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Use of Scanned Aerial Images in Photogrammetric Resection and Intersection

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Abstract: The main objective of this paper is to determine object coordinates of points using digital aerial images by employing co linearity condition equations. The iterative solution was used to solve the co linearity condition equations to determine the exterior orientation parameters of a stereo pair. This was followed by determining the three-dimensional ground space coordinates of check points using photogrammetric measurements. Bahry industrial area was used as a test image. Image coordinates were measured by scanner. The ground coordinates of the same points were determined using real time kinematic GPS. The results were compared with their corresponding computed values using analytical photogrammetric measurements. The three-dimensional ground coordinates of points were used to generate a contour map from a real time GPS and Photogrammetric data. The obtained Root Mean Square error (RMSE) in X, Y, Z coordinates were found to be ±0.562 m, ±0.488 m, and ± 0.629 m, respectively.

Keywords: *Stereo pair, ground points, check points, RTK GPS, interior orientation, exterior orientation, digital photogrammetric work.*

1. INTRODUCTION

In recent years, with the advent of electronic computers and improved photogrammetric equipment and techniques, much needed for control points have been established by photogrammetric methods. This done from only sparse networks of field surveyed ground control points (GCP's). The fundamental photogrammetric problem is the determination of three-dimensional coordinates from overlapping images. Exterior orientation aims to define the position and rotations of the camera at the time of exposure [1].

Space resection is a procedure used to determine the exterior orientation parameters associated with one or more images based on known GCP's. It can be used to determine six exterior orientation parameters, assuming that the interior orientation parameters are available with a least three ground control points in each image. Furthermore, the space intersection is a technique commonly used to calculate the X, Y and Z coordinates of points that are present in the overlapping areas of two or more photographs taking into account the availability of the interior orientation and exterior orientation parameters

The advances in digital photogrammetric work have brought many changes to traditional photogrammetric procedures and products. Although these advances caused exciting changes to the users of photogrammetric work, there is still a role for analytical photogrammetric work to play, particularly in traditional sector mapping and other engineering applications such as mapping, architecture, archeology, etc. Bahry industrial area was used as a test image. Having the photographs in digital image formats availed them in a suitable form for computer manipulation and processing [2].

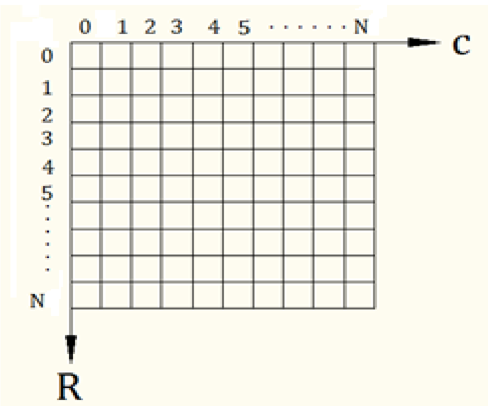
A digital image is a computer compatible pictorial rendition in which the image is divided into a fine grid of picture elements or cells. The image consists of an array of integers, often referred to as brightness values or digital numbers, each quantifying the gray level, or degree of darkness, at a particular pixel. When an output image consisting of many thousands or millions of these pixels is viewed on a computer screen or television, the image looks likes a continuous tone picture. Digital images are produced through a process referred to as discrete sampling. In this process, a small image area (a pixel) is “sensed” to determine the amount of electromagnetic energy given off by the corresponding patch of surface of the object. Discrete sampling of an image has two main features, geometric resolution and radiometric resolution [3].

A digital image is the representation of the scene which has been digitized both in spatial coordinates and brightness. Hence, the image can be considered a matrix whose row and column indices identify a point in the image, while the corresponding digital number of the matrix represents the grey level at that point. The elements of the matrix are usually referred to as image elements or picture elements abbreviated as pixels [4]. Generally, the most convenient method for expressing locations in an image is to use pixel coordinates. In this system, the image is treated as a grid of discrete elements, ordered from top to bottom and left to right, as illustrated in **Fig. 1**. In principle, digital images may be obtained in two different ways. Using analog systems, based on cameras with film and a scanner for digitizing the information stored in the image and digital systems, based on linear sensor arrays capable of storing digital data directly in-flight. That is digital cameras are replacing analog ones.

Scanners are necessary for extracting digital information from analogue imagery. The main use of scanners today is in the digitization of aerial images. Photogrammetric scanners are devices used to convert photographs from an analog form to a digital one.

Image orientation refers to the determination of parameters describing specific photogrammetric models for mapping points, lines and areas from one coordinate system to another one. Thus, image orientation belongs to the class of coordinate transformation problems. Coordinate systems relevant to photogrammetric work is the object, the model, and the image and pixel or stage coordinate system. Orientation procedures play a fundamental role in the object reconstruction process of photogrammetric work.

Photogrammetric orientation models are generally non-linear and usually solved by the least squares approach. In this way, the least squares adjustment can run automatically and a more refined treatment (e.g. robust procedures and re-weighted least squares) can gradually be performed. It is obvious that all methods can start if preliminary values of the unknown parameters are known [5].



where R is the row number and C is the column number

Fig. 1. Pixel Coordinates System

The interior orientation is required for the reconstruction of the bundle of rays. The location of the projection center has to be known in relation to the image points together with the geometric influence of the lens system. The calibration certificate of the camera provided by manufacturers includes the location of the principal point, the focal length and the radial symmetric lens distortion. This is sufficient for the traditional handling of single models because the remaining differences against the mathematical model of perspective geometry are small. The mathematical model of perspective geometry is expressed by the co linearity equations, as follows:

$$x_a = x_0 - f\left[\frac{m_{11}(X_A - X_L) + m_{12}(Y_A - Y_L) + m_{13}(Z_A - Z_L)}{m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)}\right] \quad (1)$$

$$y_a = y_0 - f\left[\frac{m_{21}(X_A - X_L) + m_{22}(Y_A - Y_L) + m_{23}(Z_A - Z_L)}{m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)}\right] \quad (2)$$

where x_a, y_a is image coordinates, f is the camera focal lens, m_{ij} are elements of rotation matrix, X_l, Y_l, Z_l camera location coordinates, and X_A, Y_A, Z_A object space coordinates .

The co linearity condition states that image point, projection center and ground point are located on a straight line [6]. The exterior orientation describes the location and orientation of the bundle of rays in the object coordinate system. There are six parameters to be determined. Namely, the projection center coordinates (X_L, Y_L, and Z_L) and the rotations on the three axes (omega, phi and kappa).

The co-linearity condition, illustrated in **Fig.2**, expresses the basic relationship in which an object point and its image lie on a straight line passing through the perspective centre of a lens. The co linearity equations contain the coordinates of the object point as well as the exterior and interior orientation parameters. Image coordinates of each point are considered as observations.

GPS methodology is often employed for establishing survey coordinates. A GPS brings into play a surveying system that can isolate the position of a point on the earth's surface by making simultaneous observations on several orbiting NAVSTAR navigational satellites. Essentially, an electronic receiver measures the distances between the ground point and a minimum of four satellites. However, the intersection of the divergent rays establishes the spatial coordinates of the observing station. The courses operating satellites are predicted and tracked by the National Geodetic Survey. The anticipated ephemerides (positional) information is broadcast by the satellite. Several continuous tracking stations are scattered throughout the world, charting the paths of the satellites. Both the tracking data and broadcast information are available to the user, with the former providing more accurate data for processing receiver information [7]. **Fig. 3** depicts a point position at the intersection of four satellite ranges. R1 through R4 measured pseudo-ranges between the receiver and satellites.

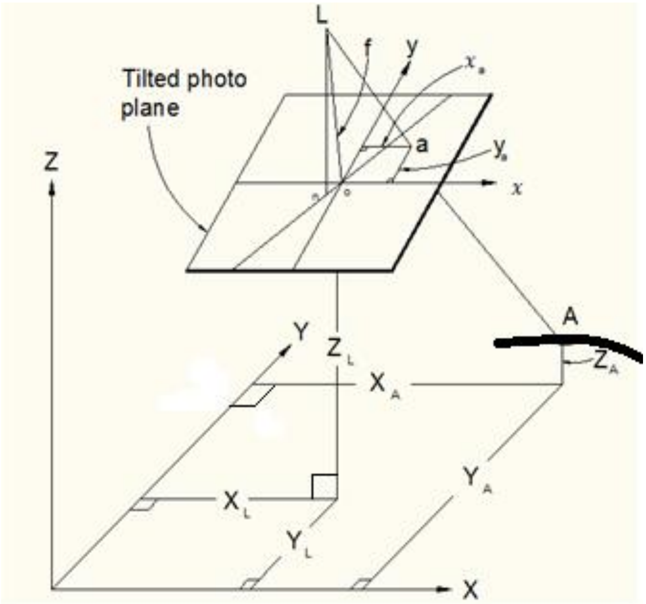


Fig. 2. The Co-linearity Condition

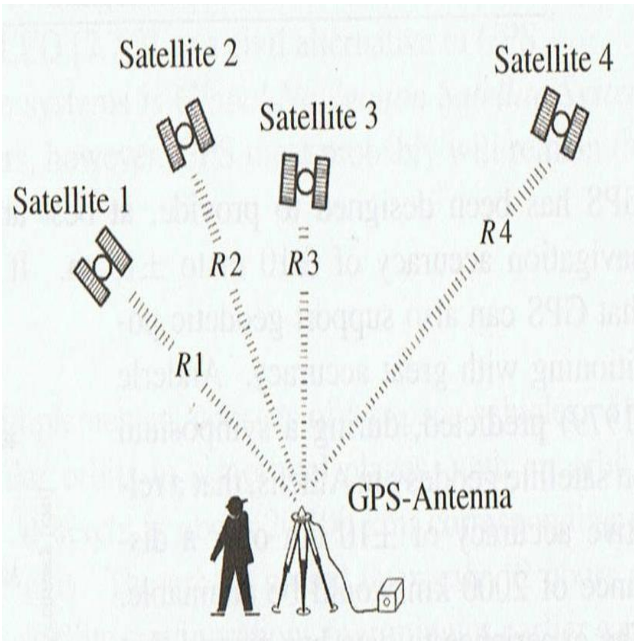


Fig. 3. Resection Satellite Ranges

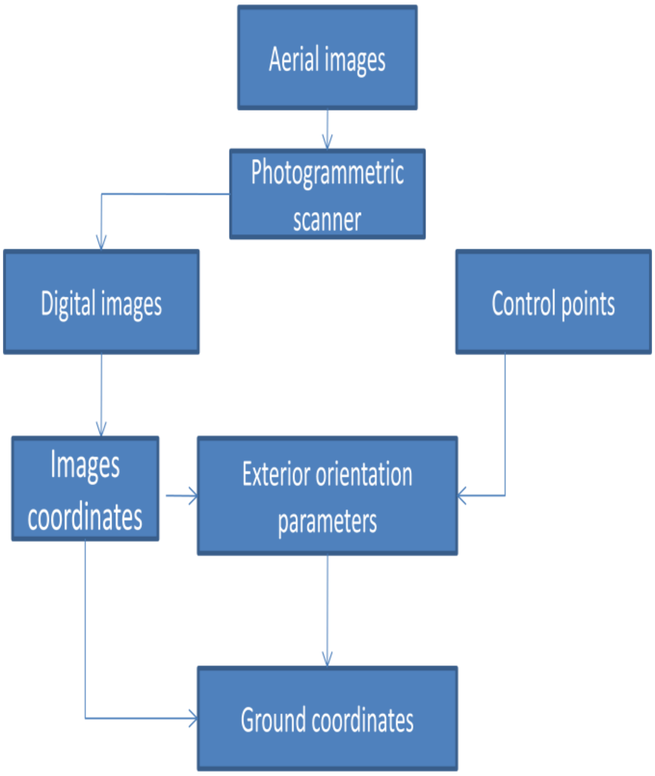


Fig. 4. Flow chart of work

2. METHODOLOGY

The flow chart in **Fig.4** shows the steps carried out in this paper.

Space resection is used to determine the six elements of exterior orientation (ω, ϕ , κ,X_L, Y_L, X_L) of photograph. The linearised forms of the space resection of co linearity equations for a point a are as follows:-

$$B_{11}d\omega + b_{12}d\varphi + b_{13}d\kappa - b_{14}dX_L - b_{15}dY_L - b_{16}dZ_L = J + v_{x_a} \quad (3)$$

$$b_{21}d\omega + b_{22}d\varphi + b_{23}d\kappa - b_{24}dX_L - b_{25}dY_L - b_{26}dZ_L = k + v_{y_a} \quad (4)$$

where, b's are coefficients equal to partial derivatives. dω, dφ, dκ, dX_l, Dy_L, Dz_L are the unknowns, J and K are the functions evaluated at initial approximations.

Two equations are formed for each control point, which gives six equations if the minimum of three control points is used. If four or more control points are used, more than six equations can be formed, allowing a least squares solution.

$$AX = L + V \quad (5)$$

where, A is the matrix containing the partial derivatives with respect to the unknown parameters, including exterior orientation, X is the matrix containing the corrections to the unknown parameters, L is the matrix containing the input observations (i.e., image coordinates and (GCP) coordinates, V is the matrix containing the image coordinate residuals.

The variance component can be determined by the following equation:

$$\hat{\sigma}_0^2 = \sqrt{\frac{(V^T V)}{r}} \quad (6)$$

$\hat{\sigma}_0^2$ is the variance, r is the degree of freedom and equal the number of observation equation minus number of unknowns, or r = m – n.

Standard deviations of the adjusted quantities are:

$$S_{X_i} = \hat{\sigma}_0^2 \sqrt{Q_{X_i X_i}} \quad (7)$$

S_{X_i} is the standard deviation of the ith adjusted quantity, i.e., the quantity in the $Q_{X_i X_i}$ is the element in diagonal of matrix $(A^T A)^{-1}$.

To calculate the coordinates of points by space intersection method, co linearity equations will be used. Co linearity equations of the linearised form can be written for each new point. The only remaining unknowns in these equations are dX_A, dY_A, and dZ_A. These are corrections to be applied to the initial approximations for object space coordinates of ground point A. The linearized forms of the space intersection equations for point a are as follows:-

$$b_{14}dX_A + b_{15}dY_A + b_{16}dZ_A = J + v_{x_a}$$
(3- 4)
$$b_{24}dX_A + b_{25}dY_A + b_{26}dZ_A = k + v_{y_a}$$
(3-5)

The space point will yield four equations, two equations from each photograph. Each space point has a stereo pair, photo

The space point will yield four equations, two equations from each photograph. Each space point has a stereo pair, photo right and photo left. Two equations of this form can be written for point $a_1$of the left photo and two more for point $a_2$of the right photo; hence four equations result, and three unknown dX_A, dY_A, and dZ_A can be computed by using least squares solution. These corrections are added to the initial approximations to obtain revised value for X_A, Y_A, and Z_A. The solution will be repeated further until negligible corrections (0.001mm) are reached.

The matrix equation for calculating residuals, using space resection method, after adjustment is as follows:-

$$\tilde{V} = A\hat{X} - L$$

$$\hat{X} = (A^T PA)^{-1} A^T PL$$
(3-6)

where,
$\tilde{V}$ is the vector of residuals,
A is the coefficient matrix,
$\hat{X}$ is the vector of unknown,
P is the matrix of weights of the observations,
L is the vector of constants.

RMSE is the tool for assessing the accuracy of computed object space coordinates. It is defined as the square root of the average of the squared discrepancies (residuals).

$$RMSE_x = \sqrt{\sum \frac{(X_a - X_c)^2}{n}} \qquad (3\text{-}7)$$

where n =1 to 30.
X_a The actual object space coordinates.
X_c The computed object space coordinates.
n Is the number of total points?
Similarly $RMSE_Y$ and RMSEZ equations can be written.

2.1 Data Collection and Measurement

The data used in this study were collected and processed with in three phases. The first phase deals with the calibrated camera parameters, the aerial digital photographs used and the determinations of the coordinates of ground points to be used in the study. The second phase deal with reading the pixel coordinates of the fiducially marks, the control points, and the check points in the overlap area. The pixel coordinates mentioned above are then transformed to image coordinates. The third phase deals with the determinations of the exterior orientation parameters and the coordinates of the control points.

- The aerial photographs of Bahry town and image strip of overlap area are shown in **Fig. 5**. Aerial photographs of bahry town taken by an aerial camera by a Ziess-turkish company in 2002. The aerial camera is of wide angle type with a focal length of 305.57 millimeters. The coordinate of principal point are (x_0 =0.001mm and y_0 =0.002mm). The pixel size is (0.075X0.075mm) and the ground sample distance (0.4m).
- The coordinates of the ground control points were measured by GPS (The coordinates system was UTM zone 36 north). Six grounds control points are distributed in each photograph. Ground coordinates of points are illustrated in **Fig. 5**. The coordinates of these control points are shown in **Table 1**.

The ground coordinates (check points) of 30 points were measured using GPS RTK. The resulted coordinates are to be compared to the coordinates of the same points computed using photogrammetric methods. The measured coordinates are shown in **Table 2.**

Table 1. RTK-GPS Ground Coordinates of Control Points.

Control number	X (m)	Y (m)	Z (m)
1	451159.714	1729326.079	382.055
2	451687.807	1729465.862	382.005
3	452131.801	1729381.024	381.737
4	452361.372	1729397.641	382.125
5	451565.436	1728640.099	381.870
6	451513.399	1728524.059	382.074
7	451326.569	1728602.384	381.718
8	450990.751	1728548.561	381.949

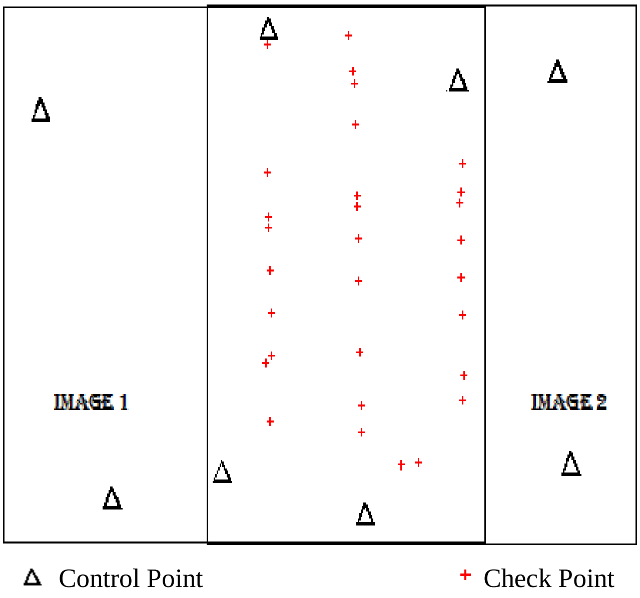


Fig. 5. Locations of ground control points and check points.

Table 2. RTK-GPS Coordinates of Check Points

Point number	$X\ (m)$	$Y\ (m)$	$Z\ (m)$
1	451692.366	1728743.203	381.391
2	451684.054	1728852.495	382.655
3	451696.133	1728866.315	381.668
4	451696.162	1728946.699	381.953
5	451694.189	1729026.480	381.284
6	451690.597	1729105.251	381.176
7	451689.923	1729125.976	381.413
8	451687.611	1729206.324	381.916
9	451688.339	1729445.956	381.644
10	451876.511	1729463.750	382.499
11	451885.378	1729396.206	382.038
12	451888.513	1729374.872	382.192
13	451892.012	1729297.403	382.117
14	451895.264	1729165.328	381.976
15	451895.769	1729145.700	382.076
16	451899.541	1729086.400	382.062
17	451900.491	1729005.900	381.483
18	451901.505	1728872.000	382.163
19	451904.781	1728774.900	381.901
20	451905.259	1728722.900	382.102
21	451999.486	1728665.300	381.836
22	452037.900	1728668.500	381.176
23	452140.752	1728782.700	382.094
24	452143.831	1728829.700	381.758
25	452141.669	1728941.400	381.989
26	452137.956	1729012.500	381.085
27	452138.688	1729081.300	381.093
28	452133.314	1729151.600	381.733
29	452138.744	1729171.600	381.638
30	452142.435	1729223.000	382.158

Table 3. The images coordinate of check points

Point number	First Photograph		Second Photograph	
	$x_1(mm)$	$y_1(mm)$	$x_2(mm)$	$y_2(mm)$
1	10.326	-50.424	-74.329	-51.765
2	9.673	-27.443	-74.92	-28.412
3	12.204	-24.623	-72.28	-25.892
4	12.492	-8.28	-71.937	-9.402
5	13.023	8.624	-71.271	7.758
6	12.787	25.045	-71.414	23.838
7	12.784	29.168	-71.45	27.924
8	12.528	45.62	-71.694	44.455
9	14.426	95.151	-69.439	93.631
10	53.383	97.76	-30.681	96.28
11	55.004	83.665	-29.037	82.298
12	55.232	79.354	-28.889	77.875
13	55.393	63.008	-28.773	61.71
14	55.344	35.911	-28.888	34.683
15	55.348	31.488	-28.89	30.56
16	55.91	19.483	-28.377	18.492
17	55.294	2.626	-29.013	1.59
18	54.94	-25.112	-29.585	-26.294
19	54.566	-44.976	-29.965	-46.077
20	54.424	-55.947	-30.177	-56.802
21	73.53	-68.444	-11.117	-69.809
22	81.729	-68.116	-2.82	-69.63
23	103.724	-45.048	19.078	-46.51
24	104.504	-35.412	20.019	-36.614
25	104.826	-12.356	20.328	-13.263
26	104.629	2.302	20.334	1.243
27	105.181	16.774	20.924	15.553
28	104.722	31.17	20.382	30.143
29	105.506	35.519	21.246	34.378
30	106.999	46.242	22.684	44.845

MATLAB scripts were created execute the following tasks as fellows:-

- Reading the pixel coordinates of the fiducially marks.
- Reading the pixel coordinates of the control points.
- Reading the image coordinates of the 30 points in the overlap area. **Fig. 7** shows the points in the overlap area and their coordinate's shows in **Table 3.**
- Applying least squares to determine the exterior orientation parameters of the photographs using the co-linearity condition equations the result shows in **Table 4.**
- Determining the ground coordinates using space intersection.

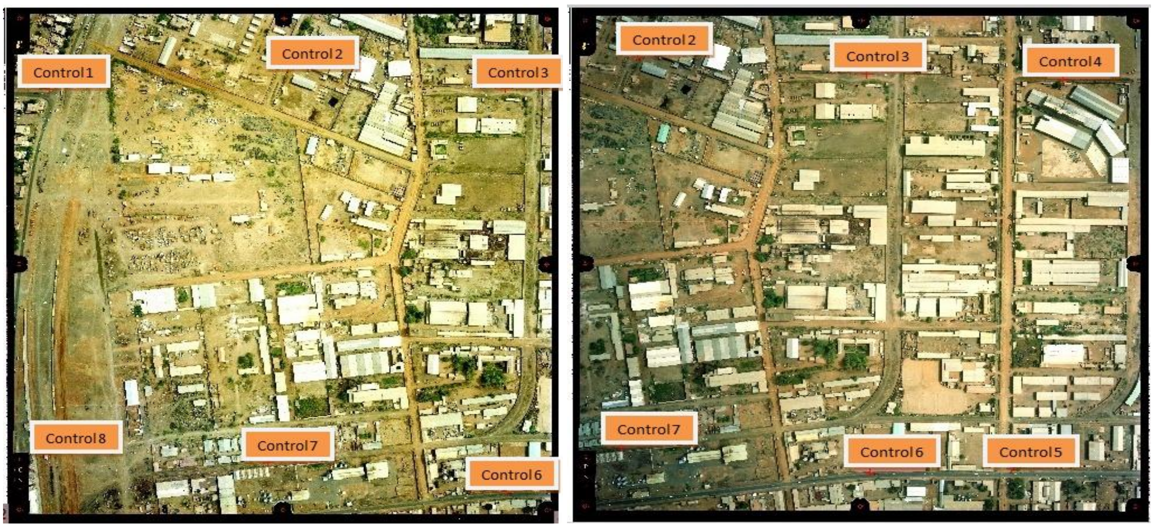


Fig. 6. The Two Images and Control Points

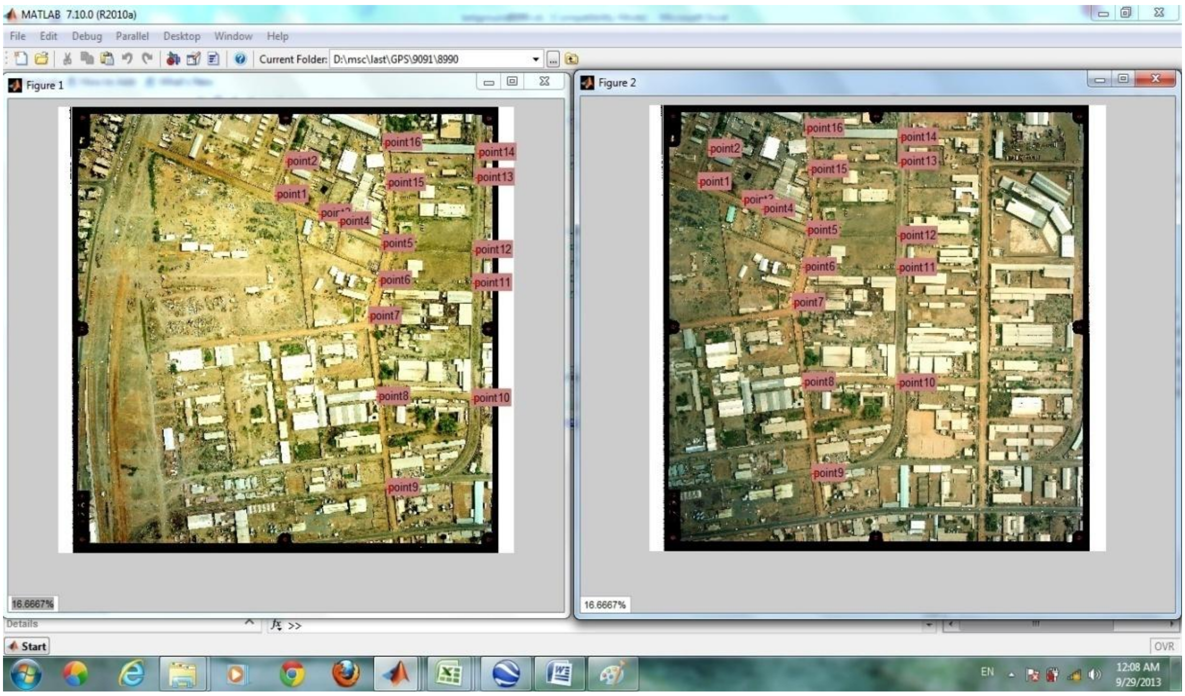


Fig. 7. Reading Image Coordinates in Two Images.

3. RESULTS AND DISCUSSION

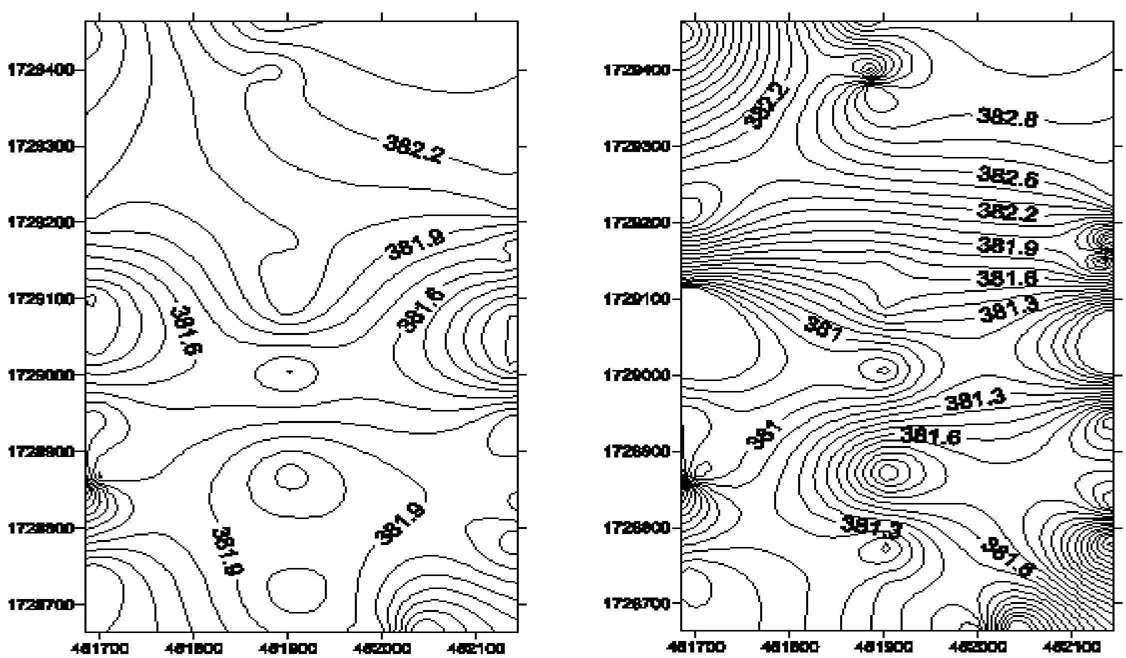
After computing the initial approximations, the exterior orientation parameters were computed from the left image and the right image. The algorithm for exterior orientation parameters were used by applying least square adjustment. This step was followed by a space intersection algorithm to determine the ground coordinates of points. The GPS coordinates of check points were taken as in **Table 2**. The results of photogrammetric surveyed of coordinate of points were shown in **Table 5**.

The difference between computed object coordinates (by photogrammetric techniques) and the RTK GPS coordinates of check points were shown in **Table 6**. The root mean square error between photogrammetric surveyed and GPS of check points in X, Y and Z were ±0.563m, ±0.488m, ±0.629m, respectively.

After determining the object space coordinates a contour map can be generated with $0.1m$ contour intervals. Contours were generated from the GPS coordinates in **Table 2** and the coordinates determined using photogrammetric means in **Table 5**. The contour maps are shown in **Fig. 8. a, b**.

Table 4. The six orientation parameters for the two images

Orientation parameters	Image 1			Image 2		
	Initial Value	Computed Value	Std	Initial Value	Computed Value	Std
Omega(Degree)	0	0.75333	0.0067	0	1.23011366	0.00663
Phi (Degree)	0	-0.25325725	0.00577	0	-0.4309844	0.00624
Kappa (Degree)	2.00338	1.94065782	0.00118	1.67702	1.94321125	0.00113
$X_L(m)$	451638.226	451627.484	0.43126	452037.61	452029.492	0.42837
$Y_L(m)$	1728981.26	1728963.916	0.45714	1729002.227	1728970.977	0.38102
$Z_L(m)$	1485.001	1853.46	0.59891	1474.42	1857.763	0.63411



(a) (b)

Fig 8. (a) a contour map from GPS coordinates, (b) a contour map from a photogrammetric coordinates

4. CONCLUSIONS

Based on the results of the investigations and the statistical analysis carried out in this paper, it is evident that useful geometrical information can be extracted from digital images. The discrepancies, between photogrammetric coordinate values and the GPS coordinate values, shows that the sets of coordinates of the points are close together. The results of the photogrammetric measurements are on average, based on RMSE in X, Y, Z, ± 0.563m, ± 0.488m, and ± 0.629m, respectively.

Nowadays, the uses of digital images and measurements can be used to generate contour maps or orthogonal photographs without any interruption or delay problems. The hardware of analog equipment and analytical plotters can be replaced or/and supplemented by qualified software. Automated acquisition of photogrammetric data guarantees fast and flexible availability of topographical three-dimensional data. We recommend that using the direct linear transformation solution with the iterative solution of co linearity condition equations to compare the results of the two systems. We also recommend that any future research in the field of digital photogrammetric works should use an image matching technique for increasing the accuracy of measuring image coordinates.

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