FISHEYE LENS CAMERA SYSTEM APPLICATION TO CULTURAL HERITAGE DATA ACQUISITION

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ABSTRACT:

The subject of usage of fisheye lens in photogrametric elaborations of architecture was brought up in this thesis. This is very essential problem, as particularly when one measures historical monuments there is no possibility to make adequate images with classical lens, which require making exposure from adequate distance. Authors made experiment consisting in comparison of elaboration of interior courtyard – well of XVIII-century town hall with application of classical and fisheye lens. There was generally presented a process of fisheye lens callibration, which is very important aspect of such analyses.

1. INTRODUCTION

Fisheye lenses provide imaging of large areas of the surrounding space by a single photo, sometimes more than 180 degrees. They enable to realize photos at very small distances, what in some elaborate engineering aspects may be particularly useful. Close range photogrammetry (central perspective) does not comply with fisheye image processing. The fundamental difference between a fisheye lens and classical lens is that the projection from 3D ray to a 2D image position in the fisheye lens is intrinsically non perspective. The fact that not all fisheye lenses give hemispherical image has to taken into consideration. In our experiment we used fisheye lens with focal lens of 10.5 mm, whose image is not hemispherical. Application of such type of fisheye lens gives more possibilities of usage of images in close range photogrammetry by eliminating from the image everything beyond 170° of the FOV , and simultaneously preventing retrieval of image radius. Images were taken with Kodak DCS 14n Pro digital camera, f=10.5mm, with matrix 4500x3000 pixels.

Fisheye lens has a very large distortion for which the polynomial distortion used here would not converge. For such a lens the image coordinate should be represented as being ideally proportional to the off-axis angle, instead of the tangent of this angle as in the perspective projection. Then, a small distortion could be added on top of this. Furthermore, the position of the entrance pupil of a fisheye lens varies greatly with the off-axis angle to the object, therefore this variation would have to be modeled viewed objects are very far away [Gendery, 2001].

Usage of processed images coming from fisheye lens seems to have many applications, especially in Close range photogrammetry. Elaboration of photogrammetric documentation of historical objects located in narrow alleys of old cities may be indispensable necessity when *restoration* works are initiated. In alleys 2-4 meters wide, making photogrammetric documentation by means of classical methods may require from several dozens to several hundreds of images, while using fisheye lens would decrease their number to several or maximum several dozens.

It is obvious that processing such images to orthoimages is more complicated because there are no prepared applications for such approach to the problem possible yet. After normalizing images from fisheye lens one can construct a 3D model or create an orthoimage of historical objects elevation. The orthoimage will be stuck with errors of fisheye calibration and *RMSE* of detail location will be 2 times bigger than in analogue image coming from classical images. In some cases, so significant minimizing the number of images in an orthoimage creation process will make the creation *at all* possible. It will be a low-cost system in data acquisition and documenting cultural heritage, which will probably be also usable in archeology.

2. CAMERA AND PROJECTION MODEL

The perspective projection of a pinhole camera can be depicted by the following formula:

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

where: θ- angle between the optical axis and the incoming ray
f - focal length
r - distance between the image point and the principal point

The calibration of dioptric camera involves the estimation of an intrinsic matrix [Hartley, 2003] along with a projection model. The intrinsic matrix, which maps the camera coordinates to the image coordinates, is parameterized by principal points, focal length, aspect ratio and skewness.

A circular fisheye camera results from the size of the image plane charged coupled device (CCD) being larger than the image produced by the fisheye lens [Ho, 2005].

The existing projection models can be divided into two aspects:

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

First aspect; 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:

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

Second aspect; fisheye lenses are habitually designed to obey one of the succeeding projections:
equidistance projection

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

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. Let a 3D ray from pp of the lens is specified by two angles θ and φ (figure 1).

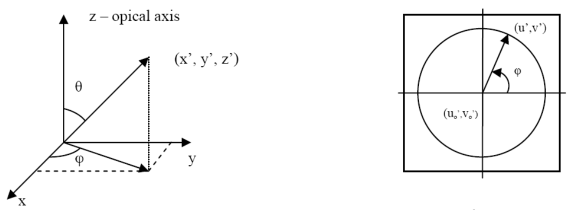

Figure 1. (a) Camera coordination system and its relationship to the angles θ, φ; (b) From polar coordinates (r,φ) to orthogonal coordinates (u',v').

Together with the angle φ between the light ray reprojected to *xy* plane and the *x* axis of the camera centered coordinate system, the distance *r* is sufficient to calculate the pixel coordinates:

$$u = (u', v', 1) \qquad (5)$$

in some orthogonal image coordinate system , as

$$u' = r \cdot \cos\varphi \qquad (6)$$
$$v' = r \cdot \sin\varphi \qquad (7)$$

The complete camera model parameters including extrinsic and intrinsic parameters can be recovered from measured coordinates of calibration points by minimizing an objective function with denotes the Euclidean norm[Bakstein, 2002].

$$J = \sum_{i=1}^{N} \left\| \tilde{u} - u \right\| \qquad (8)$$

where: N - number of points
ũ - coordinates of points measured in the image
u - coordinates reprojected by the camera model

3. ORIENTATION

Before photogrammetric handling of terrestrial or aerial photography, the orientation of this data has to be done. This process influences directly on accuracy of further investigations, and sometimes errors made in this stage disable getting final product with required accuracy. In case terrestrial photographs, terratriangulation is very important photogrammetric process and much more difficult than aerotriangulation. This is most problematic when the object is a monumental building with irregular shapes and when taking photos is very difficult, especially when we have to do with images made with fisheye lens. Terratriangulation is understood as a determination of precise elements of absolute orientation of each photo in a block and its accuracy. By the reason of terrestrial objects character and the method of taking photos, external orientation parameters for each photograph will not be identical or similar as in case aerial photographs. Figure 2 presents stereopair, which contains one wall of interior elevation (well) of XVIII century town hall. Taking into consideration the size of the well and the impossibility of adequate choise of exposure places with usage of classical lens (Focal lens 24 mm) 86 images were made, which created stereopairs with proper cover. When fisheye lens was used only 8 images were made, which created 4 stereopairs, one stereopair of each wall.

Figure 2. Stereopair of one wall made with fisheye lens

4. EXPERIMENTAL RESULTS

Results of orientation are very important especially when one takes into consideration further usage of them, like in this case for creation vector drawing. Errors of mutual orientation (P_y) directly affect on "vector" error. But despite of larger errors of stereopairs made with fisheye lens, shorter time and easibility of images making are more essential.
On four walls of "town hall well" there were measured 20 control points and 12 check points with error ±0.004 m.

	X	Y	Z
Standard Deviation [m] Control points	0.0045	0.0035	0.0049
Maximum Residuals [m] control points	-0.0092	0.0070	-0.0097
Standard Deviation [m] check points	0.0054	0.0051	0.0065
Maximum Residuals [m] check points	-0.0095	0.0085	-0.0102

Table 1. Results of orientation of block of images made with lens f=24mm

	X	Y	Z
Standard Deviation [m] Control points	0.0098	0.0112	0.0135
Maximum Residuals [m] control points	0.0155	0.0173	-0.0189
Standard Deviation [m] check points	0.0118	0.0165	0.0187
Maximum Residuals [m] check points	0.0238	0.0210	-0.0304

Table 2. Results of orientation of block of images made with lens f=10.5 mm (fisheye)

Maximum error P_y amounted 2.32 pixels for stereopair made with fisheye lens, and for classical – 0.81 pixel.

4. CONCLUSIONS

Usage of fisheye lens, particularly in photogrammetry, where approach to the objects is difficult, will become a standard soon. Although accuracies are presently 3-4 times worse than of images made with application of classical lens, simplification (reduction of images number) and in some cases the only possibility to make images, will bring about development of this method. Accuracy of elaboration from images made with fisheye lens can be increased by increase of accuracy of process of lens callibration, which is key factor in this method.

5. REFERENCES

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