DEM (DIGITAL ELEVATION MODEL) PRODUCTION AND ACCURACY MODELING OF DEMS FROM 1:35.000 SCALE AERIAL PHOTOGRAPHS

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ABSTRACT:

Aerial photographs and satellite imagery have been evaluated manually by the operators for a long time for the extraction of the contour line and DEM data. Computer technology and digital image processing technologies have been developed and this development provides to perform these extraction processes automatically or semi-automatically. The aim of making the processes automatic is to increase the speed of collecting the data and to reduce the cost. Many researches are made about the production of digital elevation models from different data sources and with different methods. In all of the studies, digital elevation models having different resolutions and different data sources are produced and the accuracies of digital elevation models are investigated. The results of these studies vary according to the source data, resolution, ground control point distribution, production method, topography, and reference data for the accuracy assessment. In this study, digital elevation models are produced by automatic image matching and from contour lines which are compiled from 1:35.000 scale aerial photographs and the accuracies of digital elevation models are assessed. Optimum data collection interval and accuracy of digital elevation models are investigated. Automatic image matching and photogrammetric compilation methods for digital elevation model production are compared. Accuracies are also investigated according to the resolution of digital elevation model and slope of topography. The results showed that the accuracy is correlated highly with digital elevation model resolution and 8 to 16 meters of DEM resolution is appropriate for DEMs produced by automatic image matching from 1:35.000 scale aerial photographs. A higher resolution of DEM does not affect the accuracy of DEM.

1. INTRODUCTION

1.1 Digital Elevation Models

Digital Elevation Models (DEMs) have become a widely used tool and product in the last 20 years. They provide a snap shot of the landscape and landscape features while also providing elevation values. They have allowed us to better visualize and interrogate topographic features. A Digital Elevation Model (DEM) is generically described as a spatially geo-referenced data set that is a popular way of encoding the topography for environmental modeling purposes. They are also directly compatible with remotely sensed data sources and are able to represent complex terrain units given the DEM has an adequate resolution. Aerial photographs and satellite imagery have been evaluated manually by the operators for a long time for the extraction of the contour line and DEM data. Computer technology and digital image processing technologies have been developed and this development provides to perform these extraction processes automatically or semi-automatically. The aim of making the processes automatic is to increase the speed of collecting the data and to reduce the cost. Digital elevation model production has been the one of the most automated process of photogrammetry.

Although, formats and accuracy for some formats of digital elevation models are standardized, data sources, quality of data sources and production methods of digital elevation models to provide or improve the standards are not determined clearly. Nonexistence of standards and production criteria causes loss of time and money and production of digital elevation models without known standards and accuracies. Also these nonstandard productions cause data loss of digital elevation models which are needed dense work and source. Many researches are made about the production of digital elevation models from different data sources and with different methods. In all of the studies, digital elevation models having different resolutions and different data sources are produced and the accuracies of digital elevation models are investigated. The results of these studies vary according to the source data, resolution, ground control point distribution, production method, topography, and reference data for the accuracy assessment. On the other hand, the accuracies are investigated in these studies, but the duration of digital elevation model productions are neglected generally. This situation prevents the optimization of production.

Bolstad and Stowe (1994) produced DEMs from 1:40.000 scale aerial photographs and SPOT panchromatic pairs with automatic correlation technique and tested the accuracy of these DEMs and their derivative surfaces (slope, aspect). The produced DEMs were compared and differences of up to 82 meters were observed. Approximately 63 percent of the differences were 10 meters or less, and 90 percent were less than 22 meters.

Accuracies of DEMs derived from different data models were assessed by Li (1994). One of the DEMs was derived from photogrammetrically measured contour data and the other was the gridded data from aerial photographs. As a result, he suggested that contouring could be a better sampling strategy for better accuracy.
Photogrammetry provides the most frequently used data sources and techniques for generating digital elevation models (Stocks

and Heywood, 1994), either by direct generation of digital elevation models or indirectly via its use in topographic mapping for production of contour lines. Photogrammetry either involves stereoscopic techniques for interpretation of aerial photography or digital image correlation applied to aerial photographs.

1.2 Workflow

This paper discusses different techniques (manual, and automatic) of extracting DEMs and their error evaluation. Prior to using DEMs for various applications, it is prudent to analyze errors of the extracted DEMs to ensure that they meet the required accuracy standards.

In this study, digital elevation models are produced by automatic image matching from 1:35.000 scale aerial photographs and the accuracies of digital elevation models are assessed. Also digital elevation models are produced from contour lines which are compiled from the same sources. Optimum data collection interval and accuracy of digital elevation models are investigated. Automatic image matching and photogrammetric compilation methods for digital elevation model production are compared. Accuracies are also investigated according to the resolution of digital elevation model and slope of topography. Some solutions are suggested for the areas having high errors. Two different test regions are used for the study. First region is Tortum which is a very mountainous area. Second region is an area at the proximity of Urla.

10 meters interval contour lines were compiled from stereo models for İzmir region. First digital elevation model was produced from these contour lines. At the second stage, a digital elevation model was produced from the same area by automatic image matching. These digital elevation models are compared with 51 check points which are measured at the aerial triangulation. Root Mean Square Error (RMSE) of the digital elevation model produced from contour lines is found to be nearly 3 meters. RMSE of digital elevation model produced by automatic image matching is found to be nearly 6 meters.

DEMs were produced from stereo models by automatic image matching for Tortum region also. 18 digital elevation models with the resolutions changing from 2 meter to 256 meters were produced by automatic image matching. Digital elevation models are compared with 3D vector data which were compiled more precisely. RMSE of the digital elevation model is found to be nearly 5 meters. Also the accuracies of digital elevation models changing with the resolution of digital elevation model and slope of topography is tried to be modeled with a polynomial equation. The results showed that the accuracy is correlated highly with digital elevation model resolution and 8 to 16 meters of DEM resolution is appropriate for DEMs produced by automatic image matching from 1:35.000 scale aerial photographs. A higher resolution of DEM does not affect the accuracy of DEM.

2. DEM PRODUCTION FROM 1:35.000 SCALE AERIAL PHOTOGRAPHS

2.1 Study Area

Two different test regions are used for the study. First region is Tortum which is a very mountainous area. Second region is an area at the proximity of Urla.

Urla area shows the characteristic of the region, with agriculture and urban lands dominating valley bottoms and deciduous forests covering steeper areas. The area is generally rural.

Tortum area is generally covered by forests. Slope changes between 0 and 63^{o} and height between 1348.6 and 2946.5 meters.
Zeiss RMK TOP15 camera was used for the aerial photography of both regions. Aerial photographs were scanned with 21 micron resolution.

2.2 DEM Production

DEMs were produced by automatic image matching for the both region. At Tortum region, 18 different resolutions (2, 4, 8, 16, 24, 32, 40, 48, 56, 64, 80, 96, 112, 128, 160, 192, 224, 256) DEMs were produced from 2 aerial photographs. The produced 8 meters resolution DEM is shown in Figure 1. At Urla region, an 8 meters resolution DEM was produced from 8 aerial photographs. The produced 8 meters resolution DEM is shown in Figure 2.

Figure 1. 8 meters resolution DEM (Tortum)

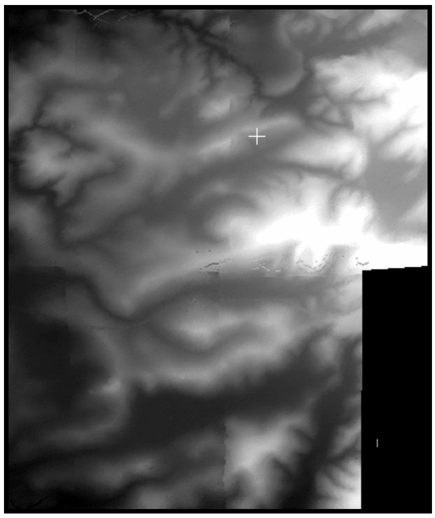

Figure 2. 8 meters resolution DEM (Urla)

Also digital contour lines with 10 meter interval were captured manually from the stereo pair at Urla region. An 8 meters resolution DEM was generated from the captured contour lines. The produced 8 meters resolution DEM is shown in Figure 3.

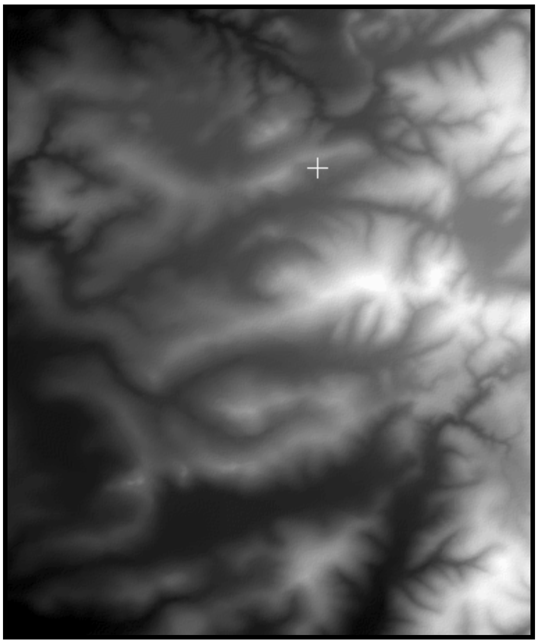

Figure 3. 8 meters resolution DEM (Urla)

2.3 Accuracy Assessment

To test the accuracy of DEMs produced at Urla region, coordinates of the 51 aerial triangulation points were used. Average error of these points is 0.04 meter and RMSE is 0.37 meter. Height values of these points are compared with the DEMS and accuracies are calculated. The results are shown in Table 1. In a study conducted by Li (1994), accuracies of DEMs generated from contour lines were investigated. The results show that the accuracies changes between the 1/3 to 1/5 of contour interval. The results at Urla region support this study.

	Image Matching	Contour Lines
Average Error (m.)	3.28	2.87
Absolute Average Error (m.)	3.68	2.91
RMSE (m.)	± 5.79	± 3.19

Table 1. Errors of DEMs for Urla region

Since the DEM generated from contour lines has better accuracy, this DEM was used as a reference DEM and compared with the matched DEM. The results are shown in Table 2. To compare a DEM with a higher accuracy DEM can give more dependable results since the not only at a few points the accuracies are tested, all the DEM is compared and tested.

Average Error (m.)	3.96
Absolute Average Error (m.)	4.15
RMSE (m.)	± 7.40

Table 2. Errors of DEMs for Urla region

To test the accuracies of DEMs, changing with resolution and slope, produced by image matching at Tortum region, the compiled 3D vectors of the region are used. The vectors consist of 395 lines with approximately 7000 points. The vectors are shown in figure 4. Also a slope map of rhe region is produced to find the affect of slope over accuracies of DEMs.

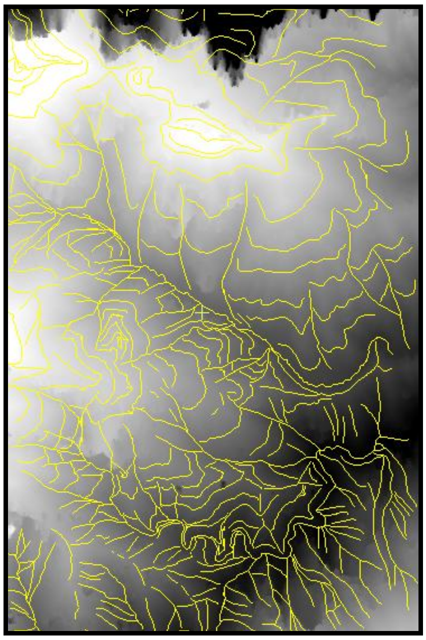

Figure 4. 3D reference vectors

The 3D vectors are compared at 6773 points with 18 different resolution DEMs and the RMSEs are calculated. Accuracies changing with the DEM resolution are shown in Figure 5. It can be easily seen in the figure that when the resolution of DEM decreases, also the accuracy of DEM decreases. Accuracies changing with the slope are shown in Figure 6. Again it can be easily seen in the figure that when the slope increases, the accuracy of DEM decreases.

When the resolution of DEM increases, the production time and the size of the DEM file also increase. So generally it is not logical to produce a very high resolution DEM. Also at a certain level, the increase at the resolution will not change the accuracy. It is important to determine this level. In Figure 5 it can be seen that resolutions better than the approximately 8 meters resolution don't affect the accuracy of DEM.

As a result, compiling big amount of DEM is unrealistic in a typical production environment and bigger intervals are used for DEMs (I.S.M., 1997).

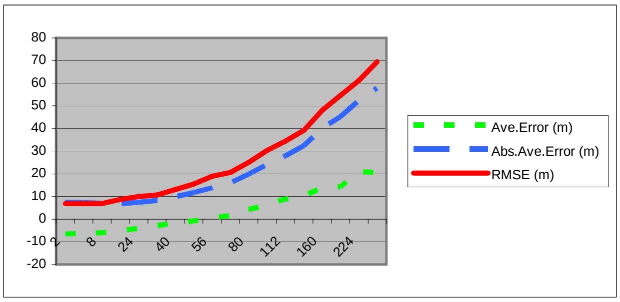

Figure 5. Accuracies changing with DEM resolution

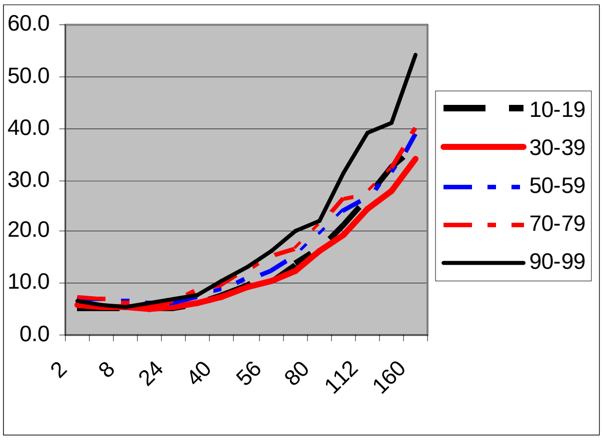

Figure 6. Accuracies changing with slope

The errors of 8 meters resolution DEMs produced from 1:35.000 scale aerial photographs by image matching and contour line capturing are shown in Table 3 for both region. The results show that DEM produced from contour lines has approximately two times better accuracy according to the DEMs produced by image matching.

DEM Source	Abs.Ava. Error (metre)	Ava.Error (metre)	RMSE (metre)
Contour Lines (Urla)	2.9	2.9	± 3.2
Image Matching (Urla)	3.7	3.3	± 5.8
Image Matching (Tortum)	5.7	-4.7	± 5.2

Table 3. Errors of DEMs

3. MODELLING OF ACCURACY ACCORDING TO DEM RESOLUTION AND SLOPE

The accuracies of DEMs were tried to be modelled according to the resolution of DEM and the slope of the topography. 18 DEM at Tortum region were used for modelling. A polynomial model ($Z=a+bX+cY+dXY+eX^2+fY^2$) is calculated by adjustment. In this model z is the accuracy of DEM, X is the resolution of DEM in meters and Y is the slope of the topography as percentage. Since the calculated d, e, and f constants are very small and can be ignored, another model ($Z=a+bX+cY$) is calculated. Calculated polynomial coefficients are given in Table 4. To test the coefficients, statistical "t" test is used. 99% confidence level is used for the test. At this confidence level, table value is 2.33. If a calculated test value of a coefficient is bigger than 2.33, it means that this coefficient is reliable with 99% confidence level. At the table it can be seen that all test values except the coefficient of XY are bigger than 2.33. When the table is examined, it can be seen that the strongest value is the coefficient of Y (resolution). The errors have a constant value and mostly increase with the resolution affect.

	z=a+bx+cy+d xy+ex2+fy2	**Test Value**	**z=a+bx +cy**	**Test Value**
a	0.206 ± 0.084	2.448	0.699 ± 0.049	14.306
b	0.063 ± 0.002	25.663	0.035 ± 0.001	58.106
c	0.224 ± 0.001	202.160	0.213 ± 0.000	751.517
d	-1.192e-005 ± 8.035e-006	***1.484***		
e	-2.215e-004 ± 1.886e-005	11.743		
f	-4.202e-005 ± 4.034e-006	10.417		

Table 4. Polynomial coefficients

According to the second order polynomial calculated from "resolution-slope-error" data, a surface is generated and shown in Figure 7. At this surface, it can be seen that accuracy decrease approximately linearly with the decrease at the resolution and the effect of resolution is dominant.

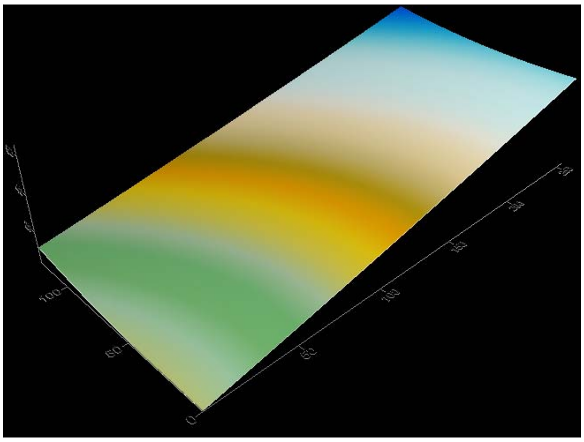

Figure 7. Accuracies changing with resolution and slope

4. RESULTS AND CONCLUSIONS

DEMs are produced from 1:35.000 scale aerial photographs by image matching and contour line capturing. The results show that RMSE of DEMs produced from contour lines is approximately ± 3 meters and RMSE of DEMs produced by image matching is approximately ± 7 meters. DEMs produced from contour lines seem to have approximately two times better accuracy.

Different resolution DEMs are produced from 1:35.000 scale aerial photographs by image matching and accuracies of DEMs according to resolution of DEMs and slope of the topography are tried to be modelled. The results show that accuracies decrease with the decrease at the resolution and increase at the slope. But the affect of resolution seems to be dominant. Image matching algorithms works better at the low slope topography.

The accuracy of DEM produced from contour lines is nearly 1/3 of the contour interval and this result supports the previous studies.

To use a more accurate reference DEM to test the accuracy of another DEM is more reliable method especially for the DEMs produced by image matching. If the point coordinates are used to test the accuracy, generally these points are selected from feature points which can be seen at the imagery such as road junctions etc. In such areas image matching algorithms woks better and calculated heights are more accurate. But these kinds of points don't represent all the DEM, especially the low featured areas. So if the point coordinates are used for the accuracy test, it should be thought that the real accuracy is worse than the calculated value.

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