3D DIGITAL RECONSTRUCTION OF COMPLEX OBJECTS THROUGH INTEGRATION OF RANGE DATA AND DIGITAL IMAGES

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KEY WORDS: 3D Reconstruction, Range data, Digital images, Registration

ABSTRACT: This paper is concerned with the integration of range data and digital images for accuarte 3D reconstruction of complex objects. In this study, unorganized point clouds and image sequences were taken from different viewpoints using a 3D digitizer. The 3D unorganized points and image sequences were used for pair-wise registration among all the two scan pairs. Later, all the pair-wise registration parameters were used as initial transformation parameters for multiple registrations. The performance of the proposed system is investigated through experimental results involving real datasets. Experimental results showed that the average normal distances between the two scans were less than 0.3 mm after simultaneous registration, which indicated that the proposed methodology is effective and efficient.

1. INTRODUCTION

The advent of digital 3D scanning devices has provided new means digitally by building geometric and photorealistic 3D models. Some research has been conducted utilizing either range data or digital iamges in order to specifically cater to complex object model generation. This paper is concerned with the integration of range data and digital images for accuarte generation of complex objects. Some research has been conducted utilizing either range data or digital iamges for complex object model generation(Akca,2005; Allen,2003; Chang,2008). In contrast, the proposed methodology is designed to combine digital images and range data acquired by a laser range finder for complex object reconstruction. In this paper, 3D unorganized points and image sequences were used for automated pair-wise registration of two adjoining range data sets. Later, all the pair-wise registration parameters were used as initial transformation parameters for multiple registrations. The performance of the proposed system is investigated through experimental results involving real datasets. Experimental results showed that the average normal distances between the fist and last scans were less than 0.3 mm after simultaneous registration, which indicated that the proposed methodology is effective and efficient.

2. SYSTEM CONFIGURATION

The setup in this research consists of a 3D digitizer VIVD 910 from KONICA MINOLTA, a rotatable platform on which the object was placed, a mechanical impulse device, a personal computer and a software for data acquisition called Polygon Editing Tool. In addition to distance data, furthermore, this 3D digitizer can also be used to acquire color image data. The rotatable platform is designed to capture datasets in a convenient way. It is composed of a planar patch, a stepper motor which can drive the platform to rotate. The object is placed on the center of the rotatable platform. Once the platform is driven to rotate at a given angle, e.g. 12 degrees, the digitizer can capture the datasets one time. In this way, the sequential datasets of the object could be acquired automatically. The datasets include 3D unorganized point clouds and corresponding digital images, and they were shown as Figure 1. Figure 1a) is the range data presented by discrete point clouds in green, and the corresponding digital image is shown as Figure 1b). Meanwhile, the point clouds are also imposed on the digital image, which is shown in Figure 1c).

Figure 1 a) range data; b) digital image; c) the range data imposed on the digital image

3. THE PRINCIPLE OF SCHEME

3.1 Pair-wise Registration

Registration of two scans plays an important role in the object reconstruction. Considering the complexity of the objects and the characteristics of unorganized point clouds, it is hard to find two conjugate points among the unorganized point clouds from two adjoining viewpoints. However, in this research, the correspondent relations between one scan and the digital image provides a clue for registration. The underlying concept of registration is that the problem of searching two conjugate 3D points from two scans will turn into the problem of searching two correspondent points in the digital images. After that, the 3D correspondences in range data can be located through the correspondent relations between the scans and digital images. This provides a promising way to acquire good initial alignment values between two scans from different viewpoints.

Assuming there are two scans Scan 1 and Scan 2, (Xp, Yp, Zp) are the coordinates of one point in one scan. The alignment parameters can be defined by three translation and three rotation parameters. Through more than 3 conjugate points in two 3D scans, the initial alignment parameters between one individual pairs can be resolved through 3D similarity transformation.

The transformation parameters between two scans can be calculated, and these transformation parameters are taken as initial values for iterative closest point (ICP) algorithm to estimate the accurate alignment parameters(Besl,1992). Figure 2a) shows the matching results between two digital images, b) demonstrates two scans before registration, and Figure 2c) shows the registration results after ICP algorithm. The average normal distance between the correspondences is computed as the accuracy and it is 0.13mm. It can also be seen that the offsets are quite big between the two scans before registration. The result after the ICP algorithm revealed a high quality of fit between two surfaces from the pair-wise registration.

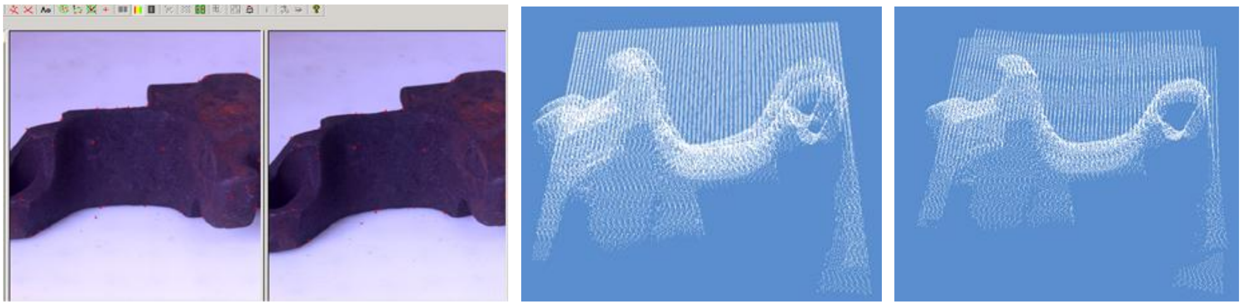


Figure 2 a) conjugate points in one image pair; b) two scans before registration; c) two scans after registration.

3.2 Seamless Registration of multiple scans

As mentioned above, n pieces of scans of the object were obtained. It was essential to develop an effective approach to register all these n scans seamlessly. The n pieces could be integrated together by employing the transformation parameters acquired from pair-wise registration. However, the error propagation of these parameters could possibly lead to error accumulation. In order to minimize the error accumulation of the pair-wise registration parameters, all the scans were registered simultaneously in a multiple surface registration procedure.

Transformation parameters between individual pairs of surfaces were computed through pair-wise surface registration introduced before. If the coordinate system of one scan was taken as the reference frame, other scans could be transformed from their own reference frames to this common reference coordinate system by using the transformation parameters between individual pairs. For one scan, there were two ways for it to transform into the common reference frame: direct way and indirect way. For example, if we have 9 scans, Scan 9 could be transformed into the common reference frame, which was defined by scan 1, by utilizing the pair-wise transformation parameters between Scan 9 and Scan 1 directly. Also, this integration could be completed by transforming Scan 9 to Scan 8 first, and then transforming it to scan 7, and so on, till it was transformed into the common reference frame of Scan 1. Ideally, the two transformed scans from scan 9 to scan 1 in the direct way and indirect way should be identical. However, this was almost impossible to achieve because of error propagation. Therefore, a methodology to refine the registration of n scans was developed. It was proposed to process all the scans simultaneously, that was to solve all the transformation parameters of all the individual scan pairs except for the transformation parameters between the first scan and the last scan with the initial transformation parameters acquired.

Assuming there were m scans in the research, Scan 1, Scan2, …, and Scan m. The transformation function between each scan pair, for example Scan i and Scan i+1, could be expressed as follows.

$$SF_i = F_i(SF_{i+1}) \qquad ①$$

Where, SF_i is scan i, SF_{i+1} is scan i+1, and F_i is the transformation function between these two scans.

As for point P $\{X_m,Y_m,Z_m\}$ in the last scan m, it could be transformed into the reference frame of scan 1 directly to obtain the new coordinate values $\{X'_m, Y'_m, Z'_m\}$, shown as Equation ②. Meanwhile, the point could be transformed into the common reference frame in the indirect way as described before to obtain a new coordinate values $\{X''_m, Y''_m, Z''_m\}$, which was expressed as Equation ③. Since $\{X'_m, Y'_m, Z'_m\}$ and $\{X''_m, Y''_m, Z''_m\}$ both represent the new coordinates in the reference frame of point $\{X''_m, Y''_m, Z''_m\}$ from scan m, therefore, the two coordinates should be identical ideally as shown by equation③.

$$\begin{bmatrix} X'_m \\ Y'_m \\ Z'_m \end{bmatrix} = \begin{bmatrix} X_{m,T} \\ Y_{m,T} \\ Z_{m,T} \end{bmatrix} + S_m R_m(\Phi_m, \Omega_m, K_m) \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix} \quad ②$$

Where

Xm, Ym, Zm are the coordinates of a point P in the Scan M,

X'_m, Y'_m, Z'_m are the coordinates of the transformed Point with respect to the common reference frame of Scan 1 in the direct way,

$X_{m,T}, Y_{m,T}, Z_{m,T}$, are three translations between one scan pair Scan m and Scan 1,

$R_m(\Phi_m, \Omega_m, K_m)$ is the rotation matrix between the scan pair Scan m and Scan 1 as defined by the rotation angles Φ_m, Ω_m, K_m,and

S_m is a scale factor between the scan m and scan 1.

$$\begin{bmatrix} X''_m \\ Y''_m \\ Z''_m \end{bmatrix} = R_1 R_2 \dots R_{m-1} \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix} + \begin{bmatrix} X_{1,T} \\ Y_{1,T} \\ Z_{1,T} \end{bmatrix} + R_1 \begin{bmatrix} X_{2,T} \\ Y_{2,T} \\ Z_{2,T} \end{bmatrix} + R_1 R_2 \begin{bmatrix} X_{3,T} \\ Y_{3,T} \\ Z_{3,T} \end{bmatrix} + \dots + R_1 R_2 \dots R_{m-1} \begin{bmatrix} X_{m-1,T} \\ Y_{m-1,T} \\ Z_{m-1,T} \end{bmatrix} \quad ③$$

Where

X_m, Y_m, Z_m are the coordinates of a point P in the Scan M,

X'_m, Y'_m, Z'_m are the coordinates of the transformed point with respect to the common reference frame of Scan 1 in the indirect way,

$X_{i,T}, Y_{i,T}, Z_{i,T}$ are three translations between one scan pair Scan i+1 and Scan i, i range from 1 to m-1,

$R_i(\Phi_i, \Omega_i, K_i)$ is the rotation matrix between one scan pair Scan i+1 and Scan i as defined by the rotation angles Φ_m, Ω_m, K_m, i range from 1 to m-1,and

S_m is a scale factor between one scan pair Scan i+1 and Scan i, i range from 1 to m-1.

Equation ③ could be simplified as

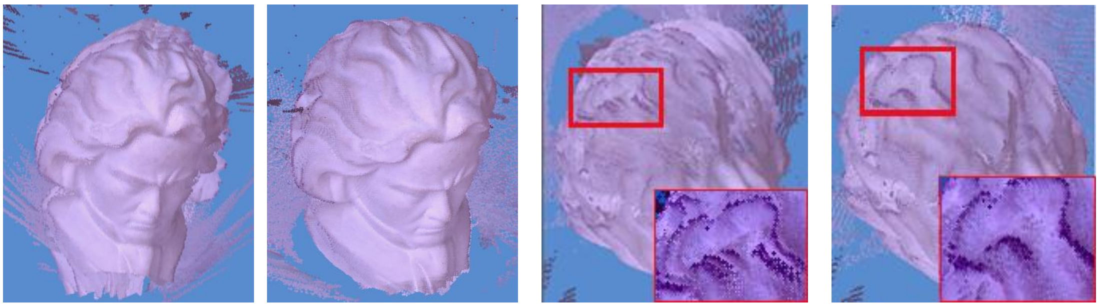
$$SF_1 = F_m(SF_m) \quad ④$$

where, SF_1 is the first scan Scan 1, SF_m is the last scan Scan m, and F_m is the transformation function between the scan m and scan 1 in the indirect way.

Considering all the transformation function between the scan pairs together and the relations between the last scan and the first scan, the transformation parameters could be resolved simultaneously according to the following equation.

$$\begin{cases} SF_1 = F_1(SF_2) \\ SF_2 = F_2(SF_3) \\ \ldots \\ SF_i = F_i(SF_{i+1}) \\ \ldots \\ SF_{n-1} = F_i(SF_{i+1}) \\ SF_1 = F_m(SF_m) \end{cases} \quad ⑤$$

This procedure was called multiple registrations in our research. With these procedures, the transformation parameters could be resolved. Meanwhile, the average normal distances between the first scan and the last scan were also computed before multiple registrations and after multiple registrations, and they were 3.24mm and 0.17mm respectively. Besides, the registration results were also presented in Figure 3. Figure 3a) shows the result without multiple registrations, it could be easily noticed that there were some disclosure, while there was almost no disclosure shown in Figure 3 b), which indicated that the multiple registrations were quite effective and necessary. In addition, Figure 3c) shows the disclosure in detail and Figure 3d) shows the good registration result in detail at the same location.



a) Result before multiple registrations b) Result after multiple registrations c) Result before multip registrations in detail d) Result after multiple registrations in detail

Figure 3 Results before multiple registrations and after

4. Experimental Results and Discussion

To evaluate the performance of the proposed methodology for 3D digital reconstruction of complex objects using range data and digital images, the proposed approach has been implemented in Visual C++ platform. For faithful reconstruction of any object from the range data it is necessary to take sufficient scans and sufficient overlap between different scans are ensured. In this paper, the rotation angle was set as 10 °. Pair-wise registrations were conducted on the datasets obtained from different angles, and the registration results were shown in Figure 4.

All the pair-wise registration parameters were computed by using the pair-wise registration algorithm introduced above, and these parameters were used as input for multiple registrations to complete seamless registration. According to the transformation parameters computed by the procedures between the scan pairs, all the unorganized points in other scans can be transformed into the first common reference in order to implement a complete model. Figure 5 shows the registration results with different rotation angles. In this figure, a) show the results without color information, b) shows the point clouds with color information, c) shows the final results without noise points.

Meanwhile, the RMS value was 0.14mm.

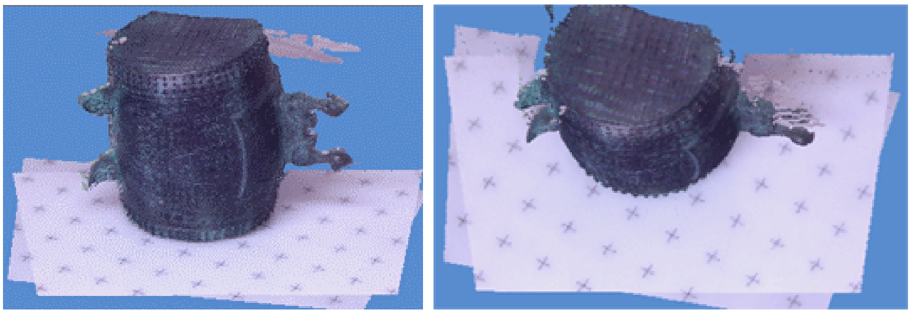
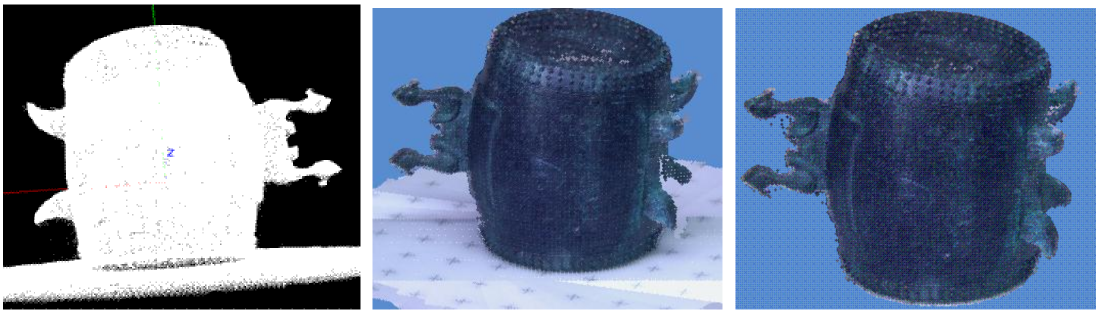


Figure 4 Pair-wise registration results with angle of rotation at 10 °from different viewpoints



a）Multiple Registration result without RGB b)Registration result with RGB c)The whole model without noise

Figure 5 Multiple Registration Result

5. CONCLUSIONS

We have introduced an automated approcah to reconstruct complex objects from range data and digital images. To conlcude, the combination of range data with the digital iamges, will lead to more encouraging results in comparison to using either of the two separte data sources alone. The proposed pair-wise registration and multiple registration procedures make use of the correspondent relations between the range data and digital iamges. The experimental results with real data collaborate the potential of this approach. Experimental results show that the proposed technique can be used to realize 3D reconstrcution of complex objects.

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