Photogrammetric method of virtual model generation for complex 3D objects

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ABSTRACT

For realistic virtual model generation two main problems have to be solved: to achieve the required geometric accuracy in object description and to obtain the highest reachable texture similarity. Recently digital close-range photogrammetry offers precise and flexible means for the first problem solution - accurate geometric 3D reconstruction. Besides images acquired for 3D reconstruction can be used for adequate photometric modeling - generation of realistic object texture. The close-range photogrammetry technique for accurate geometric and photometric modeling is well developed for 2.5D (depth) object models. But for complex 3D objects which 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 common Delaune triangulation procedure for all points of objects. So the orthophoto can not be generated because of surface singularity. The paper presents the approaches for these problems solution. It describes the method for reconstruction of the uniform surface of complex 3D objects having object space coordinates cloud and the method for accurate texture generation from a set of object images obtained from various view points. The results of objects reconstruction and texturing are given along with the description of GosNIIAS close-range photogrammetric system description.

Keywords: close-range photogrammetry, 3D reconstruction, texture, triangulation

1. INTRODUCTION

Last years the demand for accurate 3D models for various applications grows rapidly. Different sensors and techniques such as laser rangefinders, still and video-cameras, mechanical digitizers are used to obtain spatial object coordinates[1,2]. Digital close-range photogrammetry provides accurate and powerful technique for automated non-contact simultaneous measurements of great amount of object space coordinates resulting in 3D coordinate cloud. For depth (so called 2.5D) models 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 their surface reconstruction from point clouds can be produced by common Delaune triangulation procedure. Also model texturing can be performed by well-known images 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 several fragments which surfaces can be presented as single valued function $z_i = f_i(x, y)$. 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 its assembling.

The paper presents the method for uniform surface reconstruction for complex 3D objects. The approach is based on choice of space figure (like sphere, cylinder etc.), on which object space coordinate cloud can be projected single valued. At the same time the method for united texture generation for considered models is presented.

2. 3D POINTS CLOUD GENERATION

To develop methods for complex 3D objects reconstruction the digital photogrammetric system was created in State Research Institute of Aviation System (GosNIIAS). It includes:

- Personal computer as central processing unit
- Set of digital high-resolution CCD cameras
- Frame grabber for image capture
- Set of testfields for purposes of camera calibration and orientation
- Structured light projector
- Dynamic tools for cameras arrangement
- Original coded targets for automated correspondence problem solution in calibration and orientation tasks
- Original software for image processing , system calibration and object 3D reconstruction.

GosNIIAS close-range digital photogrammetric researching system is shown in Fig. 1.

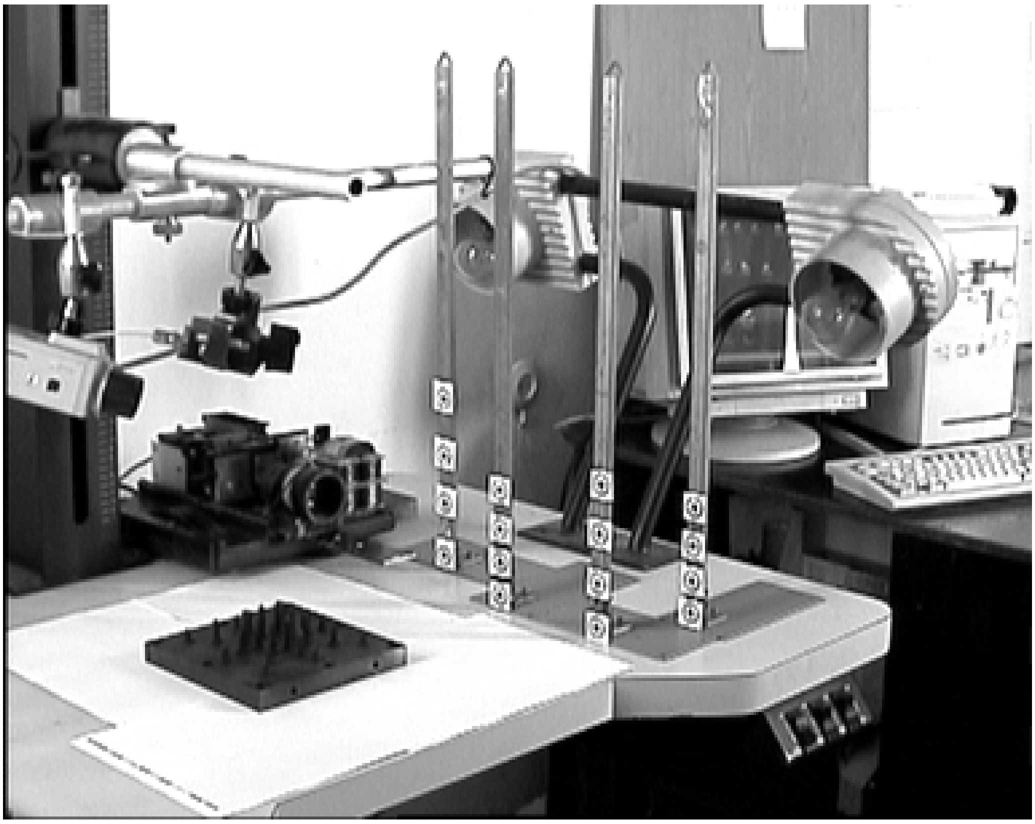
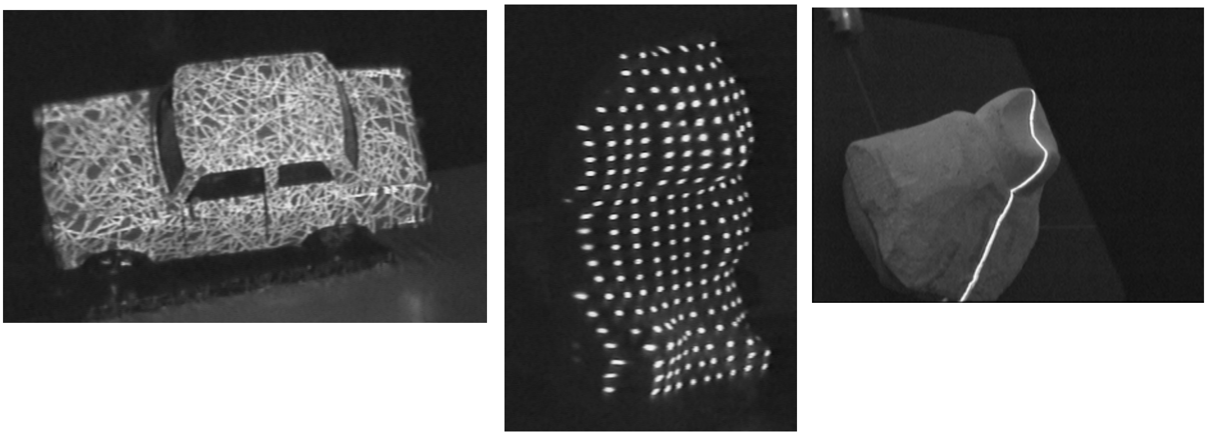


Figure 1: Researching photogrammetric system of State Research Institute for Aviation System.

The developed software for Windows-95 allows to preprocess images for correspondence problem solution, to calibrate cameras, to perform image exterior or relative orientation, to measure object 3D coordinates and to reconstruct object's model.



a) b) c)

Figure 2: Methods for Spatial reconstruction.

The set of methods for non-contact 3D measurements based on correlation, epipolar geometry, external orientation is developed. They allow to reconstruct 2.5D models by set of object images in structured light in a) stochastic (fractal) form, b) contrast points form and c) contrast line form. The sample images of objects to be reconstructed in mentioned structured lights are shown in Fig. 2.

For reconstruction of true 3D models the last method is used. It allow to obtain 3d point cloud of whole object in single coordinate system. Besides 3D points are obtained as meridians on the objects. This information is used for selecting the origin of spherical coordinate system when generating the uniform surface for given 3D point cloud.

3. UNIFORM 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.

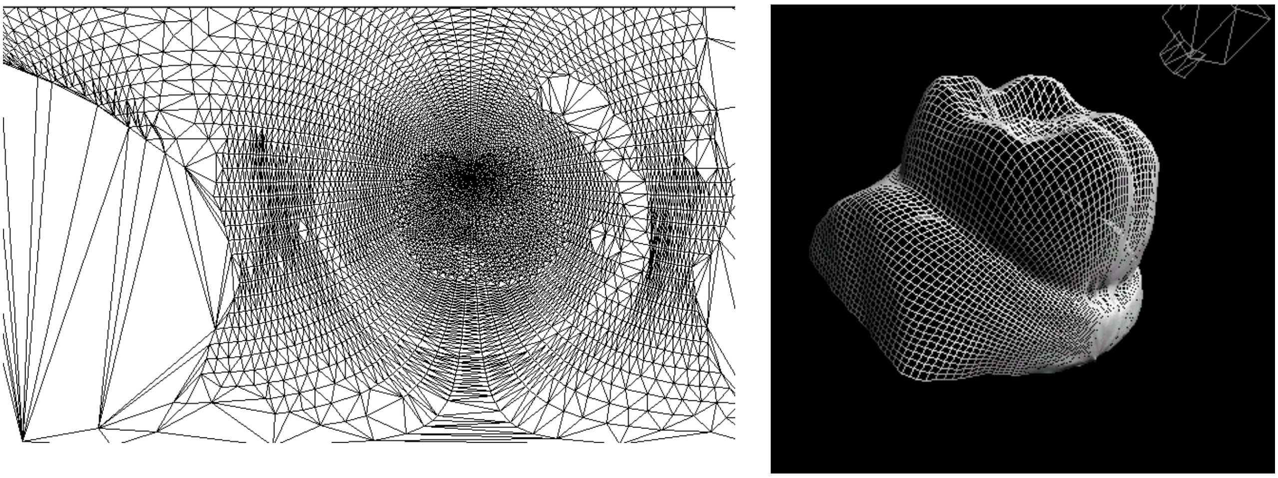
For surface generation it is proposed to select space figure (like cylinder, sphere, etc.) on which object point cloud can be projected single valued. The kind of space figure is selected based on object configuration but the approach to uniform surface reconstruction can be illustrated for sphere.

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 $\left(r_j, \lambda_j, \varphi_j\right)$ for every point are found. Then λ, φ coordinates with distance metric $\left\| (r\lambda)^2 + (r\varphi)^2 \right\|$ are used for Delaunay triangulation procedure performing which result in the list of 3D points 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

3. ACCURATE TEXTURE GENERATION

The original method is developed for the photorealistic texture generation. 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 allow to use a set of object digital images from different view points for uniform photorealistic texture creating. 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.

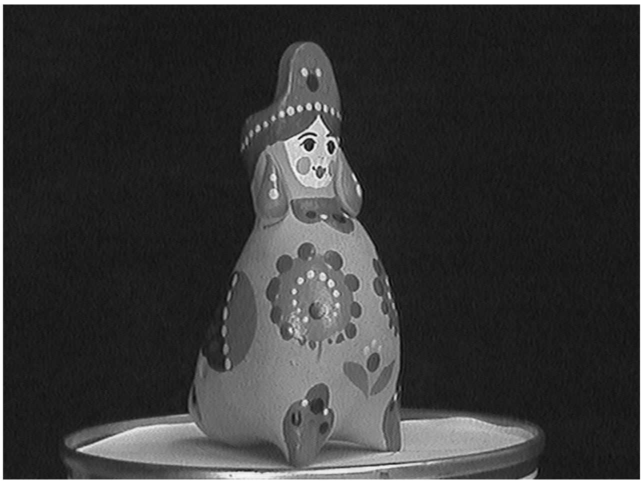
The method is developed for two variants of object images available: a) image exterior orientation is known or can be determined b) image exterior orientation is unknown.

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

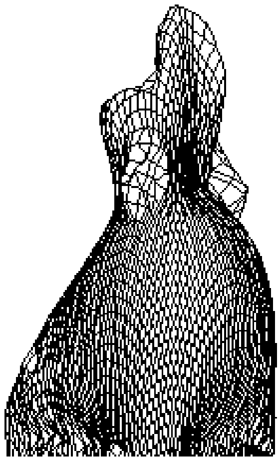
- mesh discrete and texture scales computation;
- image coordinate for mesh bundles computation;
- image linear transformation parameter determination
- image transformation

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[3]. This allows to find image EO parameter by technique based on reference points.

In Fig. 4(a) the object "Dymkovskaya igrushka" to be reconstructed is presented. The results of uniform surface generation is shown in Fig. 4(b).



a)

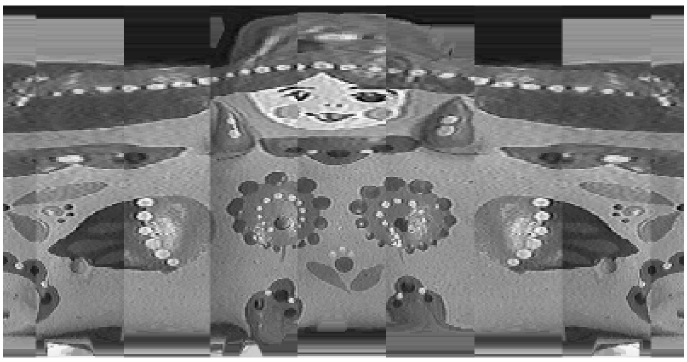


b)

Figure 4: 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.



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

a) b)

Figure 5: Texture generation and model applying

CONCLUSION

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

The uniform surface from 3D point cloud obtained in single coordinate system is generated using spherical coordinate system for triangulation procedure. Then the list of triangles is used 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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