DIGITAL AEROTRIANGULATION

Mr. Mahmood H. Al-Ani Dr. Hussain Zaydan Ali Miss Fanar Mansour
University of Baghdad m College of Engineering,
Department of Surveying

ABSTRACT

One of the major advantages of digital photogrammetry is the potential to automate production processes efficiently , thus substantially improving the price \ performance ratio for photogrammetric products. The other major advantage of digital photogrammetry is increasing the accuracy of the final output results .

Image processing and computer vision techniques have successfully been employed for facilitating automated procedures in digital aerial images such as interior orientation , relative orientation , point transfer in photogrammetric block triangulation , and the generation of DTM S .

Digital aerotriangulation including image import and image minification , interior orientation , point transfer , control point measurements , bundle block adjustment , which is one of the most complex processes in digital photogrammetry and the automation of this process was one of the challenges in the photogrammetric community in the early nineties .

The goal of this research is building a digital aerotriangulation package that have been implemented on Baghdad University as study area using Pentium III personal computer with Jaderia program that have been written by the researcher herself , to be the first trial of digital aerotriangulation in Baghdad University .

The results of the implemented work was $RMS_X = 8.114m$, $RMS_Y = 8.372m$ & $RMS_Z = 22.785m$, and this is due to a lot of errors that have been faced during the various phases of this work..

الخلاصة

ان واحدة من بين الفوائد الرئيسية للمسح التصويري الرقمي هو امكانية تقليل خطوات الانتاج وبكفاءة عالية ، ولهذا يمكن فعليا تحسين القيمة ومعدل الاداء في نتائج المسح التصويري . كذلك واحدة من الفوائد الرئيسية الأخرى للمسح التصويري الرقمي هو زيادة الدقة في النتائج النهائية للعمل

ان تقنيات المعالجة الصورية (image processing) ورؤية الحاسبة (computer vision) قد طبقت بنجاح لزيادة فعالية خطوات العمل أوتوماتيكيا في الصور الجوية الرقمية مثل التوجيه الداخلي (interior orientation) والتوجيه النسبي (relative orientation) ونقل النقاط (point transfer) في عمليات التثليث الجوي لمنطقة معينة وكذلك في انتاج نمذجة الارتفاعات رقميا (DTM) .

التثليث الجوي الرقمي يشمل عمليات تعليم النقاط بعلامات لتبيان أهميتها والتوجيه الداخلي (interior orientation) وانتقال النقاط (point transfer) وقياسات نقاط الضبط وكذلك عملية تصحيح القياسات بطرق متعددة منها طريقة الأشعة (bundle) والتي تعتبر واحدة من أكثر العمليات تعقيدا في المسح

التصويري الرقمي ، والتقليل من صعوبة هذه العمليات هو واحد من أهم الأهداف التي تسعى اليها مؤسسات المسح التصويري في التسعينات من القرن الماضي .

ان الهدف من هذا البحث هو بناء مجموعة من البرامجيات المتكاملة لعملية التثليث الجوي الرقمي باستخدام حاسبة شخصية نوع (PentiumIII) وبرنامج (Jaderia) والذي تمت كتابته من قبل الباحثة ليكون أول تجربة في التثليث الجوي الرقمي في جامعة بغداد .

KEY WORDS
Digital Photogrammetry : Digital Aerotriangulation

INTRODUCTION

Digital aerial triangulation has been an increasingly interesting topic of research and development in digital photogrammetry for a number of years. The two tasks of measuring the image coordinates of tie points and of computing the orientation parameters, which were well separated in analytical photogrammetry, are more and more being merged into a single process. At the same time a shift of focus concerning the results of aerial triangulation can be observed. While in earlier times point densification was the primary goal, currently the orientation parameters themselves are of growing importance.

Over the last few years various digital aerial triangulation software systems with different degree of automation have been developed and have become commercially available, either as stand-alone packages or as part of a Digital Photogrammetric Workstation. These systems have been introduced into practice, and users have started to report on obtained results.

THE STUDY AREA

Here in this work, two strips of eight aerial photographs having an approximate scale of 1:3000 for part of Baghdad City showing Baghdad University. The block contains 16 full ground control points; with 4 check points **Fig.(1).**

Black and white overlapped aerial photographs are used to generate the ground positions of the tie-pass points, and the specifications of these photographs are shown in **Table (1).**

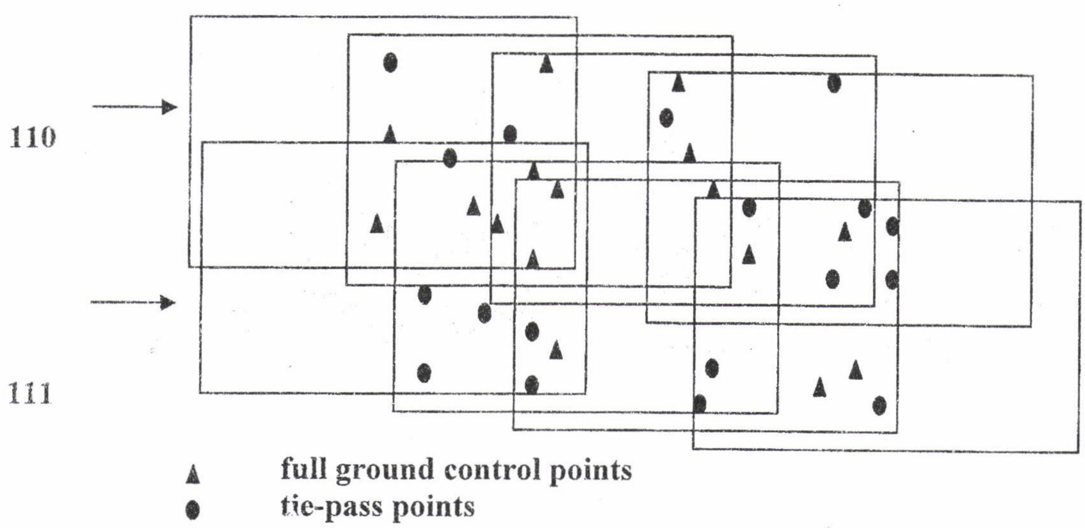

Fig. (1) The Block Under Study

Table (1) Specifications of the used photographs

The study area	Baghdad
Camera type	MRB /15 (W.A.)
No. of strips	2
No. of photos per strip	4
Photo scale	1: 3000
Flying height	456.48 m.
Focal length	152.16 mm.
Forward overlap	60%
Side lap	60%
No. of fiducial marks per photo	4
Format	23 × 23 cm.
Date	July 1985

DIGITAL AERIAL TRIANGULATION STEPS

In an automated production, the digital aerial triangulation in this research is divided into several processing steps, which include, scanning the photographs, measuring the pixel position of each point appears in each photo, using affine transformation to transform the machine into photo coordinates, and finally using bundle block adjustment to compute the ground positions of the tie-pass points [Thomas Kersten, 1999].

Scanning Of The Aerial Photographs:

Eight black-and-white overlapped aerial photographs are used. They are scanned at a resolution of 400 dpi, this gives pixel size of 63.5 μm (corresponding to 0.19 m ground resolution) on a LG Scanner.

A Pentium computer with processor (CPU) 733 MH is used in this work. It has a 128 MB memory and 20 GB hard disk. This computer is supplied with a 3.5 high-density floppy disk and a mouse. A super VGA color display monitor with 640 × 480 pixels is used to display image data on the screen. These kinds of computers are necessary to deal with this kind of work (especially to increase the speed of matching techniques).

Measurements Of The Scanner Coordinates Using Matching Techniques:

The measurements of the scanner coordinates on digital images is done using digital stereo image matching package, and this is done after the photos being digital and stored on the hard disk of the computer.

The major steps in this scheme that used in this research are listed below:

1- Edge detection for both images to generate a binary valued image from a detailed one containing the boundaries of the scenes or objects within the original image. The original (left) image f (x, y) undergoes a gray scale edge enhancement by linear or non-linear processing to produce the right image field g (x,y) with accentuated spatial brightness changes. Next a threshold operation is performed to determine the pixel location of significant edges.

2- Find the most interest points to be matched from the output of step 1. For the highest level (n), interest points are extracted. The edge map, which is a binary image, can be used to extract the interest points. The interest points' extraction depends on the information content within each window, which is measured by calculating the number of edge pixels within the window.

3- Cross-correlation between the left & right photos using cross-correlation factor > 0.98 depending on the pixel locations resulted from step 2. The cross-correlation measure between a template (T) and the search region at location (u,v) can be implemented as follows:

$$R(u,v)=\sum_{x}\sum_{y} S(x,y)\,T(x+u,y+v) \quad (1)$$

The correlation function given in eq. (1), although simple in nature, has the drawback that it is sensitive to such changes in amplitude of $S(x,y)$ and $T(x,y)$. Even though cross-correlation is an accurate method to find the similarity of two windows; it tends to fail in case of scaling and rotation, if the rotation angle is relatively large [Mohamed A. Naji, 1994].

Transformation Of Digitizing System To Image System:

To transform the points locations from the digitizing system (column & row) to the aerial image system (x & y), the two-dimensional Affine coordinate transformation has been used. The term two-dimensional means that the coordinate systems lie on plane surface [Fadhil H. Abdul-Rudah,1999].

In the case of this work the (XY) comparator coordinates system was represented by the digitizing system (column & row) (computer screen system). While the image system was represented by the (xy) digital aerial image system. The control points that used to solve this transformation were the classical four fiducial marks.

The system of equations that obtained from applying the least squares method to equations (2) & (3)

$x = a_1 + a_2X + a_3Y$.......(2)

$y = b_1 + b_2X + b_3Y$.......(3)

which named as the observation equations, can be expressed in matrix form as follows:

$$A \cdot X = L + V \text{ ....(4)}$$

where:

$$A_{8*6}=\begin{bmatrix}1 & X_1 & Y_1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & X_1 & Y_1\\ 1 & X_2 & Y_2 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & X_2 & Y_2\\ 1 & X_3 & Y_3 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & X_3 & Y_3\\ 1 & X_4 & Y_4 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & X_4 & Y_4\end{bmatrix} \quad X_{6*1}=\begin{bmatrix}a_1\\ a_2\\ a_3\\ b_1\\ b_2\\ b_3\end{bmatrix} \quad L_{8*1}=\begin{bmatrix}x_1\\ y_1\\ x_2\\ y_2\\ x_3\\ y_3\\ x_4\\ y_4\end{bmatrix} \quad V_{8*1}=\begin{bmatrix}v_{x_1}\\ v_{y_1}\\ v_{x_2}\\ v_{y_2}\\ v_{x_3}\\ v_{y_3}\\ v_{x_4}\\ v_{y_4}\end{bmatrix}$$

The Approximate Values

The bundle adjustment needs as starting values approximate values of the orientation parameters of all photographs and of the unknown coordinates of all terrain (tie-pass) points. If good approximate values of the orientation parameters are available, they should be supplied to the program. Starting from such values, only one iteration of the adjustment will be needed [G.H.Schut, 1980].

A space resection of the scanned photograph using available ground control and the corresponding photo coordinates is used to compute the approximate values of the elements of the exterior orientation. These elements are the spatial coordinates of the projection center (X_L, Y_L, Z_L) and the three rotation angles (ω, ϕ, χ) [Shaker Farhan Ahmed,1999]. The resulting photo coordinates of the control points together with the corresponding ground coordinates are used to solve space resection problem.

The linearized forms of the space resection collinearity equations are [Wolf, Paul R., 1982]

$$v_x = b_{11}d\omega + b_{12}d\phi + b_{13}d\chi - b_{14}dX_L - b_{15}dY_L - b_{16}dZ_{L+J} \quad (5)$$

$$v_y = b_{21}d\omega + b_{22}d\phi + b_{23}d\chi - b_{24}dX_L - b_{25}dY_L - b_{26}dZ_L + K \quad (6)$$

where:

v_x & v_y	residual errors in measured *x&y* image coordinates
$d\omega, d\phi, \& d\chi$	corrections to initial approximations for the orientation angles of the photo
$dX_L, dY_L, \& dZ_L$	corrections to initial approximations for the exposure station coordinates

The collinearity equations can be used to determine the approximate values of the $X, Y,$ and Z ground coordinates of the tie-pass points whose images appear in the overlap area of a stereo pair of vertical photos. This procedure is called space intersection. Space intersection requires that the six elements of exterior orientation for the two overlapping vertical photos be known. The linearized forms of the space intersection equations for point E are [Wolf, Paul R., 1982]:

$$v_{x_e} = b_{14}dX_E + b_{15}dY_E + b_{16}dZ_E + J \quad (7)$$

$$v_{y_e} = b_{24}dX_E + b_{25}dY_E + b_{26}dZ_E + K \quad (8)$$

where:

v_{x_e} & v_{y_e}	residual errors in measured x & y image coordinates of point e
$dX_E, dY_E, \& dZ_E$	corrections to initial values of the object space coordinates of the point E

Applying The Least Squares Adjustment (Bundle Method) Of TheCase Study

A simultaneous least squares adjustment of all the measurements in a photogrammetric mapping problem can be formulated by the use of condition and observation equations. In the case of digital aerotriangulation, the basic measurements include:(1) the photo coordinates of the relevant image points on the photographs; (2) the ground coordinates of at least three control points; and (3) auxiliary data on the exterior orientation of the photographs. The purpose of the least squares adjustment is then to determine the most probable solution for the ground coordinates of all the unknown points and the exterior orientation parameters of all the photographs [Salama C.C., 1980]. The bundle method projective relationship between the ground space coordinates of a point and the image plane coordinates can be derived from a re-arrangement of the general math model:

$$x = -f\left[\frac{m_{11}(X - X_L) + m_{12}(Y - Y_L) + m_{13}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)}\right] \quad ...(9)$$

$$y = -f\left[\frac{m_{21}(X - X_L) + m_{22}(Y - Y_L) + m_{23}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)}\right] \quad ...(10)$$

For each image point measured on the eight photographs of this block that consists of two strips (110,111), one pair of equations like the above can be written. A typical bundle triangulation solution solves for the exposure parameters and unknown ground coordinates.
The observation equations for photo coordinates will be [Salama C.C., 1980]:

$$V_{ij} + \overset{e}{B}_{ij} \overset{e}{\Delta}_i + \overset{s}{B}_{ij} \overset{s}{\Delta}_j + E_{ij} = 0 \qquad (11)$$

for j=points in the object space=1,n, where n equal to no. of points that appear in each photo which differs from photo to photo. i= no. of photos, in this case i=1,8

Where:

$$V_{ij} = \begin{bmatrix} V_{1j} \\ V_{2j} \\ . \\ . \\ V_{8j} \end{bmatrix} \qquad \overset{e}{B}_{ij} = \begin{bmatrix} \overset{e}{B}_{ij} & & & 0 \\ & \overset{e}{B}_{2j} & & \\ & & \ddots & \\ 0 & & & \overset{e}{B}_{8j} \end{bmatrix} \qquad \overset{s}{B}_{ij} = \begin{bmatrix} \overset{s}{B}_{1j} \\ \overset{s}{B}_{2j} \\ . \\ . \\ \overset{s}{B}_{8j} \end{bmatrix}$$

$$\overset{e}{\Delta}_i = \begin{bmatrix} \overset{e}{\Delta}_1 \\ \overset{e}{\Delta}_2 \\ . \\ . \\ \overset{e}{\Delta}_8 \end{bmatrix} \qquad \overset{s}{\Delta}_j = \begin{bmatrix} \overset{s}{\Delta}_1 \\ \overset{s}{\Delta}_2 \\ . \\ . \\ \overset{s}{\Delta}_n \end{bmatrix} \qquad E_{ij} = \begin{bmatrix} E_{1j} \\ E_{2j} \\ . \\ . \\ E_{8j} \end{bmatrix}$$

The observation equations for exterior orientation parameters will be: -

$$\overset{e}{V}_{i} - \overset{e}{\Delta}_{i} + \overset{e}{E}_{i} = 0 \qquad (12)$$

Where

$$\overset{e}{V}_{i} = \begin{bmatrix} \overset{e}{V}_{1} \\ \overset{e}{V}_{2} \\ \cdot \\ \cdot \\ \overset{e}{V}_{8} \end{bmatrix} \qquad \overset{e}{E}_{i} = \begin{bmatrix} \overset{e}{E}_{1} \\ \overset{e}{E}_{2} \\ \cdot \\ \cdot \\ \overset{e}{E}_{8} \end{bmatrix}$$

The observation equations for survey coordinates will be:

$$\overset{s}{V}_{j} - \overset{s}{\Delta}_{j} + \overset{s}{E}_{j} = 0 \qquad (13)$$

where

$$\overset{s}{V}_{j} = \begin{bmatrix} \overset{s}{V}_{1} \\ \overset{s}{V}_{2} \\ \cdot \\ \cdot \\ \overset{s}{V}_{n} \end{bmatrix} \qquad \overset{s}{\Delta}_{j} = \begin{bmatrix} \overset{s}{\Delta}_{1} \\ \overset{s}{\Delta}_{2} \\ \cdot \\ \cdot \\ \overset{s}{\Delta}_{n} \end{bmatrix} \qquad \overset{s}{E}_{j} = \begin{bmatrix} \overset{s}{E}_{1} \\ \overset{s}{E}_{2} \\ \cdot \\ \cdot \\ \overset{s}{E}_{n} \end{bmatrix}$$

The collection of all observation equations mentioned above will be :

$$\overline{V} + \overline{B}\,\overline{\Delta} + \overline{E} = 0 \qquad (14)$$

where

$$\bar{V}=\begin{bmatrix} V_{ij} \\ {}^{e}V_{i} \\ {}^{s}V_{j} \end{bmatrix} \qquad \bar{B}=\begin{bmatrix} {}^{e}B_{ij} & {}^{s}B_{ij} \\ -I & 0 \\ 0 & -I \end{bmatrix} \qquad \bar{\Delta}=\begin{bmatrix} {}^{e}\Delta_{i} \\ {}^{s}\Delta_{j} \end{bmatrix} \qquad \bar{E}=\begin{bmatrix} E_{ij} \\ {}^{e}E_{i} \\ {}^{s}E_{j} \end{bmatrix}$$

The normal equations for the case study are:

$$\bar{B}^{T}\overline{WB\Delta}+\bar{B}^{T}\overline{WE}=0 \qquad (15)$$

or

$$\overline{N\Delta}+\bar{U}=0 \qquad (16)$$

The weight matrix here ($\bar{W}$) is taken as:

$$\bar{W}=\begin{bmatrix} W_{1} & & & & 0 \\ & \ddots & & & \\ & & W_{8} & & \\ & & & {}^{e}W & \\ 0 & & & & {}^{s}W \end{bmatrix}$$

After substituting the values of $\bar{E}, \bar{W}$, and $\bar{B}$ the result will be:

$$\begin{bmatrix} {}^{e}B^{T}\,W\,{}^{e}B+{}^{e}W & {}^{e}B^{T}\,W\,{}^{s}B \\ {}^{s}B^{T}\,W\,{}^{e}B & {}^{s}B^{T}\,W\,{}^{s}B+{}^{s}W \end{bmatrix}=\bar{N}=\begin{bmatrix} {}^{e}N+{}^{e}W & {}^{es}N \\ {}^{es}N^{T} & {}^{s}N+{}^{s}W \end{bmatrix}$$

where:

$${}^{e}N={}^{e}B^{T}\,W\,{}^{e}B$$

$${}^{e}B=\begin{bmatrix} {}^{e}B_{1} & & \\ & \ddots & \\ & & {}^{e}B_{} \end{bmatrix} \qquad W=\begin{bmatrix} W_{1} & & 0 \\ & \ddots & \\ 0 & & W_{} \end{bmatrix}$$

THE ROOT MEAN SQUARE ERROR (RMSE) AND THE FINAL RESULTS OF DIGITAL AEROTRIANGULATION

RMS error is the distance between the input (source) location of a GCP, and the re-transformed location for the same GCP. In other words, it is the difference between the desired output coordinate for a GCP and the actual output coordinate for the same point when the point is transformed with transformation matrix [Shaker Farhan Ahmed 1999].

In this work, the R_x, R_y, and R_z are (8.114m), (8.372m), and (22.785m) respectively, the final adjusted exterior orientation parameters of each photo are listed in tables (2&3) & the final adjusted ground coordinates of the control & tie-pass points are listed in **Table (4).**

Table (2) Adjusted Exterior Orientation Parameters of strip 110 (digital part)

	Photo 11038	Photo 11040	Photo 11042	Photo 11044
χ (Rad.)	-0.5696	-0.4423	-0.4645	-0.3963
ϕ (Rad.)	-0.0013	0.0237	-0.0014	-0.0119
ω (Rad.)	-0.0888	-0.0335	-0.0078	0.1513
X_L (m.)	441771.846	442002.485	442248.634	442455.513
Y_L (m.)	3681580.465	3681415.345	3681187.279	3680970.560
Z_L (m.)	458.238	459.635	468.147	459.772

Table (3) Adjusted Exterior Orientation Parameters of strip 111 (digital part)

	Photo 11141	*Photo 11143*	*Photo 11145*	*Photo 1147*
χ *(Rad.)*	-0.5199	-0.4987	-0.4849	-0.1681
ϕ *(Rad.)*	-0.0611	-0.1088	-0.0099	-0.1252
ω *(Rad.)*	-0.0574	0.0020	0.0570	0.1435
X_L *(m.)*	441599.887	441838.000	442133.880	442262.119
Y_L *(m.)*	3681210.209	3680998.441	3680842.346	3680633.439
Z_L *(m.)*	460.120	477.731	471.928	435.907

Table (4) Adjusted Ground Control & tie-pass points (digital part)

Point No.	X (m)	Y (m)	Z (m)
100	442023.255	3681366.657	34.896
1	442240.809	3681621.474	36.248
10382	441582.022	3681363.349	36.661
11411	442029.042	3681308.021	36.025
500	441783.944	3681363.365	36.248
200	442240.809	3681621.474	36.248
10400	442023.255	3681366.657	34.896
10402	442029.042	3681308.021	36.025
4	442302.210	3681564.862	36.611
600	441847.143	3681121.055	36.429
2	442328.411	3681022.377	36.338
300	442302.210	3681564.862	36.611
10420	441847.143	3681227.693	42.836
700	442328.411	3881022.377	36.338
11451	442410.343	3680861.848	36.255
400	442119.253	3681435.664	33.164
3	441602.434	3680804.751	36.182
800	441684.587	3681227.025	36.957
10442	441806.267	3680885.888	33.066
5	441821.667	3680760.191	36.185
11471	441821.667	3680592.565	36.185
11410	441602.434	3681227.025	36.182
11412	441966.895	3680543.576	36.052
900	441695.751	3681144.081	32.477
1000	441684.587	3680885.888	36.957
11430	441966.895	3680543.576	36.052
11432	441806.267	3680760.191	33.066
1100	441821.667	3680592.565	36.185
1200	441966.895	3680543.576	36.052
11472	442455.306	3680913.449	50.129

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