Non-metric Digital Cameras of Zoom-dependent Image Point Refinement

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ABSTRACT: Non-metric digital cameras have recently gained their increasing popularity in photogrammetric applications. To achieve quality performance, the interior camera parameters, among others, are of great concern. Camera calibration is designed to determine interior orientation parameters for effectively refining the image point so that object-to-image correspondence under collinearity property can be well justified. There are, however, some situations where camera calibration, especially for zoom-dependent cameras, is hard or impossible to operate. Therefore, alternative ways of supplying interior orientation parameters must be considered. This study employed correction models, instead of actual calibration, to determine the general interior orientation parameters. The recorded calibrated data sets of the very same camera on different principal distances would serve as database and the parameters of correction models that fit the camera information of metadata to equivalent or nearly equivalent calibration are to be determined. The alternative way of offering image point refinement developed in this study would actually support more photogrammetric mapping tasks that were once considered troublesome to tackle.

1. INTRODUCTION

Non-metric digital cameras with low cost and easily accessible convenience have recently gained their increasing popularity in photogrammetric applications. Yet, the operational instability of interior orientation parameters is of great concern (Läbe and Förstner, 2004). To achieve quality performance, camera calibration is designed to determine interior orientation parameters for effectively refining the image point so that object-to-image correspondence under collinearity property can be well justified. Images may be acquired in some situations where camera calibration, especially for zoom-dependent cameras, is hard or impossible to operate. For a zoom-dependent camera, it is very difficult, if not impossible, to duplicate the principal distance in the camera calibration laboratory as it was used during image acquisition. The principal distance recorded in the header of image can be only regarded as approximate. Therefore, alternative ways of supplying interior orientation parameters with sufficient quality are indeed in demand taking the afore-mentioned conditions into consideration. This study adopted correction models proposed in Fraser and Al-Ajlouni (2006) to determine the general interior orientation parameters when permitted no actual camera calibration. The recorded calibrated data sets of the very same camera on different principal distances would serve as database and the parameters of correction models that fit the camera information of metadata to equivalent or nearly equivalent calibration are to be determined. The applicability of offering image point refinement developed in this study has been demonstrated in this work through the preliminary tests.

2. METHOD

2.1 Image Point Refinement Based on Collinearity Condition

Imaging geometry of perspective projection can be well explained by the collinearity condition where the image point, the perspective center, and the associated object point lie on a same line (Mikhail et al., 2001). However, considering the real imaging scenario where lens distortion, sensing element misalignment. and atmospheric refraction would bent the imaging rays and the original of the photo coordinate system and the principal distance are left to be precisely determined, image point refinement is crucial to a quality image-to-object correspondence. A typical formula commonly applied in photogrammetric image refinement can be seen in Eq.(1) where the principal point offset, the correction s of both radial and decentering lens distortions, and film or sensing element distortion are added to the coordinates of the actual image point, allowing a realization of collinearity property (Wolf and Dewitt, 2000).

$$\begin{cases} \Delta x = -x_0 + \bar{x}(K_1 r^2 + K_2 r^4 + K_3 r^6) + P_1(2\bar{x}^2 + r^2) + 2P_2 \bar{x}\bar{y} + b_1 \bar{x} + b_2 \bar{y} \\ \Delta y = -y_0 + \bar{y}(K_1 r^2 + K_2 r^4 + K_3 r^6) + 2P_1 \bar{x}\bar{y} + P_2(2\bar{y}^2 + r^2) \end{cases} \tag{1}$$

where x_0, y_0 are the principal point offset; $\bar{x} = x - x_0$, $\bar{y} = y - y_0$ with x,y the image coordinates; r is the point distance to the origin; K_1~K_3 are the coefficients of radial distortion, P_1, P_2 are the coefficients of decentering distortion, b_1, b_2 are coefficients of film shrinkage or sensing element distortion. The parameters shown in Eq.(1) together with the principal distance are normally obtained through camera calibration procedures and applied to refine image point coordinates. When the camera calibration is not possible or hard to operate, the alternative way of getting parameters for image point refinement is to refer to the approximate principal distance given in image header and conduct fitting algorithms using the results of those calibrated principal distances, as detailed in the following paragraph.

2.2 Fitting Functions for Interior Orientation and Lens Parameters

The refinement proposed in Fraser and Al-Ajlouni (2006) can be seen in Eq.(2) where only K_1 is considered for radial distortion while neglecting decentering distortion. Eq.(3) requires estimating the coefficients of a_0, a_1 , b_0 , b_1, b_2, b_3 , d_0, and d_1 before f, x_0, y_0 and K_1 can be derived. Based on the mathematical model with separated parameters to linear (or unlinear) of polynomial equations where the effect of K_2, K_3, P_1, P_2 are tiny to ignore them (Fraser and Al-Ajlouni, 2006) can be seen in Eq.(2).

$$\begin{cases} \Delta x = x_a - x_0 + (x - x_0) K_1 r^2 \\ \Delta y = y_a - y_0 + (y - y_0) K_1 r^2 \end{cases} \\ with\ r^2 = (x - x_0)^2 + (y - y_0)^2 \tag{2}$$

$$\begin{cases} f = a_0 + a_1 f_h \\ x_0 = b_0 + b_1 f \ ; \quad y_0 = b_2 + b_3 f \\ K_1 = d_0 + d_1 f^{d_2} \end{cases} \tag{3}$$

where f_h is the principal distance recorded in the header of image; a_0, a_1 are the coefficients of linear model for principal distance; b_0~b_3 the coefficients of linear models of principal point offset; d_0,d_1,d_2 the coefficients of radial distortion model (d_2 is between -3.1 and -0.2). To increase both the flexibility and quality of refinement models, this study has considered K_2, P_1 and P_2 and integrated them into the fitting models and image refinement as shown in Eqs.(4) and (5), respectively.. It is evident that two data of the associated parameter is minimally required to determine the model coefficients.

$$\begin{cases} f = a_0 + a_1 f_h \\ x_0 = b_0 + b_1 f \ \ ; \ \ y_0 = b_2 + b_3 f \\ K_1 = c_0 + c_1 f \ \ ; \ \ K_2 = c_2 + c_3 f \\ P_1 = d_0 + d_1 f \ \ ; \ \ P_2 = d_2 + d_3 f \end{cases} \tag{4}$$

$$\begin{cases} \Delta x = (x - x_0)(K_1 r^2 + K_2 r^4) + P_1(2(x-x_0)^2 + r^2) + 2P_2(x-x_0)(y-y_0) \\ \Delta y = (y - y_0)(K_1 r^2 + K_2 r^4) + P_2(2(y-y_0)^2 + r^2) + 2P_1(x-x_0)(y-y_0) \end{cases} \tag{5}$$

It is quite often to have more than two data for estimating the targeted parameters. Least-squares adjustment can be a well justified tool for parameter estimations. In addition, calibrated parameters are usually associated with their quality, say standard deviations. Therefore, a weighted least-squares adjustment for fitting interior orientation and lens distortion parameters, as modeled in Eqs.(6) and (7), features the significance of this study.

$$A\xi + e = w, e \sim (0, \Sigma = \sigma_0^2 P^{-1}) \tag{6}$$

where A is design matrix whose elements are gained from taking partial derivatives with respect to unknown parameters; ξ is the vector of unknown parameters; e is the vector of observed errors, w is the discrepant vector of observed equations; Σ is the dispersion matrix of observations; σ_0^2 is variance component; $P = \sigma_0^2 \Sigma^{-1}$ is the weight matrix.

Then, the least-squares adjusted parameter vector $\hat{\xi}$, ~~and~~ the residual vector $\tilde{e}$, the a posteriori variance component $\hat{\sigma}_0^2$, and the posterior variance and covariance matrix of parameters $\hat{\Sigma}_{\hat{\xi}}$ can be seen in Eq.(7).

$$\begin{cases} \hat{\xi} = (A^T PA)^{-1}(A^T Pw) \\ \tilde{e} = w - A\hat{\xi} \\ \hat{\sigma}_0^2 = \dfrac{\tilde{e}^T P\tilde{e}}{d.o.f.} \\ \hat{\Sigma}_{\hat{\xi}} = \hat{\sigma}_0^2 (A^T PA)^{-1} \end{cases} \tag{7}$$

2.3 Data validation

Choosing any principal distance in zoom-ring to implement camera calibration and using the correction model to fit all interior orientation parameters. Finally, comparing both of them, by discussing the parameters of the quantity and image point refinement to determine whether the correction models can support this study.

3. EXPERIMETAL EVALUATION

The experiment now uses camera of Nikon D80 at five focal settings (18/24/35/45/55mm) to collect their calibration of images. The I.O model can fit out the 20mm principal distance recorded in the header of image, then compare the interior orientations with camera calibration by Photomodeler. The camera figures shown in Tables 1.

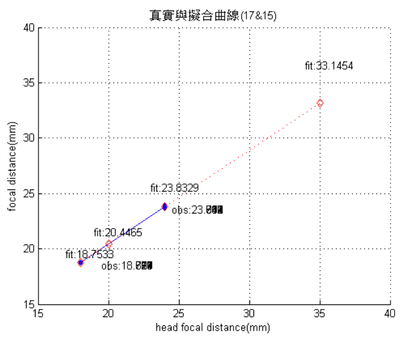
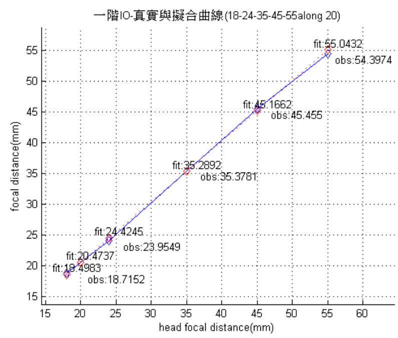
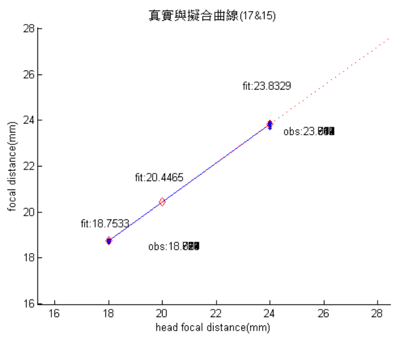
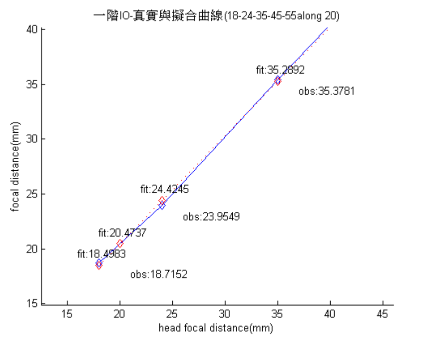
Tables 1. Camera specification of Nikon D80

Camera		Zoom lens	
Sensor pixels	10,750,000pixels	Effective Pixels	10,200,000 pixels
Sensor size	23.6 x 15.8mm	Sensor type	CCD
Maximum Pixels	3872 x 2592		

3.1 Experimental result

Because of data on hand is limited, now discussing two cases, one is using two different principal distances for 18mm and 24mm (sum=31), the other is using five principal distances for 18/24/35/45/55mm (sum=5). By linear indirect observation fitting unknown coefficients of each interior orientation parameters, then give the recorded principal distances in image header (20mm) to obtain all parameters. Shown in Table.2 are two cases of principal distance of fitting result in figures (blue one is ordinal observed values, red one is fitted principal distances).

Tables 2. Two cases of fitting result

	Case1: No.1~31 (18/24mm)	**Case2: No.1~5 (18/24/35/45/55mm)**
Fitting result		
Fitting result (zoom-out)		

The fitting results are shown in Table.3 first row. Assume the second row is most probable value, the averages result of 20mm principal distance calibrations between 2014/07/09 and 07/15 and compare their diff values in third row.

Table.3 Differences between fitting result of linear and practical principal distance

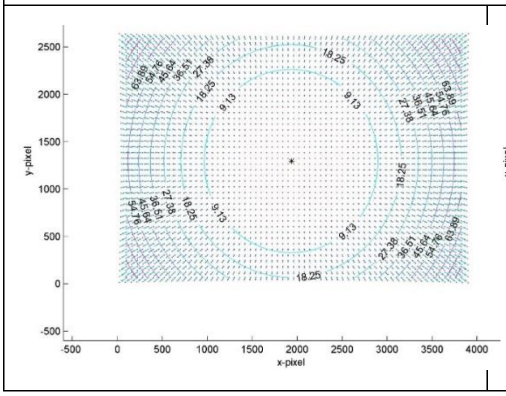
(case1:with 18mm(16)&24mm(15) / case2: with 18(1)&24(1)&35(1)&45(1)&55mm)

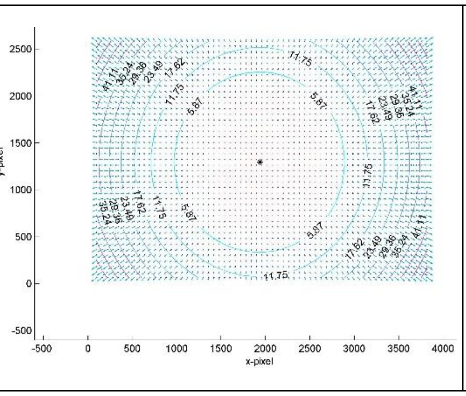
row		Input data	*f*	X_0	Y_0	K_1	K_2	P_1	P_2
i	Coefficient of fitting	Case1: (18/24mm)	20.4465	11.9754	7.9999	2.7272e-04	-2.6710E-07	-8.8628E-06	3.0306E-05
		Case2: (18/24/35/45/55mm)	20.4737	11.9652	7.9958	1.7978e-04	-1.9417e-07	-1.0439e-05	2.3524e-05
ii	Practical interior orientation of average		20.5945	11.9748	8.0098	2.3338E-04	-2.1648E-07	-1.1960E-05	2.8370E-05
iii	Diff values	Case1: (18/24mm)	-0.1480	0.0006	-0.0099	3.9340E-05	-5.0620E-08	3.0972E-06	1.9360E-06
		Case2: (18/24/35/45/55mm)	-0.1208	-0.0096	-0.0140	-5.3600E-05	2.2310E-08	1.5210E-06	-4.8460E-06

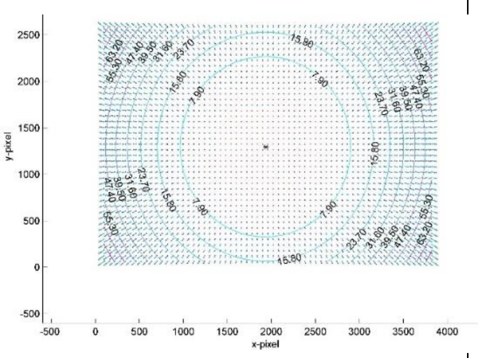
Assume row iii are true value, in Table.3, show both two cases of residuals. Then, the fitting parameters of two cases are not more different from actual average parameters. But between case1 and case2 are not absolute better, maybe could try combine case1 and case2 to observe whether can obtain better results. Shown in Table.4 are using parameters of Table.3 to calculate the image point refinement including the maximum, minimum and mean.

Table.4. Image point refinement of 20mm principal distance with add weight fitting and average actual principal distance (pixels)

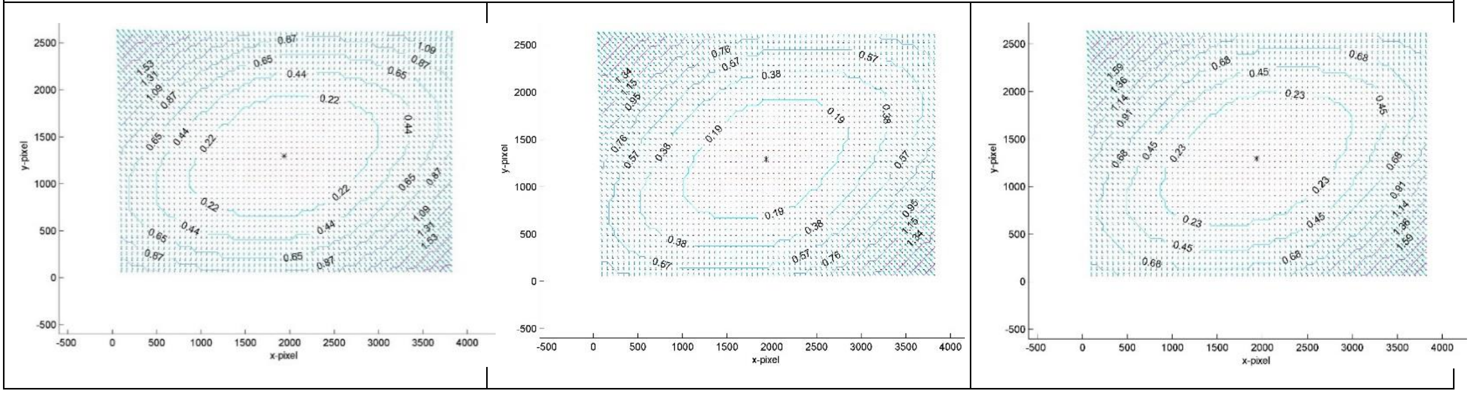
distortion	20mm fitting principal distance of image point refinement by linear **(case1)**		20mm fitting principal distance of image point refinement by linear **(case2)**		20mm average practical principal distance of image point refinement	
radial	dx_rad	dy_rad	dx_rad	dy_rad	dx_rad	dy_rad
min	±0.000474	±0.000492	±0.000358	±0.000359	±0.000386	±0.000377
max	±82.886197	±56.590414	±53.374597	±36.428687	±71.809249	±48.964609
mean	±20.627525	±12.258953	±13.428483	±7.988370	±17.765910	±10.551638
decentering	dx_tan	dy_tan	dx_tan	dy_tan	dx_tan	dy_tan
min	±0.000058	±0.000531	±0.000028	±0.000398	±0.000039	±0.000420
max	±1.539539	±1.825022	±1.465425	±0.000398	±1.719562	±1.813013
mean	±0.278897	±0.536205	±0.27469	±0.416201	±0.318590	±0.501879
Radial distortion						







Decentering distortion



3.3 Analysis Conclusion

This camera' zoom lens original has no 20mm principal distance of setting. If the photogrammetric field is hard to finish calibration by the zoom lens settings, then can use the correction model to recover approximate 20mm principal distance of interior orientation parameters. Shown in Table.3 where the results of fitting parameters that can preliminarily finish initial target and the parameters of case is better than case1. Next, shown in Table.4 of two cases' average refinements, residuals of refinement event are small (about 3~10 pixels), it means the fitting is efficient. Sum of all, case1-single range with more datum and case2-more principal distances with single data, they reflect the parameters aren't absolute better fitting in the same case. Besides, the benefit of decentering distortion is better than radial distortions. If we want to raise their accuracy of the correction model to fit, must consider quadratic or polynomial equation to obtain more nearly equivalent interior orientation parameters.

4. REFERENCES

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