Accuracy Assesment of Non-Metric Digital Camera Calibration in Close Range Photogrammetry

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ABSTRACT

In this paper two cameras have been used to determined the interior orientation parameters (IOP) for each camera. To carry out the calibration, Photomodeler Scanner software was used. The lab calibration process was completely automatic using a calibration grid. The focal length was fixed at narrowest and widest angle and the network includes a total of twelve images with ± 90º roll angles. Each zoom was calibrated for five times. After the software processing, the camera calibration parameter values were obtained.The paper presents the results and the accuracy of this calibration method, Furthermore the overall RMSs obtained from the calibration for both cameras are in micron but calibration cannot be considered as constant or fixed for non-metric cameras, because such cameras have different (IOP) for each capture.

تقيم الدقة للكاميرا الرقمية الغيرمترية المعيرة لاغراض التصوير القريب

الخلاصة

في هذا البحث تم أستخدام كاميرتان غيرمترية لايجاد عناصر التوجيه الداخلي لكل كاميرا. المعايرة تمت بأستخدام برنامج (Photomodeler software) المعايرة المختبرية تمت بصورة أوتماتيكية كاملة بأستخدام نموذج (شبكة) المعايرة . تم تثبيت البعد البؤري على أضيق واوسع زاوية والعمل تضمن أثنا عشر صورة بزاوية دوران ٩٠ درجة . كل بعد بؤري تم تعيرة خمسة مرات ، بعد معالجة البرنامج للصور تم الحصول على قيم عناصر التوجيه الداخلي لكل بعد بؤري . وكذلك تم الحصول على قيم RMS من المعايرة لكلا الكاميرتين كانت بالمايكرون لكن لا نستطيع ان نعتبر المعايرة ثابتة للكاميرا الغير مترية ، بسبب كون ان هذه الكاميرات لها عناصر توجيه داخلي مختلفة في كل لقطة.

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INTRODUCTION

Camera parameters commonly discovered through calibration procedures include the computed principal distance or focal length (c) of the lens, parameters (x_p, y_p), which denote the coordinates of the center of projection of the image (principal point), and lens distortion coefficients (k_1, k_2, k_3, p_1, p_2) where the terms k_i represent coefficients of radial lens distortion and p_i terms represent coefficients of decentring distortion caused by a lack of centering of lens elements. For calibrating the camera, an accurate determination of the interior orientation parameters is needed. For more accurate results, the calibration images should be taken under conditions that are similar to the field samples. The aim of this work is the establishment of an efficient and accurate digital camera calibration method to be used in particular working conditions.

MATHMATICAL MODEL OF DIGITAL CAMERA CALIBRATION

This calibration is based on the method of space resection . It bases on collinearity equation, take image point coordinates as observations, and get to internal and external orientation elements of the camera, distortion factor and other additional parameters. Take account of the correct item, the collinearity equations is:

$$(x - x_0) + \partial x = -c\frac{m_{11}(X-X_L)+m_{12}(Y-Y_L)+m_{13}(Z-Z_L)}{m_{31}(X-X_L)+m_{32}(Y-Y_L)+m_{33}(Z-Z_L)} \quad \ldots (1)$$

$$(y - y_0) + \partial y = -c\frac{m_{21}(X-X_L)+m_{22}(Y-Y_L)+m_{23}(Z-Z_L)}{m_{31}(X-X_L)+m_{32}(Y-Y_L)+m_{33}(Z-Z_L)} \quad \ldots (2)$$

Where

$\partial x, \partial y =$ an additional parameter represent the lens distortion (radial and tangential)

$\delta x = x'(k_o + k_1 r^2 + k_2 r^4 + \ldots) + p_1(r^2 + 2x'^2) + 2p_2 x' y'$

$\delta y = y'(k_o + k_1 r^2 + k_2 r^4 + \ldots) + 2p_2 x' y' + p_2(r^2 + 2y'^2)$

The mathematical model of collinearity equations with addition parameters are:

$$AV + B^e\Delta^e + B^i\Delta^i + B^s\Delta^s + E = 0 \quad \ldots (3)$$

Where A, B^e, B^i, B^s are the coefficient matrices in which

$$A_{2n*2n} = \begin{bmatrix} \partial F(x)/\partial(x,y) \\ \partial F(y)/\partial(x,y) \end{bmatrix} \qquad B^e{}_{2n*6m} = \begin{bmatrix} \partial F(x)/\partial(e.o) \\ \partial F(y)/\partial(e.o) \end{bmatrix}$$

$$B^i{}_{2n*ap} = \begin{bmatrix} \partial F(x)/\partial(AP) \\ \partial F(y)/\partial(AP) \end{bmatrix} \qquad B^s{}_{2n*3n} = \begin{bmatrix} \partial F(x)/\partial(X,Y,Z) \\ \partial F(y)/\partial(X,Y,Z) \end{bmatrix}$$

n=no. of points
m=no. of photo
aP=no. of additional parameters

Due to the form of the central projection equations, matrix A is equal to the identity matrix.

The vectors of alteration Δ, of residuals V, and of discrepancies E are expressed explicitly as [7]:

$$\Delta^{e}_{6m*1} = \begin{bmatrix} d\omega \\ d\varphi \\ d\kappa \\ dX_L \\ dY_L \\ dZ_L \end{bmatrix} \quad ; \quad \Delta^{i}_{ap*1} = \left[d_{AP} \right] \quad ; \quad \Delta^{s}_{3n*1} = \begin{bmatrix} dX \\ dY \\ dZ \end{bmatrix}$$

DESCRIPTION OF DIGITAL CAMERA

The two primary types of digital cameras used in this paper are Nikon (COOLPIX AW100 with resolution16 megapixels), its zoom (5-25) mm and SANYO (E1075, resolution 10 megapixels), with zoom (5.7-17.1) mm. The shapes of these cameras are shown in Figure (1) and (2) respectively, and their main characteristics of these cameras are illustrated as follows in two Tables (1) and (2) respectively.

Figure (1) Nikon Coolpix AW100 [4].

Figure (2) SANYO (E1075) [5].

Table (1) Camera's Main Characteristics (Nikon) [4].

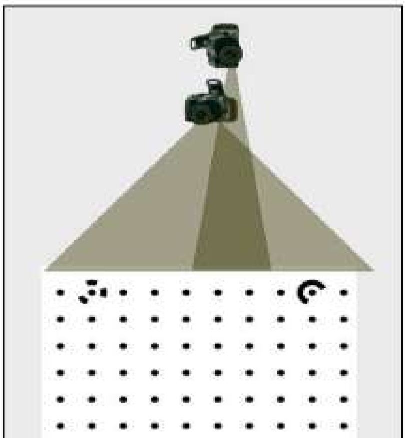
Type	Compact digital camera	
Effective Pixels	Approx. 16 mega pixels	
Image Sensor Size	1/2.3-in.type CMOS :Approx. 16.79 million pixels, (6.4286×4.8214) mm.	
Pixel Size	0.00139 mm;	
Lens Mount	5x optical zoom. Nikkor lens	
Focal Length	(5-25)mm (angle of view equivalent to that of 28-140 mm)	
Recording pixels	(1) Large:	Approx. 16 mega pixels (4608 × 3456)
	(2) Medium:	Approx. 8.00 mega pixels (3264 × 2448)
	(3) Small:	Approx. 3 mega pixels (2048 × 1536)
	(4) RAW:	Approx. 16 mega pixels (4608 × 3456)
Focusing Modes	Focus range (from view) ,focus-area selection	
Focusing range	Approx. 50cm. (1ft-8in.) to ∞ (W); approx. 1m. to∞ (T)	
Shutter Speeds	1/1500sec. to 1secs.	
Depth-of-field preview	Enabled with depth-of-field preview button	
Image type	JPEG	

Table (2) Camera's Main Characteristics (SANYO) [5].

Type	Digital Camera	
Effective Pixels	Approx. 10 mega pixels	
Image Sensor Size	(6.4125x4.8094) mm	
Pixel Size	0.00175mm;	
Lens Mount	3x optical zoom lens	
Recording pixels	(1) Large:	Approx. 10.00 mega pixels (3664 × 2748)
	(2) Medium:	Approx. 5.00 mega pixels (2048 × 1536)
	(3) Small:	Approx. 2.00 mega pixels (1600 × 1200)
	(4) RAW:	Approx. 10.00 mega pixels (3664× 2748)
Focusing Modes	Multi zone –center- selected area	
Shutter Speeds	1/2000sec. to 2secs.	
Depth-of-field preview	99% by LCD	
Image type	JPEG	

DIGITAL CAMERA CALIBRATION

For the most accurate results, the camera must be field calibrated. To field calibrate, simply photograph a special grid (see Figure 3).



Figure(3) Calibration Grid Positions.

The grid can be found in the PhotoModeler Pro 6 folder (typically under program file in the c drive) and should be printed close to the size of the project. PhotoModeler has a special calibration project built-in. A calibration project requires that about 6 and 12 photos of the grid should be taken. For best results, a minimum of two photos should be taken per side, one in a landscape position and the other in a portrait position See Figure (4) and Figure (5) respectively.

Figure (4) Landscape position.

Figure (5) Portrait Position.

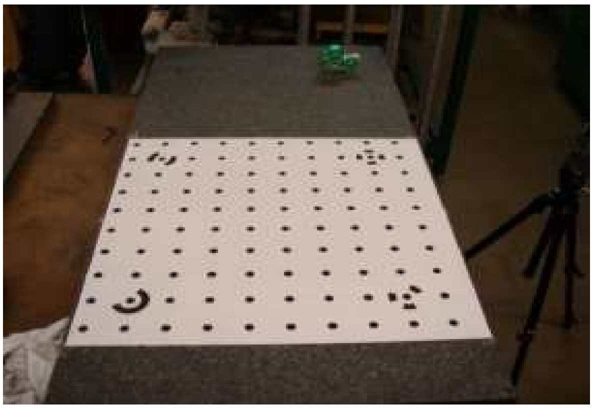


Figure (6) Bad Exposure.

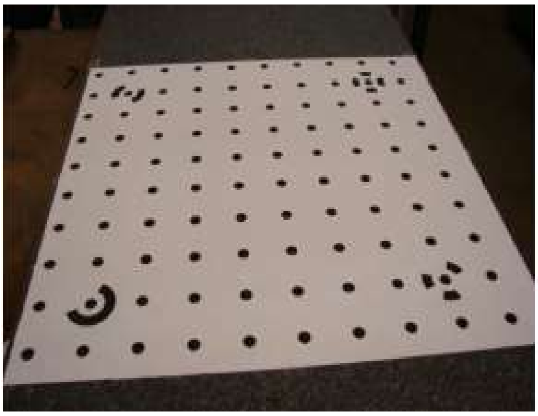


Figure (7) Good Exposure.

For the best results in both calibration and measurement photographs, take a step closer to the object. For example, the good photograph in Figure (7) with the calibration grid and the bad photographinFigure (6) [Photomodeler]. PhotoModeler software to establish the mathematical model of the digital camera, and locating points also calibrating the mathematic model. The image with standard calibration points printed on a piece of paper its size is (21 × 29.7) cm, then place the paper on the flat floor, the camera is fixed on a tripod, taking three photos from each of the four directions.

CALIBRATION AND RESULTS

Twelve images from different locations and different angles for each time are taken. In this study, each zoom is calibrated for five times. The results are illustrated in the following four tables in (3), (4), (5), and (6) respectively.
To ensure the calibration accuracy of the results, the obtained images should at least be full of 80% of the frame [6].

The calibration images should be taken under similar conditions to the lap samples for most accurate results. When using the PhotoModeler software for mathematics, 12 images arranged at regular orientation.

Table (3) Calibration results of main parameters for camera Nikon (CoolpixAW100), with fixed focal length (5mm).

	A1	A2	A3	A4	A5
c(mm)	5.2667±6.5E-4	5.2368±2 E-3	5.2637±8.8E-4	5.2652±5.2E-4	5.2646±5.9E-4
x_P(mm)	3.2665±5E-4	3.2655±1E-3	3.2726±7.7E-4	3.2697±4.5E-4	3.2693±5.5E-4
y_p(mm)	2.4295±6.4E-4	2.4137±2E-3	2.4278±8.5E-4	2.4262±5.1E-4	2.4282±6.5E-4
K1	-2.78E-4±1.9E-5	-7.29E-4±3.6E-5	-1.75E-4±2.9E-5	-1.88E-4±1.9E-5	-2.6E-4±2.3E-5
K2	-2.34E-6±1.2E-6	2.45E-5±2.6E-6	-5.824E-6±1.9E-6	-7.oo7E-6±1.2E-6	-2.929E-6±1.8E-6
K3	0	0	0	0	0
P1	-6.61E-4±6.7E-6	-6.549E-4±1.6E-5	-7.422E-5±1E-5	-6.967E-4±6.2E-6	-7.034E-4±7.3E-6
P2	1.869E-4±8.1E-6	-7.039E-5±2.2E-5	1.35E-4±1.1E-5	8.775E-5±6.7E-6	1.553E-4±8.4E-6
Image coverage (%)	90	88	82	84	88
Overall RMS (pixels)	0.3562	0.5497	0.4756	0.2869	0.3387
Δc(mm)	0.2667	0.2368	0.2637	0.2652	0.2646

Table (4) Calibration results of main parameters for camera, Nikon (CoolpixAW100) with fixed focal length (25mm).

	B1	B2	B3	B4	B5
c(mm)	25.4847±6E-3	25.4028±1 E-3	25.4161±1.4E-2	25.4775±9E-3	25.4492±1E-2
x_P(mm)	3.1725±5E-3	3.1374±1E-3	3.1099±8E-3	3.1354±5E-3	3.1067±5E-3
y_p(mm)	2.4295±6.4E-4	2.4137±2E-3	2.4278±8.5E-4	2.4262±5.1E-4	2.4282±6.5E-4
K1	3.5E-4±1.9E-5	2. 92E-4±3.6E-5	5.55E-5±0	2.9E-4±1.3E-5	2.99E-4±1.5E-5
K2	-2.95E-5±1.6E-6	-2.75E-5±1.6E-6	0	-2.26E-5±9.3E-7	-1.66E-5±1E-6
K3	0	0	0	0	0
P1	0	0	0	0	0
P2	0	0	0	0	0
Image coverage (%)	83	80	80	83	83
Overall RMS (pixels)	0.368	0.333	0.3965	0.3606	0.3663
Δc(mm)	0.4847	0.4028	0.4161	0.4775	0.4492

Table (5) Calibration results of main parameters for camera SANYO (E1075), with fixed focal length (5.7mm).

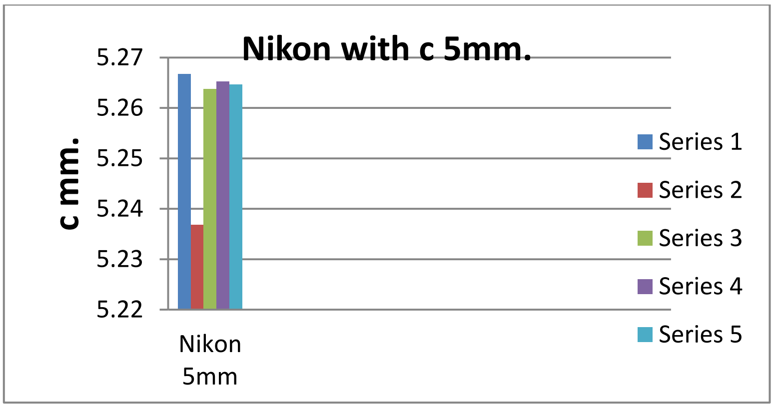
	C1	C2	C3	C4	C5
c(mm)	6.2017±5E-4	6.1929±1 E-3	6.1891±2E-3	6.2060±1E-3	6.2046±1E-3
x_P(mm)	2.9666±5E-4	2.9600±1E-3	2.9762±1E-3	2.9639±1E-3	2.9632±1 E-3
y_p(mm)	2.6588±6.1E-4	2.6768±2E-3	2.6665±2E-3	2.6722±2E-3	2.6484±1E-3
K1	4.22E-3±1.1E-5	4.23E-3±2.5E-5	4.27E-3±2.8E-5	4.26E-3±3.2E-5	4.31E-3±1.6E-5
K2	-3.98E-5±7.5E-7	-4.28E-5±2.3E-6	-5.38E-5±2.1E-6	-4.8E-5±2.6E-6	-5.14E-5±1.2E-6
K3	-5.23E-7±0	0	0	0	0
P1	-2.82E-4±4E-6	-1.69E-4±1.1E-5	-2.64E-4±9.8E-6	-2.09E-4±7.9E-6	-2.47E-4±8.2E-6
P2	4.97E-6±4.3E-6	8.91E-5±1.1E-5	2.2E-5±1.1E-5	6.59E-5±1.3E-5	-4.4E-5±9.6E-6
Image coverage (%)	90	80	87	83	92
Overall RMS (pixels)	0.2041	0.2407	0.2496	0.2375	0.2938
Δc(mm)	0.5017	0.4929	0.4891	0.5060	0.5046

Table (6) Calibration results of main parameters for camera SANYO.

	D1	D2	D3	D4	D5
c(mm)	17.1272±2E-3	17.1270±4E-3	17.2058±2E-3	17.1178±3E-3	17.1285±3E-3
x_P(mm)	3.0101±3E-3	2.9955±8E-3	3.0091±2E-3	2.9822±4E-3	3.0921±5E-3
y_p(mm)	2.7049±4E-3	2.8044±6E-3	2.7024±3E-3	2.7149±6E-3	2.7244±6E-3
K1	2.22E-4±8.1E-6	2.29E-4±1.8E-5	2.46E-4±5.2E-6	2.17E-4±1.9E-6	2.28E-4±1.1E-5
K2	5.68E-6±6.3E-7	5.18E-6±1.2E-6	4.11E-6±3.1E-7	5.66E-6±5.5E-7	3.13E-6±7.3E-7
K3	-5.23E-7±0	0	0	0	0
P1	-1.7E-4±3.6E-6	-1.25E-4±8.8E-6	-1.42E-4±2.8E-6	-1.13E-4±4.6E-6	-1.52E-4±5.1E-6
P2	-9.79E-5±4.1E-6	0	-1.11E-4±2.9E-6	-9.11E-5±5.3E-6	-6.79E-5±5.8E-6
Image coverage (%)	88	86	80	89	89
Overall RMS (pixels)	0.1920	0.4491	0.1280	0.2206	0.2406
Δc(mm)	0.0272	0.0270	0.1058	0.0178	0.0285

In above tables, c is the focal length; **(x_p, y_p)** is the image center coordinates **;(k_1, k_2, k_3)**, **(p_1, p_2)** are the radial distortion and tangential distortion coefficients of the camera lens. According to PhotoModeler tutorial a value of RMS less than 1.0 pixel indicates a good calibration and very good calibrations can have a final total error smaller than 0.4 pixels (Photomodeler). In our cases, the most lab calibrations have a final total error less than 0.4 pixels.

In representing x_p, y_p and c from the previous data obtained by calibrating the readings recorded from cameras with various focal lengths in charts, as illustrated in Figures below.



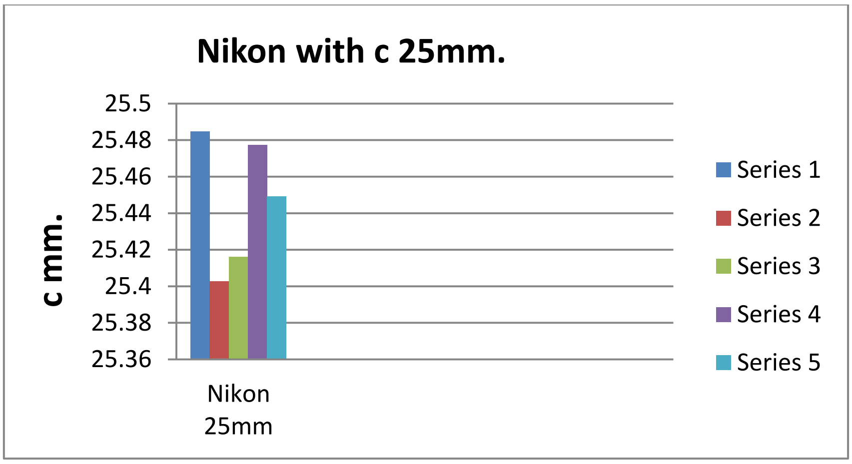
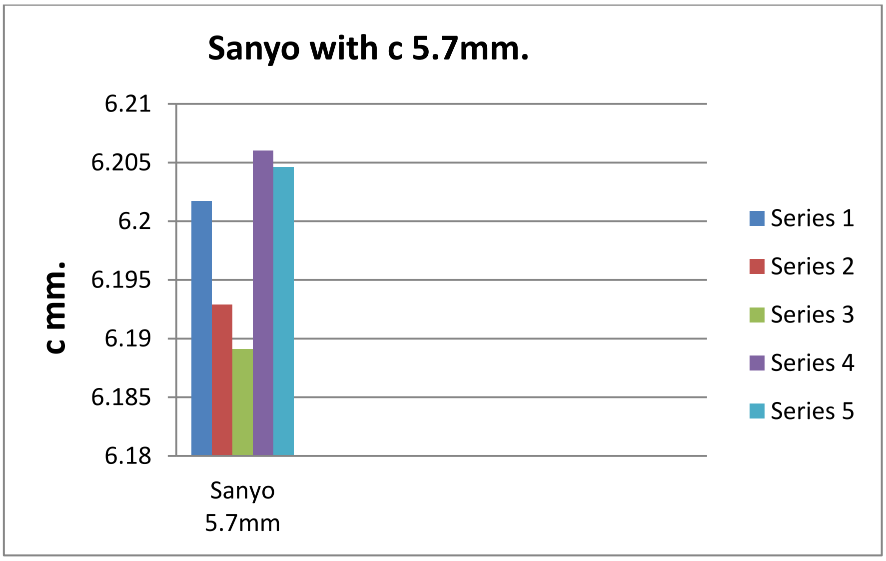


Figure (8) Comparison data of various focal lengths to the Nikon camera.



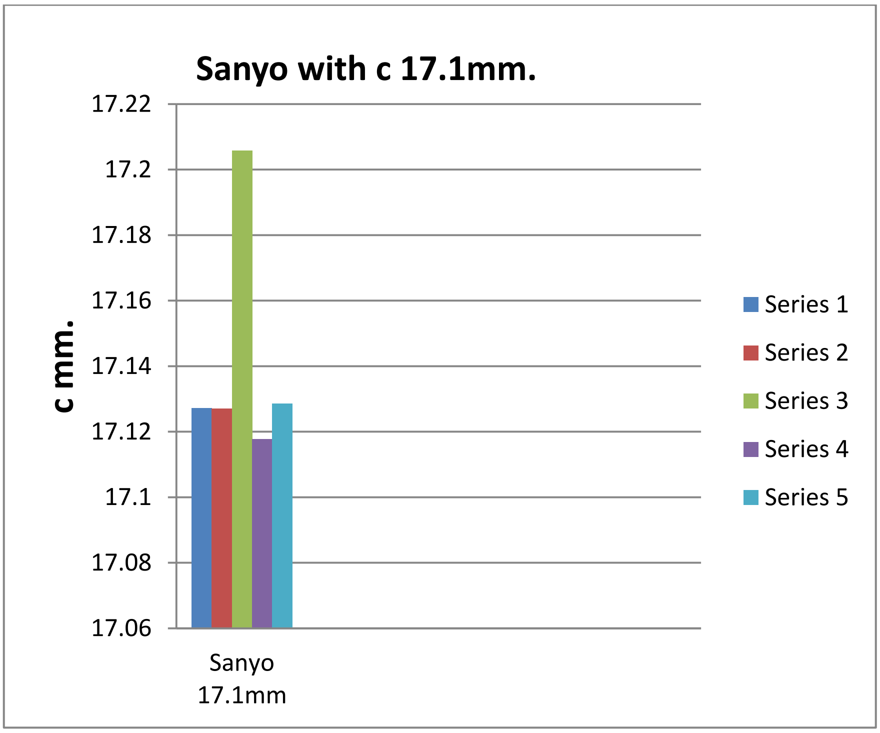


Figure (9) Comparison data of various focal lengths to the Sanyo camera.

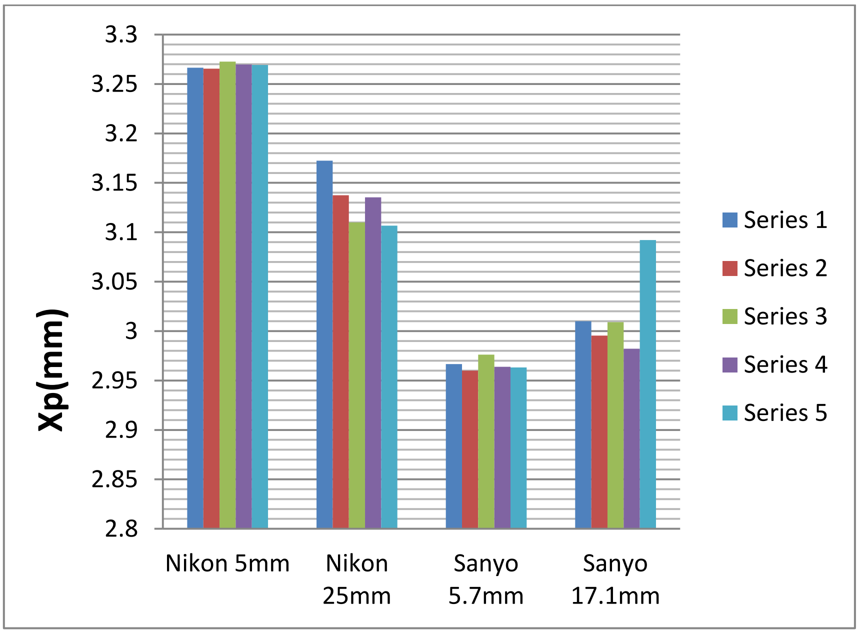


Figure (10) Comparison data of various xp to cameras.

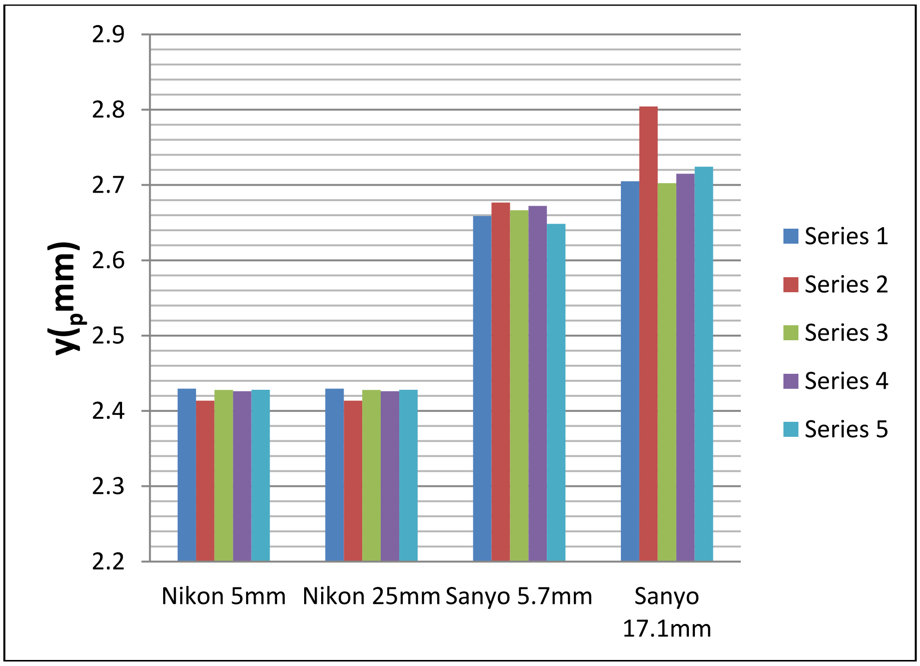


Figure (11) Comparis on data of various yp to cameras.

DISCUSSION

It is obtained that, undoubtedly, there is an error in xp, yp and c about (0.04) mm. observed during each reading with focal length (25 mm.). This error is great compared with the proposed accuracy from photogrammetry. For example, assume an object with distance (25 m.) far away from a camera station, its focal length (25 mm.), we get:

$$\text{Scale} = \frac{25}{25000} = \frac{1}{1000}$$

So, we obtain that an error with 0. 04 mm. = 4 cm.
And there is an error in xp, yp and c about (0.02)mm. observed during each reading with focal length (5 mm), assume the distance (5m.) far away from camera station, its focal length (5mm.) given:

$$\text{Scale} = \frac{5}{5000} = \frac{1}{1000}$$

Therefore, we obtain that an error with 0.02 mm. = 2cm.
Therefore, without any doubt, calibration cannot be considered as constant or fixed for non-metric cameras, because such cameras have different (IOP) for each capture. Then the (IOP) must be evaluated in site for calibration matters.
Any changes in the zoom of focus setting require new camera calibration.

CONCLUSIONS

There is no calibration for non-metric camera, simply because calibration means we have fixed values for (IOP) and they are unchangeable parameters.

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