DIGITAL AEROTRIANGULATION

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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 RMSX = 8.114m, RMSY = 8.372m & RMSZ = 22.785m, and this is due to a lot of errors that have been faced during the various phases of this work.

ان واحدة من بين الفوائد الرئيسية للمسح التصويري الرقمي هو امكانية تقليل خطوات الانتاج وبعفاء عالية، ولهذا يمكن فعلاً تحسين الاقتصاد 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 (computer vision) ورؤية الحاسبة (image processing) لزيادة فعالية خطوات العمل أتمتاتيكيا في الصور الجوية الرقمية مثل التوجيه الداخلي والتوهج النسبي (point transfer) (relative orientation) (interior orientation) (DTM) التثليج الجوي لمنطقة معينة وكذلك في انتاج نمذجة الارتفاعات رقمياً.

المثلث الجوي الرقمي يشمل عمليات تعليم النقاط بعلامات لتبين أهميتها والتوجه الداخلي (point transfer) وتوقع نقاط الضبط وكذلك عملية تصحيح وقياسات نقاط الضبط. ويتطلب انتاج التثليج الجوي لمنطقة معينة، وذلك في انتاج نمذجة الارتفاعات رقمياً.
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).
Table (1) Specifications of the used photographs

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

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 X 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:

\[
R(u, v) = \sum_{x} \sum_{y} S(x, y) T(x + u, y + v)
\]  

(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)

\[
x = a_1 + a_2 X + a_3 Y \ldots \ldots (2)
\]

\[
y = b_1 + b_2 X + b_3 Y \ldots \ldots (3)
\]

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

\[
A \cdot X = L + V \ldots \ldots (4)
\]

where:

\[
A_{8 \times 6} = \begin{bmatrix}
1 & X_1 & Y_1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & X_1 & Y_1 \\
1 & X_2 & Y_2 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & X_2 & Y_2 \\
1 & X_3 & Y_3 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & X_3 & Y_3 \\
1 & X_4 & Y_4 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & X_4 & Y_4
\end{bmatrix}
\]

\[
X_{6 \times 1} = \begin{bmatrix}
[a_1] \\
[a_2] \\
[a_3] \\
[b_1] \\
[b_2] \\
[b_3]
\end{bmatrix}
\]

\[
L_{8 \times 1} = \begin{bmatrix}
x_1 \\
y_1 \\
x_2 \\
y_2 \\
x_3 \\
y_3 \\
x_4 \\
y_4
\end{bmatrix}
\]

\[
V_{8 \times 1} = \begin{bmatrix}
x_{x1} \\
x_{y1} \\
x_{x2} \\
x_{y2} \\
x_{x3} \\
x_{y3} \\
x_{x4} \\
x_{y4}
\end{bmatrix}
\]
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 \((\omega, \phi, \chi)\) [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]

\[
\begin{align*}
\nu_x &= b_{11} d\omega + b_{12} d\phi + b_{13} d\chi - b_{14} dX_L - b_{15} dY_L - b_{16} dZ_L + J \\
\nu_y &= b_{21} d\omega + b_{22} d\phi + b_{23} d\chi - b_{24} dX_L - b_{25} dY_L - b_{26} dZ_L + K
\end{align*}
\]

where:

- \(\nu_x\) & \(\nu_y\) 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 \(X, Y, Z\) 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]:

\[
\begin{align*}
\nu_{x_E} &= b_{14} dX_E + b_{15} dY_E + b_{16} dZ_E + J \\
\nu_{y_E} &= b_{24} dX_E + b_{25} dY_E + b_{26} dZ_E + K
\end{align*}
\]

where:

- \(\nu_{x_E}\) & \(\nu_{y_E}\) 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 The Case 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:

\[
x = -f \left[ \frac{m_0(X - X_e) + m_1(Y - Y_e) + m_2(Z - Z_e)}{m_0(X - X_e) + m_1(Y - Y_e) + m_2(Z - Z_e)} \right] ...
\]

\[
y = -f \left[ \frac{m_0(X - X_e) + m_1(Y - Y_e) + m_2(Z - Z_e)}{m_0(X - X_e) + m_1(Y - Y_e) + m_2(Z - Z_e)} \right] ...
\]

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]:

\[
V_j + B_j \Delta_i + B_j \Delta_j + E_j = 0
\]

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:

\[
V = \begin{bmatrix}
V_{1j} \\
V_{2j} \\
\vdots \\
V_{8j}
\end{bmatrix} \quad \Delta = \begin{bmatrix}
\Delta_1 \\
\Delta_2 \\
\vdots \\
\Delta_8
\end{bmatrix} \quad E = \begin{bmatrix}
E_{1j} \\
E_{2j} \\
\vdots \\
E_{8j}
\end{bmatrix}
\]
The observation equations for exterior orientation parameters will be:
\[ V_i - \Delta_i + E_i = 0 \]  
(12)

Where
\[ V = \begin{bmatrix} V_1^e \\ V_2^e \\ \vdots \\ V_n^e \end{bmatrix}, \quad E = \begin{bmatrix} E_1^e \\ E_2^e \\ \vdots \\ E_n^e \end{bmatrix} \]

The observation equations for survey coordinates will be:
\[ V_j - \Delta_j + E_j = 0 \]  
(13)

where
\[ V = \begin{bmatrix} V_1^s \\ V_2^s \\ \vdots \\ V_n^s \end{bmatrix}, \quad \Delta = \begin{bmatrix} \Delta_1^s \\ \Delta_2^s \\ \vdots \\ \Delta_n^s \end{bmatrix}, \quad E = \begin{bmatrix} E_1^s \\ E_2^s \\ \vdots \\ E_n^s \end{bmatrix} \]

The collection of all observation equations mentioned above will be:
\[ \bar{V} + B\Delta + E = 0 \]  
(14)

where
The normal equations for the case study are:

\[ \overline{B}^T \overline{W} \overline{B} \overline{\Delta} + \overline{B}^T \overline{W} \overline{E} = 0 \]  

or

\[ \overline{N} \overline{\Delta} + \overline{U} = 0 \]

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

\[ \overline{W} = \begin{bmatrix} W_1 & 0 \\ \vdots & \ddots & \ddots \\ 0 & \cdots & W_s \\ W_s & \cdots & W \end{bmatrix} \]

After substituting the values of \( \overline{E}, \overline{W}, \) and \( \overline{B} \) the result will be:

\[
\begin{bmatrix}
 e^T & e & e & e^T & e \\
 B & W & B + W & B & W \\
 B & W & B & B & W + W \\
 B & W & B & B & W + W
\end{bmatrix}
= \overline{N}
= \begin{bmatrix}
 e & e & e \\
 N + W & N \\
 N & N + W
\end{bmatrix}
\]

where:

\[ \overline{N} = B \overline{W} B \]
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)

<table>
<thead>
<tr>
<th></th>
<th>Photo 11038</th>
<th>Photo 11040</th>
<th>Photo 11042</th>
<th>Photo 11044</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi$ (Rad.)</td>
<td>-0.5696</td>
<td>-0.4423</td>
<td>-0.4645</td>
<td>-0.3963</td>
</tr>
<tr>
<td>$\phi$ (Rad.)</td>
<td>-0.0013</td>
<td>0.0237</td>
<td>-0.0014</td>
<td>-0.0119</td>
</tr>
<tr>
<td>$\omega$ (Rad.)</td>
<td>-0.0888</td>
<td>-0.0335</td>
<td>-0.0078</td>
<td>0.1513</td>
</tr>
<tr>
<td>$X_L$ (m.)</td>
<td>441771.846</td>
<td>442002.485</td>
<td>442248.634</td>
<td>442455.513</td>
</tr>
<tr>
<td>$Y_L$ (m.)</td>
<td>3681580.465</td>
<td>3681415.345</td>
<td>3681187.279</td>
<td>3680970.560</td>
</tr>
<tr>
<td>$Z_L$ (m.)</td>
<td>458.238</td>
<td>459.635</td>
<td>468.147</td>
<td>459.772</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Photo 11141</th>
<th>Photo 11143</th>
<th>Photo 11145</th>
<th>Photo 1147</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi$ (Rad.)</td>
<td>-0.5199</td>
<td>-0.4987</td>
<td>-0.4849</td>
<td>-0.1681</td>
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<tr>
<td>$\phi$ (Rad.)</td>
<td>-0.0611</td>
<td>-0.1088</td>
<td>-0.0099</td>
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<td>$\omega$ (Rad.)</td>
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<td>$Y_L$ (m.)</td>
<td>3681210.209</td>
<td>3680998.441</td>
<td>3680842.346</td>
<td>3680633.439</td>
</tr>
<tr>
<td>$Z_L$ (m.)</td>
<td>460.120</td>
<td>477.731</td>
<td>471.928</td>
<td>435.907</td>
</tr>
</tbody>
</table>
Table (4) Adjusted Ground Control & tie-pass points (digital part)

<table>
<thead>
<tr>
<th>Point No.</th>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
</tr>
</thead>
<tbody>
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<td>3681366.657</td>
<td>34.896</td>
</tr>
<tr>
<td>1</td>
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<td>3681621.474</td>
<td>36.248</td>
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<td>10382</td>
<td>441582.022</td>
<td>3681363.349</td>
<td>36.661</td>
</tr>
<tr>
<td>11411</td>
<td>442029.042</td>
<td>3681308.021</td>
<td>36.025</td>
</tr>
<tr>
<td>500</td>
<td>441783.944</td>
<td>3681363.365</td>
<td>36.248</td>
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<td>200</td>
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<tr>
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REFERENCES


Wolf, Paul R., (1982), Elements of photogrammetry , 2nd edition, John Wily & Sons, New York,