3D OBJECT MODEL RECONSTRUCTION BASED ON LASER SCANNING POINT CLOUD DATA

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ABSTRACT

Three dimensional (3D) reconstruction has been widely applied in urban planning, digital city, and the conservation of cultural/archaeological heritage etc. to re-build 3D object geometry. In the situation where the objects are irregular and have structure-complex, the use of conventional methods is time-consuming and mostly not practicable because of the workload involved and the detail of roofs or footprints cannot be modelled and low accuracy. The paper introduces the method of reconstructing 3D object model based on point clouds acquired by 3D terrestrial laser scanner including data acquisition, data processing, multiple scan registration, 3D modelling and texture mapping. The experiment result shows that, the method can effectively and quickly reconstruct 3D object geometry with many details, especially in 3D city model and cultural/archaeological heritage.

1. INTRODUCTION

The automation of 3D object reconstruction especially man-made objects has drawn the attention of many researchers over the last few years. Several approaches are often used for constructing 3D models. One of the most commonly used is the bottom-up and top-down. However, these techniques have some limitations with respect to details it can model, accuracy and efficiency. For further readings on these issues, see (Stoter, 2003; Bignone et al., 1996; Grün et al., 1998; Vosselman, 1999; Lowe, 1991, Foerstner, 1994; Hofmann et al., 2002; Haala, 1999; Suveg, 2002). In recent years, Terrestrial Laser Scanners (TLSs) allowing rapid and very dense surveys of structures within an hour have been one of the improved technologies developed. This allows millions of angles and distances to be gathered onto a structure, creating a point cloud (Gethin and Laura, 2005). Most of the available TLSs measure ranges to objects of several hundred metres, with a single-point accuracy of 1∂ = 1.4-15mm at 50m (Ingensand, 2006). Detailed investigations of TLS accuracy (Boehler and Marbs, 2002) and comparison with digital photogrammetry have been conducted under laboratory conditions (Lichti et al., 2002). This approach offers several advantages over the others. For example, there is full automation in the process, none-contact, higher resolution, efficient, higher accuracy and precision etc. Therefore it can be widely applied in many areas such as urban planning, digital city, conservation of cultural and archaeological heritage and many others. This paper describes an approach of 3D object reconstruction conducted using a commercially available 3D TLS. The paper starts with the introduction, the principle of laser scanning and workflow of 3D object reconstruction is in section 2. Section 3 discusses on data acquisition using Riegl VZ-400 laser scanner (Riegl, 2009). Data processing and finally the conclusion of the paper is in section 4 and 5, respectively.

2. THE PRINCIPLE OF 3D LASER SCANNING TECHNIQUE

2.1 The principle of 3D laser scanning

The laser transmitter emits a short pulse, which is split into two parts; one of which is sent to the receiver and starts the time measurement unit, and another is sent to the object. When reaching the surface of the object being scanned, the laser pulse is backscattered, and part of it returns to the detector. The latter is amplified in the receiver and sent to the device called time discriminator, which performs the timing and stops the time measurement unit. The time interval t between the emission of the pulse and reception of the return pulse is measured with the time-to-digital converter, by counting the number of clock pulses of high-frequency oscillator (clock), using a digital counting technique along with an analog interpolation method. The range to the target is computed as r= ct/2 where r is the range from the scanner to the target, c is the speed of light in air (≈3.108 m/s) and t is the two-way travel time of the laser pulse (Yuriy, 2009). To each point one oblique distance(s') and two orthogonal angles (φ and θ) are measured (Staiger, 2003) (Fig. 1). Together with the additionally registered intensity (i) of the returning distance signal each point is described in a 3D local coordinate system (SOCS) as shown in Eq. 1:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} r\ \cos\varphi\ \cos\theta \\ r\ \sin\varphi\ \cos\theta \\ r\ \sin\theta \end{bmatrix} \qquad (1)$$

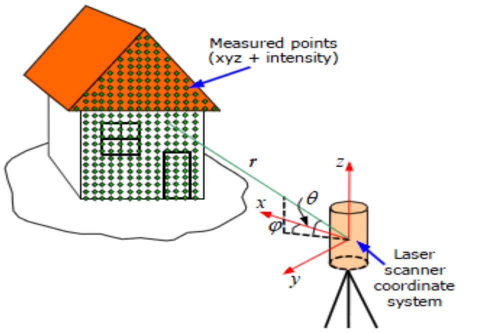

Fig. 1 The principle of 3D laser scanning (Yuriy, 2009)

2.2 The workflow of 3D model construction based on TLS point cloud data (Fig. 2)

3. DATA ACQUISITION

In this study, a lion statue was chosen to scan. The scanning was controlled by the Riegl RiSCAN PRO operating and processing software modules version 1.5.3b3.

Setting up the laser scanner starts by first levelling and centering TLS. TLS can be slightly tilt, the tilt inductor built-in Riegl VZ-400 can compensate for this tilt. Place the targets to ensure that at least 3 targets (a roundness retroreflective target of 5cm radius) between two adjacent scan stations will be scanned by TLS, distributed over not on the same line, and approximately 20% to 30% of overlapping areas must be provided in order to get a registration of two adjacent scans. For the first time of scanning, a low resolution is used to acquire data covering the complete field of view (FOV) of TLS and determine its tilt angle more accurately. Then, define a rectangular FOV of the target and the range to the scanner and chose a suitable angle resolution for fine scan (we used angle resolution of 0.05^0 in this study). After all corresponding parameters are set, fine scan was conducted. Find out target's approximate positions to scan them with a high resolution to measure their coordinates for later registration. Finally, photo-taking was conducted with the Nikon D300s camera attached to the scanner. In this research, five scan stations arranged in order to capture the whole lion statue.

4. DATA PROCESSING

The data processing stage was carried out in the RiSCAN PRO and Geometric Studio 3D modelling software modules version 10.

4.1 Registration

The process of registration of the various scan positions in the PRCS (Project Coordinate System) is the determination of the rigid-body transformation paramaters from the SOCS (Scanner's Own Coordinate System): 3 translations along the 3 coordinate axes (ΔX, ΔY, ΔZ) and 3 rotations around the 3 coordinate axes (ω, φ, κ). In this experiment, two approaches were applied to determine these parameters including target-based and common-natural-point-feature-based regi- tration. Target-based approach is conduc-ted by using the coordinates of the targets scanned in the two SOCSs. If 3 targets between two adjacent scans are not enough, common natural point features were used to register. It is possible that the other scan data show alignment errors. The main reasons for this problem may be an unstable reflector set-up, non-optimal reflector positioning or measurement errors. Also the two cases "chain" and "ring" are problematic. In these cases, each scan position is registered to it's direct predecessor. At the end, there will be a more or less bigger error between the last and first scan position of the chain or ring (Riegl, 2009). To minimize these errors, multi station adjustment (MSA) was used to improve the accuracy of registration. MSA started with the parameters including search radius of 0.15m and maximum tilt angle of 5^0. We got the final error of standard deviation of 5mm with a very good overlap-ping and alignment between 5 scans (Fig. 3).

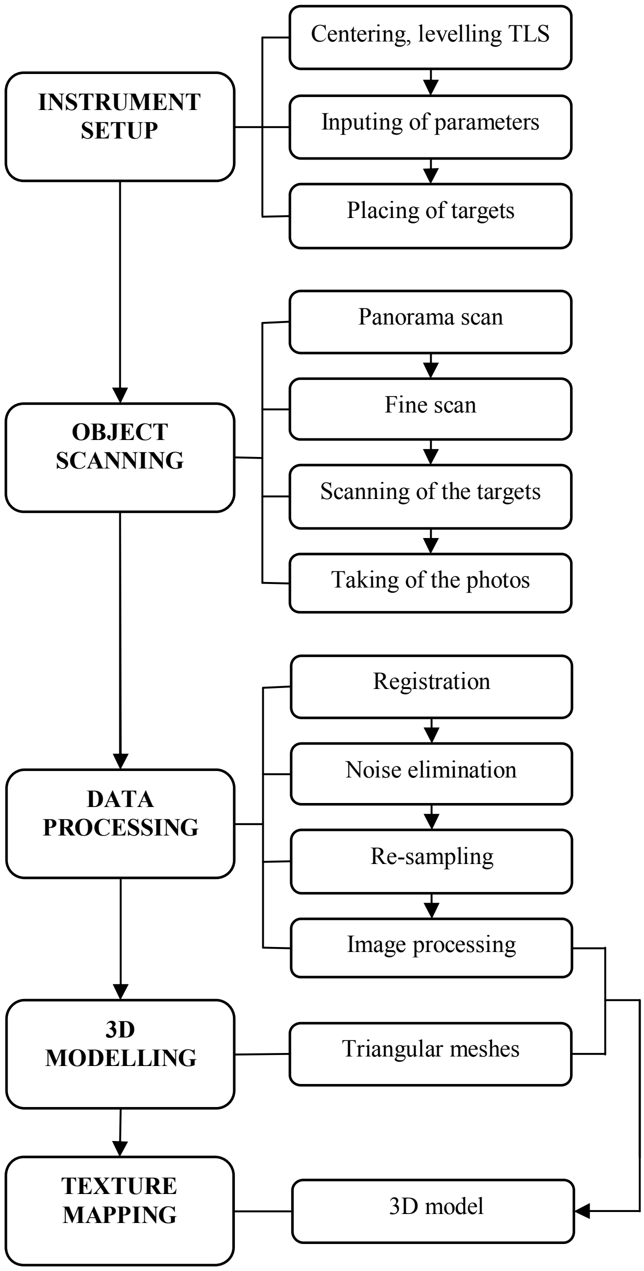

Fig.2 3D model reconstruction based on TLS

4.2 Data pre-processing

After the point clouds have been registered, the "raw" point clouds can not be used directly for a specific purpose (Lingua, 2001, Iavarone, 2003) because they contain "noise" and redundant information. Therefore, they must be pre-processed before 3D modelling.

The first step of the data processing is reducing of "noise" of all point clouds. Scanning a site captures everything in the selected field-of-view, undesired objects (people, mining equipments, control rooms, road surfaces, electricity supply poles etc.). The data in the scan overlaps is redundant and "noise" comes from multipath reflection, surface reflection (Thanh, 2011), thus must be removed by filtering utilizing statistical approaches to leave a clear slope for generating DTM later. The scan data is acquired sequentially on a more-or-less regular grid in a Ψ-∂ plane, whereas ∂ and Ψ denote the polar angle and the azimuth angle respectively. By resampling a scan, a new grid in the Ψ-∂ plane is generated. During the process of resampling all range and amplitude data falling within one cell of the grid is averaged. Data processing reduces file sizes and speeds up modelling algorithms. After data preprocessing, point clouds of the scanned object were extracted, then exported to *.wrl format to import to Geomagic Studio for further processing.

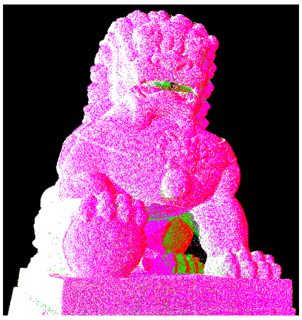

Fig.3 Five registered point cloud scans

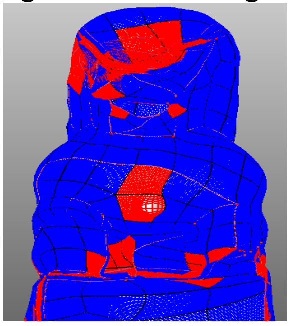

Fig.4 3D mesh after grid construction

4.3 3D modelling

The steps of 3D modelling shown in Fig. 5: ① Construct triangular network model: the scanned object is irregular and discrete points. It is necessary to generate its surface. Constructing triangular network model is a simple way to recover the object of topological relation and real surface. ②Edit polygons: there may be some gaps in point clouds, because some objects covers the lasers during the scanning, therefore no triangular network is constructed in these regions. Filling gaps is an approach to compensate for this missing data. Constructing triangles from overlapping areas generates intersecting triangles and a problematic mesh, it is necessary to edit these triangles. ③ Reconstruct polygons: redundant and error features must be wiped off or reconstructed. If this work cannot be done due to intersecting triangles, come back to the last step to reedit polygons. ④Polygon quantity adjustment: constructing triangular network from discrete point clouds causes redundant a number of triangles. For example, a plane can be constructed by two triangles, scanning with a high resolution and high density of point clouds makes a plane often constructed by more than two triangles. Adjusting the number of triangles is to reduce file sizes. If the density of point clouds are low, subdividing polygons to ensure the object's features. ⑤Triangular relaxation: adjusts the crease angle between selected triangles (or between all triangles if none are selected) such that the mesh becomes more flat. ⑥ Polygon detection and correction: check the whole model for if any intersecting triangles, if yes then repeat step 2 to step 6. ⑦Contour extraction: this work can be done automatically or by hand for later patch construction, if the object is very irregular and complex, it is recommended that extraction should first be done automatically then edit error contours. ⑧ Edit contours: problematic contours should be edited to insure the real features. ⑨ Patch construction: the object's contours are base lines, patches are expanded based on the constructed contours. Patches are four-sided, used for grid construction. ⑩ Edit patches: there may be some problematic regions of a patch layout such as intersecting patches, poor patch angles, high degree corners, high deviation patches etc. To edit these patches, move the vertices of intersecting patches, delete high degree corners then reconstruct that patch. ⑪ Grid construction: puts an N×N grid in every patch on the shape object. The green grids are good generation, the red grids are problematic regions. In this case, go back to step 10 to reedit patches, then reconstruct grids. ⑫ NURBS surface generation: generates a NURBS surface based on the grids that lie on patches that lie on panels (Fig.4)

4.4 Texture mapping

Texture mapping was carried out in RiSCAN PRO by using the images collected in the scanning stage. At first, these images must be processed such as adjust the brightness among images, eliminate redundant information that warded off some regions of the object in Photoshop etc. The use of wide-angle lens of 20mm causes local distortion on the surface, the undistortion of the images must therefore be done before texturing. Generally, one only covers a part of the mesh due to the limited field of view of the camera and therefore only assigned to a part of it. Texturing was done separately for each part, it was put them together to get the whole 3D object model (Fig. 6).

5. CONCLUSIONS

This paper reviews the method of reconstructing 3D object model based on point cloud data acquired by TLS, RiSCAN PRO and Geomagic Studio were used to control the scanning stage, multiple scan registration, data preprocessing, 3D modelling and texture mapping. The result has shown that point clouds can be effectively applied in many areas such as urban planning, digital city, and the convservation of cultural/archaeologi-cal heritage etc. However, it is found from this experiment that, further study need to be done such as reducing of large point cloud file size (original point clouds of 8GB for scanning lion only) and reconstr-ucted model file size (the textured model of lion statue of 11Mb in size), redundant information, the point cloud registration accuracy improvement, and a fast georefrencing approach to transform the registered point clouds into a chosen external (geodetic) coordinate system to integrate with other geospatial data etc.

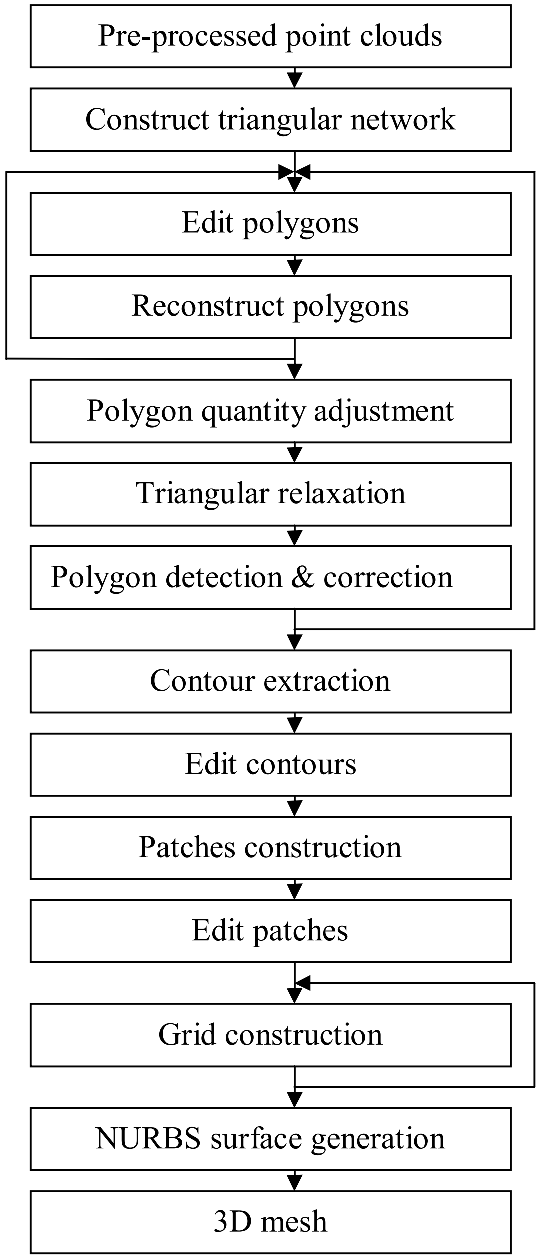

Fig.5 The workflow of 3D modelling

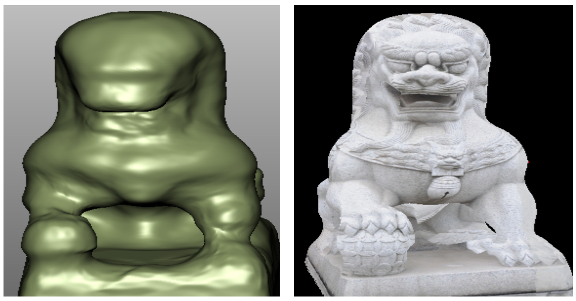

Fig. 6 Untextured mesh and 3D model

6. ACKNOWLEDGEMENT

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