APPROACH TO ACCURATE PHOTOREALISTIC MODEL GENERATION FOR COMPLEX 3D OBJECTS

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ABSTRACT

Due to the progress in computers and sensors development the number of virtual reality application (VR) grows significantly. Different sensors and techniques such as laser range finders, still and video cameras, mechanical digitizers are used to obtain spatial object coordinates for producing 3D models. The two main requirements to the produced model are the accurate geometry reconstruction and the realistic texture generation. The means of digital close-range photogrammetry are quite enough to satisfy those requirements. The same images can be used as for accurate 3D-geometry reconstruction as for adequate photometry modeling - generation of realistic object texture.
The close-range photogrammetry technique for accurate geometric and texturing modeling is well-developed for 2.5D (depth) object models. But for complex 3D objects that have no single valued plane projection there are some problems with surface reconstruction and texture generation. In this case uniform surface can not be reconstructed by traditionally used Delaunay triangulation procedure for all points of objects. So the orthophoto can not be generated because of surface singularity. The paper considers the approaches for these problems solution. It describes the method for reconstruction of the uniform surface for some classes of complex 3D objects represented in form of object space coordinates cloud. Also the method for accurate texture generation from a set of object images obtained from various viewpoints is presented. The results of object reconstruction and texturing are given along with the description of developed close-range photogrammetric system.

1 INTRODUCTION

Last years the growing number of applications has a demand for accurate and realistic 3D models. Along with the requirement of metric object geometry description many tasks have a need for photorealistic model presentation (another words accurate texture mapping). The latter requirement is important for some kind of expertise task such as recognition, identification based on 3D models when texture information significantly contributes for valid solution.

The first step of 3D-model reconstruction is to obtain cloud of object spatial coordinates. It can be performed using various means beginning from mechanical measurement machine to laser range finder (Chikatsu H., 1997, Wehr A., 1997.). If spatial coordinates cloud represent depth (so called 2.5D) model such as digital terrain model (DTM) object surface can be presented as single valued function *z* from *x* and *y* arguments $z = f(x,y)$. So the surface reconstruction from point cloud can be produced automatically by common Delaunay triangulation procedure. In case of generating 3D coordinate cloud by digital photogrammetry technique model texturing can be performed by well-known image orthotransformation procedure using the same images as for DTM generation.

For complex 3D object which surface can not be presented as single valued function of two arguments in Cartesian system of coordinate the problem of surface reconstruction becomes more complicated. If object model in coordinates cloud form is obtained it can be divided into some number *n* of fragments so that for each fragment its surface can be presented as single valued function $z_i = f_i(x,y); i = 1,\ldots,n$. Then the fragments can be integrated in united surface. This approach requires a lot of manual operation such as points model division into fragments and fragments integration. Besides precision of reconstruction can decrease while dividing into fragments and assembling.

The paper presents the method for uniform surface reconstruction for some classes of complex 3D objects. The approach is based on choice of special type projection which is single valued for all points of 3D coordinates cloud. It allows representing whole surface as uniform triangulation mesh. The accurate united photorealistic texture is generated for considered 3D models by transformation the set of images.

2 CLOSE-RANGE PHOTOGRAMMETRIC SYSTEM

2.1 Hardware configuration

The presented methods for complex 3D object reconstruction was developed as a part of research digital close-range photogrammetric system. The processing kernel of system is Pentium personal computer. Also hardware includes:

- Set of high-resolution color and black and white CCD cameras of PAL standard for image acquisition
- Frame grabbers for image capture
- Set of test fields for purposes of camera calibration and orientation
- Controlled structured light projector
- Controlled turn-table for object positioning
- Original coded targets for automated correspondence problem solution in calibration and orientation tasks

The view of digital close-range photogrammetric system is shown in the Fig. 1.

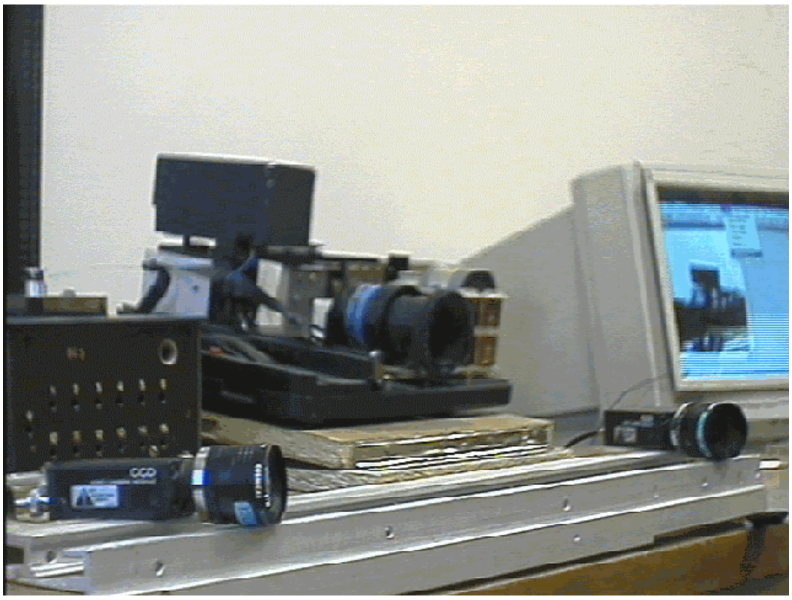


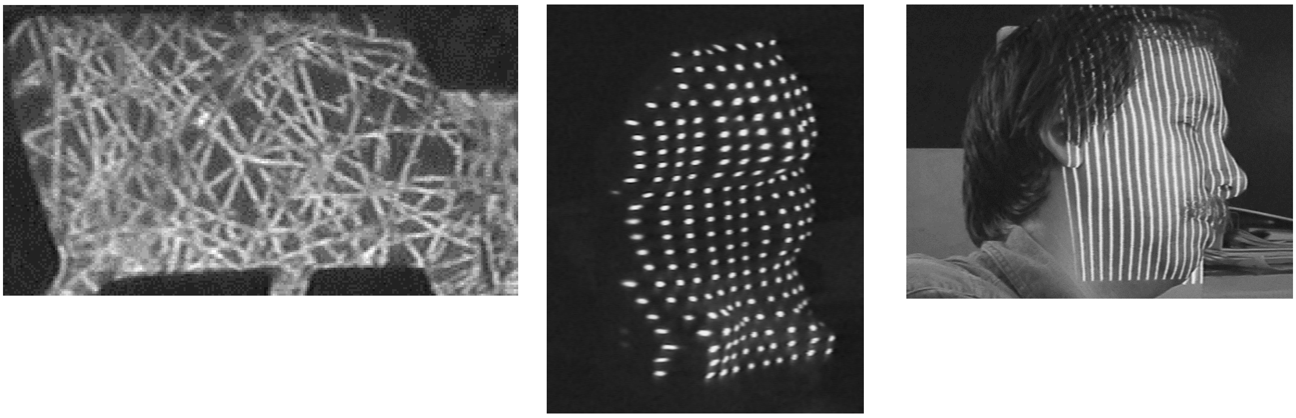
Figure 1. Digital close-range photogrammetric system

2.2 Software outline

The original software is developed for Windows 95. It supports the complete technology of system calibration, orientation and object 3D reconstruction.
The software provides:

- Image capturing and preprocessing
- Automated cameras calibrating (camera internal orientation determining)
- Automated exterior and/or relative cameras orientation based on calibrated test fields
- Automated coded target recognition and identification with subpixel image coordinates measurement
- Feature extraction for automated correspondence problem solution for images obtained in special types of structured light
- Point non-contact 3D measurements in manual and automated (for points marked by coded targets) mode
- Automated multiplied points3D measurements (surface scanning) for images structured light
- Automated 2.5D surface generation based on standard Delaunay triangulation
- Accurate texture mapping (orthophoto generation)

Some methods for automated multiplied non-contact 3D measurements producing a cloud of spatial object coordinate are developed. They are based on image acquisition in structured light of a stochastic (fractal) form (a), contrast points form (b) and contrast stripes form (c). The sample images of objects to be reconstructed in corresponding structured lights are shown in Fig. 2. The first method is based on correlation, the latter use exterior orientation (EO) and epipolar geometry for 3D reconstruction.



(a) (b) (c)

Figure 2: Structural light for spatial reconstruction.

The developed techniques for automated multiplied points3D measurements allow to produce 3D-point cloud for following surface reconstruction. The metric characteristics of generated VR models are provided by calibration procedure with the accuracy being at the level of 1/10 pixel.

3 SURFACE RECONSTRUCTION

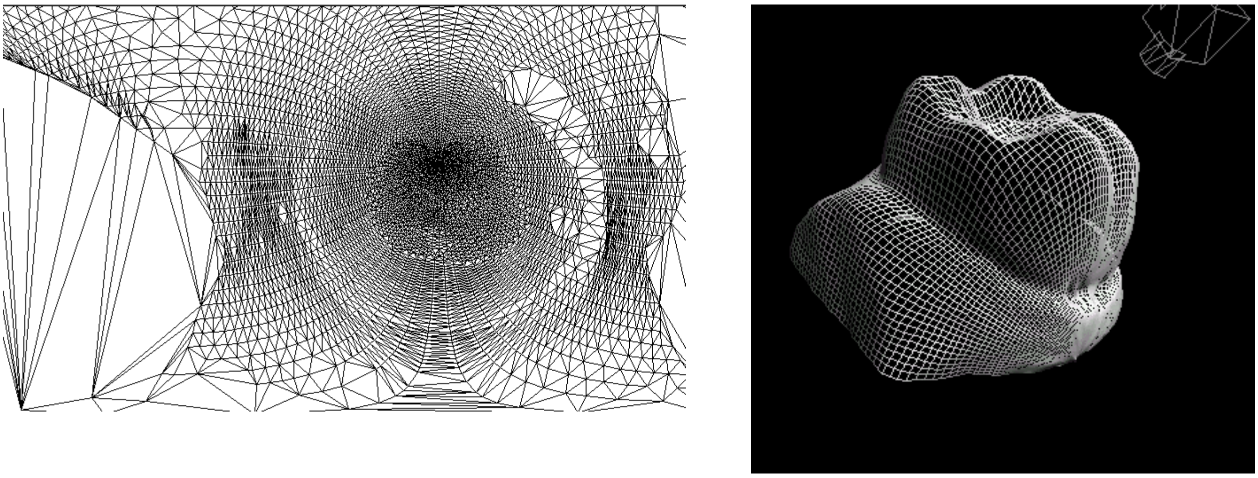
The spatial coordinates for complex 3D object such as sculpture, tooth, etc. can be obtained by various means and usually they are presented as coordinate cloud $P = \{(x_j, y_j, z_j)\}$ in given Cartesian system of coordinates. To determinate the surface of reconstructed object it is necessary to set links between points. It can be done by common Delaunay triangulation procedure if points can be single valued projected on the plane. For closed object such a plane does not exist.

For surface generation it is proposed to take special projection. The first approach selects the space figure (like cylinder, sphere, etc.) on which object point cloud can be projected single valued. The kind of space figure is selected based on object configuration but the approach to uniform surface reconstruction can be illustrated for sphere.

The points in 3D cloud can be represented as set of clusters each cluster containing union of points for given image acquisition condition (for object meridian in our method of 3D cloud generation). Then it is necessary to find the origin of spherical coordinate system providing single valued function $r = f(\lambda, \varphi)$. This problem is solved by following procedure. The first iteration for coordinate system origin is computed as center of weight for 3D-point cloud. Then for every point *j* the condition of single value is checked. For performing this check every point of first cluster (meridian) is connected with the set of points of the next meridian resulting in the set of 3D faces which represent the local surface between sequential meridians. If vector $\bar{r}_j$ intersect this surface the new origin is selected providing the condition of not intersecting considered local surface. If not then the next meridian is processed.

Then the procedure repeated until the optimal origin is found or another space figure is tested. If procedure is failed the uniform surface can be generated only by object fragmentation.
In selected coordinate system spherical coordinates $(r_j, \lambda_j, \varphi_j)$ for every point are found. Then λ, φ coordinates with distance metric $\| (r\lambda)^2 + (r\varphi)^2 \|$ are used for Delaunay triangulation procedure performing which result in the list of 3D point's links in triangles form. The typical sample (tooth model) of triangulation mesh in λ, φ coordinates is shown in Fig. 3 (a).

Then the obtained list of triangles is used for surface presentation in Cartesian coordinate system. The result of surface reconstruction in Cartesian coordinates is presented in Fig. 3 (b).



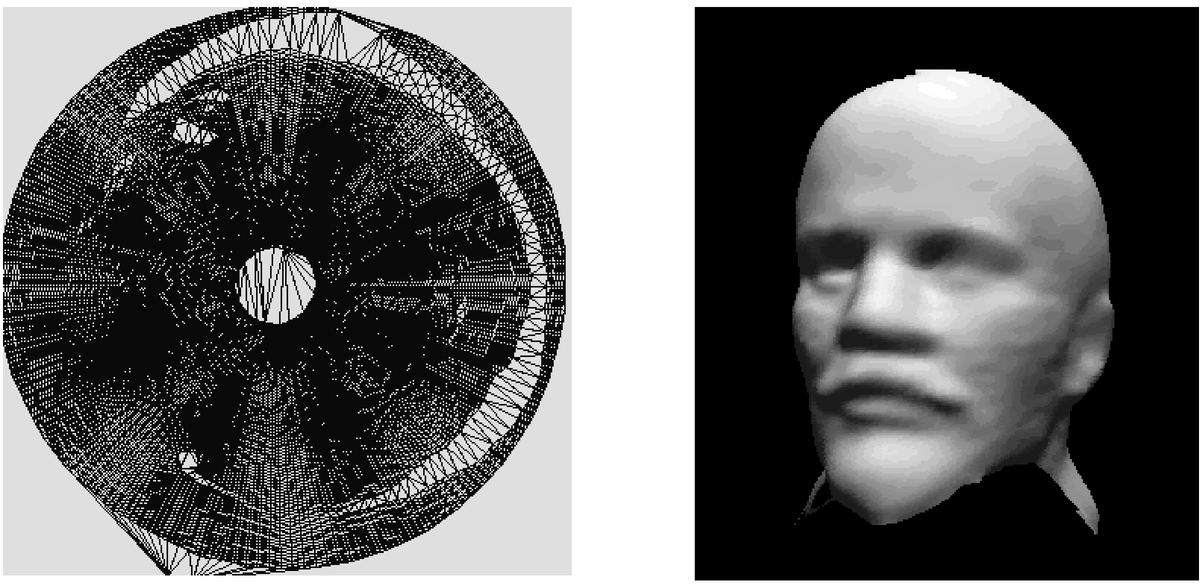
(a) (b)

Figure 3: Results of surface reconstruction

The second technique is to choose special type of projection for establishing single valued links between spatial points. The example of such kind of projection is "radio location" projections on a reference plane. The plane coordinates of projected points are given by following relations:

$$\begin{aligned} x' &= R\cos\zeta \\ y' &= R\sin\zeta \end{aligned} \tag{1}$$

where *R* is the distance to point *(x,y,z):* $R = \sqrt{x^2 + y^2 + z^2}$; $\zeta = arctg(\frac{x}{y})$



(a) (b)

Figure 4: Results of surface reconstruction

Fig.4. presents the triangulation mesh of radio location projected 3D points (a) and the reconstructed uniform surface (b).

4 TEXTURE MAPPING

The original method is developed for the photorealistic texture generation and accurate mapping. The method deals with uniform 3D model obtained by above technique and presented in triangulation form. For texture generating it is converted into regular mesh model presentation, which allows using a set of object digital images from different view points for uniform photorealistic texture creation. Regular mesh is obtained by following procedure. For every point (x_j, y_j, z_j) its Cartesian coordinates transform into spherical or cylinder coordinate system. Then the number of mesh bundles is determined providing accurate model geometry presentation. For each bundle its height in new coordinate system is computed by finding the triangle including given points and linear interpolating between the triangle tops.

The next problem to be solved is to perform model mesh segmentation into fragments providing the best texture generation from given set of images. For creating accurate orthophoto to select model fragment so that image transformation caused by object curvature would be lowest. To find model mesh segmentation satisfying this condition the map of normal to the model surface is computed and for each image the model fragment is determined providing two conditions: minimum fragment curvature for given image and closed model generation.

For achieving accurate uniform texture the orthophoto for the object's fragments is created using appropriate image and fragment model as regular mesh. Then texture fragments are integrated in united texture model.

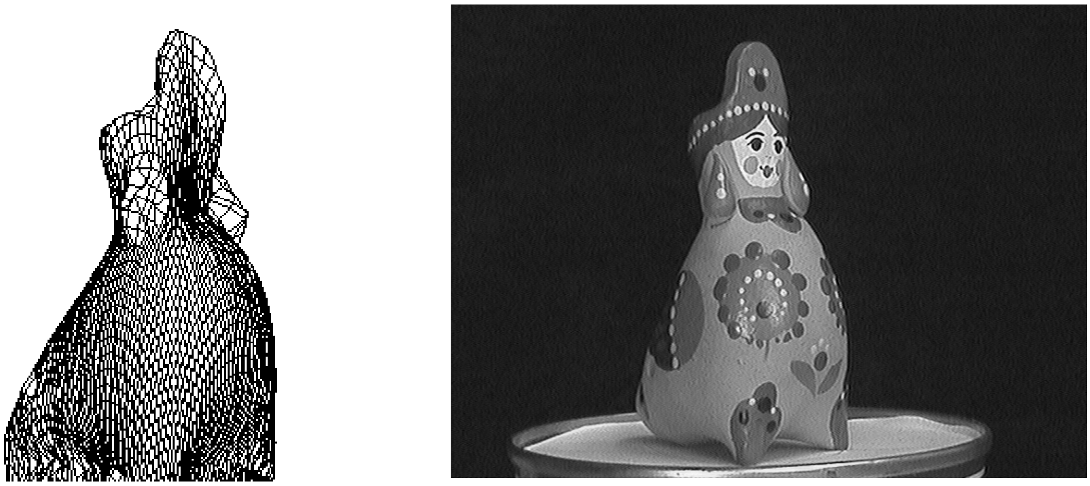
The method is developed for two variants of object images available: (a) image exterior orientation is known or can be determined and (b) image exterior orientation is unknown.

If image exterior orientation is known the texture for each fragment is generated by well-known image orthotransformation procedure including the following steps:

- mesh discrete and texture scales computation;
- image coordinate for mesh bundles computation;
- image linear transformation parameter determination
- image transformation

If image exterior orientation is unknown the parameters of exterior orientation is found using 3D model and original software. To determine exterior orientation parameters operator marked the corresponding reference points on 3D model and in the image (Knyaz, 1998). This allows to find image EO parameter by technique based on reference points.

In Fig. 5(a) the object of traditional Russian folk art "Dymkovskaya igrushka" to be reconstructed is presented. The results of uniform surface generation using spherical projection are shown in Fig. 5(b).

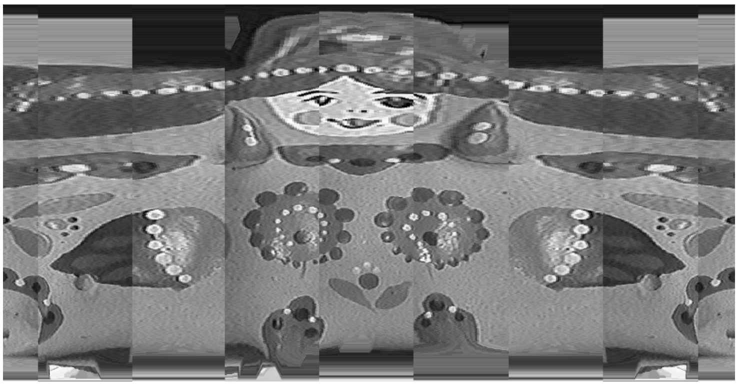


(a) (b)

Figure 5: Results of reconstruction

Then the described procedure of uniform texture orthphoto has been performed resulting in image shown in Fig. 5(a). For texture generation 8 images of object has been used. The image exterior orientation has been known due to special camera orientation procedure based on testfield image acquisition. Testfield has 24 reference points. The standard deviation for reference points was 0.12 mm.

The image shows good accuracy in uniform texture generation: the maximum error in contour links consist 0.43 pixel. It is provided by using uniform 3D model which has no DTM errors caused by integration of fragments obtained in different coordinate systems.



(a)

(b)

Figure 5: Texture generation and model applying

The results of using obtained model in virtual environment are demonstrated in Fig.5 (b).

5 CONCLUSION

The approach for photorealistic 3D models creation for VR is proposed. It includes the stage of uniform surface generation for closed 3D object and the stage of accurate texture production.

The uniform surface is generated from 3D-point cloud using special points' projection for the following Delaunay triangulation procedure. Then the list of triangles is used to present surface in Cartesian coordinates in triangulation form or to transform to regular mesh form. The accurate texture is generated using a set of object images for best object texture presentation. The uniform texture is produced as an union of particular orthophotos for object segments.

The results of method applying demonstrate good precision in object reconstruction and texture generation. Closed model has no DTM errors caused by fragments assembling. It results in accurate texture generation having no contour errors on the fragments' borders.

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