Study on Reverse Engineering of Historical Architecture Based on 3D Laser Scanner

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Abstract. Repair and maintenance of historical architecture includes reinforcement of configuration, repair of figure and so on. All these need surveying information such as blueprint etc. 3D laser scanning technology is one of the important technique methods to acquire spatial data. It scans the architecture point by point quickly; registers and joints point cloud to simulate the shape by computer; reconstructs 3D model accurately finally. It also produces construction drawing including ichnography, elevation, and cutaway. In addition, detail structure and vignette can be got by close-range photogrammetry method, which produces the orthoimage and linear drawing. This method is especially fit for surveying historical architecture that lacks construction records.

1. Introduction
Protective historical architecture has important historic, scientific and artistic value as a relic in the human evolution. It’s an exigent role to info-study on historical architecture including recording the location, structure, and construction style in multi-form and taking relevant protection action. The development of 3D computer graphics makes the reconstruction of 3D object come true. Compared with 2D graphics, digital 3D model has more abundant information and it is closer to living objects. Therefore, to construct 3D model of historical architecture can record shape, construction style and structure richly. Besides, it supplies the basic data for record file and repair protection.

Various 3D laser scanning systems have developed these years, and its applications will accelerate industrial technique level. 3D laser scanning technology is a whole-automatic and high precision three-dimensional scanning. It consists of optics, machine, electron and computer techniques. The main principle is: scan the object outline point by point; gain spatial coordinates and color information of points on the surface; joint the data to simulate the shape by computer; finally construct the architecture model accurately.

2. Principle and trait of 3D laser scanning technology
3D laser scanner combines non-cooperation laser range finder and angle measure system. This make us create dense digital surface model quickly and effectively. The principle of 3D laser scanner is: emit laser and reflected when touching the object; gain distance S, horizontal angle α and vertical scanning angle θ. Generally, ground 3D laser scanner uses instrument coordinate system: X is in landscape orientation scanning cover, Y is vertical to X in the landscape orientation scanning cover and Z is vertical to landscape orientation scanning cover (see Figure 1). Then the point coordinates can be calculated from equation (1).
3D laser scanning technology can measure 3D coordinates point on object surface. Therefore, it belongs to three-dimensional measurement technology. Compared with the traditional surveying method, laser scanning technology has particular superiority as follows:

- is a sort of untouched measure system;
- gain the 3D coordinates, reflecting intensity etc. on object surface;
- rapidity of data acquisition, great quantity of data and high accuracy;
- work under all kinds of environments;
- extensive application.

3. Apply laser scanning technology to historical architecture reconstruction

As a new surveying method, 3D laser scanning technology scans the architecture without damage. This is significant to architecture protection and repair: it can not only reconstruct the actual shape but also transform data to CAD file.

3.1. Introduction of airplane building

Airplane building (see Figure 2) is located in 174 Changhai Road in Shanghai (Changhai hospital now), which was built in 1935. It is one of the historical protective architectures in Yangpu district. Dong Dayou, one of the famous architects in China, designed airplane building that looks like a biplane. All the architecture blueprints have been lost, while the building structure is kept well. The hospital wants to repair it without altering the original figure. Thereby construction ichnography,
elevation, cutaway etc. and some special architecture details should be surveyed, and all these files can be saved.

According to the actuality of the building and technique conditions, we decided to use a laser scanner from Co. Faro to scan the building and reconstruct the model. At last, the data and relative files must be produced.

3.2. 3D modelling
Scan the building and acquire amounts of 3D points, which is called point cloud. Register different stations of point cloud, triangulate, fit surface and then reconstruct the 3D model. Modeling process includes several steps as follows:

- **Data acquisition**
  Acquire 3D coordinates on the object surface by 3D laser scanner. Besides, geometry position, density of point cloud and image information can be obtained.

- **Data registration**
  It’s impossible to capture the whole object with one scan. So it need scan from different stations. Data registration is to put all point cloud together by coordinate transform.

- **Data preprocessing**
  This process involves data evaluation and filtering. Data evaluation is to find skipped and repeated area when scanning and decide whether to measure again. Data filtering is to reduce noise, smooth noise and resample data.

- **Surface fitting**
  The purpose of surface fitting is to reconstruct a concise and accurate surface. It can not fit the complex free-surface with only one. Hence segment data to dissimilar areas is combined and used to fit each surface, then joint to a whole one.

- **Products producing**
  3D model is constructed based on surface and feature. It can produce ichnography, elevation, and cutaway.

3.3. Airplane building scanning

3.3.1. Preparation. Before scanning, we should inspect environment nearby and confirm the number of scan stations, station position and also the controlling targets. Because of the complex shape of airplane building, nine scan stations and 6 targets are set out of the building. The station position is shown in Figure 3.

![Figure 3](image.png)

**Figure 3.** Station position.

We put Faro 3D laser scanner on the selected position, dispose targets and connect the scanner and computer. Then scanner works automatically according to scan parameters.
In order to gain integrated data, the inside and top of building are also scanned.

3.3.2. **Data processing.** After scanning, point cloud is transmitted to work space and modelling under software of reverse engineering. Generally speaking, 3D modelling includes point cloud, polygon and surface, totally three phases.

- **point cloud phase**
  Nine point cloud of different station are scanned outside the building. Data registration can transform them to the same coordinate system and obtain registered 3D point cloud. Many registration methods have been advanced. One of them is to use controlling targets. Posit the target on the linking place, and then register data by connecting targets. Another is by means of station coordinates. Measure all the station coordinates before scan. Therefore point cloud is under the same coordinate system. The other is to make use of mathematical arithmetic such as quaternion, six-parameters, iterative closest point (ICP), geometric feature constrained (GFC) registration and so on.

- **polygon phase**
  (1) wipe off fragmentary polygons
  We call the polygon that doesn’t intersect with main part or that is interlaced “fragmentary polygon”. Fragment wiping off in software can only wipe off the fragmentary polygons which don’t intersect with main part, while the interlaced ones must be wiped off manually. But the holes after deleting these polygons should be filled.
  (2) fill holes
  The number of holes depends on the data integrality and the number of fragmentary polygons. The principle of filling holes in software is based on curvature around hole. Smaller the hole is or clearer the boundary is, higher the accuracy will be. When filling holes, if some fragmentary polygons are involved, we should wipe off the fragmentary polygons first. And when we finish all the holes, wipe off fragmentary polygons again. Actually, filling holes creates some new fragmentary polygons. Repeat former steps until there are no holes and fragmentary polygons.

- **surface phase**
  (1) construct patches
  The pivotal step of constructing patches is patch partition, which is based on surface analyses. Patches should not be divided too small. Otherwise the surface will be too fragmentized to continue following steps. Certainly, patches should not be divided too large, otherwise the quality of surface will be bad since it is hard to capture the shape of point cloud. Commonly, patches, where many characters are, are many and minute, and vice versa.
  The fundamental is: (a) make curvature change of every patch uniform so as to improve surface quality; (b) make every patch four-side surface as soon as possible.
  We can also edit patches by moving, increasing, decreasing and changing direction manually in order to adjust distribution.
  (2) construct grids
  When we finish editing patches, run “construct grids”. The grids can be made symmetrical and coherent artificially likewise. In general, denser the grids are, high accuracy the surface has. Otherwise, the data file will be too large to be convenient.

- **export file**
  We can run 3D compare between surface and point cloud after 3D modeling (see Figure 4). Import the model to other software after satisfying precision and producing CAD entity model.
We can construct 3D model according to fitting surface and characteristic lines. Export it as *.igs file to produce construction projects such as ichnography, elevation, cutaway etc. (see Figure 5)

![3D model of airplane building](image)

**Figure 4.** 3D model of airplane building.

(a) ichnography                                (b) west elevation

(c) south elevation                             (d) east elevation

**Figure 5.** Construction drawing of airplane building.

4. **Detail collections by close-range photogrammetry**

Generally speaking, 3D model reconstructed by scan data has no texture. Besides, scan data can’t keep the details well especially such as detail structure and texture. For detail structure and vignette, we can take use of close-range photogrammetry method, which produces the orthoimage and linear drawing.

4.1. Image rectifying based on parallel

As we all know, it’s hard to dispose controlling points around every vignette. Because Not only it costs more time but also sometimes it’s impossible to dispose controlling points. The product we need is only the exact scale but not the absolute position. So we choose linear character to rectify image of plane vignette.

Figure 6 shows rectifying process. Firstly, we define two parallels in direction X, Y; secondly, calculate angles of exterior orientation elements; then measure two distances in direction X, Y and calculate scale coefficient; at last, rectify image.
In addition, we can produce linear drawing based on the orthoimage. As Figure 7 shown, the linear drawing of a certain plane vignette describes vignette mode and the style in detail and fulfils measuring requirements.

4.2. Curving pattern unfolding
There are two dragon patterns carved on column beside front door of airplane building. We need to unfold curving pattern to plane one. Firstly, dispose seven controlling points on column; then calculate exterior orientation elements and column surface fitting parameters; unfold curving image. Figure 8 shows the original dragon pattern, which is inflected near the verge.

As Figure 9 shown, scale of unfolded dragon pattern is identical. The drawing can be saved as file and used as texture. We can also produce linear drawing (see Figure 10) from unfolded pattern.
5. Conclusion
3D laser scanning technology can acquire 3D point cloud quickly with high accuracy. This meets the needs of historical architecture surveying and protection. 3D laser scanning technology can replace traditional measuring methods completely in historical architecture surveying. 3D point cloud can be gained by laser scanner, then construct the 3D model. In addition, detail structure and vignette can be got by close-range photogrammetry method, which produces the orthoimage and linear drawing.

Surveying of Historical architecture based on 3D laser scanning technology can not only reduce field work, improve efficiency but also provide different kinds of products such as 3D model, CAD construction drawing and so on. 3D laser scanner is growing towards high speed, high accuracy, large range and multi-information etc at present. All these will impulse laser scanning application to historical architecture surveying and protection.

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