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THE ACCURACY OF MOBILE PHONE CAMERA INSTEAD OF HIGH RESOLUTION CAMERA IN DIGITAL CLOSE RANGE PHOTOGRAMMETRY

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ABSTRACT

With the rapid development in the resolution of mobile phone cameras and low cost of this mobile phone camera, it is important to determine the possibility of using it in digital close range photogrammetry. The main objective of this research is to evaluate the accuracy of mobile phone camera and comparison with the accuracy of high resolution camera in digital close range photogrammetry. Experimental test has been carried out to study the effect of using the mobile phone cameras on the accuracy instead of high resolution camera. The different three mobile phone cameras and high resolution camera have been used for data acquisition of a test field. The results of the accuracy for different cases are given. The obtained results showed the possibility of using the mobile phone cameras in digital close range photogrammetry application.

Keywords: Digital Close Range Photogrammetry, Mobile Phone Camera, Accuracy, High Resolution Camera.

1. INTRODUCTION

Nowadays, digital close range photogrammetry is most important sciences for data collection and large data storage. Close range photogrammetric science became important and reliable tool for many applications such as architectural photogrammetry, biomedical and bioengineering photogrammetry (biostereometrics) and industrial photogrammetry.

During the last years, the manufacturers of mobile phones, decided to exploit the possibilities of digital technology, and to offer the opportunity of image recording using digital cameras via mobile phones [1]. Already, mobile phone's companies produced mobile phones, with embedded cameras, with resolutions over 13 megapixels (Mp) image format.

This product gives us the opportunity to take photographs of any object we may face at anytime instantaneously. This new facility in the mobile phone generation could enable us to use it in the digital photogrammetric field [10]. To use this tool in close range photogrammetry, first we must find out its accuracy.

In order to examine the potential of three different types of mobile phone cameras and high resolution CCD camera was carried out by the author. An important aspect of the usability of these cameras for photogrammetric purposes is their geometric stability and accuracy. Therefore the interior orientation parameters where determined using an accurately measured test field. Consequently, for evaluating the gadget's accuracy and applicability, their cameras are put to test in everyday close-range photogrammetric applications.

2. CHARACTERISTIC OF EXPERIMENTAL INSTRUMENTS

Three different types of mobile phone cameras and high resolution CCD camera (Nikon D 3100) were used for this research (figure 1). The first mobile phone was a Samsung note III, the second mobile phone was a Samsung S5 and the third mobile phone was a Sony xperia z2 all with built-in cameras. The technical specification for mobile phones cameras used in this research was given in table 1 [6] and the technical specification for Nikon D 3100 camera was given in table 2 [7].

Figure 1: Cameras used in our tests: (a) Samsung Note III, (b) Samsung S5, (c) Sony Xperia Z2, (d) Nikon D 3100

Table (1): Technical Specifications of the Mobile Phones Cameras [6]

properties	Samsung Note III	Samsung S5	Sony xperia z2
Image format	13 MP, 4128 x 3096 pixels,	16 MP, 5312 x 2988 pixels,	20.7 MP, 5248 x 3936 pixels,
Horizontal resolution	72 dpi	72 dpi	72 dpi
vertical resolution	72 dpi	72 dpi	72 dpi
lens	Dual Shot, Simultaneous HD video and image recording, geo-tagging, touch focus, face/smile detection, panorama, HDR	1/2.6" sensor size, 1.12 µm pixel size, Dual Shot, Simultaneous HD video and image recording, geo-tagging, touch focus, face/smile detection, HDR	1/2.3" sensor size, geo-tagging, touch focus, face detection, HDR, panorama
Focal length	4.0 mm	5.0 mm	5.0 mm
Optical zoom	NO	NO	NO
focus	autofocus	autofocus	autofocus
Output format	Only JPEG	Only JPEG	Only JPEG
Flash	LED flash	LED flash	LED flash

Table (2): Technical Specifications of the Nikon D 3100 Camera [7]

Type	Digital single-lens reflex
Sensor	23.1 mm × 15.4 mm Nikon DX format RGB CMOS sensor, 1.5 × FOV crop, 4.94µm pixel size
Maximum resolution	4,608 × 3,072 (14.2 effective megapixels)
Lens	Interchangeable, Nikon F-mount
Flash	Built in Pop-up, Guide number 13m at ISO 100, Standard ISO hotshoe, Compatible with the Nikon Creative Lighting System
Shutter	Electronically-controlled vertical-travel focal-plane shutter
Shutter speed range	30 s to 1/4000 s in 1/2 or 1/3 stops and Bulb, 1/200 s X-sync
Exposure metering	TTL 3D Color Matrix Metering II metering with a 420 pixel RGB sensor
Metering modes	3D Color Matrix Metering II, Center-weighted and Spot
Focus areas	11-area AF system, Multi-CAM 1000 AF Sensor Module
Continuous shooting	3 frame/s
Viewfinder	Optical 0.80x, 95% Pentamirror
ASA/ISO range	100–3200 in 1/3 EV steps, up to 12800 as boost
Flash bracketing	2 or 3 frames in steps of 1/3, 1/2, 2/3, 1 or 2 EV
Rear LCD monitor	3.0-inch 230,000 pixel TFT-LCD
Storage	Secure Digital, SDHC and SDXC compatible

3. DESCRIPTION OF THE TEST FIELD

The photogrammetric test field at the surveying laboratory (Civil Engineering Department, Faculty of Engineering, Kafrelsheikh University, Egypt) was used. The three dimension coordinates of 40 well distributed ground control points (GCP) and check point (CP) with varying heights were measured using a Multi-Station Intersection as shown in figure 2. The Multi-Station Intersection system consists of three Sokkia Reflector less Total Station (SET330RK) and one processing computer unit, which is connected to them. After an initialization step, three operators simultaneously measure the vertical angles and horizontal directions of the targeted point. The system calculates the three dimension coordinates (by Multi-Station intersection) and the precision values in real-time. The average precision values of the ground control points (GCPs) and check point (CP) are ±0.2, ±0.4 and ±0.2 mm for X, Y and Z axes, respectively. The ground control points (GCPs) and check point (CPs) listed in table (3). The cameras settings such as zoom factor, focus, white balance etc. were kept constant during the test procedure.

Figure 2: The 3D Test Field

Table (3): The 3D coordinates of 40 well distributed ground control points (GCP) and check point (CP)

Point	$X_{(m)}$	$Y_{(m)}$	$Z_{(m)}$
1	100.804	103.278	11.060
2	100.755	103.279	10.844
3	100.283	103.280	10.957
4	100.254	103.266	11.220
5	100.000	103.677	11.722
6	99.990	103.689	11.579
7	99.975	103.701	11.406
8	100.162	103.705	11.717
9	100.167	103.709	11.634
10	100.200	103.737	11.367
11	100.198	103.743	11.184
12	100.220	103.742	10.965
13	100.771	103.717	11.342
14	100.741	103.724	11.016
15	100.696	103.731	10.821
16	100.813	103.319	11.478
17	100.672	103.229	11.469
18	100.499	103.206	11.481
19	100.216	103.191	11.510
20	100.822	103.544	11.353

Point	$X_{(m)}$	$Y_{(m)}$	$Z_{(m)}$
21	100.213	103.411	11.418
22	100.744	103.750	11.483
23	100.591	103.726	11.490
24	100.080	103.769	11.538
25	100.281	103.234	11.421
26	100.926	103.657	11.192
27	100.762	103.687	11.181
28	100.607	103.631	11.157
29	100.482	103.659	11.147
30	100.339	103.691	11.136
31	100.224	103.715	11.135
32	100.674	103.357	10.952
33	100.739	103.286	11.163
34	99.985	103.705	11.045
35	100.542	103.692	11.443
36	100.315	103.481	10.882
37	100.834	103.683	11.639
38	100.054	103.649	11.363
39	100.186	103.638	11.531
40	100.682	103.583	11.492

Also, in order to accomplish the maximum accuracy and to have favorable intersection angles, handheld gadgets were set so that the Base-to-Height ratio was equal approximately to 0.25 (where H is the taking distance and B is the base distance between the two gadget stations). Figure 3 shows the handheld gadgets configuration for the camera test procedure [1].

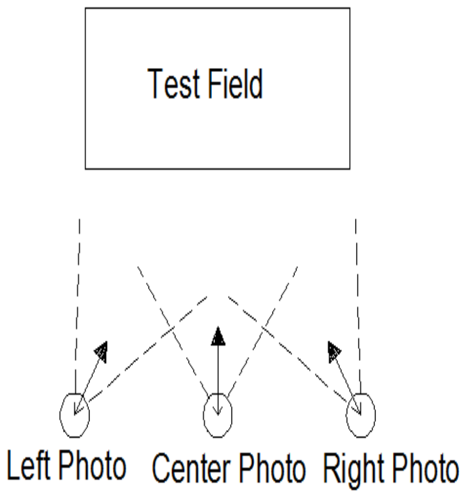

Figure 3: The camera station configuration

4. MATHEMATICAL MODEL

Abdel Aziz and Karara [4] proposed a simple method for close range photogrammetric data reduction with non- metric cameras; it establishes the direct linear transformation (DLT) between the two-dimensional coordinates, and the corresponding object- space coordinates.

The direct linear transformation (DLT) between a point (X, Y, Z) in object space and its corresponding image space coordinates (x, y) can be established by the linear fractional equations:

$$f = x + \Delta x - \frac{L_1 X + L_2 Y + L_3 Z + L_4}{L_9 X + L_{10} Y + L_{11} Z + 1} \qquad (1)$$

$$g = y + \Delta y - \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1}$$

Where:
L_1, L_2 L_3…L_{11} are the transformation parameters
X, Y and Z are the object space coordinates

$$\Delta x = \bar{x}(k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2\bar{x}^2) + 2p_2 \bar{x}\bar{y} \qquad \Delta y = \bar{y}(k_1 r^2 + k_2 r^4 + k_3 r^6) + 2p_1 \bar{x}\bar{y} + 2p_2(r^2 + 2\bar{y}) \qquad (2)$$

Where:
$\bar{x} = x - x_o \qquad \bar{y} = y - y_o \qquad r^2 = (x - x_o)^2 + (y - y_o)^2$

x, y are image coordinates
p_1 and p_2 are two asymmetric parameters for decentring distortion
k_1 , k_2 and k_3 are three symmetric parameters for radial distortion
r is the radial distance from the principal point [2], [3]

Equation 1 results from the equation of the central perspective in a trivial manner; Δx, Δy are systematic deformations of the image, i.e. deviations from the central perspective. Equation 1 can be solved directly for the 11 transformation parameters (L_1, L_2 L_3 …L_{11}) if there are at least six points in the image whose object-space coordinates are known. Equation 1 is rewritten to serve in a least squares formulation relating known control points to image coordinate measurements:

$$v_x = L_1 X + L_2 Y + L_3 Z + L_4 - xX L_9 - xY L_{10} - xZ L_{11} - \Delta x \qquad (3)$$
$$v_y = L_5 X + L_6 Y + L_7 Z + L_8 - yX L_9 - yY L_{10} - y Z L_{11} - \Delta y$$
and $A = = L_9 X + L_{10} Y + L_{11} Z + 1$

The first pair of equations is applied to each photographed point and represents the direct linear relationship between photo coordinates and object space-coordinates. This produces 2n equations for n control points.

The maximum number of unknowns is 16 (L_1 to L_{11}, k_1, k_2, k_3, p_1, p_2). The values of the unknowns will be updated by adding a small correction to each computed value. This means that the adjustments will be performed using the least-squares principle. In this study, the combined least–squares adjustment has been applied to obtain an optimal estimate of both the coordinates and residuals by minimizing the sum of squares of the weighted residuals [11].
Here, the mathematical model has the following form:

$$F_{c,1}(X_{u,1}, L_{n,1}) = 0.00 \qquad (4)$$

Where:
F: denotes the functional relationship between X and L
C: number of all possible independent functions relating the vectors X and L in the model.
U, n: number of unknowns and the observations respectively.

5. LEAST-SQUARES ADJUSTMENT

After linearization, the model will be:

$$B_{c,n} V_{n,1} + A_{c,u} X_{u,1} + W_{c,1} = 0.0 \qquad (5)$$

Where:
B, A are the coefficient matrices
W is the misclosure vector = d – AL
d is a column vector of constants
X vector of unknowns
V vector of residuals
L vector of observations

$$B_{c,n} = \left.\frac{\partial F}{\partial L}\right|_{X_o,L} \qquad A_{c,u} = \left.\frac{\partial F}{\partial X}\right|_{X_o,L}$$

Then the quadratic form to be minimized is expressed in Eqn. 6 [9]

$$\Phi = V^t PV - 2K^t (BV + AX - W) = \text{minimum} \qquad (6)$$

Then the solution of the total system of normal equation is shown in Eqn.7

$$\begin{bmatrix} V \\ K \\ X \end{bmatrix} = \begin{bmatrix} -P & B^t & 0 \\ B & 0 & A \\ 0 & A^t & U \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ W \\ 0 \end{bmatrix} \qquad (7)$$

After (L_1 to L_{11}, k_1, k_2, k_3, p_1, p_2) parameters of each stereo pair of photos become available, it can be computed the object space coordinate (X, Y, Z) of any points appear in each photos of stereo pair, by applying the DLT equations with additional parameters (Equ.2). By rearranging these equations it can be represented in matrices forms (for m photos) as shown bellow.

$$\begin{bmatrix} x_i''^1 L_9^1 - L_1^1 & x_i''^1 L_{10}^1 - L_2^1 & x_i''^1 L_{11}^1 - L_3^1 \\ y_i''^1 L_9^1 - L_5^1 & y_i''^1 L_{10}^1 - L_6^1 & y_i''^1 L_{11}^1 - L_7^1 \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ x_i''^m L_9^m - L_1^m & x_i''^m L_{10}^m - L_2^m & x_i''^m L_{11}^m - L_3^m \\ y_i''^m L_9^m - L_5^m & y_i''^m L_{10}^m - L_6^m & y_i''^m L_{11}^m - L_7^m \end{bmatrix}_{(2m,3)} \times \begin{bmatrix} X_I \\ Y_I \\ Z_I \end{bmatrix}_{(3,1)} = \begin{bmatrix} L_4^1 - \mu_i''^1 \\ L_8^1 - \eta_i''^1 \\ \vdots \\ \vdots \\ L_4^m - \mu_i''^m \\ L_8^m - \eta_i''^m \end{bmatrix}_{(2m,3)} \qquad (8)$$

Where: $\mu = x + \Delta x$, $\eta = y + \Delta y$

6. ASSESSMENT OF ACCURACY

there are two different methods can be used to evaluate accuracy: one can evaluate accuracy by using check measurements and determining from these check measurements the value of appropriate accuracy criteria; and one can use accuracy predictors. In this study, check measurements will be used to evaluate accuracy [5].

In this study, we consider n (i = 1,2...n) check points in the studied object that is points whose true coordinates are known but not used in the photogrammetric computations. Then if X_{it},Y_{it} and Z_{it} are the true coordinates of the check points, and X_{iph},Y_{iph} and Z_{iph} its photogrammetric coordinates, an estimation of the MRXYZ spatial residual is

$$MRXYZ = \sqrt{\frac{1}{n}\sum_{1}^{n}(X_{iph} - X_{it})^2 + (Y_{iph} - X_{it})^2 + (Z_{iph} - Z_{it})^2} \qquad (9)$$

Analogous quantities can be estimated for three axes:

The X- direction: $MRX = \sqrt{\frac{1}{n}\sum_{1}^{n}(X_{iph} - X_{it})^2}$

The Y-direction: $MRY = \sqrt{\frac{1}{n}\sum_{1}^{n}(Y_{iph} - X_{it})^2}$

The Z-direction: $MRZ = \sqrt{\frac{1}{n}\sum_{1}^{n}(Z_{iph} - Z_{it})^2}$

7. RESULTS AND DISCUSSIONS

To study the possibility of use the mobile phone cameras in a close range photogrammetry. Several runs were carried out using Matlab programs, one using high resolution CCD camera and the three others with different types of mobile phone cameras. A Matlab program has been designed for computation of the spatial coordinates (X, Y, Z) of the n checkpoints, the maximum and minimum residual in the X, Y and Z-direction, the maximum and minimum spatial differences among the n checkpoints and the variance-covariance matrix of the parameters [8]. It is to be mentioned that the determinations of the residuals have been carried out for four cases: 1-DLT using Samsung Note III mobile phone camera, 2-DLT using Samsung S5 mobile phone camera, 3-DLT using Sony xperia Z2 mobile phone camera, 4-DLT using high resolution CCD camera (Nikon D 3100). The estimated accuracy and standard deviations (SD) for the space coordinates will also be presented in tabular form. Tables 4 and 5 summarize the obtained results by the iterative least-squares adjustment algorithm described in the previous four cases.

Table (4): Statistics for the obtained 3D coordinate differences associated with different cameras at the used checkpoints (in mm)

(δ X)	Case - 1	Case - 2	Case - 3	Case - 4
max	52.3187	46.6762	31.4921	28.42822
min	8.7652	7.9853	4.0875	3.5321
(δ Y)	Case - 1	Case - 2	Case - 3	Case - 4
max	66.6924	53.7129	36.8164	31.4915
min	18.838	11.7381	6.7204	5.0215
(δ Z)	Case - 1	Case - 2	Case - 3	Case - 4
max	47.5923	42.5276	21.8432	19.4815
min	12.96487	9.6532	3.5632	3.0264
Pos.	Case - 1	Case - 2	Case - 3	Case - 4
max	97.21188	82.899578	53.144379	46.684121
min	24.4905457	17.167769	8.6352664	6.8447271

Case–1: DLT using Samsung Note III mobile phone camera
Case – 2: DLT using Samsung S5 mobile phone camera
Case –3: DLT using Sony xperia Z2 mobile phone camera
Case – 4: DLT using high resolution CCD camera (Nikon D 3100)

Table (5): Statistics for the evaluated standard deviations of the 3D coordinates, as extracted from the evaluated variance-covariance matrix, associated with different cameras.

Std (δ x)mm	Case - 1	Case - 2	Case - 3	Case - 4
max	21.6483484	19.23995789	12.981011	11.71934216
min	4.31109806	4.838806308	2.4767956	2.142051882
Std (δ y)mm	Case - 1	Case - 2	Case - 3	Case - 4
max	66.7423053	55.37155399	37.9524	32.45432861
min	20.0097207	23.15888664	13.258938	9.880410639
Std (δ z)mm	Case - 1	Case - 2	Case - 3	Case - 4
max	33.7712835	31.07503164	15.960489	14.23177093
min	13.0683716	11.00464372	4.0617193	3.454692474

Using insight into Tables 4, 5 some interesting points is noted:
- In the X, Y and Z direction, the best accuracy has been obtained, when case-4 is used (DLT using high resolution CCD camera (Nikon D 3100))
- According to the obtained results, the minimum position error is provided by case-4, when high resolution CCD camera (Nikon D 3100) is used.
- The accuracy of residual in the X, Y and Z-direction in case of using Sony xperia z2 mobile phone camera is much closed from case of using high resolution CCD camera (Nikon D 3100)

Using insight into Table 4 one can notice that, there is an improvement in the standard deviation of the individual point coordinates, when case-3 (DLT using Sony xperia z2 mobile phone camera) and case-4 (DLT using high resolution CCD camera (Nikon D 3100)) are involved in photograph, which is a local measure of improved precision of final resulting point coordinates. From all of the above discussions, it can be seen that case-3 (DLT using Sony xperia z2 mobile phone camera) and case-4 (DLT using high resolution CCD camera (Nikon D 3100)) provides good results for the X, Y and Z coordinates.

To study the influence of increasing the number of ground control points upon the accuracy, the solutions will be repeated, using different numbers of ground control points, starting with nine points and ending up with sixteen by increasing one point at a time. Figure 4 shows the relation between the accuracy and the number of ground control points. From Figure 4 one can notice the followings:

- The accuracy improves with increasing the number of ground control points until the number of ground control points reaches 14 points, and then there is a slight significant improvement upon increasing the ground control points.

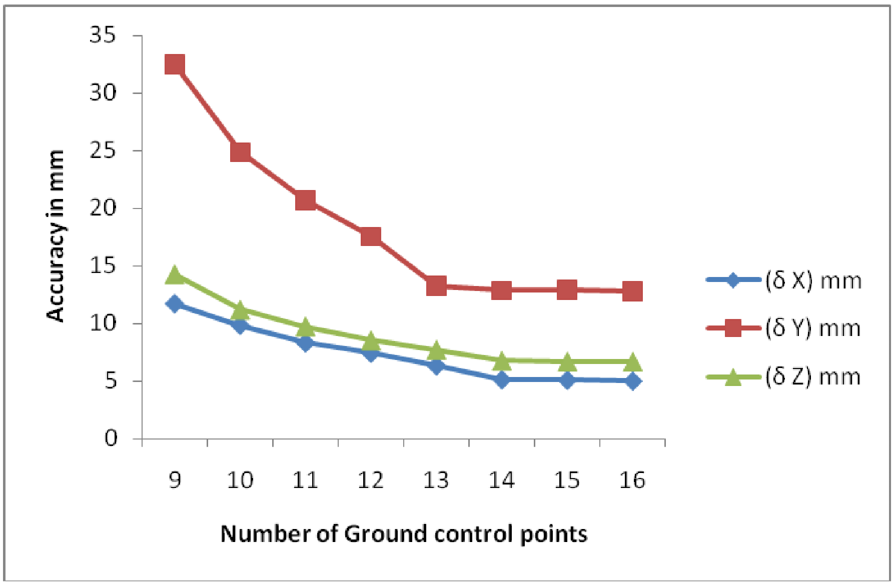

Figure 4: Relation between the accuracy and the number of ground control points

8. CONCLUSIONS

The mobile phone camera has been used and the obtained accuracy is discussed and presented. Without any information about the interior–orientations and distortion–correction parameters, the iterative least–squares adjustment algorithm can be used to solve the nonlinear transformation equations with these parameters as additional unknowns. Based on the experimental results, the following conclusions can be drawn:

- The mobile phone camera is efficient;
- The mobile phone camera has proved to be fast and useful;
- The accuracy of mobile phone camera in digital close range photogrammetry can be given good results in comparison with high resolution camera.
- Whenever the mobile phone camera resolution increases, the photogrammetric coordinates is increased.

Regarding the influence of ground control points upon the obtained results, one can conclude that:

- Control points should surround the object of interest, and should be well distributed as best as possible throughout the object–space.
- The obtained accuracy improved rapidly with increasing the number of control points until control reaches a certain limit, after that there is no significant improvement.

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