AUTOMATED CALIBRATION TECHNIQUE FOR PHOTOGRAMMETRIC SYSTEM BASED ON A MULTI-MEDIA PROJECTOR AND A CCD CAMERA

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ABSTRACT:

Recently multi-media projectors became commercially available for using in 3D reconstruction application. They have a number of features which make them attractive for using in photogrammetric application. The main of these features are high technical characteristics (such as brightness, contrast, signal/noise ratio, resolution) and a reasonable price. And the main advantages of multi-media projector is a capability of intellectual lighting for applying smart algorithms for accurate correspondence problem solution. The traditional configuration of a close range photogrammetric system is two calibrated cameras and a structured light projector. In such a scheme the projector has no need to be calibrated. Projector calibrating allows to increase productivity of 3D reconstruction system and to reduce its cost due to one CCD camera eliminating. To apply common bundle adjustment procedure for a projector calibration it is necessary to solve a problem of determining spatial coordinates for reference points lighted (or "observed") by the projector. Two techniques for projector calibration are presented. Both of them use standard bundle adjustment program and planar test field with coded targets for calibration procedure automation. The first technique uses two calibrated cameras for producing "virtual" spatial test field. The second technique supposes generating synthetic "images" of a test field observed by the projector. Then the parameters of interior orientation for the camera and the projector are found by standard bundle adjustment procedure.

1. INTRODUCTION

1.1 General Instructions

Traditionally close-range photogrammetric system includes two (or more) cameras and structured light projector for automation of correspondence problem solution. For camera calibration a test field with known spatial coordinates of reference points is applied. A set of test field images acquired from different points is used for camera interior orientation parameters estimation.

On the other hand projector could be concerned as an inverse camera and after calibration it could be used for object spatial coordinates calculation. Some techniques were developed for projector calibration (Gühring, 2000; Shen, 2000; Sadlo, 2005;).

For calibration ABW LCD 640 Cross projector the planar test field consisted of an aluminium plate, with a sheet of self-adhesive paper showing white dots on a black background, was used (Gühring, 2000). The projector is able to project horizontal and vertical patterns, so it was modelled as an inverse camera. Two-dimensional image coordinates were obtained by phase shift and line shift processing. So the projector was calibrated using a planar test field and a convergent setup. All visible target points are measured and identified fully automatically. The image coordinates for the camera are obtained by computing the weighted censored. After that, corresponding projector coordinates are computed with sub-pixel accuracy by a sampling at the centroid positions.

Another approach (Shen, 2000) uses two or more target points for each light beam for estimating the parameters of the light beams by a 3D line-fitting algorithm. A high precision calibration plane is placed in sequence at distinct depths along the light beam direction and its position and orientation are measured by the coordinate measuring machine (CMM). By projecting the light beams on the calibration plane, points in a grid are formed and their 3D coordinates can be calculated for determining the parameters of the light beams.

A technique with two joint test fields (one for a camera, another for a projector) was proposed by F. Sadlo et al (Sadlo, 2005). A calibration pattern in form chess-board was projected on a plane with similar calibration pattern printed on this plane. Printed pattern with known reference point is used for plane orientation estimation, so spatial coordinates of projected pattern can be found.

Recently multi-media projectors became convenient and accessible mean for producing PC-controlled structural light of given structure. For camera calibration a set of images of a test field with known spatial coordinates is used. Then parameters of camera model are found by least mean square procedure using test field reference points images as observation. The calibration of a projector provides the improvement of 3D reconstruction system. The problem of a projector calibration with the technique applied for camera calibration is to determine spatial coordinates of reference points lighted (or "observed") by the projector.

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Two techniques for projector calibration are proposed. Both of them use standard bundle adjustment program and plane test field with coded targets for calibration procedure automation. The first technique uses two calibrated cameras for generating “virtual” spatial test field. The projector projects a pattern in a form of coded targets grid on a white plane observed by two oriented cameras. The cameras acquire images of the pattern at different plane positions. Then spatial coordinates of projected coded targets are calculated using known cameras orientation. These 3D coordinates are concerned as spatial test field for projector calibration.

The second technique is used for calibration a system including one CCD camera and a multi-media projector. The camera has no need to be preliminary calibrated. It used for test field image acquisition and for generating “image” observed by the projector. The projector “image” is generated by writing in synthetic image the intensity of each projector pixel reflected from observed scene. For calibration a set camera images and projector “images” of test field is captured. Then parameters of interior orientation for the camera and the projector are found by standard bundle adjustment procedure.

2. PHOTOGRAMMETRIC SYSTEM

2.1 System outline

The photogrammetric system used for 3D reconstruction includes two SANYO VCB-3385P cameras and BENQ PB2140 multimedia projector.

The exterior view of the photogrammetric system is presented in Figure 1.

Figure 1. The view of the photogrammetric system

SANYO VCB-3385P camera has 768x576 pixel resolution and BENQ PB2140 multimedia projector has 800x600 pixel resolution.

2.2 Calibration procedure

For camera calibration original software is used. It performs the estimation of camera model parameters basing on a set of images of a test field with known spatial coordinates.

The initial data for bundle adjustment procedure is

- Spatial coordinates of test field reference points
- Image coordinates of reference points in the images of test field acquired from various points of view
- Initial approximate values for camera interior orientation parameters

For camera calibration a planar test field with a grid of reference points is used. Reference points are marked with original coded targets (Knyaz V., 1999) which provide robust and precise reference point coordinate determination in the image and reliable recognition of reference point number.

The image of the test field with coded targets is shown in Figure. 2.

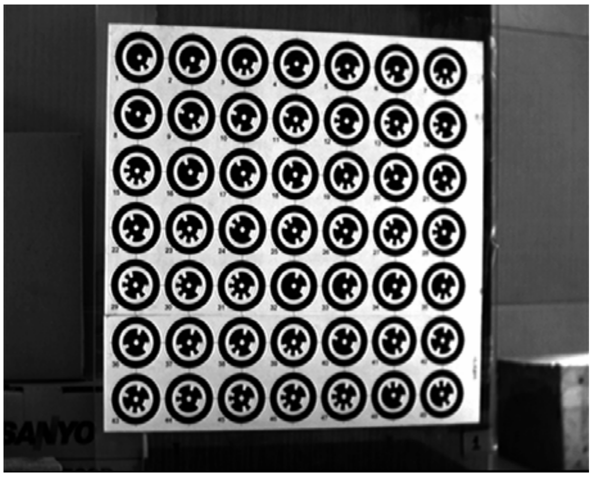


Figure 2. The image of the test field

Image coordinates of reference points marked by coded targets are determined automatically with sub-pixel accuracy by ellipse operator. The additional parameters describing CCD camera model in co-linearity conditions are taken in form:

$$\Delta x = a\bar{y} + \bar{x}r^2K_1 + \bar{x}r^4K_2 + \bar{x}r^6K_3 + (r^2 + 2\bar{x}^2)P_1 + 2\bar{x}\bar{y}P_2$$
$$\Delta y = a\bar{x} + \bar{y}r^2K_1 + \bar{y}r^4K_2 + \bar{y}r^6K_3 + 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$
$$\bar{x} = m_x(x - x_p);\ \bar{y} = -m_y(y - y_p);\ r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

where x_p, y_p,-the coordinates of principal point,
m_x, m_y - scales in x and y directions,
a – affinity factor,
K_1,K_2,K_3 – the coefficients of radial symmetric distortion
P_1,P_2 - the coefficients of decentring distortion

Image interior orientation and image exterior orientation (X_i, Y_i, Z_i – location and α_i,ω_i,κ_i and angle position in given coordinate system) are determined as a result of calibration.

The estimated parameters vector includes:

- exterior orientation parameters of all the images
- interior orientation parameters of both cameras
- coordinates X, Y of all the object reference points excluding two points determining object space coordinate system. With the plane test field assumption Z coordinates of all points is taken to be zero.

The calibration procedure is executed automatically performing the following steps:

- reference points recognition and their image coordinate determination in all acquired images;
- initial values for exterior orientation parameter definition;
- exterior orientation of the images, with test field reference points coordinates and interior orientation parameters being frozen;
- complete unknown parameters vector is estimated in condition of precise knowing relative distances.

The residuals of co-linearity conditions for the reference points after least mean square estimation σ_x, σ_y are concerned as precision criterion for calibration.

3. PROJECTOR CALBRATION USING TWO CAMERAS

First method for multimedia projector calibration uses two calibrated cameras for creating virtual spatial test field for projector interior orientation parameters estimation.

3.1 Camera calibration

The cameras applied for projector calibration were preliminary calibrated using the procedure described in 2.2. The results of camera calibration are shown in Table 1.

	Left camera	Right camera
m_x	0.00849439	0.00845617
m_y	0.0085223	0.0084848
b_x	349.05547125	340.65892428
b_y	278.87410398	304.25018521
a	-0.00007535	-0.00006946
K_1	0.00163377	0.00160678
K_2	0.00003600	0.00005544
K_3	-0.00000186	-0.00000422
P_1	-0.00005455	-0.00003223
P_2	-0.00011305	0.00012367
$\sigma_{x,\ mm}$	0.029	
$\sigma_{y,\ mm}$	0.022	

Table 1. Results of the cameras calibration

The system exterior orientation is also determined during calibration procedure. Then calibrated cameras system is used for calculating the 3D coordinates of virtual test field produced by projecting a special pattern on a screen.

3.2 Projected pattern

For applying the standard bundle adjustment procedure it is necessary to have spatial coordinates of reference points “observed” by the projector. The coordinates of projection of coded targets on a plane surface are concerned as reference points coordinates. Coded targets are used for automated reference point identification and measurement.

An image of a coded target grid is used as a special pattern for virtual test field generating (Figure 3). The size of the coded targets is taken enough for their recognizing in camera images.

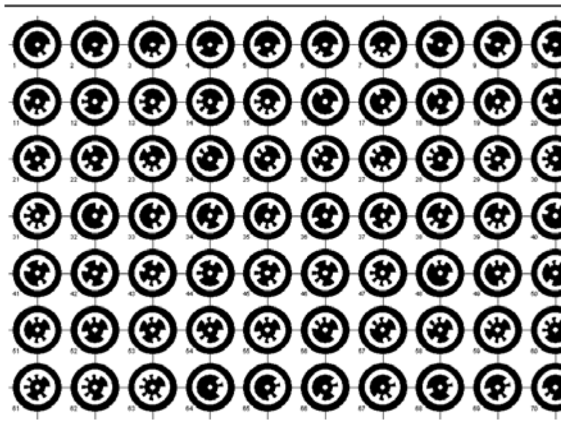


Figure 3. Special pattern with coded targets

The coded targets pattern is projected on a screen and images of the screen are acquired for further processing. The screen is installed in various positions relatively the photogrammetric system so the projected coded targets are located approximately uniformly inside the working space of the system. No special requirements to the screen are made.

3.3 Virtual test field generation

A set of stereo pairs is acquired by the photogrammetric system for various position of the screen (Figure 4). Then coded targets are detected in the images with sub-pixel accuracy and spatial coordinates of the projected coded targets for each stereo pair are calculated basing on results of camera calibration and exterior orientation.

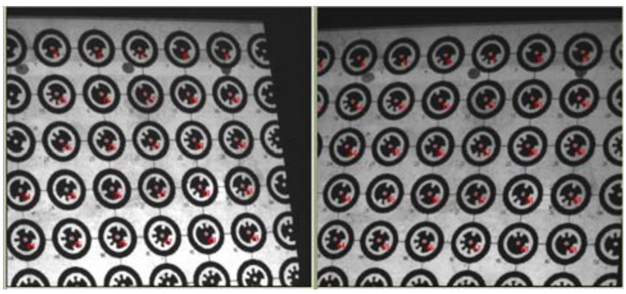


Figure 4. Stereo pair of projected test field

This array of 3D coordinates is concerned as a spatial test field for projector calibration.

3.4 Projector calibration

Then bundle adjustment is performed with the following initial data:

- Image coordinates of coded targets of the special pattern
- Spatial coordinates of reference points for all position of the screen (the virtual test field created by the special pattern projection).

The image coordinates of coded targets of the special pattern are calculated with sub-pixel accuracy by technique used for coded target image coordinate measurement.

The results of projector interior orientation parameter estimation are presented in Table 2.

	Projector
m_x	0.00831560
m_y	0.00830448
b_x	405.57689582
b_y	554.10482713
a	-0.00026678
K_1	0.00024345
K_2	0.00000499
K_3	-0.00000042
P_1	-0.00004026
P_2	-0.00015402
$\sigma_{x,\ mm}$	0.053
$\sigma_{y,\ mm}$	0.106

Table 2. Results of the projector calibration using two cameras

For projector exterior orientation the same virtual test field is used. It gives exterior orientation parameters in the same coordinate system as the cameras because the reference points the virtual test field are given in the real test field coordinate system.

4. PROJECTOR CALBRATION USING “IMAGES” FROM PROJECTOR

Another approach for projector calibration supposes acquiring images as they are seen by projector. To generate these images special technique is developed. For creating these images the CCD camera of the system is used.

4.1 Projector “image” generating

The projector “image” is a synthetic image of the size according to projector resolution. In each pixel of this synthetic image the intensity of a surface point of the observed scene intersected by corresponding projector light beam is registered.

Projector lights by single light beam projecting one pixel. The working space is observed by the camera which registers the intensity of the reflected beam and this intensity is assigned to corresponding pixel of a synthetic image of the projector.

For projector calibration a set of projector “images” of the test field is generating, the test field being with different orientation relatively the photogrammetric system. A set of the test images form camera is acquired along with projector images generating. One of the synthetic projector images with detected coded targets is presented in Figure 8.

Figure 8. A synthetic image of the projector

Then the test field images acquired by the camera and “by” the projector are used for the camera and the projector joint calibration.

4.2 Projector calibration

The bundle adjustment is performed with the following initial data:

- Image coordinates of reference points of camera images
- Image coordinates of reference points of projector “images”
- Spatial coordinates of reference points of the test field

The results of the projector and the right camera interior orientation parameter estimation by described technique are presented in Table 3.

	Projector	Right camera
m_x	0.00830533	0.00846205
m_y	0.00829383	0.0084779
b_x	405.57122500	341.207155
b_y	567.39640424	304.070311
a	-0.00028506	-0.00006891
K_1	0.00028378	0.00155748
K_2	-0.00000811	0.00004994
K_3	0.00000000	-0.00000408
P_1	-0.00004192	-0.00003714
P_2	0.00022430	0.00013204
$\sigma_{x,\ mm}$	0.046	
$\sigma_{y,\ mm}$	0.037	

Table 3. Results of the projector calibration

The results of projector calibration by both developed techniques are in a good agreement. Both calibration approaches give the similar values for camera model parameters.

The second technique (generating synthetic projector images) gives the better characteristics of the calibration σ_x, σ_y because of better image resolution (and therefore better accuracy of coordinates measurement).

5. APPLICATION RESULTS

The object taken for 3D reconstruction is a plaster model of Phobias, (the satellite of Mars) shown in the Figure 9.

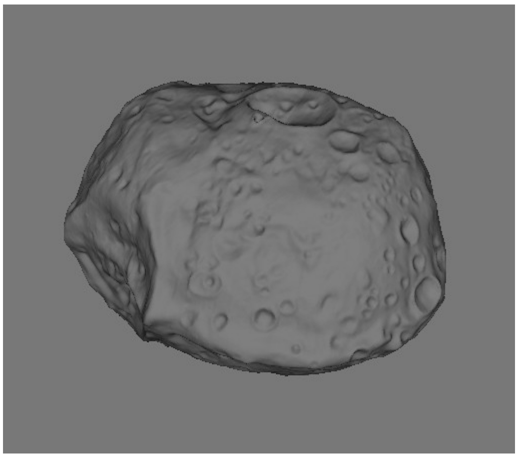
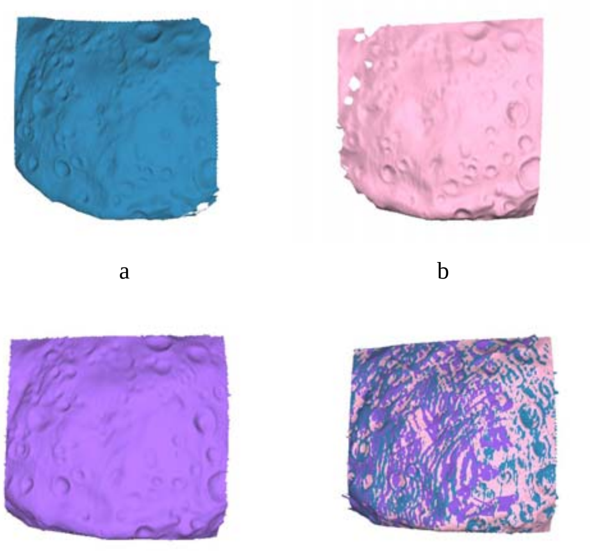


Figure 9. Test object for 3D reconstruction

Figure 9 presents the results of surface 3D reconstruction performed with the use of the photogrammetric system. The first 3D model (a) is obtained using two cameras configuration. The second (b) and the third (c) 3D models are reconstructed using camera-calibrated projector configuration with interior orientation parameters obtained by virtual test field and projector "image" techniques correspondingly. All three 3D models (shown in different colours) in object coordinate system are shown in Figure 9d.



a b

c d

Figure 9. Surface 3D reconstruction by different system configuration

Figure 9 demonstrates good accuracy of the projector calibration and the advisability of applying the camera-calibrated projector configuration for the purposes of 3D reconstruction instead of two cameras configuration.

6. CONCLUSION

Two methods for multi-media projector calibration are proposed. They use the standard bundle adjustment procedure and special techniques for preparing initial data for calibration. The first one creates virtual spatial test field by projecting special pattern and calculating reference points coordinates using two calibrated cameras.

The second approach uses synthetic images of a real test field "observed" by a projector. Projector "images" are produced with the aid of the second camera of the photogrammetric system.

Both techniques give adequate estimation of projector interior orientation parameters, the latter being more accurate due to better accuracy of reference points coordinates measuring in the images.

7. REFERENCES

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