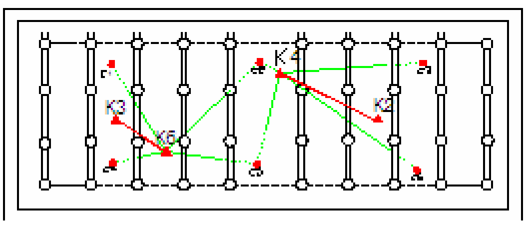

Fig 3 Control Network of the Gate of Supreme Harmony

Fig3 shows the network of the Gate of Supreme Harmony. In the control network: K4,K2,K3,K6 is control points on the ground of the building, C1 to C6 is control point on the ceiling which make a control on the station of ceiling.

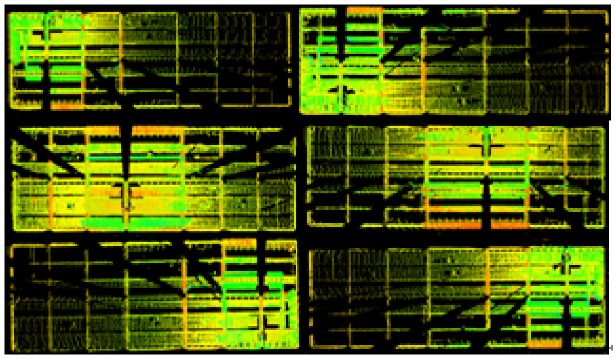

Fig 4 Plan of Raw Range Images

The original range images acquired shown as Fig 4. Each station contains only one control point due to shield of framework. 36 points are acquired and 4 pairs of planar features are extracted for registration.

The following figure (Fig 5) show the comparison between pairwise and integrated registration methods.

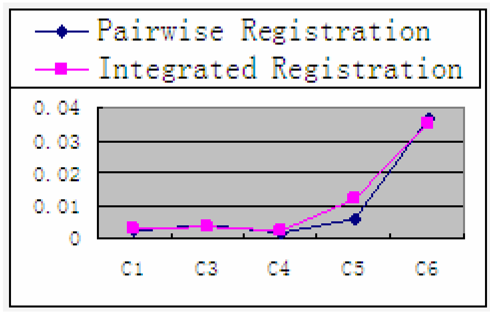

Fig 5 Registration by different methods with Control network

For pairwise registration, its equal-weight registration, the precision of registration is affected by points C5 and C6 obviously; Black broken line shows the result of integrated registration. With Posterior Variance, the weight values of C1,C3 and C4 is 1,while C5 is 0.009 and C6 is 0.001, the mean square error of integrated registration RMS is 0.000457. It is obviously improve the quality of registration.

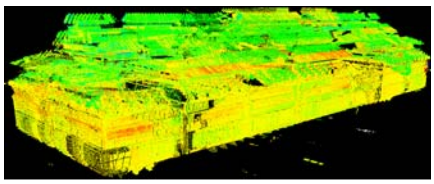

Fig 6 Result of Integrated Registration

4. CONCLUSIONS AND FUTURE WORK

There have been more and more applications of Terrestrial LIDAR in large Scale projects as motioned above. In these applications, there are more obscured objects, large amount of data and span and it's hard for the traditional methods to meet the precision required. The registration based on features is smart and more practice in these applications. The Integrated Registration we proposed could solve this problem efficiently. In Integrated Registration, robust parameter adjustment is used to make the errors rational distributed. The error equation and random model is given in the paper, the algorithm is programmed. The data of the Gate of Supreme Harmony and Beijing National Stadium is tested are registered with the method. Through performing test and analysis of the result, it is concluded that integrated registration could eliminate the cumulated error efficiently and improve the quality and speed of registration.

Feature registration is practice for its smart and less calculated amount, while registration on range images could improve the precision in case that some of the control constraints that is not precise enough. For integrated registration, it would be better if the ICP algorithm is taken into account.

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