A TECHNIQUE OF DIGITAL SURFACE MODEL GENERATION

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ABSTRACT It is usually a time-consuming process to real-time set up 3D digital surface model (DSM) of an object with complex surface. On the basis of the architectural survey project of "ChiLin Nunery Reconstruction", this paper investigates an easy and feasible way, that is, on project site, applying digital close range photogrammetry and CAD technique to establish the DSM for simulating ancient architectures with complex surface. The method has been proved very effective in practice.

1 Introduction

The reconstruction project of ChiLin Nunery in Hong Kong is an unprecedented event both in the history of Buddhism and in the field of ancient architecture. ChiLin Nunery is comprised of the main hall, 14 timber structures and one seven-floor pagoda externally covered with wood. The ChiLin Nunery is the largest man-made timber structure building in the world. Its design and construction spans over several years and numerous advanced equipment and technology have been applied during the process. Quality supervision through surveying is an indispensable part of the project execution. However, traditional 2D plane and elevations can not meet the requirement. Conventional and modern survey techniques have been jointly used to make 3D simulation for the models and pre-assembly of all timber members by computer. Other auxiliary quality control measures have also been taken to monitor and supervise the whole construction process in detail. In this way quality and progress of the project have been guaranteed.

During the project process, a key issue is how to establish the DSM of timber members in a quick and accurate manner. The number of timber members is numerous, and their shapes are diverse. It is almost impossible to achieve this purpose through the conventional surveying method. This paper presents an easy and feasible way to solve this problem. We obtained digital images of the structural members by digital cameras on project site, acquired quickly three dimensional coordinates of key parts in the objects by close range photogrammetry and then established DSM of the members by AutoCAD. The method was proved very effective in practice.

2 Data acquisition by digital close range photogrammetry (DCRP)

2.1 Basic principles of DCRP

Photogrammetry is a technique for obtaining information about the position, size and shape of an object by measuring their images instead of by measuring them directly. The term "close range photogrammetry" is used to describe the technique when the extent of the object to be measured is less than 100 meters and cameras are positioned close to it. Images are obtained from camera positions all
around (and sometimes inside) the object. Camera axes are parallel only in special cases; usually they are highly convergent, pointing generally towards the middle of the object. The coordinates of points on the surface of an object are often required to be of high homogeneous accuracy throughout the object space. On the basis of an understanding of the physical processes of imaging and measurement, mathematical models are devised from the basis of numerical methods to produce 3D coordinates of discrete points on the object. These coordinates are usually estimated by least squares.

Photogrammetry has a long history and it now enters the digital era. In reality, with the continual development in computer and related technology, digital close range photogrammetry has great potential and flexibility in its current application. In developed countries, it has been widely used in industry, architecture, archeology, biology, sports, chemistry and other disciplines.

### Table 1 Parameters of digital camera for engineering survey

| Parameter                  | Fujifilm DS-7                                                                 | Sony MVC-FD7                                      |
|----------------------------|------------------------------------------------------------------------------|-------------------------------------------------|
| Focus                      | $F = 5.7 \text{ mm}(38 \text{ mm on } 35 \text{ mm camera})$                 | $F = 4.2 \text{ mm}\text{-}42 \text{ mm adjustable}$ |
| Focus distance             | Near: 45 mm–80 mm                                                             | 0.45 m–infinite distance                        |
|                            | Macro: 9 mm–13 mm                                                             |                                                 |
| Image size                 | 4.8 mm$\times$3.5 mm                                                          | 4.8 mm$\times$3.5 mm                            |
| Pixels                     | 640$\times$480                                                                | 640$\times$480                                  |
| Storage                    | SIMM (30 PCs/card)                                                            | 3.5 floppy disk                                  |
| Port                       | LPT                                                                           | N/A                                             |

2.2 Digital camera

The simplest data acquisition equipment is a digital camera that can obtain the image data of objects. There are various kinds of digital cameras, the prices of which range from several hundred to several hundred thousand US dollars. Of course, the higher the price, the higher the performance of the cameras and its resolution. When there is special requirement on survey accuracy, it is necessary to have professional camera with high performance and high-resolution. For ordinary users, common cameras are their natural choice. In the reconstruction project of Hong Kong and Chilin Nunnery, a common digital camera has been used. Please refer to Table 1 for the specification and technical parameters of the camera.

2.3 The PhotoModeler—the software of digital close range photogrammetry

The PhotoModeler software package is a product of EOS system, USA. It consists of two parts: camera self-rectification and photogrammetry software. The measurement errors during PhotoModeler data processing are mainly caused by camera parameters, instability of external elements is low precision of homogeneous signal points. The accuracy of external elements and mainly determined by the measurement accuracy of control points, while the accuracy of the camera parameters depends upon its controlling method.

The parameters of the camera such as the focus distance of the camera, coordinates of the principal point of the images, sizes of the images, and the lens distortion are all obtained through self-rectification. The precision of the camera could be controlled by the rectification program in the PhotoModeler package. Take at least 6 overlapped photographs of rectification module at the up, below, left and right points, read accurately and label the homogeneous points (angles of the triangles), and then use the camera rectification program to rectify the parameters.

The following is a set of rectified parameters of Fujifilm digital camera:
- Main focus: 5.6045 mm
- Image size: 4.691 6 mm$\times$3.500 0 mm
- Coordinates of the main point: 2.328 5 mm, 1.725 9 mm
- Longitudinal abnormal reflection coefficient
Sectional abnormal reflection coefficient:

\[ P_1 = -0.000302 \quad P_2 = 0.00003591 \]

This is a quick but rather coarse way of calibration. It is not suitable for calibration of high-resolution cameras such as Kodar DCS series. In the meanwhile, since the calibration of cameras is carried out with different methods under different circumstances, the results achieved by several calibrations for the same camera are not identical. The authors made use of the relative control method, plumb rectification method and distance control as predefined conditions to locate the optimal set of parameters as the final rectification result.

The photogrammetry software package PhotoModeler is based on Windows platform, which quickly snaps the detail from the photographs and obtains the DSM of objects by applying the principle & method of digital photogrammetry.

2.4 Flow chart of data acquisition

Fig. 1 shows the flow chart of data acquisition by PhotoModeler.

![Flow chart of data acquisition](image)

1) Establishing the control system. In photogrammetry, control data are both absolute control data and relative control data (for example, known distance; known angle). We use relative control data because it is very easy to obtain.

2) Labeling special point line on the objects. Many members have less texture, so it is very difficult for data acquisition by PhotoModeler. Label special point line on the objects to correlate the characteristics, and the positions of signal points in the images can be precisely determined. As a result, the DSM of spatial models can be constructed more accurately when points and lines that varied obviously are labeled out and the survey precision of the surface points on the models and the matching precision are improved.

3 Using CAD to set up DSM of objects

Since coming into publication, AutoCAD has developed at an astonishing speed. The software is updated so frequently that even in the reconstruction project of the Hong Kong Chilin Nunnery, its three versions, namely version 11.0, 12.0 and 14.0 have been used.

AutoCAD has powerful image building and editing functions. With a fully open structure, it provides multiple development tools such as menus, image patterns, linear patterns, sample drawing, AutoLisp compiler and a development system based upon computer language C, which is extremely helpful for CAD users to develop and extend the functions of the software according to users' own needs. In addition, AutoCAD can exchange data with other image processing or text editing software through object linking and embedding (OLE), this is a property that enhances its applications.

In 3D image processing, AutoCAD provides two modeling techniques, i.e. linear frame and surface description modeling technique and solid object modeling technique. The former sets up firstly the linear frame of the objects, then on the surface of the objects, 3D models are constructed (as shown in Fig. 2). The process is intuitionistic but involves complicated steps. The latter sets up the 3D model through the combination, intersection, cutting and other treatment of simple 3D objects after complex calculation. Though it is only simple procedures, the data to be processed are very huge and the technique demands a high computer configuration. In practice, modeling techniques are selectively used with regards to the actual conditions of different members for efficiency and suitability. Compared with the 2D image processing ability of AutoCAD,
its 3D image processing ability is less powerful, especially in the field where there is special requirement on 3D precision. In the reconstruction project of the Hong Kong Chilin Nunnery, in view of the specific traits of the structure members, AutoLisp was used to improve and extend the functions of 3D image processing of the software, an action that speeds up the modeling process and ensures the proper execution of the project.

Fig. 2 The model of linear frame and the model of object

4 Application examples

4.1 Setting up the DSM of lotus-shaped tower cap

Fig. 3 is the drawing of the central lotus-shaped pedal for the clock tower of the Hong Kong Chilin Nunnery. Its main part is of round shape. The diameter of the bottom surface is 756.9 mm, that of the upper circle is 1080 mm, and its height is 288.2 mm. It is composed of 8 lotus petals. It is very difficult and time-consuming to obtain the surface point coordinates or traits to establish DSM by ordinary surveying method.

First some signals were made on the surface of the lotus-shaped member. Then a digital camera (pre-calibrated) was used to take 6-8 pieces of 100% overlapped photographs under fine weather (from a distance of approximately 1 m with or without tripod). At the same time, a steel ruler was used to measure accurately at least one unit length on the lotus-shaped member. The quality of the photographs was checked immediately on site. The photographs were retaken if the quality was not satisfactory.

Then the image data were transferred into computer and image-processing software such as Adobe Photoshop was used to edit and handle the images mainly by image cutting, edge strengthening and color deepening. After image data processing, the files were saved into the engineering image data directory.

The method of using PhotoModeler to carry out photogrammetry processing is similar to the bundle adjustment method. At first, 4-6 images were selected from the engineering image data directory. The parameters of the camera were given. All the points to be determined were marked separately or relatively on the photographs. At least one distance relative control was stipulated to match the images and obtain the multiple homogeneous quadrants coordinates. Then software was used to calculate by bundle adjustment method to obtain the 3D coordinates of all points to be determined. The results were then saved into DXF format files.

In AutoCAD, first the data obtained through PhotoModeler were edited and compiled with reference
to the characteristics and actual relative control parameters of the lotus-shaped member. The 3D image processing functions of AutoCAD and the software developed by the authors were used to set up the DSM of the lotus-shaped tower cap, as Fig. 4 shows.

![Figure 4](image-url)

**Fig. 4** PhotoModeler treatment and DSM generation

4.2 Setting up the DSM of "Zhiwen" of the main hall

Fig. 5(a) shows the "Zhiwen" of the main hall of Chilin Nunnery. It is symmetrical, with the length of 1660 mm, the width of 700 mm, and the height of 1200 mm.

"Zhiwen" is the decoration on the top of the ridges of the main hall. In Buddhism, it is the pedestal for the God of rain, with the shape like fishtail. It is completely cast by copper and plated with one piece of 24K gold foil covered with gold powder. The work of photography was done on its model.

In the same way above, a digital camera was used to obtain sufficient overlapped images. PhotoModeler was used to carry out photogrammetry processing. 4-6 images were selected from the engineering image data directory. In AutoCAD the data were edited and compiled, lines were connected and surface was constructed, and the DSM of "Zhiwen" was set up (Fig. 5(b)).

![Figure 5](image-url)

**Fig. 5** "Zhiwen" and its DSM

5 Conclusion

Close range photogrammetry and AutoCAD method as described in this paper brings about satisfactory results in its application to the reconstruction project of the Hong Kong Chilin Nunnery in order to obtain the 3D models of objects. The major purpose of taking this method is to overcome the difficulty of architecture supervision. The sizes of the frame of the model have been accurately determined through engineering survey and relative control and the neighboring members can be easily assembled. In practice, the relative close range photogrammetry precision acquired with such a method is between 1/200 and 1/400 by analyzing the redundant survey while the relative precision allowed for Chinese ancient architecture is normally 1/100.

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