APPLICATION OF DIGITAL CAMERA WITH FISHEYE LENS IN CLOSE RANGE PHOTOGRAMMETRY

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ABSTRACT

In c fast and effective measurements are very important especially when access to untypical, big objects (for example bridges, silo etc.) or buildings in narrow streets is difficult. The application of fisheye lens in hard-to-reach places is possible because of its construction. The filed of view is almost 180 degrees and is much wider than in classical lenses. The same, we can make model or orthoimage of particular object on very small distance in very short period of time. Nevertheless it is connected with the fact, that fisheye lens has a great distortion, and variable resolution (in different places in the image). In paper we will present calibration of fisheye lens. For this purpose authors of this publication have made a fisheye lens calibration model with special test field, and also have examined resolving power, and have developed a method of orthorectification. Using of such images reduces significantly number of photos necessary in terratriangulation process and in creating of orthoimages. In many cases, we can generate an orthoimage using only one image, that comes from camera with fisheye lens, what results in elimination of mosaic process. In order to achieve best results, we have made orthoimages of building façade using both: classical and fisheye lenses. Fish eye lens can be used to architectonic documentation, to creating orthoimage of cultural heritage and in building displacement monitoring.

INTRODUCTION

In close range photogrammetry creation of orthophoto of building facade is very common task. It is especially important, when we want to make a documentation of historical objects located in narrow alleys of old cities. For this purpose 3D model of façade is needed. In some cases (for example narrow streets) we are forced to take a great number of photos at small distance or we cannot take an image of whole wall at all. Under such circumstances we can use fish-eye lenses and generate a 3D model. There is no matter if this is a façade model or it is just a model of the close object. Sometimes, when the station is not in the middle of the object height, and protruding elements covers some parts of the façade, the 3D model generation is very difficult. We can always refine such model by marking flat elements and edges, or excluding windowpanes from model generation process. This approach refines both: model and final result. But the authors intention is testing of the model, that was generated in the automatic correlation process without its strengthening by any additional elements. Therefore, there will be possibility to observe the influence of the fisheye lens calibration and terratriangulation process on the final product – orthophoto.

Because of specification of fisheye lens (which is not hemispherical – 170^{o} FOV and has large distortion), before generating ortho image, we have to know the value of the distortion. (Currently, there is no application processing such images into orthoimage). This orthoimage will be stuck with errors of fisheye calibration and *RMSE* of detail location will be 2 times bigger than in analogue image from classical images.

CAMERA CALIBRATION MODEL

In the cameras with classical lenses the perspective projection can be presented as:

$$r = f \cdot \tan\theta \qquad (1)$$

where: θ- angle between the optical axis and the incoming ray *f* - focal length

r - distance between the image point and the principal point

Calibration of such cameras usually leads to determination of the inner orientation parameters: principal points, focal length, aspect ratio and skewness, by transformation of the camera coordinates to the image coordinates.

For camera with the fisheye lens we can define a projection model as relations:

- fisheye image radius (r) vs. its corresponding perspective image radius (r'),
- fisheye image radius (r) vs. incident angle (θ).

The parameters r and r' are the distances from the distortion center to the distorted image point and the corresponding perspective image point respectively. In both images, the center is the same. The adequate distances can be transformed as:

$$r' = r + K_1 \cdot r^3 + K_2 \cdot r^5 + ... \qquad (2)$$

Simultaneously we can present the fisheye lens projection models as:

equidistance projection

$$r = f \cdot \theta \qquad (3)$$

or *orthogonal projection*

$$r = f \cdot \sin\theta \qquad (4)$$

The projection from 3D rays to 2D image positions in a fisheye lens can be approximated by the imaginary equidistance model.

Distortion

To the precise determination of distortion value in radial and tangential direction we used differential geometry relations and the 3D test field (fig.1). These relations describe the value of curvature in every segment of photographed test.

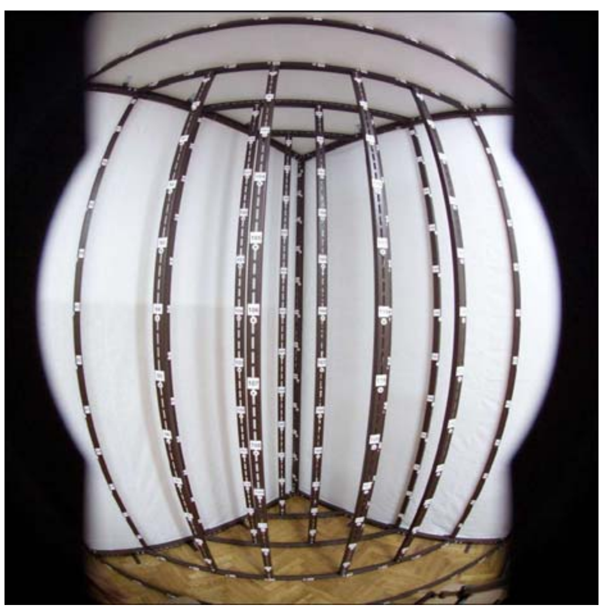

Figure 1. Calibration test 3D.

On the test, there is 230 calibration points were located uniformly on the test frame with an error $m_{xyz}= \pm 0.0007$ m. The test points are located on the metallic elements forming in the space a straight segment. Image of these points in the image is a circular sector on the plane. The test is painted special super matt paint, precluding light reflections. On the test there is no shadows on its background. Because the lens elements of real fisheye lens may deviate from precise radial symmetry and they may be inaccurately positioned causing the fact, that the projection is not exactly radially symmetric. Kannala and Brandt proposed adding two distortion terms: in the radial and tangential direction. In our investigations we propose determination of distortion using proper mathematical relations: between this segment in the space and the arc on the plane (in every segment of photographed test). Each point on the test was located on it with the accuracy of 0.5 mm.

In the image, each control point lies on the fragment of ellipse (fig.1), therefore we can say, that plumb lines (elements of the test construction) in the image are conic sections (the fragments of the ellipses). On the basis of the ellipse equation and the fact, that the center and the radius of the osculating circle (in the point) is the center and the radius of the curvature, we determine the coordinates of these curvatures centers and their radiuses.

$$\xi = \frac{c^2}{a^2}\cos^3 t \qquad \eta = -\frac{c^2}{b^2}\sin^3 t \tag{5}$$

where $c^2=a^2-b^2$. the curvatures centers determine an evolute of the ellipse (eliminating t, we get evolute equation for ellipse):

$$(a\xi)^{2/3} + (b\eta)^{2/3} = c^{4/3} \tag{6}$$

Then, by making a regression of the curve we obtain a straight line fitted to this curve. The straight line (linking curvature centers and plumb line points) containing curvature radius will intersect a regression straight line. Intersection will determine the location of the control points without distortion and without shifts as well (fig. 2). The distance between point laying on the curve and the same point on the intersection is a distortion value. Distortion is positive, when the curvature radius intersect straight line and negative, when the radius pass by the straight line.

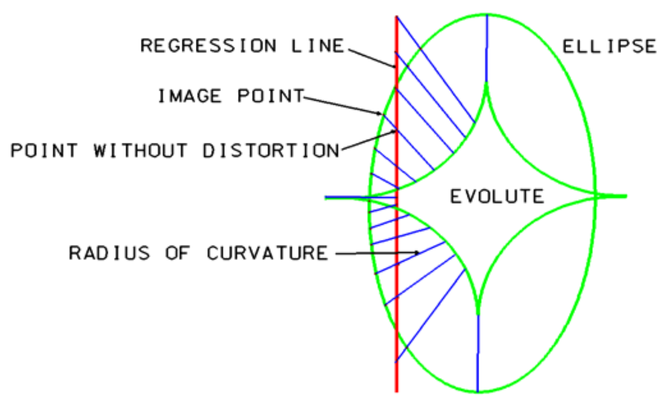

Figure 2. Schema of distortion determination idea.

Detailed description of the precise calibration and results of the experiments can be found in publication [Kedzierski 2008]. There are also another methods of the calibration of the camera with fisheye lens, proposed by Kannala, Backstein or Ho [Kannala 2004, Backstein 2002, Ho 2005].

EXPERIMENT: TERRATRIANGULATION AND 3D MODELS

Terratriangulation

Process of determination of absolute orientation parameters and assessment of its accuracy is defined as terratriangulation. Terratriangulation is much more difficult than aerotriangulation, because external orientation angular parameters for each photo are different (unlike aerial photos). Furthermore, very often objects, buildings have irregular shapes, or protruding elements and also access to them is more troublesome (for example hard-to-reach monumental objects). Because mathematical adjustment bases on colinearity equations we have to remember about proper choice of number and location of control points and appropriate angle of intersection.

The terratriangulation bases on the corrected images. Additionally, the object in the image has to be placed properly (margin, overlap between stereopairs).

The practical test filed for our research was a façade of the four-store building. We choose 40 evenly (regularly) distributed control points (error of position +- 0.003 m) as it is shown in the figure 3.
In our experiment we used KODAK Pro with the 10.5 mm and for comparison with the 24 mm focal length. Whole process was made using PI-3000 software.

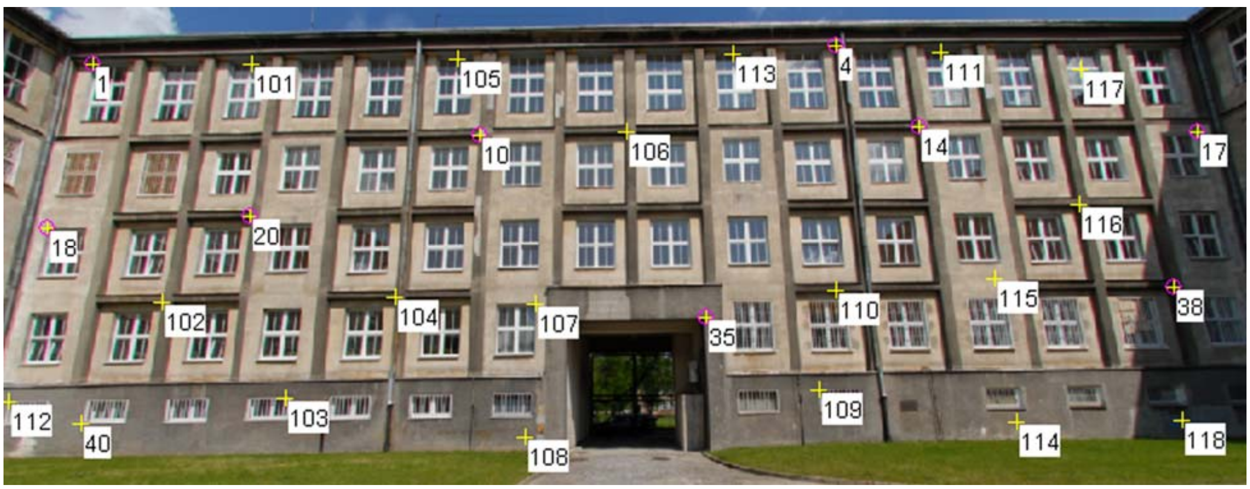

Figure 3. Control and tie points distribution on the building façade.

For images acquired with the fisheye lens, B/H ratio is very high (for 24 mm focal length, this ratio is 0.15).
Table 1 contains some of the results of the terratriangulation. Coordinate system is like in close range photogrammetry – Y is a depth.

Table 1. Terratriangulation accuracy on the control points and σ_0

	Focal lens 10.5 mm			Focal lens 24 mm		
Control points coordinates	X	Y	Z	X	Y	Z
m [mm]	19	24	9	5	1	5
v_{max} [mm]	-41	-50	-15	11	2	-9
Number of control points	9			6		
σ_0 [μm]	5.6			4.5		

Table 2 shows the results of accuracy assessment of steropairs and 2D resolution (XZ) and resolution in Y direction for the focal length 10.5 mm.

Table 2. Accuracy assessment of stereopairs. Resolutions

N° of pairs	Base[m]	Distance to the object [m]	B/H	Resolution XZ [m]	Resolution Y [m]	Parallax [μm]
5 - 4	15.263	16.584	0.92	0.012	0.013	6.3
4 - 6	10.976	21.465	0.51	0.016	0.031	4.9

Of course it is cause by very close distance to the object. For comparison, if we use classical 24 mm lens for this façade we need at least 9 stereopairs, and with the fisheye lens (10.5 mm) only two (by similar image scales).

3D Models

Very important part of orthoimage generation process is a 3D model. Usually for automatic generation of 3D models Area Based Matching method is used. Algorithm searches homologous points by the criterion of correlation coefficient value. In case of ground imagery and building façade 3D model generation, correlation coefficient have should be established as 0.90. It is conditioned by the fact, that protruding objects like windowsills or cornices cause problems connected with their shadows. To obtain 2-3 pixels accuracy of the cross correlation method correct initial position of correlation windows is required.

The biggest influence on radiometric and geometric image deformations have: illumination, light reflection, object shape etc.). Figure 4 presents 3D model of building façade. Model resolution 25 cm.

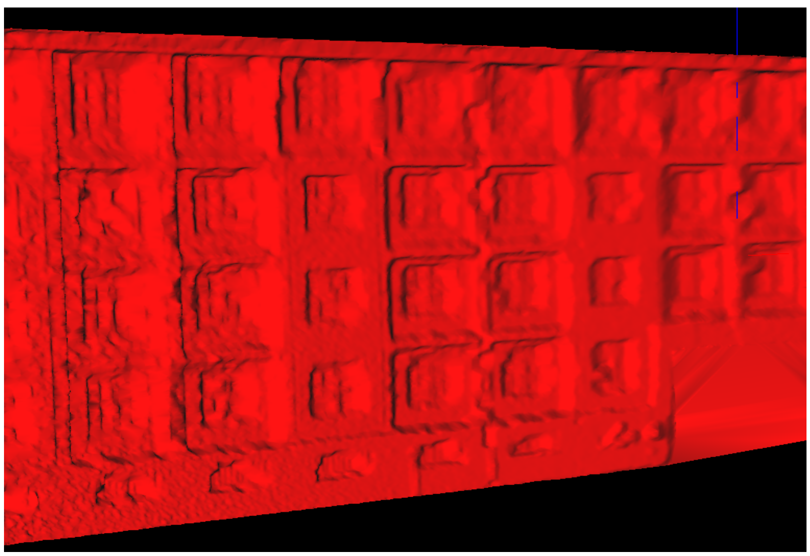

Figure 4. Screenshot of the 3D model made in PI-3000 (for camera with 10.5 mm focal length lens).

We can see that the most inaccurate elements are window glasses and edges.

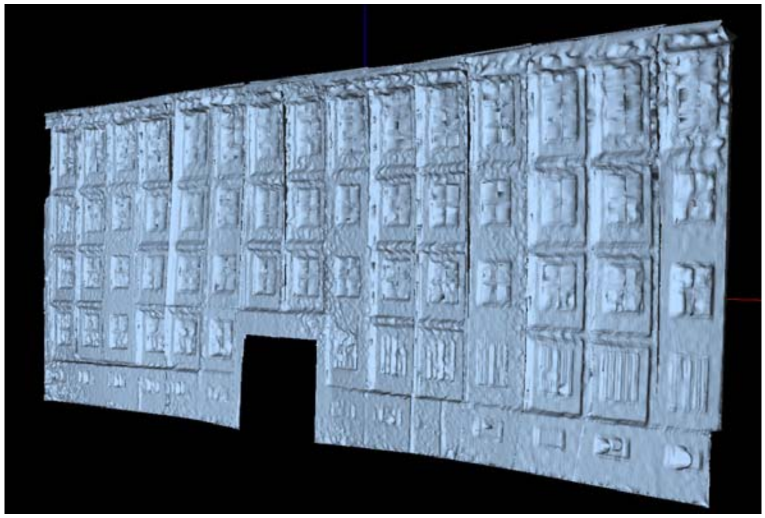

Figure 5. Screenshot of the 3D model made in PI-3000 (for camera with 24 mm focal length lens).

The second model comes from 24 focal length lens. The differences are easy to notice. Especially comparing details such as edges. Though models were generated with the same resolution, it seems that model generated from classical lens images gives more details (is sharper). It follows from the fact, that model was generated from the 'raw' photos. In generation of the model from fisheye lens camera, images were processed (calibrated), free from distortion and equalized in scale (almost like in classical central projection formulation).

ORTHOIMAGE

An orthoimage was generated with the 1 cm step. To accuracy analysis of orthoimages (from building façade) all window frames were measured and compared with dimensions in the orthoimage. All windows in the same floor are identical and should be identical in the orthoimage. In fact there is not so. General errors are not significant, except one place in upper corner (error of checked distance 5%).

Figure 6. First image – raw image, second image – image after distortion.

Figure 7. Orthoimage.

An orthoimage was generated using only one image fro camera with the fisheye lens. Figure 6 and 7 present particular steps and changes of the image into orthoimage. Errors of the orthoimage can be caused by the radiometry errors after calibration and photograph exposition of this tall building (some missing places under or above windowsills).

CONCLUSIONS

Using fisheye lens in close range photogrammetry gives great possibilities in acquiring photogrammetric data of places, where access to the object is very difficult. But such lens have very specific optical and geometrical properties resulting from great value of radial distortion. In alleys 2 - 4 meters wide, making photogrammetric documentation by means of classical methods may require from several tens to several hundreds of images, while using fisheye lens would decrease their number to several or maximum several tens. Therefore, we can say that using fisheye lens in close range photogrammetry will be a low-cost system in data acquisition and documenting cultural heritage, which probably can be also usable in archeology.

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