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Full Length Research Paper

Photogrammetric observing the variation of intrinsic parameters for zoom lenses

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Today non-metric cameras are used widespread in close-range photogrammetric applications. Such professional cameras can be combined with both digital and mechanical zooming satisfactorily. Optical behavior of the lenses is changed depending on the feature of the optical system used during the zooming process. This so-called change is arranged by optimizing the number of pixels used on the digital sensor, on the projection plane. The problem of high definition, digital, non-metric professional cameras is that while sharpening the image, it deteriorates the definition of the image plane. Industrial cameras, which are used in industrial production, can overcome this problem by using additional image enhancement instruments. These digital non-metric cameras, which are generally used in close-range photogrammetry and in architectural photogrammetry, are calibrated by fixing for maximum and minimum zooming focal length and they are suitable to be used in this range. In this study, an Olympus E10 camera is calibrated to meet the need for the modification, for different focal lengths. Its calibration data, which is obtained in 3D test field, together with the distortions on the object, is used to detect the optical behavior of zooming object for mechanic zooming.

Key words: Camera calibration, zoom lens distortion, close range photogrammetry, parameter estimation, parameter analysis.

INTRODUCTION

The purpose of this study is to indicate the principal point coordinates among distortion values at the time of the zooming of objectives in three-dimensional test surface. This means the focus of the study is the correlation between zoom behavior and off the shelf camera behavior in three-dimensional area. In line with this situation, an appropriated zooming could be chosen without calibration process. In this case, intrinsic parameters of lenses can be calculated approximately without calibration step. There are several works on calculation of radial lens distortion parameters for off the shelf lenses (Tsai, 1987). However, most of them have two dimensional calibration fields and most of them use image processing techniques. Thus, intrinsic parameters and projection center coordinates can be calculated with a two-dimensional accuracy. Focal length and its accuracy is three-dimensional (Fraser, 1997; Fraser and Shortis, 1992; Devernay and Faugeras, 1995). This paper suggests that if we have minimum and maximum focal lengths with the accuracies of a three-dimensional test field, we can choose the best zooming for the object we have measured, without feeling a need for image processing techniques (Pers and Kovacic, 2002; Choi et al., 2006; Ergun and Baz, 2006). Thus, both the best intrinsic values for the camera and zooming behavior of the lenses can be predicted before the calibration step (Atkinson, 1996).

This paper, after the brief introduction above, formulates the research in five main subtitles. The rest of this paper is organized as follows: Section 2 points out the cruciality of radial distortion. In section 3, the experiment was explained in details. In section 4, results and discussions were shared and reconsidered. Finally, section 5 gives an account of the limitations and error rates for the future works.

RADIAL DISTORTION OF LENSES

The radial distortion causes straight lines in the space of the object, which is rendered as curved lines on the film or on the camera sensor. It originates from the data of the transverse magnification. In other words, the lens has various focal lengths and magnifications in different areas

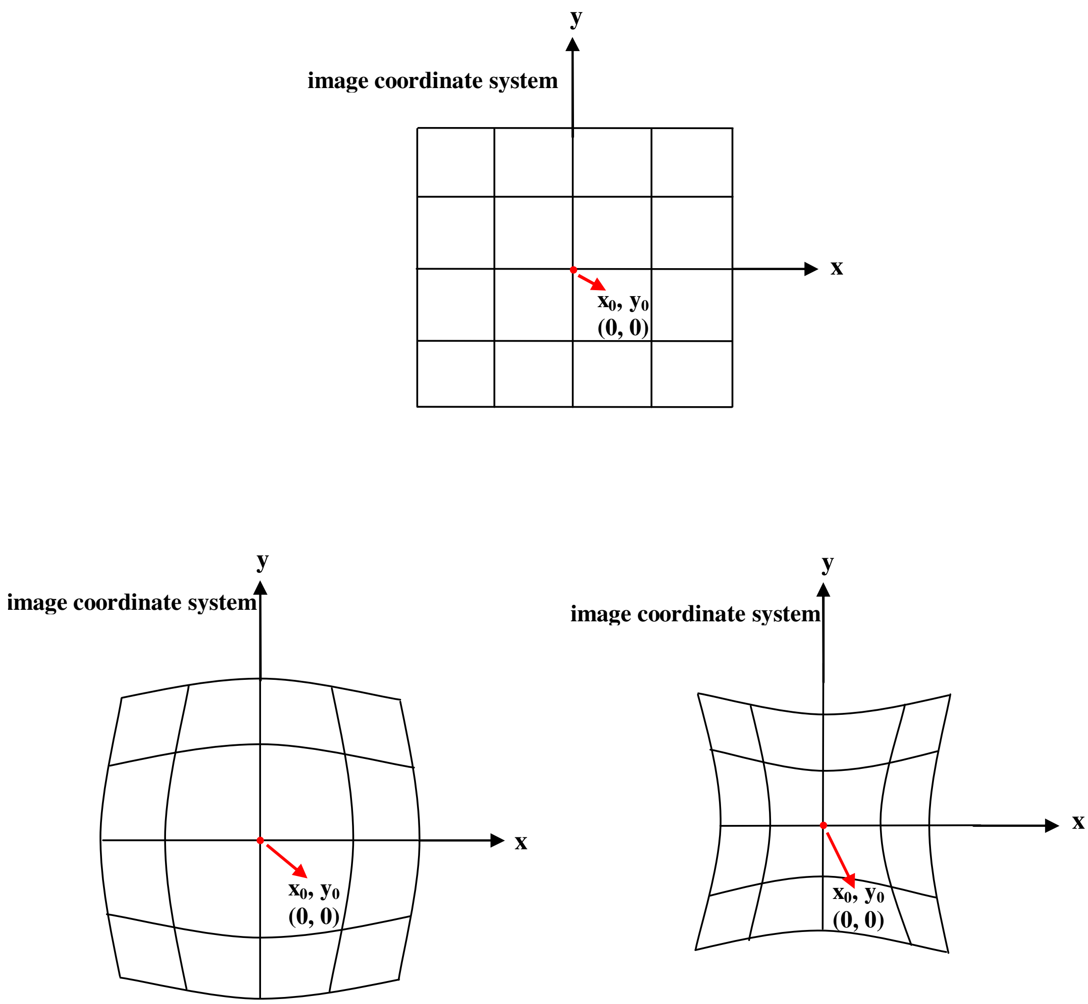


Figure 1. Distortion effect in image coordinate system.

areas. The radial distortion deforms the whole image, even though every point is in focus. This radial distortion causes the geometrical errors in the surface of the tile, which are detailed in CAD representation.

Due to the design and manufacturing processes, lens produces some geometric errors in images. The six major types of errors are spherical aberration, come astigmatism, field curvature, lens radial distortion and chromatic distortion. Among these errors, lens radial distortion is the most severe one, especially in wide-angle lenses (Choi et al., 2006). This paper mostly focuses on radial lens distortion. The radial distortion causes straight lines in the object space rendered as curved lines on the film or camera sensor. This effect has been shown in the Figure 1. In other words, the lens has numerous focal lengths and magnifications in various areas. Despite that every point is in focus, radial distortion deforms the whole image. The x_0 and y_0 are the datum of the image coordinate system as well

For the sake of the control over manufacturing costs, majority of the digital cameras are equipped with lenses having spherical surfaces (Choi et al., 2006). These spherical lenses have inherent radial distortion and must be corrected by manipulating the system variables (indices, shapes, spacing, stops, etc). The degree and order of compensation are varied from one manufacturer to another or even in different camera models by the same manufacturer. Therefore, lens from separate camera models may have different degrees of radial distortion. Apart from the lens design, the degree of the radial distortion is related to the focal length (Ergun and Baz, 2006), (Atkinson, 1996).

MATHEMATICAL MODEL

The lens distortion model can be expressed by being written as an infinite series as Formula 1. The degree and order of compensation are varied from one manufacturer to another or even in different camera models of the same manufacturer. Therefore, lenses used by separate camera models may have different degrees of radial dis-

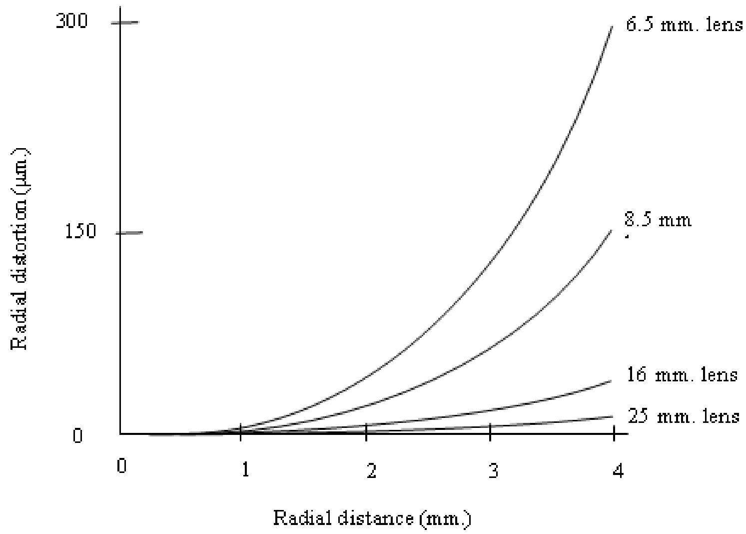


Figure 2. Distortion graphic with focal length.

tortion. Variations in angular magnification with the angle of incidence are usually interpreted as radial lens distortion. Design and construction of metric cameras ensure that such distortion is minimized, but calibration is usually necessary. Radial lens distortion is usually expressed as a polynomial function of the radial distance from the point of symmetry, which usually coincides with the principal point:

$$\delta r = K_1 r^3 + K_2 r^5 + K_3 r^7 \tag{1}$$

Where δr is the radial displacement of an image point, $r^2 = (x - x_0)^2 + (y - y_0)^2$, (x, y) are the fiducial coordinates of the image point. (x_0, y_0) are the fiducial coordinates of the point of symmetry, (commonly the principal point) and K_1, K_2 and K_3 are coefficients whose values depend upon the camera focal setting. The distortion δr is resolved into two components by photogrammetric method:

$$\delta r_x = \delta r (x - x_0) / r \tag{2}$$

and

$$\delta r_y = \delta r (y - y_0) / r \tag{3}$$

In order to achieve a higher accuracy, we use the first-order and second-order distortion parameters, K_1 and K_2 to measure the degree of distortion in an image. The lens radial distortion can be written as a formula 1. The radial distortion has been shown in Figure 2.

Decentering distortion is due to a lack of centering of lens elements along the optical axis (Atkinson, 1996). Decentering distortion parameters are invariably coupled with x_0 and y_0. This distortion is usually an order of magnitude or more less than radial distortion. It also varies depending on the focus, but to a much less extent. P_1 and P_2 are the tangential lens distortion, is the displacement of a point the image caused by misalignment of the components of the lens. The projective coupling between P_1 and P_2 and the principal point offsets increases with expanding focal length and can be problematic for long focal length lenses. Therefore, tangential lens distortion has not been considered in this study. The extent of coupling can be diminished through both use of a 3D object point array and the adoption of higher convergence angles for the images.

If the level of lens distortion is known, the image coordinates may be adjusted before the bundle adjustment. This process is known as image refining. Even in case of some distortion, the refining is ineffective, because with non-metric cameras, it changes in time. It is more effective for the image defects to be reduced by introduction of additional parameters into the mathematical instrument:

$$x_i - x_0 + \Delta x_0 = -f\,\frac{m_{11}(X_i - X_0) + m_{12}(Y_i - Y_0) + m_{13}(Z_i - Z_0)}{m_{31}(X_i - X_0) + m_{32}(Y_i - Y_0) + m_{33}(Z_i - Z_0)}$$
$$y_i - y_0 + \Delta y_0 = -f\,\frac{m_{21}(X_i - X_0) + m_{22}(Y_i - Y_0) + m_{23}(Z_i - Z_0)}{m_{31}(X_i - X_0) + m_{32}(Y_i - Y_0) + m_{33}(Z_i - Z_0)} \tag{4}$$

m_{ij} are the elements of the rotation matrix within nine parameters. X_0, Y_0, Z_0 are the coordinates of projection centre. f is the focal distance (c_k) of principle point. Here, the additional parameters, Δx_0 and Δy_0, are functions of some unknowns and perform in adjustment together with the rest of unknowns (Atkinson, 1996).

EXPERIMENTAL STUDY

The Olympus E10 digital DSLR camera contains a 4 megapixel CCD sensor with a format size of 2240 × 1680 pixel with approximately 3.9 µm pixel size. Table 1 shows the technical properties of the camera. In this study, in order to perform a metric calibration of the digital camera, a 3D calibration test field was used. It contained 112 circular coded targets on it. Images were taken from different angles for each focal distance setting by using the calibration field. Thus, 5 images for 9 mm, 5 images for 13 mm, 5 images for 18mm, 5 images for 25 mm and 5 images for 36 mm were shot for the 3D calibration field. It is obvious that by acquiring more images for a scene, better geometrical accuracy can be achieved for projection center and 3D target coordinates. However, in many cases of close range and architectural applications a few numbers of images are available for stereo and convergent orientation. Therefore, lower level of accuracy can be achieved for such cases (on the job calibration).

The bundle adjustment was used to calculate geometrical calibration parameters and distortion parameters photogrammetrically with additional parameters using PICTRAN software package, as shown in Figure 3. Because of the bundle adjustment process, calibration parameters, inner orientation parameters, image shot center coordinates for each image and the corrections of these values were calculated for all focal length settings. 3D coordinates of the coded targets were calculated using geodetic surveying techniques and conventional photogrammetric approach. The coordinates estimated with conventional surveying techniques were

Table 1. Technical specification of Olympus E10.

Geometric resolution (pixel)	Pixel number	Pixel size (μm)	CCD size (mm)	Lens focal (mm)
2240 × 1680	3763200	3.9	8.8 × 6.6	8.8 - 36

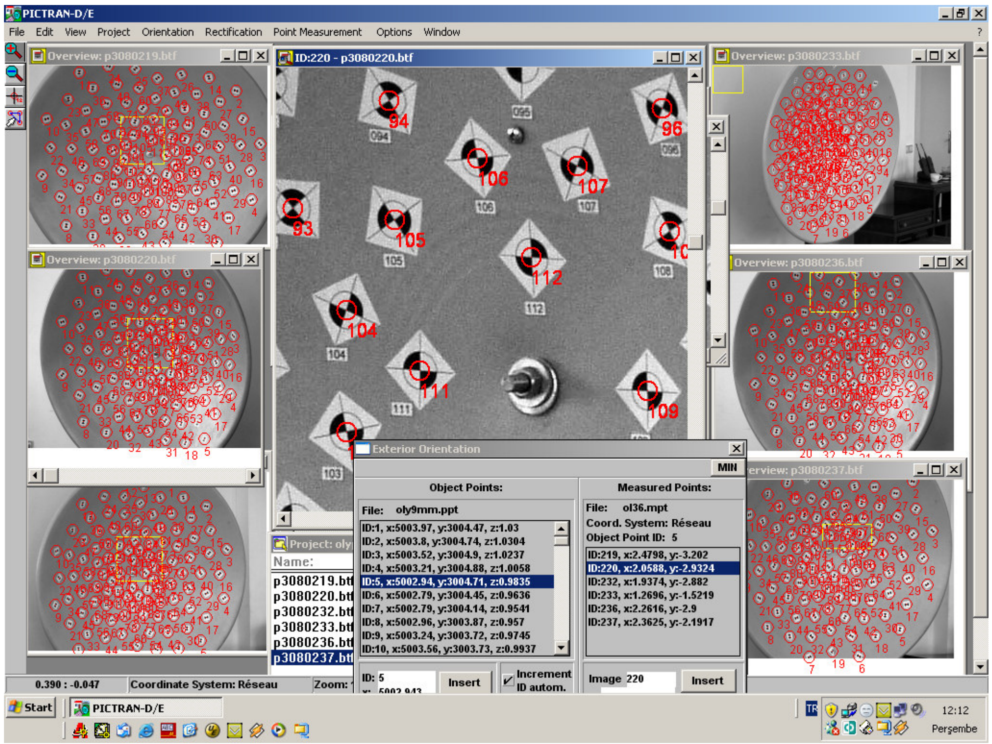


Figure 3. Calibration setup in 3D calibration field.

assumed as the real coordinates, which were produced at ± 0.04 mm accuracy in a real scale. However, the accuracy of the control points have been assumed without errors geome-trically so that the estimated errors of the adjustment have not be dependent the weight matrix of the target points. Bundle adjustment with additional parameters, which is an iterative method, was applied for the all focal distances and, thus, the geometrical calibration and distortion parameters were photogrammetrically estimated. This method provides iterative corrections to the image coordinates. When the iterations are completed, correction terms are minimized. Then, the calibrated values of inner orientation parameters and focal length are calculation

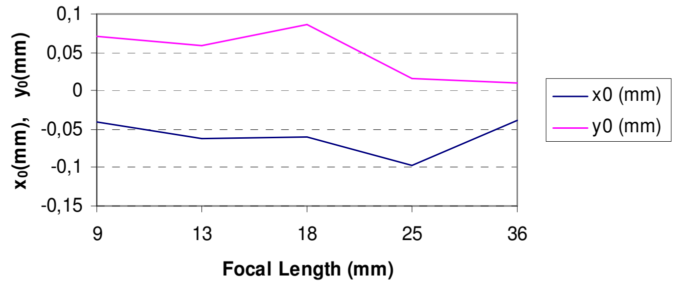
RESULTS AND DISCUSSION

The base point of image coordinate system had to approach zero with the variation of focal length as c_k, after the adjustment process. In this case, the deviation of the base point coordinates was expressed as x_0, y_0 which were shown in sinusoidal behavior with the focal graphic. The other point in the graphic appeared when the extreme points of the graphics were in the focal lengths (c_k) of 18 and 25 mm. In the calibration process of these two focal lengths, the same deviation behavior was also shown in Figures 4a and b.

The deviation of focal length and deviation of base point coordinates for image coordinate system were exa-mined in Figure 4a and b. The Δx_0 and Δy_0 functions were commensuration mathematical models with the same focal distances. This means, the optical radial effects in the image coordinate system were homogenous. These stable effects were formulated by polynomial distortion function.

The parameter of camera calibration, x_0, y_0 and c_k, were calculated with the bundle adjustment correlation. In image coordinate system, the axes of the system were perpendicular to each other. Therefore, the effects of calibration had to coincide to the axes for Δx and Δy derivations. This was shown in Figure 5a and b.

However, the pixel number of the axes was different because of the rectangular sensor dimension. Thus, the total deviation of x_0 and y_0 was different from each other. This means the total radial error of the x and y axes were different values in respect to each other. The radial distortion parameter (K_1) decreased to zero with the increasing focal length in Figure 6a and b, shows this deviation to us. The results of this graphics show us that the longer focal length is, the more accuracy for this focal distance interval is. Therefore, the distortion deviation a



b

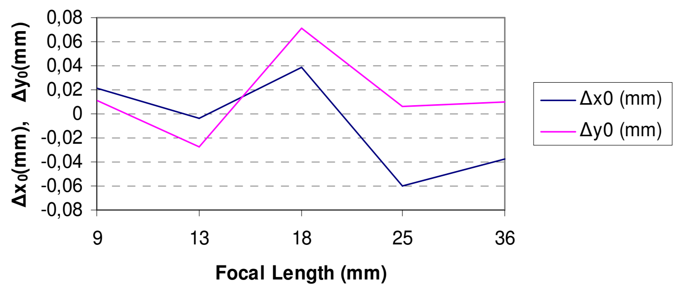
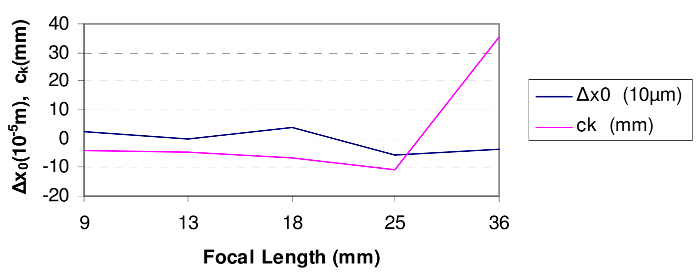


Figure 4. Graphics of x_0,y_0 (a) and x_0,y_0 deviation (b) in calibration process.

a



b

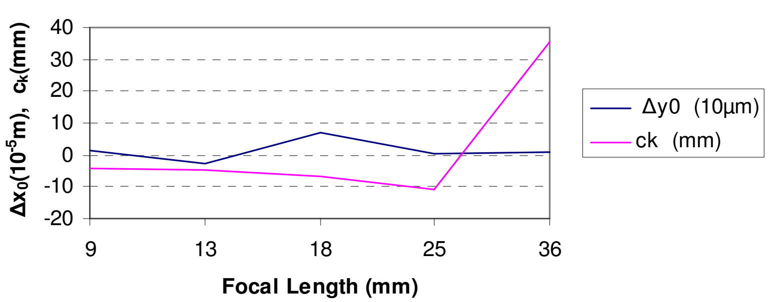


Figure 5. Graphics of x_0 (a) and y_0 deviation with focal length.

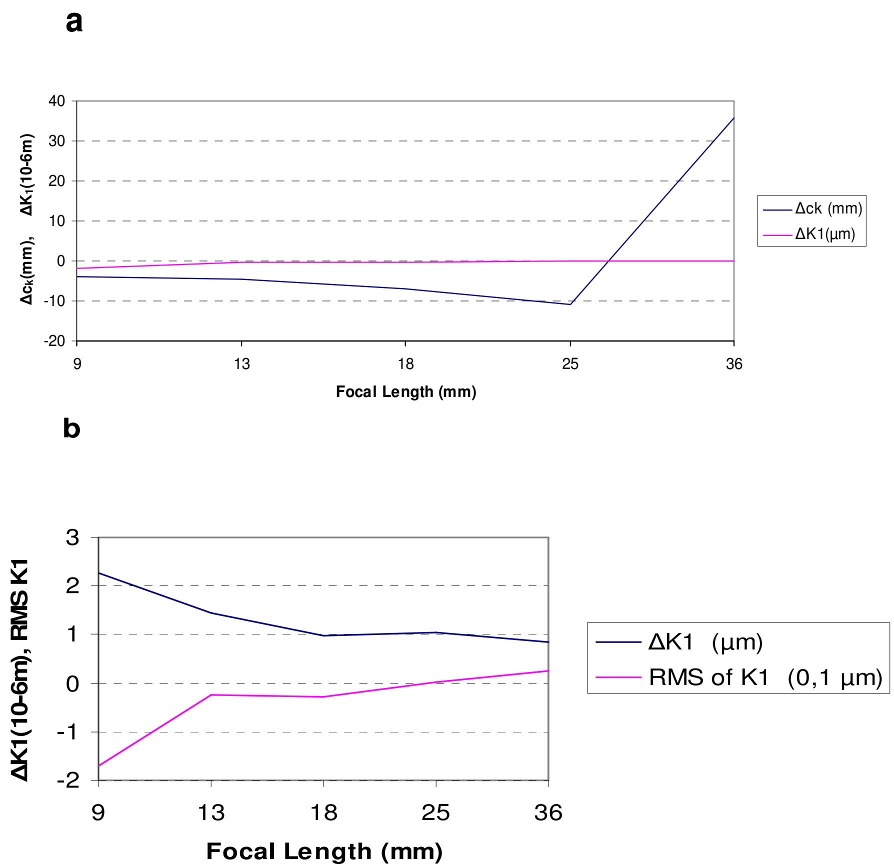


Figure 6. Graphics of c_k deviation (a) and RMS deviation (b) with distortion parameter K_1.

and its accuracy (root mean square) close to zero focal by focal.

CONCLUSION

In this experiment, Δc_k was questioned with minimum and maximum focal distances. The minimum deviation of Δc_k was 4.533 mm and maximum deviation of Δc_k was 7.004 mm. After this designated deviation, the radial distortion deviation was examined within this interval. In this interval, the root means of Δc_k were increased with the focal distance. The fish eye lenses with shorter focal lengths give better radial distortion with the shorter imaging distances. These results point out that the reception is true for also photogrammetric process.

It can also be determined by the effective imaging distance for radial distortion in zooming cameras with the 3D calibration field by means of photogrammetric adjustment. This means, if we can determine the effective imaging distance for zooming cameras, the calibration parameters could be interpolated between maximum and minimum focal lengths. It was directly used in the orientation process without post processing. In the future, the calibration process for the radial lens distortion might be calculated from the distortion function with the zooming lens online in image capturing process without calibration field. For this purposes, first, the new microprocessor might be integrated to the digital camera. Then, the digital camera calibrated in three dimensional calibration fields, might satisfy different focal distances. This microprocessor calculates the distortion function with the information of the zoom and the focal length in digital camera, as being online. This technical prudence could be benefited in the close range photogrammetric applications for architectural and cultural heritage documentation as well.

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