SOME TESTS OF TLS IMAGE MATCHING FOR RECONSTRUCTION OF 3D ARCHAEOLOGICAL OBJECTS

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ABSTRACT

Three Line Sensor (TLS) systems, as a kind of new technique for digitizing and recording of archaeological objects with high accuracy and resolution, have been widely used in archaeological field in recent years. For reconstruction of 3D spatial models, the algorithms and system of TLS image matching have been developed and reported by Wu and Murai in 1996. In this paper, we reported some of our results for using Wu and Murai's system and discussed how to make improvements for our applications. Three parts of works have been reported, which include how to use the system for real large TLS image matching, how to fast generate orthoimages based on 3D models, and how to create 3D virtual archaeological objects for visualization. Finally, some examples are given to show the efficiency of our approaches.

1. INTRODUCTION

Recently, there are considerable interests in automated extraction of 3D information from archaeological objects. Digital close-range photogrammetry based on the high-resolution images captured by CCD three line scanners (TLS) has played very important role in the field of recording and visualization of cultural heritages. One of central tasks in digital photogrammetry and computer vision is to reconstruct the forms and structures of objects by image matching based on two or more images in the scene. During the recent decades, many image matching techniques (such as area based matching, feature based matching, and relation based matching) have been investigated by many researchers both in the fields of photogrammetry and computer since, but there are still many unsolved problems need to be improved.

For the reconstruction of archaeological objects using linear CCD camera, the algorithms and system of image matching have been developed and reported by Wu and Murai in 1996. The image data were obtained by a triplet of linear CCD cameras (Three Line Scanner) and registered to satisfy the epipolar constraints. The advantages of this system are mainly included as follows:

1) It can generate a dense disparity map for accurately measuring 3D objects;
2) The algorithms are robust due to eliminate mismatches using the extra images;
3) The algorithms are based on the disparity constraint of the TLS images and without needs explicit knowledge of the camera's parameters.

In this paper, we reported some of our testing results for

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using Wu and Murai's system and discussed how to make improvements for our applications. Three parts of works have been reported, which include how to use the system for real large TLS image matching, how to fast generate orthoimages based on 3D models, and how to create 3D virtual archaeological objects for visualization. Finally, some examples are given to show the efficiency of our approaches.

2. TLS IMAGE CAPTURING

Linear CCD camera has a linear array of solid semi-conductive elements which enables it to record one line of an image simultaneously. A two-dimensional image can be produced by a linear CCD camera if movement is introduced between sensor and the object of interest. The motion can apply to the object or to the camera and dependent on which is moved, the image produced will be different. A linear CCD camera with N elements produces a line image of N pixels at each time. The ith column (pixel) of each scanline is captured by the ith element. A MxN image can be created by moving the CCD camera and recording the data M times. Each line of the image, which is produced by different elements at certain time, is a perspective projection image. Each column of the image, which is produced by moving the camera and recording by certain element at different time, is a parallel projection image.

Stereoscopic vision system can be formed by using two or more than two linear CCD cameras. The introduction of a second linear CCD camera arrangement enables a stereoscopic view to be created after the movement of the camera or object has taken place. The stereoscopic linear CCD camera produces two or more than two perspective images of a given scene. The binocular disparity inherent in the images will allow the observer to fuse the picture information and perceive depth in the resulting three dimensional image.

In our stereoscopic line-scan system, a three line scanner (TLS) has been used. TLS has a set of three detector arrays at vertical, forward and afterward angles on a same focus plane of a wide angle lens camera [Fig.1]. Three complete images are captured by moving the camera by a series of step motions and capturing a new line of image data at each step. The related parameters of our TLS are shown in Tab.1.

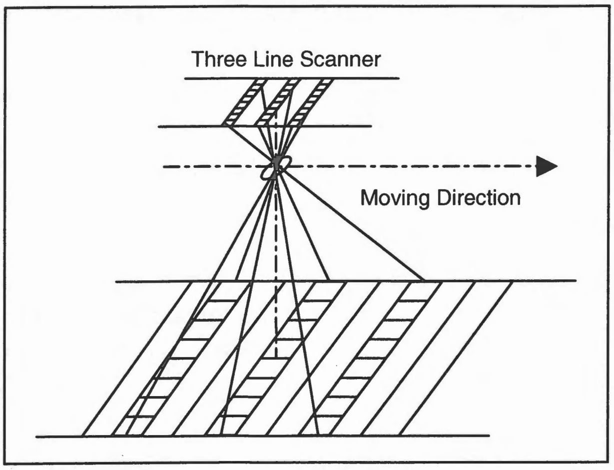

Fig.1 The scanning mode of three line scanners

Tab. 1 Parameters of the three line scanner

Sensors	5000 elements linear sensor x 3
Element size	5 μm x 5 μm
Pitch	7 μm
Lens	Zeiss Biogon 38.4 mm f4.5-22
Data resolution	8 bits
Sample rate	10 MHz
Interval of sensors	15.5 mm
Stereo angle	±21.5°

After image capturing by a TLS, the following several kinds of pre-processes are needed to register the images based on our testing:

1). Scaling the images in X direction based on the parameters of the scanning speed to register the pixels with the same size in X and Y directions;
2). To modify the brightness of the images captured by three linear scanners to the same value;
3). To remove the dark noise lines in the images by line based filtering;
4). To adjust the abruptly jumped scan-lines in the images based on the neighbor line features;
5). If the moving direction of the camera is not perpendicular to the line arrangement of the CCD camera, image registration is needed to satisfy the epipolar constraint.

3. IMAGE MATCHING

The method of image matching used in the system consists of three steps: In the first step, a relaxation

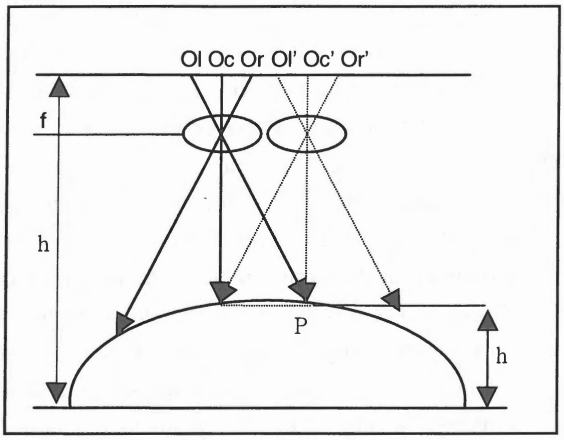

Fig.2 (a). Matching between left and center images

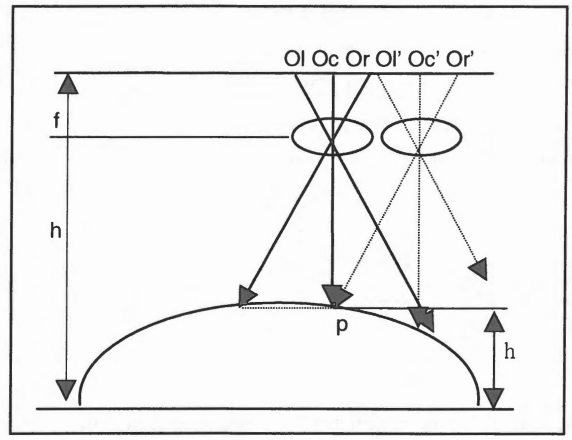

Fig.2 (b). Matching between center and right images

algorithm is applied to match the left and center, center and right images respectively. In the second step, a "disparity constrained refinement" algorithm is used to eliminate the mismatches and increase the density of the disparity estimation. In the last step, a model-based interpolation is applied to generate the final results.

3.1 Relaxation Matching

Relaxation process is a useful technique for using contextual information to reduce local ambiguity and achieve global consistency. Generally, the relaxation algorithm for image matching mainly consists of following four steps:

- Selection of candidate matching points;
- Initial matching probability/matching score estimation;
- Interactively update matching probability/ matching score;
- Relaxation and termination.

The matching algorithm used in our system also consists of above four basic steps. Compared with other existing algorithms, our algorithm has some distinguishing features. Instead of just matching some feature points, our algorithm establishes correspondence at all pixels along the scanline. Another advantage is that the initial disparity map is much denser, which makes the subsequent interpolation easier.

The innitial matching score is defined by the correlation operator. A correlation operation on a given window between point m 1(u1,v1) in the first image and the points m2(u2,v2) lying within the search area in the second image is defined as:

$$Score(m_1,m_2)=\frac{\sum_{i=-n}^{n}\sum_{j=-m}^{m}\delta_1(i,j)\times\delta_2(i,j)}{\sqrt{\sigma^2(I_1)\times\sigma^2(I_2)}} \quad [1]$$

Range: -1<=Score<=1

Where $\delta_t(i,j)=I_t(u_t+i,v_t+j)-\bar{I}_t(u_t,v_t)$, $\bar{I}_t(u,v)$ Is theaverage at point (u,v) of $I_t(t=1,2)$, and $\sigma(I_t)$ Is the standard deviation of the image in the neighborhood of (u,v). The matching pair (m1, m2) is put into the candidate set if its matching score is greater than a threshord value.

The matching score is updated by the supporting strength in the neighborhood of this candidate pair:

$$Score(m_1,m_2)=\sum_{n_1\in N(m_1)}[\max_{n_2\in N(m_2)}\frac{\mathrm{score}(n_1,n_2)}{M^{r(m_1,m_2,n_1,n_2)}}\}/N \quad [2]$$

Where M and N are constant, and r(m1, m2, n1, n2) is the distance difference given by r=ld(m1, m2, n1, n2)l. The matching sorces are updated repeatedly. The scores of some matching candidates become very low after several iterations, we delete them from the candidate set. At last, the candidates which have strong support from their neighorhood will remain in the candidate set.

3.2 Disparity Constrained Refinement

The initial disparity estimation, generated by the relaxation algorithm can be refined by using the TLS image's disparity constraint. As Fig.2(a,b) illustrated, Wu and Murai have proven that the ratio of each pixel's left and right disparities is constant. That means, for each pixel Pi, let DLi and DRi rpesent the left and right disparities in the two matchings respectively, the ratio of DLi and DRi should be constant: DLi/DRi=c. Due to noises and some mismates, some measurement errors may occur, but the average of all pixels' ratio should converge to this constant:

$$(\sum \frac{DL_i}{DR_i})/\text{n} = \sum_i (c+\varepsilon_i)/n = c + (\sum_i \varepsilon_i)/n \Rightarrow c \quad [3]$$

We can use this constrant to improve the accuracy of the matching results. The system checks the disparity estimation in the way that: if one of them os zero, use the other one to inference the estimation for it; if both are non-zero, then a consistency check is carried out. In case the left and right disparities are not consistent, one of the initial estimation is not correct. The confident score, which depends on the matching score and the disparity's local consistency, is used to decide which one is correct. We consider that the matching candidate which has weaker confident score is the mismatch one, then its value is updated by the inference value from the stronger one.

3.3 Model-based Interpolation

The disparity maps generated by our matching algorithm contain some blank points without disparity value. A model-based interpolation method is developed to assign values to them. The method is based on the very strong assumption that the observed 3D object is composed by a surface, which is a parametric function. So least-square regression can be used to fit the disparity map to pre-defined model. Once we have obtained these parameters, we can use them to improve the accuracy of the disparity map.

4. 3D MODELING AND VISUALIZATION

4.1 3D Object Modeling

By using the image matching techniques, we can get a set of 2.5D digital surfaces of an interested object in different views. To generate a single whole 3D object based on these 2.5D digital surfaces, following processes are needed:

1). Object model selection: The matching result generally contains a huge number of points each of that has XYZ coordinates in the local coordinate system. Therefore, a more suitable geometric representation of data is required in order to display and interact with this data. The most suitable representation is a voxel-based triangular mesh.

2). Coordinate system translation: The points on the 2.5D digital surfaces got from image matching are generally in their local coordinate system. A coordinate system translation is needed to integrate all spatial points in the global coordinate system.

3). Sub-object merging: Since there will be many overlaps or gaps between the successive 2.5D digital surfaces, a algorithm for sub-object merging is needed to remove the redundant data and to interpolate the data between the gaps.

4). Object editing: Due to miss matching and merging, there will be some error points in the object models. Editing is needed to check and correct these errors. Based on editing tools, you can add, delete and move polygons, vertices, or edges. You can also increase the resolution of the object, bevel the edges, optimize the number of polygons, or reorder them.

5). Boolean operation: Due to the resolution of the object, some kinds of detail features (such as holes and breaklines) will be not elimiated in the object. We can use Boolean operations (union, intersection, and difference) to recreat these features based on the selected simple parameter models.

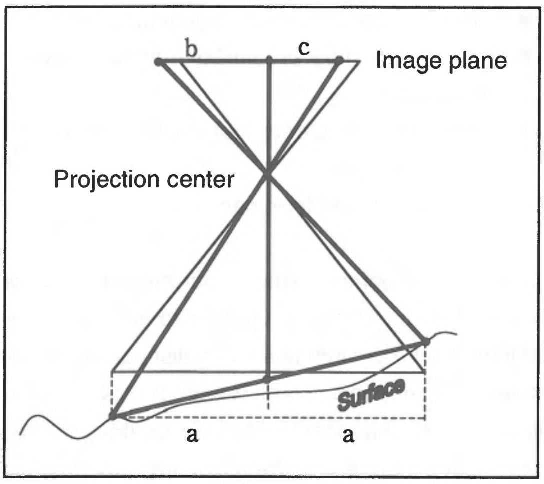

Fig.3 Perspective distortion efected by ?H

4.2 Orthoimage

In the image captured by a linear CCD camera, each line is produced by different elements at certain time, is a perspective projection image, and each column is produced by moving the camera and recording by certain element at different time, is a parallel projection image.

When we generate a orthoimage based on the TLS image and its digital surface, we only should consider the perspective distoritions [as shown in Fig.3] within each scanline.

During the orthorectification process, the effects of height upon the image perspective are removed to produce a encoded data set with an even pixel spacing in map space. For each orthoimage pixel of known x and y coordinates, the algorithm first ue the digital surface model to determine the height of the point. The relational functions for the image are then used to determine the pixel in the triangulated image corresponding to the point in object space. The intensity of this point is then assigned to output orthoimage pixel. The process is repeated until the rectifiel out orthoimage is completely filled.

4.3 Texture Mapping

While the generated geometric model is useful for 3D construction of an archaeological object, the user may need to work with orther types of data or imformation. Other sensory information, such as light intensity or texture from CCD images, can be precisely mapped into the geometric model provided that the sensor position and orientation is known in the coordinate system of geometric model. In our test working, we realized texture mapping for the geometric object based on SOFTIMAGE 3D system. Following is the working procedure:

- To separate 3D object to different 2.5D surfaces;
- To generate the orthoimage for each 2.5D surface;
- To convert the orthoimages to picture (.pic) file;
- Sequentially selecting the different 2.5D surfaces and to determine the surface sides;
- To read the different to picture files (orthoimages) and wrapping to each 2.5D surface.

5. EXPERIMENTS AND CONCLOSIONS

In this section, the examples of reconstruction of archaeological objects based on TLS image matching are demostrated. The image pre-processing and image matching were implemented on a SUN Sparc workstation by using Wu and Murai's system. 3D object modeling, orthoimage generation and texture mapping were implemented on a PC based on SOFTIMAGE 3D.

Fig. 4(a)-(c) are shown a set of TLS original images (left, center and right). Fig. 4(d)-(f) are shown a set of TLS images (left, center and right) after pro-processing. Fig.5 is shown the disparity map generated by TLS image matching. Fig.6 is shown the 3D models after model-based interpolations. Fig.7 is shown the result of texture mapping.

From above experiments we can know that the algorithms of TLS image matching developed by Wu and Murai are useful tools for reconstruction of archaeological objects. Integration of 3D object modeling and texture mapping let the system for real applications.

For feature researches, the algorithms for feature based matching will be developed for reconstruction of detail features on the objects. TLS images will be also integrated with range images caputered by laser range scanners for real-time generation of high quality orthoimages and 3D models.

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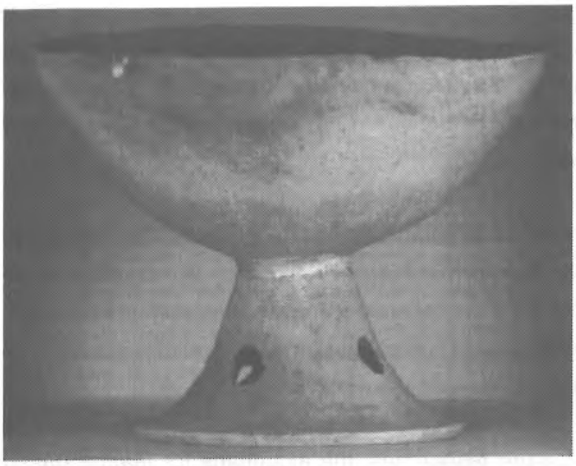

Fig. 4(a) An original left TLS image.

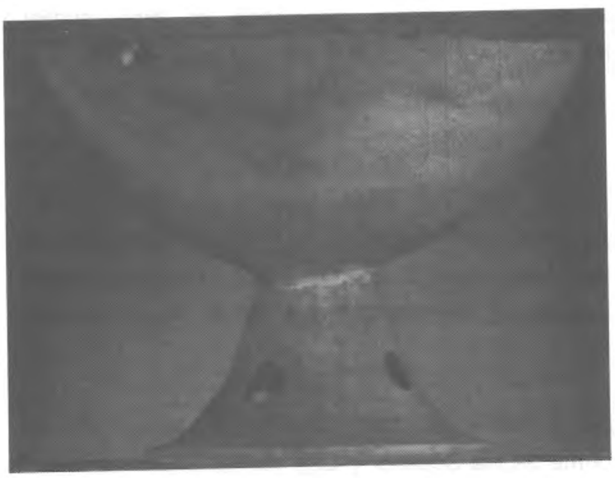

Fig. 4(b) An original center TLS image.

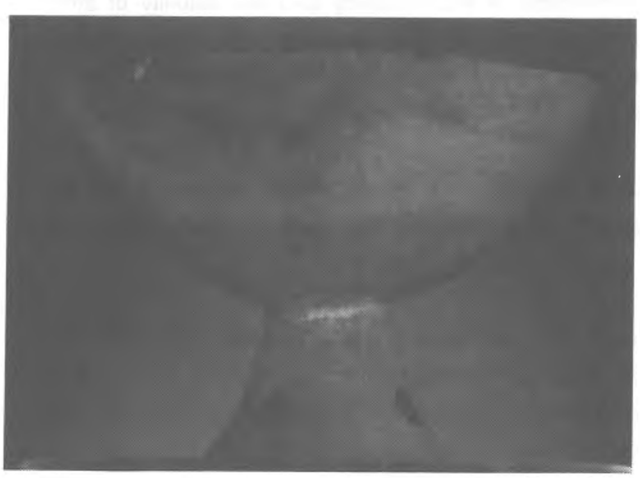

Fig. 4(c) An original right TLS image.

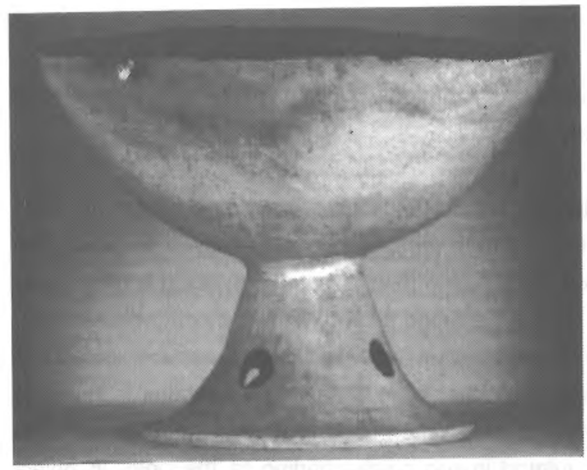

Fig. 4(d) An pro-processed left TLS image.

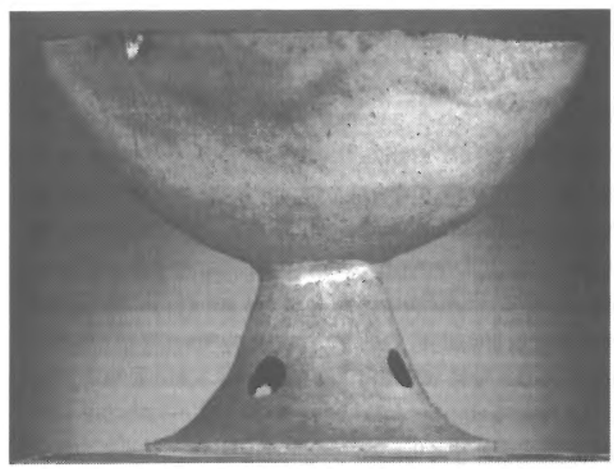

Fig. 4(e) An pro-processed center TLS image.

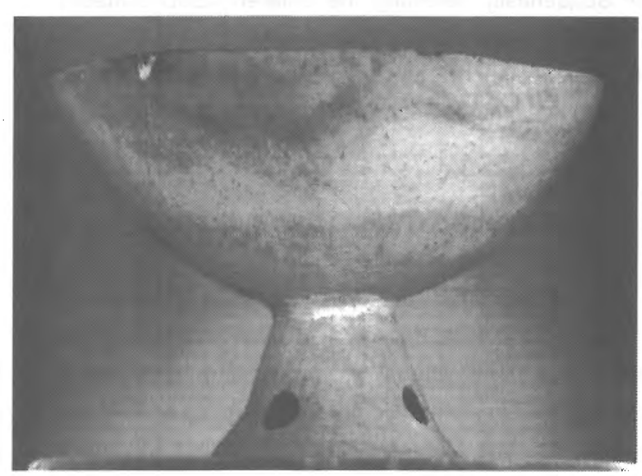

Fig. 4(f) An pro-processed right TLS image.

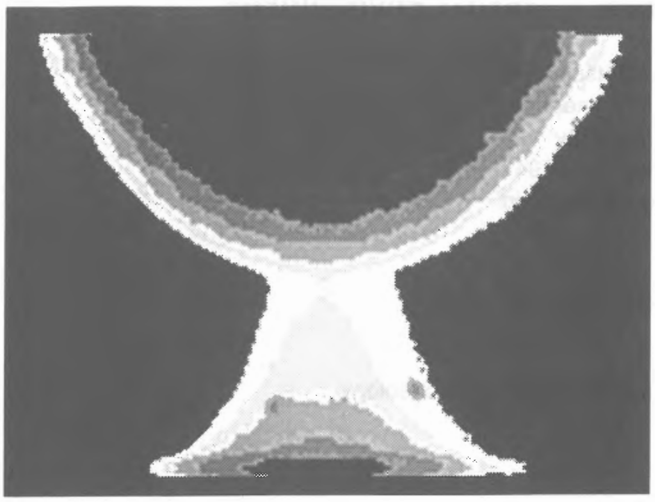

Fig.5 The disparity map generated by TLS image matching.

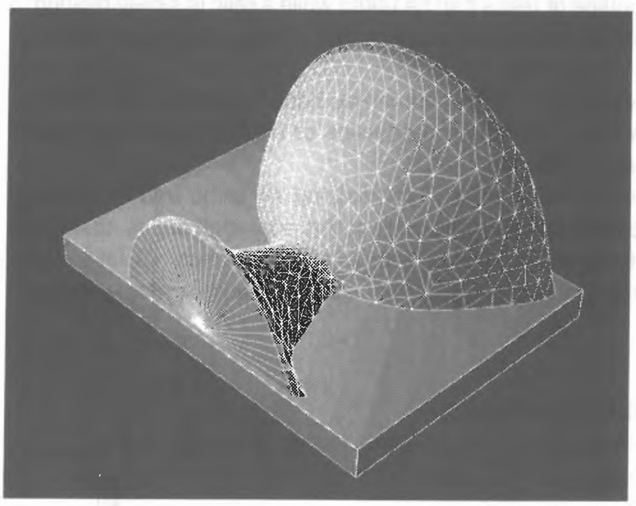

Fig.6 The 3D models after model-based interpolations.

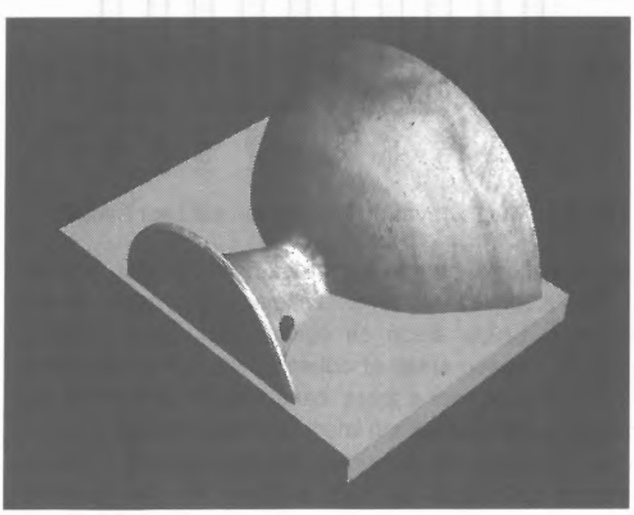

Fig.7 The result of texture mapping.