INVESTIGATION OF ACCURACY FOR DIGITAL ELEVATION MODELS GENERATED WITH DIFFERENT METHODS IN PHOTOGRAMMETRY

H.Karabork [a], F. Yildiz [a], E. Coskun [a], H.M.Yilmaz [b], M. Yakar [a]

[a] SU, Engineering Faculty, 42031 Kampus-Konya, Turkey - (karabork, fyildiz, emrec, yakar)@selcuk.edu.tr
[b] NU, Engineering Faculty, Aksaray, Turkey - (hmyilmaz@nigde.edu.tr)

Commission III, WG III/2

KEY WORDS: Digital, Photogrammetry, Analytical, Aerial, DEM/DTM, Matching, Accuracy, Software.

ABSTRACT:

This paper describes the methodology of a DEM generation from stereo aerial images and the results of experiments in terms of accuracy of generated DEM. In this study, Images, which have 1/10000 and 1/16000 scale, and a test area established about 1 km^2 in Selcuk University Campus Area were used. Aerial photographs were scanned by ZEISS SCAI Photogrammetric Scanner (pixel size is 21μ). Aerial images, which have 1/10000 scale, were restitutied by Zeiss Planicomp P3 Analytical Instrument. The DEM, which belong to test area, were produced by progressive, selective and composite sampling methods. We have developed a new software on PC's that can automatically generate DEM from stereo aerial images for restitution of images 1/16000 scale. In this software, pixel and image coordinates of points in left and right image are calculated by using colinearity equations. Left and right windows are matched and this process is repeated in various ±ΔZ range. Elevation values obtained from the best-fixed matching are automatically selected as optimum elevation value. Elevation values of points in the test area are calculated by bilinear interpolation method which uses coordinates of above points (X,Y,Z). Moreover, Elevations of points in test area are manually produced from PHOTOMOD software. RMS obtained from both analytical and digital methods are compared with similar study in the relevant literature.

1. INTRODUCTION

With rapid development of digital technology, photogrammetry has been coming into digital age. Therefore, automation of interior and relative orientation, digital terrain models and orthophoto generation is one of the most important tasks in digital photogrammetry. Digital Elevation Models (DEM) are 3D models of a part of surface on the earth. DEMs are used for topographic mapping, engineering and environmental applications, spatial data visualization, orthophoto production, and integration into Geographic Information Systems and combined analysis with other data. There are various data sources for DEM. These data sources are generally aerial photographs, satellite images, cartographic maps and measured terrestrial points. The derivation of DEM from photographs and/or digital images is one of the main tasks of photogrammetry. The photogrammetric technology may be an appropriate solution for obtaining the DEM of large areas at the present time. DEM data can easily be obtained from stereo images in photogrammetry methods. The manual measurement of DEMs in photogrammetric instruments and digital systems is expensive and time consuming. Therefore, the automation of DEM generation from aerial photographs is urgently needed (ETHZ 1999). Automation of the photogrammetric working process is one of the major subjects for image correlation. In order to generate digital elevation models of digitized aerial photographs, the automatic correlation is generally used. Correlation is calculated between a pair of stereo images in digital photogrammetry. The best-fixed points are identified.

Root Mean Square Errors (RMS) for elevations describe the accuracy of the produced DEM. RMS's are calculated by differences between field elevations of points and elevations that are obtained from points of DEM by interpolation. The image correlation and the automatic derivation of a DEM can also be used as starting for the generation of digital orthophoto (Gasior 1996).

2. IMAGE MATCHING

A major research area in digital photogrammetry is image matching. Image matching techniques may be classified as area-based matching methods or feature-based matching methods.

Area-based matching uses either correlation or least squares estimates for designating correspondence between images. The matching entity of the area-based method is gray level or spectral intensity value of the neighboring pixels in a window (Lee 1997). Cross-correlation is the classical two-image matching methods. This method match areas in one image with their corresponding areas in the other. Correlation coefficient should be used and is scaled in the range of ±1. The biggest correlation value (ρ) defines the position of the best correspondence. Cross correlation has a simple formula and is easy to implement. This method allows only for two shift parameters between reference and research window. (Gruen 1998).

$$\rho = \frac{\sum_{\xi=1}^{m}\sum_{\eta=1}^{n}(f(\xi,\eta)-\mu_1)*(g(\xi,\eta)-\mu_2)}{\sqrt{\sum_{\xi=1}^{m}\sum_{\eta=1}^{n}(f(\xi,\eta)-\mu_1)^2 * \sum_{\xi=1}^{m}\sum_{\eta=1}^{n}(g(\xi,\eta)-\mu_2)^2}} \quad (1)$$

$$-1 \le \rho \le 1$$

where

$f(\xi,\eta)$ = individual grey values of reference window
μ_1 = average grey value of reference window
$g(\xi,\eta)$ = individual grey values of corresponding part of search window
μ_2 = average grey value of corresponding part of search window
m, n = number rows and columns of reference window

Least squares method aims to define optimum match by minimizing the gray value difference of between reference and search window.

Since left image $f(\xi,\eta)$ and right image $g(\xi,\eta)$ are overlapping images of same area, $g(\xi,\eta)$ can be describe by $f(\xi,\eta)$ using linear geometric and radiometric transformation.

$$g(\xi_2, \eta_2) = h_0 + h_1 * f(\xi_1, \eta_1)$$

$$\xi_2 = a_0 + a_1 * \xi_1 + a_2 * \eta_1$$
$$\eta_2 = b_0 + b_1 * \xi_1 + b_2 * \eta_1$$

(2)

where

h_0, h_1 = linear gray value transformation parameters,
ξ_1, η_1 = the pixel coordinate in the left image
ξ_2, η_2 = the pixel coordinate in the right image
$f(\xi_1, \eta_1)$ = the gray value of pixel (ξ_1, η_1),
$g(\xi_2, \eta_2)$ = the gray value of pixel (ξ_2, η_2),
a_0, a_1, a_2 = affine geometric transformation parameters,
b_0, b_1, b_2 = affine geometric transformation parameters.

Least squares method is iterative. The parameters calculated during the initial pass are used in the calculation of the second pass and so on, until an optimum solution is determined. Least squares matching method is sensitive to initial approximations (Orthobase 1999).

The cross-correlation method adjusts for radiometric differences between the images, and it is accurate to a minimum unit of one pixel. The least squares method, on the other hand, is a generalization of correlation, does not require radiometric normalization, adjusts for geometric distortions and can reach subpixel accuracy (Lee 1997). Features based matching method determines the correspondence between two image features. This method consists of two steps. First, the features in all images, which are points or edges in general, are extracted. Then, these features are matched (Gruen 1998).

3. DESCRIPTION OF TEST DATA AND PROCEDURE

3.1 Test Area

For this study, A Test area, which lies out of the settled part in the campus of Selcuk University, is established. It is about 1 km^2 (Fig.1). Brief information about the test area is given in the Table 1.

Table 1. Location and description of the test area.

| Test Area	Description	Height Range (m)
Selcuk University (Konya-TURKIYE)	Rough Terrain	1119 to 1189
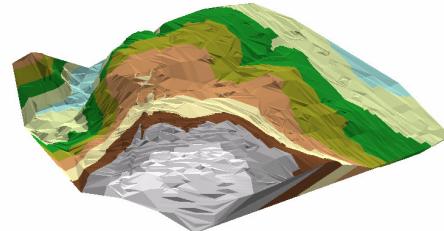
Figure 1. A view of test area

3.2 Sources of Data Sets

The Test Area, which is 1000m*1000m, consists of 440 points. The points were established with 50 m interval (Fig.2).
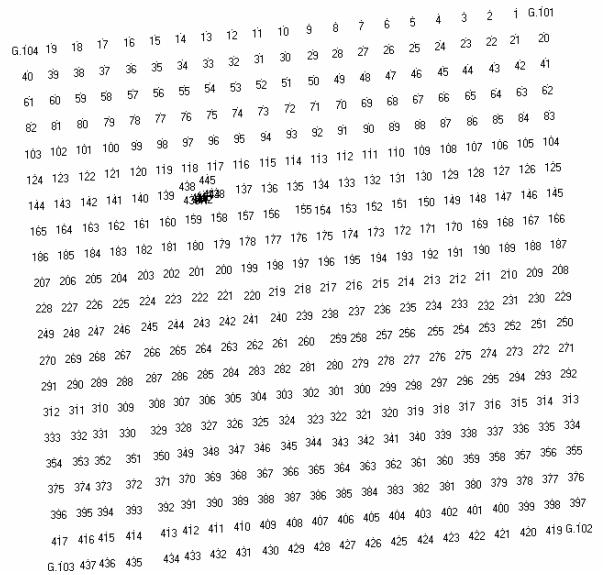
Figure 2. Distribution of points in the test area

Geodetic coordinates of these points are measured by Topcon GTS4 Total Station. Images, which have 1/10000 and 1/16000 scale, were used. Description of flying information both 1/10 000 and 1/16000 photographs scale is given in the Table 2. Photographs (1/10000 scale) are restitutied by Zeiss Planicomp P3 analytical instrument. Photographs that have 1/16000 scale were scanned by ZEISS SCAI Photogrammetric Scanner. Pixel size is 21 µm. The data sets which were obtained from photographs (1/16 000 scale) were restitutied by *PHOTOMOD* and *eComputer Imaging* software which was developed by E.Coskun and H.Karabork. Today, **PHOTOMOD** software is recognized as one of the most popular digital photogrammetric system in Russia. Photomod product line utilises latest advances in digital mapping theory and is put to every day work in many production facilities worldwide.

Photomod functionality is summarized as below:

- Central projection and pushbroom scanner imagery processing,
- Aerial triangulation,
- Automatic DTM extraction,
- Orthomosaic generation,
- On-screen 3D-digitizing in stereo mode,
- Orthomonoplotting,
- Digital maps creation and output
- DTP scanner calibration.

Montage Desktop Module is the main system used to create, delete, copy, import project; enter camera passport data and start all other system modules.

AT/Solver Module performs a full set of digital aerial triangulation computations for the block of images.

DTM Module provides a set of tools to create DTM (as triangulated irregular network-TIN) and contour lines.

Stereo Draw Module is a module of 3D feature extraction.

Mosaic Module is used to create seamless orthomosaic from source block images.

Vector Module is a powerful vector –based GIS and desktop cartography system used to create, edit and print out digital maps including cutting and merging standard map sheets.

Stereo Vector Module is used basically for vector maps updating and supports working with two monitors.

ScanCorrect is designed for the geometric calibration of desktop scanner (Photomod 2000) .

eComputer Imaging software has modules for image enhancement, interior orientation, bundle adjustment and digital elevation models (Karabork 2002).

Table 2. Description of flying information both 1/10 000 and 1/16000 scale of photograph

	1/10000 Photo Scale	1/16000 Photo Scale
Flying date	September 1995	October 1998
Flying direction	East-West	East-West
Forward overlap	%60	%70
Side overlap	%30	%20
Camera	WILD RC-8	ZeissRMKATOP30
Photographs Size	23 cm*23 cm	23 cm*23 cm
Focal length	153.29 mm	305.339 mm
Flying Height(h)	1550	4900

3.3 Description of Procedure

The data sets which were obtained from restitution of photographs (1/10000 scale) on Zeiss Planicomp P3 analytical instrument were derived from selective, progressive and composite sampling methods. The grids obtained from progressive sampling method were measured in 25 m by 25 m intervals in X and Y directions. More than 1500 points were measured with analytical instrument in progressive sampling method. Feature-specific points were measured in selective sampling method. More than 2500 points were obtained from analytical instrument in this method (Karabork 1996).

440 points is directly measured on PHOTOMOD software by means of stereoscopic model. The test area is gridded on *eComputer Imaging* software. The these grids were measured in 10 m by 10 m intervals in X and Y directions. More than 10 000 points were obtained from this software.

Heights of 440 points in test area were calculated by bilinear-interpolation method. This equation is written for the four points, which are nearest points to point at which the Z coordinate is sought.

$$Z = a_0 + X * a_1 + Y * a_2 + X * Y * a_3 \quad (3)$$

where

a_0, a_1, a_2, a_3 = bilinear transformation parameters
X, Y = plane coordinates of point in object system
Z = height of point

eComputer Imaging software follow below steps for generation DEM.

I. Needed inputs are entered in the DEM window. (Fig.3). (Inputs are names of stereo pair, first coordinates and grid interval).

II. Image coordinates of point, at which plane coordinates (X, Y) are known, are calculated by Eq.4.

$$x = x_0 - c * \frac{r_{11}*(X-X_0)+r_{21}*(Y-Y_0)+r_{31}*(Z-Z_0)}{r_{13}*(X-X_0)+r_{23}*(Y-Y_0)+r_{33}*(Z-Z_0)}$$

$$(4)$$

$$y = y_0 - c * \frac{r_{12}*(X-X_0)+r_{22}*(Y-Y_0)+r_{32}*(Z-Z_0)}{r_{13}*(X-X_0)+r_{23}*(Y-Y_0)+r_{33}*(Z-Z_0)}$$

$X_0, Y_0, Z_0, \varpi, \varphi, \chi$ values are calculated before in bundle adjustment module.

where

X_0, Y_0, Z_0 = coordinates of perspective center in object system
c = principal distance
x, y = image coordinate
x_0, y_0 = coordinate of principal point
$r_{11}, r_{12}, r_{13},$
$r_{21}, r_{22}, r_{23},$ = parameters of transformation
r_{31}, r_{32}, r_{33}
X, Y, Z = coordinates of point in object system
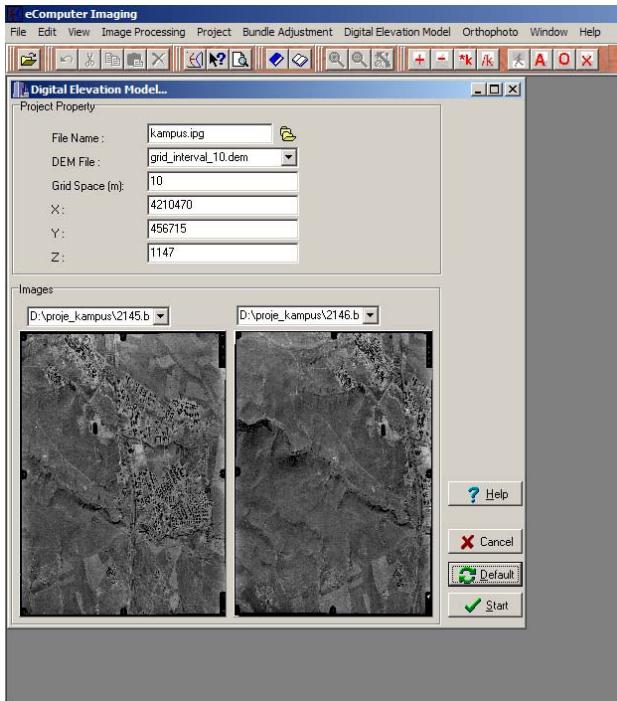
Figure 3. DEM window of *eComputer Imaging* software

III. Image coordinates are transformed to pixel coordinates. For this transformation, affine transformation parameters calculated before in interior orientation module are used. In steps II. and III, coordinates both left and right image of point known plane coordinates (X, Y) are determined.

$$\underline{A} = \begin{bmatrix} a_{1j} & a_{2j} \\ b_{1j} & b_{2j} \end{bmatrix}; l = \begin{bmatrix} x_i - a_{0j} \\ y_i - b_{0j} \end{bmatrix}; X = A^{-1} * l \quad (5)$$

where

a_0, a_1, a_2, b_0, b_1, b_2 = affine transformation parameters
x_i, y_j = image coordinates
j = image number
X = vector of pixel coordinates

IV. The windows, whose centers are already calculated at the step III, are selected for matching.
V. The Selected windows both at left and at right image are matched. Besides, Cross-correlation coefficient is calculated.

VI. X, Y plane coordinates are constant and height (Z) is altered by ΔZ. These heights (Z_i) are calculated by $Z_i = Z_{i-1} \pm \Delta Z$.

VII. II., III., IV., V., VI., steps are repeated for X, Y, and altered Z coordinates. If the process ends for $\pm \Delta Z$, VIII., step would be performed.

VIII. The best fit of cross-correlation coefficients is selected and Height value (Z) which derives the best fit of cross-correlation coefficients between reference and research window is determined as height (Z) value of (X,Y) plane coordinates

IX. X coordinate is increased by grid interval (New point is generated used).

X. Height of the nearest point is used as approximately Z coordinate for the new point.

XI. II., III., IV., V., VI., VII., VIII., IX., and X. steps are repeated for the new point.

XII. If increasing of X coordinate was ended, Y coordinate is increased by grid interval and the overall steps are repeated.

3.4 Results of the Experimental Tests

Height error and root mean square error were computed by means of Equ.6 and Equ.7.

$$\varepsilon_{zi} = Z_{GROUND} - Z_{DEM} \quad (6)$$

$$m_z = \pm \sqrt{\frac{\sum_{i=1}^{n}(\varepsilon_{zi}\varepsilon_{zi})}{n}} \quad (7)$$

where

ε_{zi} = actual error
m_z = height root mean square error
n = number of point

For this study, the extreme values of actual error, the mean of actual error and root mean square error have been derived for both 10 000 photograph scale(Table.3) and 16 000 photograph scale (Table.4). The descriptions of the terms used in Table.3 and Table.4 are as follows:

m_z = height root mean square error
mean = average value of actual error (ε_{zi})
ε_{max} = the maximum value of actual error
$-\varepsilon_{max}$ = the minimum value of actual error

Table.3 Results for 10 000 Photograph Scale

	m_z	Mean	ε_{max}	ε_{min}

|	(m)	(m)	(m)	(m)
Analytically Instrument Photographs scale 1/10000 Progressive sampling	±0.53	-0.36	+3.45	-2.77
Analytically Instrument Photographs scale 1/10000 Selective sampling	±0.47	-0.32	+1.96	-1.57
Analytically Instrument Photographs scale 1/10000 Composite sampling	±0.32	-0.13	+0.89	-0.97

Table.4 Results for 16 000 Photograph Scale

	m_z (m)	Mean (m)	ε_{max} (m)	ε_{min} (m)
PHOTOMOD Software Photographs scale 1/16000 Directly	±0.96	-0.44	+1.65	-2.92
EComputer Imaging Photographs scale 1/16000 10 m grid interval	±0.99	0.19	+3.97	-2.67

In Table 4, it can be seen that the RMS errors obtained by *Photomod* and *eComputer Imaging* are approximately same.

The values of the DEM derived from photogrammetrically different methods can be expressed in terms of a fraction of Contour Interval (CI). The results obtained from 1/10 000 photographs scale are approximately within a range from CI/4 to CI/6. Moreover, The results obtained from 1/16 000 photographs scale are approximately CI/5. These values are already equivalent values, which are within a range from CI/3 to CI/5, obtained by Li 1994. Data used by Li 1994 were obtained from contour data sets. The test areas used in Li 1994 are three of those used for the ISPRS DTM test which was conducted by Working Group 3 of Commission III.

If values in Table 3 and Table 4 are expressed in terms of "per mil of h", then these values (per mil of h) are from 0.20 to 0.34 (Table 5).

Table.5 DEM accuracy in terms of "per mil of h"

	Progres. Sampling	Selective Sampling	Compo. Sampling	Photomod	Ecomp. Imaging
mz/h (% o)	0,34	0,3	0,21	0,2	0,2
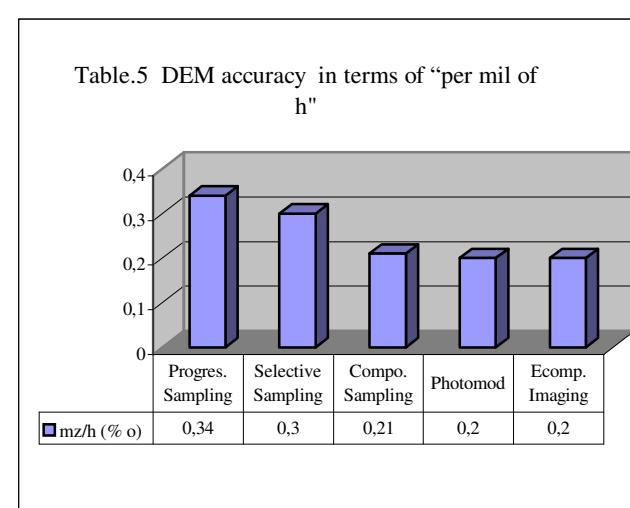
4. CONCLUSIONS

Following conclusions can be made as a result of this study. At restitution with analytic instrument, the most accurate method is composite sampling according to RMS errors. Its RMS improves 32% than those of selective method, %40 than those of progressive method. Despite the fact that the selective sampling method should deliver better results than the progressive sampling, the results show that both methods give approximately same RMS values. This shows the importance of the operator's role in the selection of points. The operator might have measured few points than required in the flat parts of the test area in this study. This drawback is removed by adding grid points in the composite sampling method. The results obtained by Photomod and eComputer Imaging software are approximately the same. But, eComputer Imaging software has a time-consuming problem. When the accuracies of the DEM's derived photogrammetrically are compared with each other in terms of per mille of flying height, the results obtained by *Photomod*, *eComputer Imaging* software and composite sampling method do not differ considerably. In this study, the role of grid intervals was not investigated. It is evident that the grid based methods give different results at different grid intervals.

5. REFERENCE

ETHZ 1999, Closed Project in Institute of Geodesy and Photogrammetry Swiss Federal Institute of Technology, "Automatic Digital Terrain Model Generation", http://www.photogrammetry.ethz.ch/research/autodtm/p1.html (accessed 21 April, 2004)

Gasior, D. 1996, Automatic Derivation of a DTM with the Helava System, OEEPE Workshop On The

Application Of Digital Photogrammetric Workstations, Lausanne

Gruen, A. 1998, DTM Generation and Visualization, Symposium on Digital Photogrammetry, pp.V-1 V-16, Istanbul

Imagine OrthoBASE Tour Guide,1999,USA

Karabork, 2002, Digital Fotogrametride Manuel ve Yari Otomatik Yöntemlerin Degerlendirme Dogruluguna Etkisi Uzerine Bir Arastirma, Ph.D. Thesis, Graduate School of Natural and Applied Sciences, Selcuk University, 143 page, Konya

Karabork, H., 1996, Fotogrametrik Modellerden Sayisal Yükseklik Modellerinin Elde Edilmesinde Secmeli ve Ilerlemeli Ornekleme Yöntemlerinin Karsilastirilmasi, Master Thesis, Graduate School of Natural and Applied Sciences, Selcuk University, 48 page, Konya

Lee, S.M. 1997, Terrain and Landcover Change Detection from Digital Elevation Models and Orthographic Images Produced with Digital Photogrammetry, Master's Degree Theses in Geography Granted by the University of California

Li, Z. 1994, A Comparative Study of the Accuracy of Digital Terrain Models (DTMs) based on Various Data Models, ISPRS Journal of Photogrammetry and Remote Sensing, 49(1), pp.2-11

Photomod User's Manuel 2000