APPLICATION OF TERRESTRIAL LASER SCANNING FOR HERITAGE CONSERVATION IN YUNGANG GROTTO

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ABSTRACT:

Terrestrial laser scanner was applied extensively in the heritage documentation in recent years, and laser point-cloud is an important sort of data source for making high-resolution 3D model. As a famous world culture heritage with thousand year history, Yungang Grotto was the first large-scale stone engraving in China which was destroyed by the wind erosion seriously and needed a rescuing conservation for its detailed 3D information. This paper presents a technological method for conserving a virtual Grotto by terrestrial laser scanner with digital images, and describes its datum processing workflow for making the Grotto's 3D model integrated with vector data, and also introduces the way of smoothing high-quality contour charts for some bodhisattva in this Grotto. The experiment proves these methods are reliably and efficiently for heritage conservation.

1. INTRODUCTION

As a sort of powerful data source for building object's 3D model, laser point cloud was applied extensively in conservation work of historical relics in recent years. And it can fulfil the requirements of high density of data, speed of acquisition and accuracy in different field (Biosca and Lerma, 2008). In particular, an area that has welcomed the new advances in technology is culture heritage preservation, where 3D modelling provides a means of recording historic sites or objects (Troccoli and Allen, 2004). Yungang Grotto was the first large-scale stone engraving in China with thousand year history which was destroyed by wind erosion seriously and needed a rescuing conservation for its detailed 3D information. This paper introduces the conservation work of Yungang Grotto by Terrestrial Laser Scanner.

The secondary paragraph is about the choice of laser scanner for getting high-quality point cloud. The third paragraph describes some pre-processing work of point cloud, including registration and build model. The fourth paragraph concentrates on a method for integrating vector-graph with digital image and point cloud. The fifth paragraph presents a way for smoothing contours of some bodhisattva statue. The sixth paragraph is a conclusion of this project.

2. CHOICE OF LASER SCANNER

2.1 About data quality standard

Until now there are seldom papers to instruct a uniform technical standard for estimating laser point-cloud's quality, but it is needed to known well for doing the documentation of culture heritage, especially when we were inquired for affording high-accuracy datum of enough convincingness to the experts of historical relics. Based on the experience from some relative works by other people, we can estimate laser point-cloud's quality by two parameters quoted below:

The first one is distance accuracy of laser scanner. Sometimes laser scanner could acquire thousands of laser reflected points in one minute on a polar coordinate system, on which it is more difficult to evaluate the quality of every point compared with precise points measured by total station. Therefore, the estimation work of laser points can be described by some special points from point-cloud of one view-point. For comparing the quality of laser points from different laser scanners, it is supposed that three kinds of ones scan a flat vertical plane separately in same conditions, it is easy to notice that someone has better scanning effect by reason of its point cloud are more thin and more regular than others (Fig.2). This is a kind of direct judgment standard about the quality.

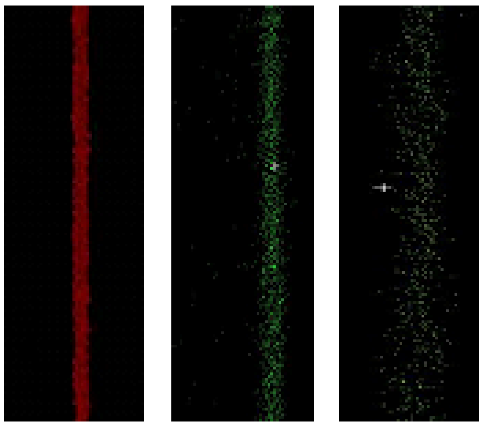

Fig.2 Laser points about a vertical plan from 3 sorts of scanners
From left to right, points captured by scanner A, B, C
Points in A are more thin and regular than the ones in B or C

The second one is space resolution. Space resolution is another important factor for evaluating point cloud quality besides distance accuracy (Boehler and Marbs 2005). It presents an ability to distinguish the minimum interval on objects. Space resolution was usually affected by the radius of laser beam and the angle resolution ability of laser scanner in the same distance condition. Higher space resolution, the more detailed characteristics of objects can be captured by laser scanner. Fig.3 gives two point-clouds of different resolution, it is obviously that left one has more sufficient descriptions of Buddha figure and it is better.

Fig.3 Compared different space resolution with two point-clouds

2.2 About the chosen of laser scanners and parameter's setting

In recent years, laser scanning technology was extensively used in the field of culture heritage surveying. Now there are some manufacturers of terrestrial laser scanner, and it is certainly that every sorts of scanner has its own special advantage. According to the preconditions quoted above and some other factors such as continuous working time, etc, Leica HDS 3000 system was chosen to become working instrument.

Parameter's setting of laser scanner is important work in laser scanning project. The parameter setting of interval range of laser point samples has a significant relationship with point cloud quality. The large parameter leads to a low precision model, oppositely a small one cause great amount redundant datum. There is an empirical equation (Bryan, P.G. Barber D. M. and Mills J.P. 2003) quoted below:

$$Q = 1 - \left(\frac{m}{\lambda}\right) \tag{1}$$

Where: Q describes the quality of point-cloud,
m is the sample interval range
λ is the minimum characteristic size of target object

In this project, the minimum interval range is set to 1cm because it is needed to recognize object's size about 2cm.

3. PRE-PROCESSING OF POINT CLOUD

The first part about data pre-processing is the registration of point cloud which includes a coordinate transformation from one scan system to another one. Such transformation involves 7 unknown parameters: 3 offsets $(\Delta X, \Delta Y, \Delta Z)$, 3 rotation angels (ϕ, ω, κ) and one scale factor λ, more than three high precision targets were used for solving all these parameters, results like as Tab.1 (Leica Cyclone Software).

Scans	Offsets $(\Delta X, \Delta Y, \Delta Z)$ (m)	Rotation
Initial	0.000, 0.000, 0.000	(0.0000,1.0000, 0.0000):0.000
1	50375.127, 30037.369, 786.464	(-0.0011,-0.0010,1.0000):135.553
2	50367.273, 30038.500, 786.214	(-0.0037, 0.0003, 1.0000):52.785
3	50354.066, 30033.364, 786.291	(0.0005, 0.0001, 1.0000):157.774
4	50339.757, 30028.233, 786.229	(-0.0010, -0.0013, 1.0000):162.220
5	50335.588, 30029.222, 786.248	(-0.0006, 0.0027, -1.0000):91.860
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Tab.1 Partial registration results

Registrations of laser point clouds from different scans are essential part for building 3D grotto's model. Because the grotto extend several kilometres, dozens of registration times are needed for the whole model and it results in the accumulated errors from the registration work:

$$\sigma_{1-n} = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 + \ldots\sigma_i{}^2 + \ldots\sigma_{n-1}{}^2} \tag{2}$$

Where: σ_{1-n} are accumulated errors of registration from scan 1 to scan n

σ_i is the accumulated error between scan $(i-1)$ to scan i and scan i to scan $(i+1)$.

A control network (Fig.4) was built based on the scanning targets with spatial coordinates for reducing accumulated error. When point-cloud registration works were being, control points on these targets were used for adjusting the accumulated errors.

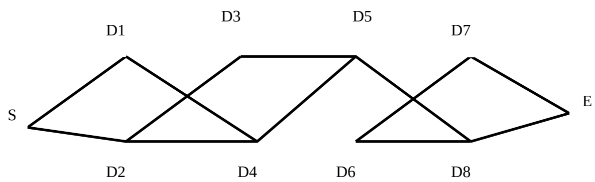

Fig.4 Control network for point-clouds registration in Yungang Grottos

And then, noises are unavoidable in the point cloud, some noises are from scanning process and others are produced by registration errors. Median filtering was chosen to reduce the noise in point cloud, threshold is an experimental value for keeping the balance between preserve effective data and eliminate noise points. Point clouds are a sort of discrete datum, normally experts of historic relic hope to get an object model of Yungang Grotto. Considering on the irregular shape of carved stones, 3D TIN was used to build the digital model of Grotto (results in Fig.5).

Fig.5 Digital triangular model of head part in No.20 grotto

4. INTEGRATED VECTOR-GRAPH WITH DIGITAL IMAGE AND POINT CLOUD

Digital images contain more texture information about objects, and vector-graphs make people easier to comprehend object's geometry. Integrated digital orthophotos with vector-graphs and making a new map for the conservation of the styles and features and structures of carved stones.

Three kinds of methods can be chosen to make vector-graph about the grotto. One is a way based on close-range photogrammetry by digital metric camera, another option is using the datum from a terrestrial laser scanner, or using a non-reflect target total station to produce vector-graph. The table quoted below gives a simple comparison about these three methods.

Method	Detail	Effective
Digital photogrammetry	Best (For high image resolution)	middle
Total Station	Not very good (Depend on operator experience)	low
TLS scanner	Good	high

Tab.2 Comparison of three methods about making vector-graphs

In Yungang Grotto project, we have mixed and used close-range photogrammetry and terrestrial laser scanning to make vector-graphs, the former is more efficient and the 3D information acquired by latter is more exhaustive.

The inner digital camera of Leica HDS 3000 has not enough pixel resolution, so using another digital camera with high resolution is necessary for the texture mapping work. Here this work is to establish mapping model from 2D digital image to 3D point cloud model. Setting $P(x, y, z)$ is the coordinate of a point on 3D model, and $p(u,v)$ is a homogenous point of $P(x, y, z)$ on 2D digital image. The matrix quoted below describes their transformation relationship:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (3)$$

Where A= $\begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \end{bmatrix}$, and expanded form of formula (3) is two polynomials as follows:

$$\begin{cases} a_{11}x + a_{12}y + a_{13}z + a_{14} - a_{31}xu - a_{32}yu - a_{33}zu - a_{34}u = 0 \\ a_{21}x + a_{22}y + a_{23}z + a_{24} - a_{31}xv - a_{32}yv - a_{33}zv - a_{34}v = 0 \end{cases} \quad (4)$$

6 pairs of homogenous points are need at least for solving all the variable value in matrix A by least-square mapping techniques, and each point on 3D model can find corresponding RGB value from the 2D images, then 3D point cloud model has texture information.

At last, integrated vector-graph with this color 3D model, we can get an idiographic map of Yungang Grotto, the result is in Fig.6

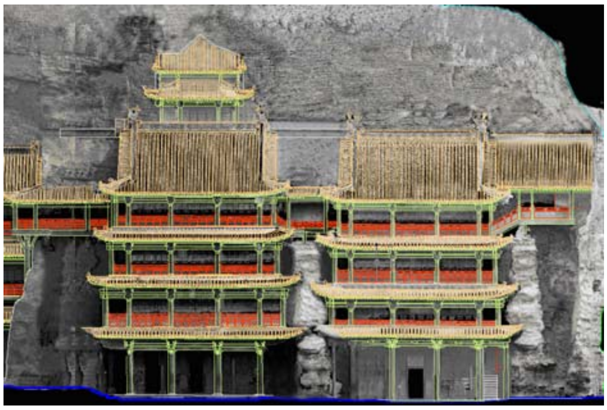

Fig.6 Partial 3D map of Yungang Grotto integrated vector-graph with digital Image and point cloud

5. SMOOTHING CONTOURS FOR BODHISATTVA STATUE

Conservation work of heritage relics needs contours for describing some certain statues more exhaustive. Sometimes statue's contours based on point cloud model are not smoothness enough (Fig.7), this is because the density of points are too intensive. A manual way is inefficient and inaccuracy for smoothing these contours. Therefore, we develop a new program to smooth them automatically. This program includes two parts: first it will delete redundant points in a certain scale for avoiding too many vertexes in very close region. And then it will fit the remained points to some curves by adaptive smoothing method, execute this program and the results show in Fig.8.

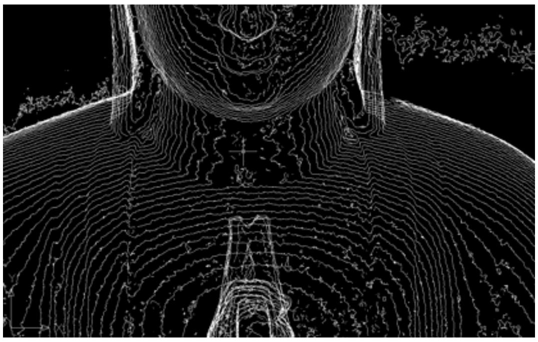

Fig.7 Unsmooth contours

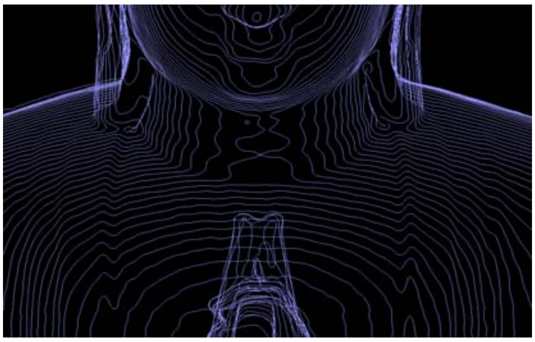

Fig.8 smooth contours

6. CONCLUSION

Nowadays, terrestrial laser scanner is applied extensively in 3D conservation and reconstruction of heritage relics, and it can provide a point cloud model with 1cm interval range at least. Sometimes the experts of historical relics also expect to conserve the relics in the form of vector-graph for the further relics' repairing work. This paper introduces a method for conserving a virtual Grotto by terrestrial laser scanner with digital images, and gives its workflow of datum processing for integrating this color 3D model with vector-graph. At last it describes the work of smoothing high-quality contours for some bodhisattva in this grotto. In Yungang Grotto project, the final products are proved to be useful for conserving and planning the 3D information of the Grotto.

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