Accurate photorealistic texture mapping for metric 3D models

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Abstract

Texturing gives a new quality to a 3D model making it more similar to real object and more adequate for human perception and understanding. Recent progress in means for spatial data acquisition and in 3D reconstruction techniques creates a background for metric 3D models generation, which could be successfully used instead of a real object for purposes of various investigations dealing with geometric data.

For such a 3D model photorealistic texturing (i.e. producing accurate texture from photograph of real object) provides a lot of valuable additional information for investigation on conditions that texture mapping is performed with high precision. In this case some geometry analysis of an object could be performed even in regions which are not spatially informative.

Below the discussion of methods for 3D model reconstruction and texture mapping is given along with description of developed methods and software for photorealistic texture generation

Keywords: *3D reconstruction, close-range photogrammetry, texture mapping.*

1. INTRODUCTION

The field of application for three-dimensional models obtained by various techniques grows rapidly during past several years. Recent progress in calibration techniques of 3D scanning systems makes it possible to achieve high accuracy of generated 3D models thus providing a good background for using such a model instead of a real object for purposes of investigations.

Metric characteristics of a 3D model allow to perform some necessary measurements for making required conclusions about real object as for instance in case of crania facial identification, when an expert has a need of measuring some reference points on a skull to generate a decision on a person identification.

However, in case of using an untextured 3D model it is rather difficult precisely to find in the 3D model points to be measured. Accurate photorealistic texturing gives new properties for a 3D model, providing an expert with additional valuable visual information. The main requirements for 3D model texturing are realistic object representation and accurate mapping.

The paper presents the developed methods for photorealistic texture mapping of so called 2.5D models and real 3D models. For a 2.5D model all surface of the model could be observed from one point of view so texturing could be made using single object image. For the case of a 2.5D model texturing methods based on object's image for various uncertainty in image acquisition condition are discussed. The possible options of the uncertainty are following: 1) image exterior orientation in object system of coordinates is given; 2) image interior orientation is known but image exterior orientation is undefined; 3) no information about image orientation (interior and exterior) is provided.

The best results could be obtained when real object's photographs with known image orientation are used for texture mapping. This is a case when 3D model is obtained by photogrammetric technique and an image is taken by calibrated camera used for 3D reconstruction also. Then a texture is generated by image orthotransformation basing on object 3D model in given coordinate system and image exterior orientation in this coordinate system. The results of texture mapping in this case are tested comparing object spatial coordinates determination by two ways: from stereo image calculations and from textured 3D model.

For the second option of image parameters uncertainty (image interior orientation is unknown, image exterior orientation is given) a method of exterior orientation based on reference points taken from 3D model being textured is proposed. The developed software allows to mark corresponding reference points in a given 3D model and in its image which is used for the 3D model texturing. After such an exterior orientation procedure a texture is generated as mentioned above by image orthotransformation.

In the third case of no information about image orientation when there is no possibility to determine 6 parameters of exterior orientation for orthophoto generation the 11 parameters of general perspective transformation are determined basing on corresponding reference points in a 3D model an in its image.

For a real 3D model it is impossible to perform photorealistic texturing using single image, because all model surface could not be viewed from one point of observation. So some special techniques based on several images processing or a special procedure for texture image generating are needed. For this case some approaches for accurate texture mapping along with results of texture generation are presented and discussed.

2. TYPES OF DATA

At present time the most widely used means for generating 3D spatial data and 3D models includes laser 3D scanners, laser range finders and photogrammeric systems.

Laser 3D scanners are based on so-called Laser Stripe Triangulation (LST) principle. A beam of laser light is projected as a stripe onto a 3D object and viewed at an angle using a video camera. The image seen on a screen reveals the contour of the object where the laser light intersects the surface of the object. Knowing the spatial positions of laser and camera in given system of coordinates allow calculating 3D coordinates of viewed illuminated points. Resulting data of a laser 3D scanner system includes 3D points cloud. Accurate texture could be obtained in case of applying a special camera calibration technique [1].

Laser range finders determine distance to the object basing on time interval between emitted and received light impulse. The scanner's pulsed laser ranging device coupled with beam

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deflection mechanisms facilitates rapid acquisition of literally millions of three-dimensional point measurements. The greatest advantage of such a system lies in the high sample density that permits accurate and detailed surface modeling. For example, the Cyrax 2400 3D laser scanner has variable spatial resolution (up to 0.5mm sample interval at a 50m range) and high accuracy (manufacturer's specifications: ±4mm in range, ±6mm in position). The Cyrax offers great potential for close range (up to 100m) metrology applications.

As with any metrology technique, measurement accuracy is critically dependent upon instrument calibration. Ground-based laser scanners are no exception, and appropriate calibration procedures are still being developed. However, traditional sensor calibration techniques, in some instances, can not be directly applied to laser scanners [2].

For texturing 3D models obtained by laser range finders additional image acquisition device is needed (e.g. digital cameras). High quality visualization could be achieved by integrating laser range finder with digital camera and by performing system calibration for accurate texture mapping [3,4].

Photogrammetric systems are usually include a set of cameras and structured light projector, which generates a special light pattern on the measured object. Structural light is used for automated correspondence problem solution. The view of photogrammetric 3D reconstruction system developed in State Research Institute for Aviation System (GosNIIAS) is shown in Figure. 1.

Figure 1: The exterior view of photogrammetric 3D reconstruction system.

For generating an accurate 3D model a photogrammetric system should be calibrated. In other words image interior orientation (principal point x_p, y_p, scales in x and y directions m_x, m_y, and affinity factor a, the radial symmetric distortion and decentering distortion) and image exterior orientation (X_i, Y_i, Z_i – location and $\alpha_i, \omega_i, \kappa_i$ and angle position in given coordinate system) should be estimated. Such a case is the most preferable for generating a texture, using images with known orientation.

So far the most adequate data for generating accurate textured 3D models is provided by calibrated photogrammetric systems, using the same images both for 3D reconstruction and for texturing. Spatial data obtained by laser system as a rule has no texturing information. So, in this case, system upgrading for accurate texturing of produced 3D model is needed or applying special technique for texturing initial data form alternative image acquisition device.

3. TEXTURE MAPPING

3.1 Image orientation given

For metric 3D model obtained by a photogrammetric system the geometry of image acquisition is precisely determined by the calibration of a system. In this case a texture image could be generated as orthophoto image, in other words image produced from real photograph by transformation to orthoscopic projection. Orthophoto is generated as an image of given dimensions in which each image pixel has an intensity and color equal to the intensity and color of the point in the initial image (photograph) corresponding to given 3D model spatial point.

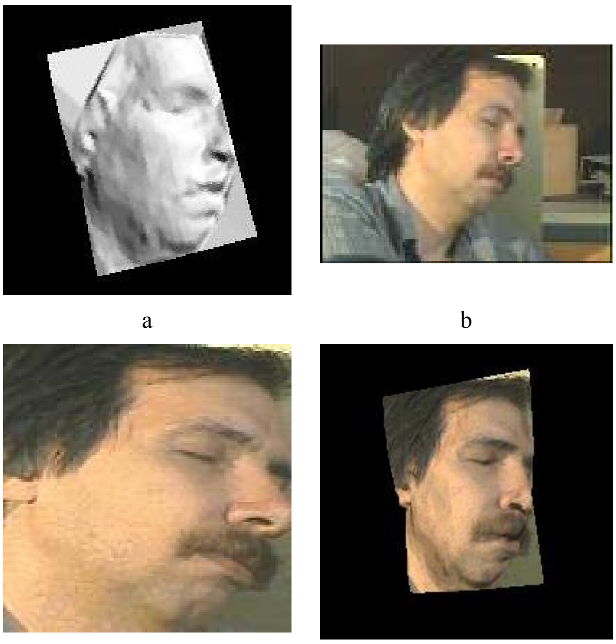
For orthophoto generation 3D model is presented in form of regular relief matrix (mesh), and each pixel of orthophoto corresponds to given matrix element. For each matrix element having coordinates X, Y, Z (and corresponding orthophoto pixel) the point with image coordinates in the photograph is found accordingly the following equations

$$
\begin{aligned}
x_a &= -f\,\frac{(X-X_0)a_{11}+(Y-Y_0)a_{12}+(Z-Z_0)a_{13}}{(X-X_0)a_{31}+(Y-Y_0)a_{32}+(Z-Z_0)a_{33}} \\
y_a &= -f\,\frac{(X-X_0)a_{21}+(Y-Y_0)a_{22}+(Z-Z_0)a_{23}}{(X-X_0)a_{31}+(Y-Y_0)a_{32}+(Z-Z_0)a_{33}}
\end{aligned}
\qquad (1)
$$

where f - camera constant, x_a, y_a – image coordinates, X_0, Y_0, Z_0 – camera spatial coordinates, X, Y, Z – object spatial coordinates, $a_{11}, \ldots, a_{33}$ – elements of transition matrix A.

The intensity and color of given orthophoto pixel is found by bilinear interpolation between neighbors in the initial photograph.

The Figure 2. presents the results of orthophoto generation for face 3D model. In Figure 2a the 3D model is shown and Figure 2b presents the initial photograph for texturing.



a b

c d

Figure 2: Results of orthophoto generation and texture mapping

Figure 2c shows the resulting orthophoto produced from initial photograph and textured 3D model is presented in Figure 2d.

The described above technique could be successfully applied for 2.5 model when each point of spatial model is presented in a corresponding image. For real 3D model a set of photographs is needed to generate texture for whole surface of an object. Then the problem could be solved by presenting 3D model in some system coordinate which allow presentation of the model in regular form and generating orthophoto from the set of images by given image transformation [5].

Another approach is to present texture as a list of correspondence between 3D model points and their image coordinates, a set of images being enough for complete surface texturing. Such a method is illustrated by samples obtained by the automated photogrammetric system for photorealistic skull 3D reconstruction [6,7].

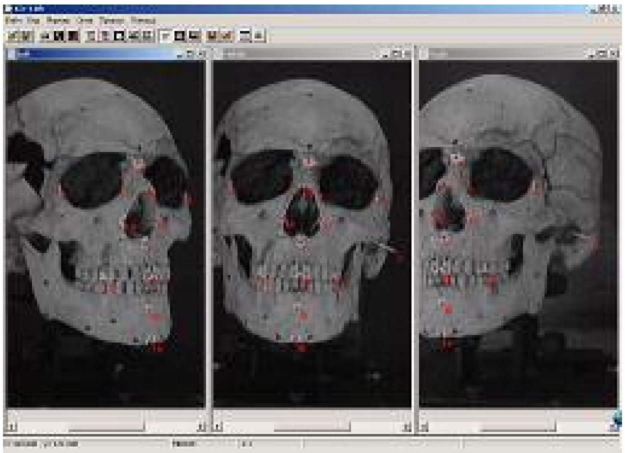


Figure 3: 3D coordinates determination from 3 images by 3D reconstruction system

The automated 3D reconstruction system (Figure 3) allows to obtain a whole skull 3D model by one step using images from three CCD cameras while turntable rotating. Automated correspondence problem solution is provided by image acquisition in stripe structural light. The accuracy of spatial coordinate determination is at the level of 0.2 mm, the point density is 100 000 points per 3D model.

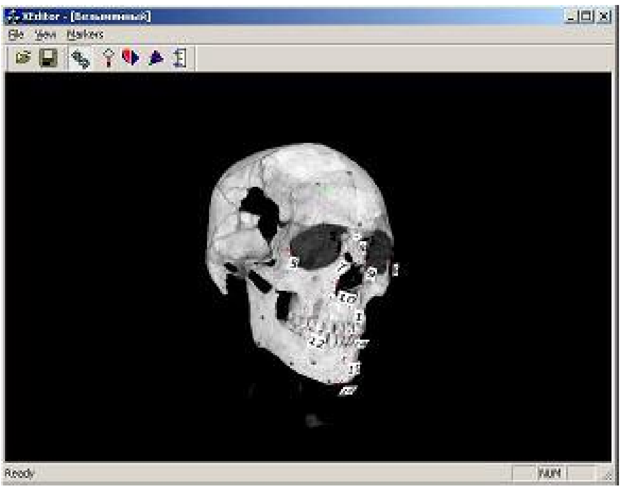


Figure 4: 3D coordinates determination from 3D model

Figure 3 presents the software interface of the 3D reconstruction system. Along with 3D model generation the software allows to measure spatial coordinates of needed points using three skull images. Points are marked by operator in the three images and their spatial coordinates are calculated basing on system calibration results.

Photorealistic texture is generated basing on seven images acquired in shadow-free lighting. The accuracy in texture continuity at the places of different images bordering is about 1/3 pixel. High quality of texture mapping provides additional wide capacities for expert work. For example, expert could determine spatial coordinates of given points from 3D model.

Figure 4 presents the software interface for 3D model visualization and measurement. The corresponding reference points are marked in the 3D model.

The results of measurement by these alternative ways are given in Tables 1 and 2.

#	X, mm	Y, mm	Z, mm
1	-2.35785	-15.4724	78.5169
3	69.38160	-29.8806	-17.7848
4	-0.50062	38.42101	56.855
5	-52.8987	17.27960	47.0341
6	48.65340	16.46890	40.8251
7	-10.1317	21.40480	55.8735
8	6.649850	20.22360	57.678
9	-0.919162	21.74780	75.8745
10	-15.1623	-0.526706	69.8748
11	10.68240	-0.500535	67.7041
12	-28.6443	-43.2372	69.6253
13	21.70460	-41.4959	68.5222
14	-1.27107	-37.9807	90.4573
15	-1.76804	-60.2332	88.625
16	-1.90353	-82.1125	94.1383

Table 1: Results of reference points measurements basing on three photographs

#	X, mm	Y, mm	Z, mm
1	-2.269840	-15.374619	78.676208
4	-0.328590	37.772644	56.836853
5	-52.713573	16.915720	47.223755
6	48.444473	15.968918	39.965820
7	-10.265533	20.695465	55.981018
8	6.573914	19.835541	57.113129
9	-0.802188	20.692749	75.864990
10	-15.225887	-0.920090	69.518585
11	10.867332	-0.617172	67.407410
14	-1.024193	-38.246689	89.675262
15	-1.550732	-60.049469	88.177185
16	-1.216293	-81.310638	93.380115

Table 2: Results of reference points measurements basing on textured 3D model

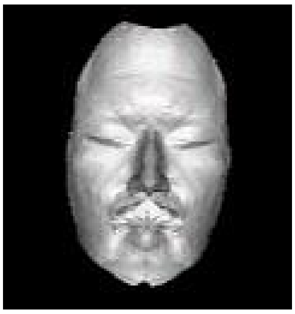
Differences in measurements by two different techniques reach the level up to 1 mm caused by possible errors in marking points by an expert. Such a measurements made on untextured 3D model give errors up to 6 mm.

3.2 Image exterior orientation unknown

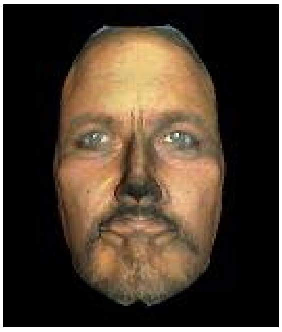
In many cases 3D model is obtained without corresponding texturing information and for photorealistic 3D model presentation used an image acquired with unknown camera orientation parameters. In such a condition the method and software is developed for generating texture on given 3D model using arbitrary image by establishing correspondence between some points of 3D model and the image. The correspondence is established by operator, marking corresponding points in a 3D model and in the given image and image exterior orientation is determined using points from 3D model as reference points. Then texture mapping is performed as in above case.

The sample of arbitrary photograph mapping on reconstructed face 3D model is shown in Figure 5. In the arbitrary image (Figure 5a) 18 reference points were marked at specific face points like a center of the eye, a tip of the nose, a corner of the mouth etc. Corresponding 18 reference points were marked in the face 3D model. The texture is a result of orthophoto generation from initial photograph using image external orientation basing on 3D model reference points.

a



b



c

Figure 5: Texturing a 3D model using an arbitrary photograph.

The result of texture mapping is presented in the Figure 5c. Figure 5c shows that given photograph does not correspond to the given face 3D model: texture at the mouth region has significant displacement with respect to the face relief. So texture mapping could be used as a check of correspondence between face 3D model and photo of potential person. Another criterion that shows the degree of correspondence between the face 3D model and the image used for texturing is the accuracy of exterior orientation procedure (errors at the reference points). For given image the errors of exterior orientation were up to 12 mm, thus showing bad similarity between image and face 3D model.

3.3 Image orientation unknown

The most common case corresponds the condition when no image geometry parameters are given and it is required to generate accurate texture for a given 3D model. Accurate texturing means in the following context coincidence of given features in the 3D model and in the image (e.g. eliminating texture displacement for Figure 5c).

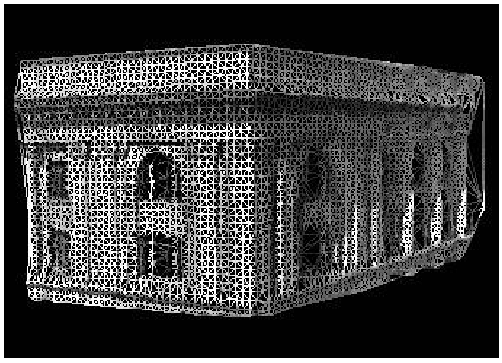
If there is no possibility to determine 6 parameters of exterior orientation (elements of transition matrix A $a_{11},\ldots,\ a_{33}$) for orthophoto generation the 11 parameters of general perspective transformation are found from the next conditions:

$$
\begin{aligned}
x_a &= \frac{p_7 x_g + p_5 y_g + p_3 z_g + p_1}{p_{11} x_g + p_{10} y_g + p_9 z_g + 1}; \\
y_a &= \frac{p_8 x_g + p_6 y_g + p_4 z_g + p_2}{p_{11} x_g + p_{10} y_g + p_9 z_g + 1};
\end{aligned}
\qquad (2)
$$

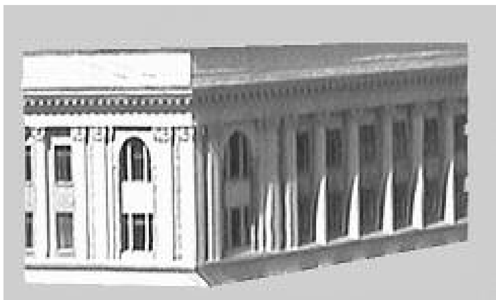
where x_a, y_a - image coordinates for space point with x_g, y_g, z_g coordinates, p_1-p_{11} - transformation parameters, determined with least mean square method.

Then orthophoto for texturing could be performed using equation (2) with known transformation parameters [8].

This technique is illustrated on building 3D model obtained by laser range finder and an image of corresponding part of building, obtained by unknown image acquisition means. Figure 6 show the 3D model (a) and an arbitrary image of the building.



a



b

Figure 6: Laser range finder 3D model of a building and its arbitrary image

The result of texture mapping by described technique is presented in Figure 7.

Figure 7: Textured 3D model of a building

4. CONCLUSION

The methods for accurate photorealistic texture mapping is developed for various types of spatial and texture data, beginning with complete definition of 3D model and image parameters as in case of photogrammetric 3D reconstruction technique and finishing with arbitrary 3D and texture data.

In case of complete knowing of 3D model and image parameters accurate texture mapping is performed in automated mode resulting in metric textured 3D model. If uncertainty in image parameters exists the problem of accurate texturing could be solved by mapping basing on reference points marked by operator.

The quality of texture mapping in case of unknown image exterior orientation parameters could be treated as a criterion of correspondence between a 3D model and given photograph.

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