3D SIMULATION AND RECONSTRUCTION OF LARGE-SCALE ANCIENT ARCHITECTURE WITH TECHNIQUES OF PHOTOGRAMMETRY AND COMPUTER SCIENCE

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ABSTRACT

3D simulation and reconstruction of architecture play an important role in the documentation and protection of cultural heritage. Photogrammetry and Computer technology are used to preserve the datum and restore the appearance of ancient architecture in our work. We perform experiments with rockery at first. Feature points on the rockery are obtained by means of photogrammetry. We mark feature points on the surface of the rockery and take photos with a non-metric digital camera. Then we use DLT (Direct Linear Transformation) to calculate the coordinates of feature points. Then the points are input into software on computer graphics (AutoCAD). A new generation algorithm for spatial convex polyhedron is presented. And the algorithm is used to construct 3D model of the 3D solid from a spatial points set. 3D model is imported into 3DMAX so that realistic material can be attached to the model. At last rendering and animation of the 3D model are completed and we got the results of simulation and reconstruction of the rockery. The results of the experiment are wonderful. As we all know, the surface texture of the rockery is much more complicated than the general components of the architecture. We use the approach mentioned above to realize the 3D simulation and reconstruction of large-scale ancient architecture successfully. Especially, the algorithm presented works very well in the process though the data volume of the ancient architecture is huge. The algorithm is used to calculate the minimum convex polyhedron of the given spatial points set rapidly. And its efficiency and practicability are verified at the same time.

1. INTRODUCTION

With the rapid development in the urban area and quick change in our surrounding environment, protection, documentation and visualization of ancient architecture in digital form become an urgent and meaningful task. Especially novel approaches and tools to work on the purpose are appreciated. Photogrammetry is widely used to reconstruct terrain, natural targets and buildings in stereovision. It is also exploited to reconstruct human skeletal trunk for clinical studies and mechanical analysis. But it is seldom used to restore the granite of complex surface and large-scale ancient architecture before. In this paper, the method and procedure of 3D simulation and reconstruction of rockery grotesque in shape are discussed first. We begin with raw materials and get the final results by means of photogrammetry and computer technology. This is the essential part in our experiment and paper. Then those methods and phases are employed to realize the reconstruction of a large ancient temple. In the third section, a new algorithm for calculating spatial convex polyhedron is put forward and discussed in detail. At last we draw some conclusions and give some proposals.

2. PRINCIPLES AND PROCEDURE

In this part, close-range photogrammetry, image processing and computer graphics are employed to restore the rockery in the park. We investigate the 3D simulation and animation of complex objects and give applicable schema for reconstruction of ancient architecture. The whole procedure of 3D reconstruction of the objects is illustrated as follows:

2.1 Construction of 3D controlling field

A number of conspicuous symbolic points are laid around the rockery. Some points are marked on the plane and treated as horizontal control points, and others are of certain height and treated as vertical control points. These controlling points are distributed evenly around the rockery and there should be some points higher that the rockery so that necessary precision of the controlling field can be ensured. An original point is set, and X axis and Y axis are designated. In the local coordinate sustema, coordinates of all controlling points are measured accurately. Thus construction of 3D controlling field is complete.

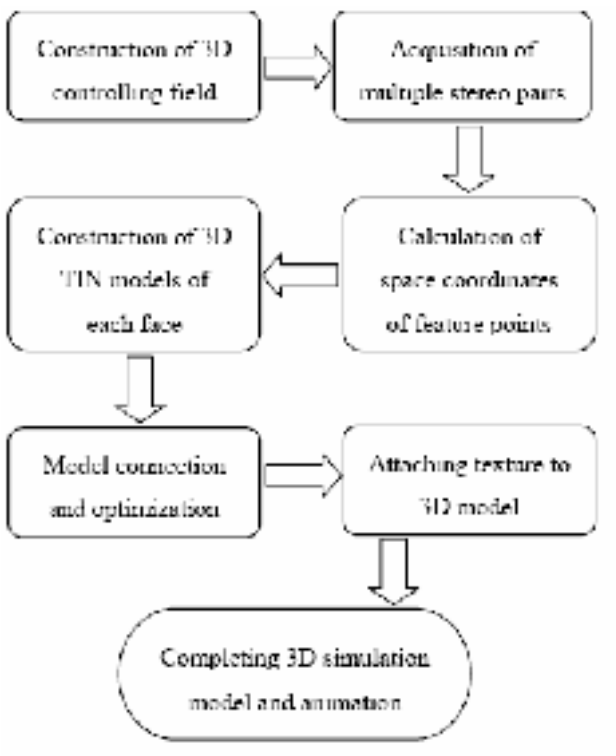

Figure 1. procedure of 3D reconstruction

2.2 Acquisition of coordinates of feature points on the rockery

Adequate feature points are marked on the convex and concave

locations on the surface of the rockery. In the condition with plenteous light, five stereoscopic pairs are taken with a non-metric digital camera on the left, front, right, back and top faces of the rockery. The codes of the feature points on the stereo pairs are specified in Photoshop 7.0 and the photograph coordinates of controlling points and feature points are measured in EADAS 8.4. A standard close-range photogrammetry method called direct linear transformation (DLT) is emplyed to compute the space coordinates of the feature points and make accuracy assessment.
Direct linear transformation is a method that sets up direct linear relation between the photo coordinates and object space coordinates. It is deduced from collinearity equations in principle. The basic equations of DLT are expressed as follows:

$$\begin{aligned} x+\frac{l_1X+l_2Y+l_3Z+l_4}{l_9X+l_{10}Y+l_{11}Z+1}=0 \\ Y+\frac{l_5X+l_6Y+l_7Z+l_8}{l_9X+l_{10}Y+l_{11}Z+1}=0 \end{aligned} \qquad (1)$$

where: x, y = photo coordinates
X, Y, Z = object space coordinates
l_i (I = 1, 2 …. 11) = transformation coefficients

As we know, coefficients l_i are functions about elements of interior orientation, elements of exterior orientation, inconsistent coefficient between y axis and x axis, and nonorthogonality between x axis and y axis. In order to calculate object space coordinates (X, Y, Z), at least three equations are required, that is, two photos should be taken. Suppose coefficients l_i of two photos are ($l_1,l_2 \ldots l_{11}$) and ($l'_1,l'_2 \ldots l'_{11}$) respectively. Omit an equation and the coordinates (X, Y, Z) can be computed with:

$$\begin{bmatrix} l_1+xl_9 & l_2+xl_{10} & l_3+xl_{11} \\ l_5+yl_9 & l_6+yl_{10} & l_7+yl_{11} \\ l'_1+x'l'_9 & l'_2+x'l'_{10} & l'_3+x'l'_{11} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} l_4+x \\ l_8+y \\ l'_4+x' \end{bmatrix} = 0 \qquad (2)$$

It is understandable that calculation process of coefficient l_i can be considered as space resection, and calculation process of space coordinates (X, Y, Z) can be considered as space intersection. (Feng, 2002)
DLT algorithm is programmed with C language on personal computer. Input and output data are formatted in text files. And we get space coordinates of all feature points and accuracy assessment results. The residual errors of partial control points derived from right stereo pairs are listed as follows (see table1).
As we can see, some residual errors are a bit larger. It might be caused by imprecise image measurement, aberrance of optical lens, etc.

2.3 Construction of 3D TIN model of the rockery

Coordinates of feature points on the front face of rockery are imported to AutoCAD 2004, and TIN model of the front face are constructed. So is done with the left, right, back, and top face of the rockery and five faces are modeled. As photos cannot be taken on the bottom face, we use several adjacent planar facets to approximate the bottom face. Model connection and optimization are performed to complete the modeling process.

Point No.	X (mm)	Y (mm)	Z (mm)
8001	0.6988	0.0772	0.5891
8002	-0.2589	0.4816	-0.1131
8003	-1.5658	0.1587	0.1394
8004	-2.0718	0.5352	-0.8670
8005	-2.8463	-0.5722	-0.5217
8007	1.1183	-0.6918	0.2543
8008	0.2252	0.2514	0.3315
8091	-0.4466	1.2361	-0.1171
8014	1.0908	0.0471	0.4934
8010	2.3153	-1.4808	0.1831
8015	-0.9187	0.4543	-0.3815
8011	2.4336	0.7913	0.1365
8012	1.1355	-0.9923	0.1089
8016	-1.2557	-0.1842	-0.2567
Average Error of Control Points			
X (mm)	Y (mm)	Z (mm)	
-0.0247	0.0080	-0.0015	
Mean Square Error of Control Points			
X (mm)	Y (mm)	Z (mm)	
1.5373	0.7068	0.3882	

Table 1. Residual errors of control points derived from right stereo pairs

2.4 Texture attachment and animation

TIN model of the rockery is imported to 3DMAX 6.0 for tecture attachment and animation. In order to reduce duplicate storage of points and edges of the model, further optimization of 3D model is performed with 3DMAX.
Realistic texture is derived from original photos and attached to each face of the rockery model. As each face of the model is attached texture separately, there may be gap or inordinance between two adjacent faces. Texture mosaic is compulsory to perfect the final model. And this is a troublesome and tedious job. After that, the model is rendered and animated with the powerful function in 3DMAX. The result of simulation and reconstruction can be demonstrated as a short time film.

2.5 Production of the experiment

The experimental production includes:
1. Five stereo pairs of the rockery faces.
2. Space coordinates of feature points of the rockery and its accuracy assessment.
3. Each face model and the whole model of the rockery.
4. Rendered model and animation.

3 3D SIMULATION AND RECONSTRUCTION OF ANCIENT ARCHITECTURE

The procedure mentioned above is introduced to reconstruct the ancient temple in our work. Most Chinese traditional ancient temples are built with various wood components only and nail or cement is not used in their construction at all. Those wood components are diverse in shape and function, and placed at different locations in a large building. These components are joined with tenons, rabbets or mortise and combined tightly with one another. So the assembly of a palace composed of thousands of wood components must be in an orderly way, and conform to certain scientific, strict rules and procedures. As the wood components vary in shape, components of regular shape can be measured with rulers in a common way, and components of irregular shape can be surveyed with photogrammetry. After we get the points and lines data of each component in AutoCAD, we need to construct its 3D solid model. Because of large amount of components, it is a burdensome job. We present a practical algorithm that will be discussed later to tackle the trouble effectively. After we get the solid model of each wood component, we can import it into 3DMAX to make animation of each model and assembling process of a whole palace. The residual procedure is almost the same as that of the rockery model. Realistic materials have to be attached to components before rendering. In the assembling process of the palace, strict assembly sequence must be abided by. And the assembling animation tells you how a real palace is assembled. We participate in the project "3D simulation and assembly of archaizing architecture in Hong Kong Chilin nunnery" in 2004. Yaoshi Palace with 5 layers needs reconstructing in our project. It consists of more than 1500 wood components and is due in 6 months to finish 3D modeling, layer assembly, whole assembly, 3D simulation and animation. As our schema and algorithm are employed, desired productions (1.55G data totally, including 165M solid models) are achieved in just more than 3 months. Working time is largely decreased, and quality of 3D models can be controlled conveniently. It indicates that our schema and algorithm is of great value. Typical wood components and a whole palace (Yaoshi Palace) are illustrated as follows:

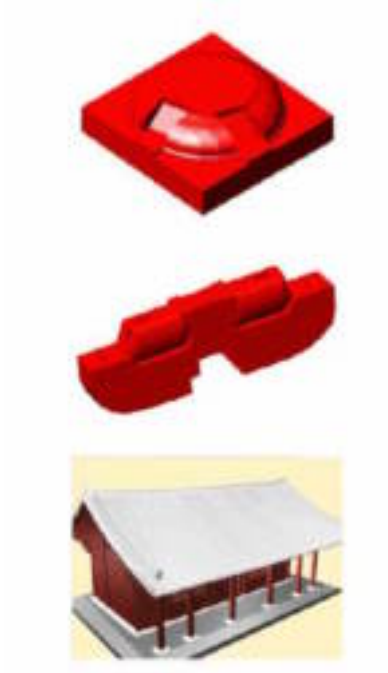

Figure 2. Typical components and whole palace

4 ALGORITHM FOR GENERATING SPATIAL CONVEX POLYHEDRON

A generation algorithm for spatial convex polyhedron is described in this section. Burdened with the workload of construct 3D solid models of a great deal of components, we investigate the effective algorithm. It aims at the spatial point sets with plenty of points and it is based on the method of extreme coordinates. The program is realized with C language and ObjectARX in AutoCAD 2004. It works very well and reduces the modeling time of the components greatly. The procedure of the algorithm illustrated as follows:

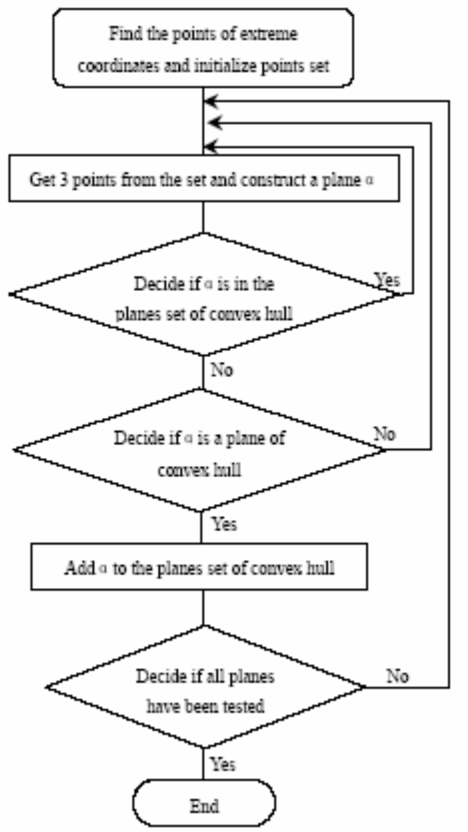

Figure 3. Algorithm procedure

CONCLUSIONS

This paper presents an applicable schema for 3D simulation and reconstruction of large-scale ancient architecture. It is applied in practice wonderfully. The experiment indicates that close-range photogrammetry can be used to reconstruct complex objects. Sufficient feature points on the object are needed to model the complex object precisely. The stereo pairs should have high resolution and good quality so that accurate photo coordinates can be attained and precise space coordinates can be acquired. Anyway, good production set high requirements to original photos. The paper also presents a practical algorithm to calculate convex hull of spatial points set. It generates sets of nodes and faces of the convex polyhedron (convex hull) and it is a new way of solving spatial minimum covering problem. Much more improved and advanced algorithm for this purpose can be investigated in our future work.

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