ACCURACY ANALYSIS, DEM GENERATION AND VALIDATION USING RUSSIAN TK-350 STEREO-IMAGES

By G. BUYUKSALIH (BUYUKSAL@KARAELMAS.EDU.TR), G. KOCAK (MGKXYZ@YAHOO.DE), MURAT ORUC, HAKAN AKCIN
Dept. of Geodesy & Photogrammetry, Karaelmas University, 67100 Zonguldak, Turkey

and K. JACOBSEN (KARSTEN@IPI.UNI-HANNOVER.DE)
Institute for Photogrammetry & Geoinformation, University of Hannover, Nienburger Str., D-30167 Hannover, Germany

Abstract

TK-350 stereo-scenes covering 200x300km on the ground with base-to-height-ratio of 0·52 have been analysed on Zonguldak testfield in the northwest of Turkey. The pixel size on the ground is 10m. Control points were digitised from 1:25 000 scale topographic maps have been used in the test. The bundle orientation was executed by the Hannover University program system BLUH and PCI Geomatica OrthoEngine AE software package. TK-350 stereo-images can yield 3D geopositioning to an accuracy of about 10m in planimetry and 17m in height. Based on these scene orientation, DEM with 40m cell size was generated by the related module of PCI system. For the validation of extracted DEM, matched data was checked against the reference DEM based on the digitised contour lines from the 1:25 000 scale topographic maps. This comparison show that accuracy results depend mainly on the surface structure and terrain slopes. Root mean square errors for Z were found to be about 27m and 39m outside and inside the forest area respectively. Matched DEM presents some systematic shifts against the reference DEM which are also visible in asymmetric shifts of the frequency distribution.

KEY WORDS: Russian TK-350 images, geometric accuracy testing, image matching, DEM generation and validation,

INTRODUCTION

THE archive of various Russian space cameras includes images acquired in more than 20 years. In particular, the image data taken by TK-350 camera since 1981 and KVR-1000 camera since 1984. For a long time, images from these cameras were used only by Russian organizations for mapping purposes. However, these images became available for a wide circle of users since 1991 with the unexpected decision of Russian government. This caused the easing of restriction from US government on American space imagery to 10m. Thus, licences were issued to several American-based companies to develop commercial satellites producing imagery to the 1m ground pixel level (Petrie, 1999; Li, 2000).

The right of commercial distribution of Russian images is reserved by the company called "Sovinformsputnik", which is the first Russian company of such type (see www.sovinfomsputnik.com) and scientific investigations on the potential of these images for mapping were mainly from this company's engineers. Amongst the Russian film-based cameras, photographs from TK-350 system are used to produce 1:50 000 and smaller scale topographic maps in addition to the DEM generation for creating orthophotos from high resolution KVR-1000 images. Based on the Sovinformsputnik's publications, "when no external ground control is used, the planimetric accuracy of these maps is typically 20-25m, and the vertical accuracy is 10m. If GPS derived control points are available, the accuracy of the maps increases to 15-20m horizontally and 5-7m vertically" (Chekalin and Fomtchenko, 2000; Lavrov, 1996 and 2000). These results were reached by the use of their locally-developed software packages.

However, the paper called "Generation of DTM using Russian Imagery" from Fomtchenko and Chekalin, and available in Sovinformsputnik web page (authors cannot find both where and when this paper published) states that: "in according to the announcement of DMA (United States Defence Mapping Agency, now NIMA) which had conducted triangulation development study using TK-350 images, the accuracy was 9m in plane and 16m in height. The obtained correlation of accuracy values not typical for TK-350 imagery, as the analyses show, is caused by non-consideration of a number of metrological parameters of the imagery". This statement reflects that NIMA results are totally reverse to the accuracy values found by Russian scientists. Unfortunately, authors cannot reach this report as well. Independent check on the mapping potential of TK-350 images seems to be crucial in this case.

In this paper, the authors first report on the results derived from the applications of different sensor orientation models to the TK-350 stereo-pairs. For this purpose, Hannover University program system BLUH and PCI Geomatica OrthoEngine Airphoto Edition (AE) V8.2 software package were utilised on the images of Zonguldak testfield. This is followed by a discussion of DEM generation process using stereo TK-350 data. The study will be completed by the validation of extracted DEM with the reference dataset.

RUSSIAN SPACE SYSTEM "KOMETA"

Although the ongoing development in electro-optical sensors, photographic images from Russian satellites are also in use for mapping. Russian Space Mapping System "KOMETA" (see Fig. 1) equipped with TK-350 and KVR-1000 film-based cameras are increasing the interest with the massive global archive data was taken into account. Comet Class spacecraft equipped with these cameras is launched periodically from the Baikonur Cosmodrome in Kazakhstan and take the images of the Earth in near-circular orbit at an average altitude of 220km for about 45 days. During the operation, on-board equipments including two star positioning cameras, a laser altimeter, navigation sensors and synchronizing devices are also active for determination of external parameters. The entire system is then retrieved from orbit and landed at the preliminary defined location for film processing.

TK-350 camera acquires true stereo-images simultaneously instead of days apart. These stereo-images can be taken by forward overlaps of 60% and 80% with the base-to-height ratios (B/H) of 0·52 and 0·26 respectively. Perspective images obtained by this camera will have a ground resolution of 10m at a typical image scale of 1:660 000 and focal length of 350·696mm. Film format is 30x45 cm, which encompasses a single image covering 200x300km in the ground. Other photographic system in the KOMETA is KVR-1000 camera which provides 2m resolution panoramic imagery with a image scale of 1:220 000. Each film frame from the KVR-1000 camera can capture an image which measures 160km by 40km on the ground. Thus the area recorded in a single TK-350 frame is also covered by seven KVR-1000 images. The respective layouts of TK-350 and KVR-1000 images are shown in Fig. 2. As can be seen from this figure, the KVR-1000 images are nested within the TK-350 images so as to provide higher resolution. Both cameras take B/W images in the panchromatic band of 0·58-0·72μm.

EXPERIMENTAL AREA

In this test, TK-350 stereo-pair taken on October 9th, 1986 with a 60% forward overlap and B/H of 0·52 has been used. Image scale was 1:610 000 at the shooting height of 214km. Fig. 3 shows the left component of this stereo-pair with the layout of the GCPs determined for the bundle orientation. As it can be seen with the drawn polygon on the figure, main experimental test site was City of Zonguldak and its close vicinity which will be called as "Zonguldak testfield" thereafter. This testfield covers nearly a 120x90km^2 area in the ground which is only the small part of the TK-350 image because of its large format. Image area including Zonguldak testfield cannot be cut from the whole image because of the risk of losing the fiducial marks which will be used in the inner orientation of TK-350 images. In this case, whole image is used in the test and, in total, 135 uniformly distributed GCPs have been digitized from the 1:25 000 scale topographic maps in the interest area. Accuracy of these GCPs can be expected in the range of 7·5m. On TK-350 images, linear features appeared sharp enough, so GCPs are mainly selected from road crossings and bridges. Digital image coordinates for GCPs were measured manually using GCPWorks module of PCI system with the sub-pixel point determination.

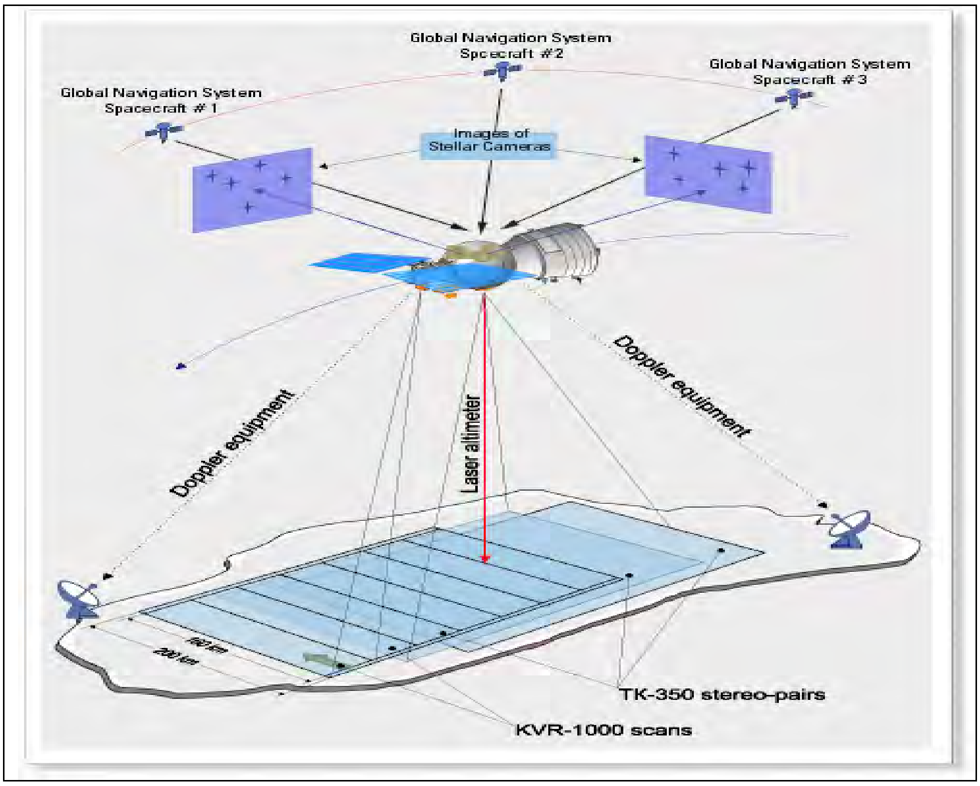

FIG. 1. Russian Space System “KOMETA” equipped with TK-350 and KVR-1000 satellites

CALIBRATION OF TK-350 FRAMES

Since TK-350 images are the hardcopy photographic materials, they have first to be converted in digital form by a scanner. However, because of their extreme large format with a size of 45x30cm, these frames cannot be scanned by a standard photogrammetric image scanners. Therefore, they were scanned by the EskoScan 3648 scanner located at Survey Administration in Hannover, called LGN (Landesvermessung Geobasisinformation Niedersachsen) with a pixel resolution of 1500dpi (16·93µm). In this case, single digital TK-350 image with a size of 27508x18497 pixels requiring memory space of about 0·5Gb was obtained. EskoScan 3648 scanner is a flatbed scanner produced by Danish Company Purup-Eskofot, which can scan a material up to A0 format. Before this work, it was calibrated geometrically by the Institute for Photogrammetry and GeoInformaion

(IPI) of Hannover University with an accuracy of 1·8μm using high-precision calibration glass plate.

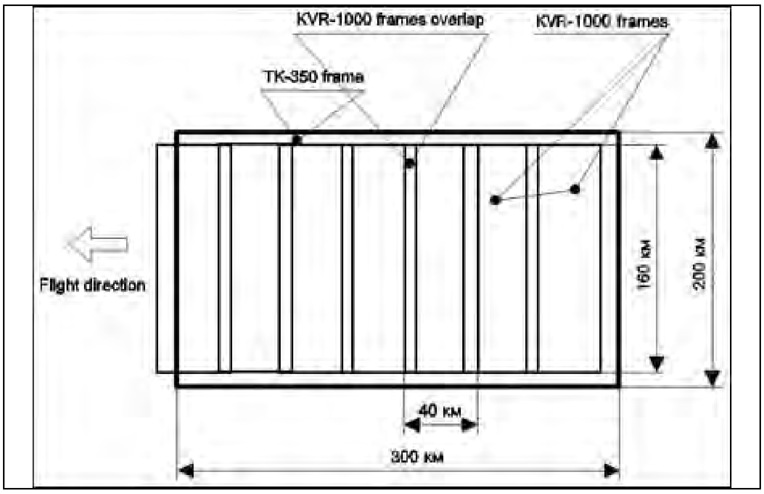

FIG. 2. Imaging configuration of TK-350 and KVR-1000 cameras

Due to the extreme large format of TK-350 photographs, image deformations can be expected, by this reason image accuracy had to be checked by means of 1073 reseau crosses available on the TK-350 images with a spacing of 10mm. For this purpose, two different coordinate sets were created. First set includes the coordinates of crosses measured on digital images by IPI program DPLX and in the unit of pixels. The second set consists of coordinates measured by analytical plotter Zeiss Planicomp P1 located at IPI. An analysis of the reseau crosses was made at first with the P1 measurements against the nominal grid coordinates. Then the digital pixel values of crosses against P1 measurements were evaluated to separate different error sources. For these analyses, affine transformation was used to respect the film deformations. All accuracy results from these calibration works are combined in Table I.

Planicomp P1 was calibrated more than once and found to be very precise with a measuring accuracy of 1μm. Systematic discrepancies between the Planicomp P1 measurements and the nominal reseau positions reflect the general image deformations. The random part refers to the local image deformations, which are also limited, in this case. The comparison of the positions of reseau crosses in digital images against the locations measured by Planicomp P1 on the photo shows the accuracy of the point determination on the digital image and the accuracy of the image scanner used in this test. The systematic differences of 7·3μm and 6·4μm for image 324 and of 2·4μm and 4·1μm for image 326 confirms the accuracy of the EskoScan 3648 scanner. The random errors which are in the range of 0·3 up to 0·4 pixels verify that no general geometric problems exist and corresponds to the accuracy of manual measurements on digital image.

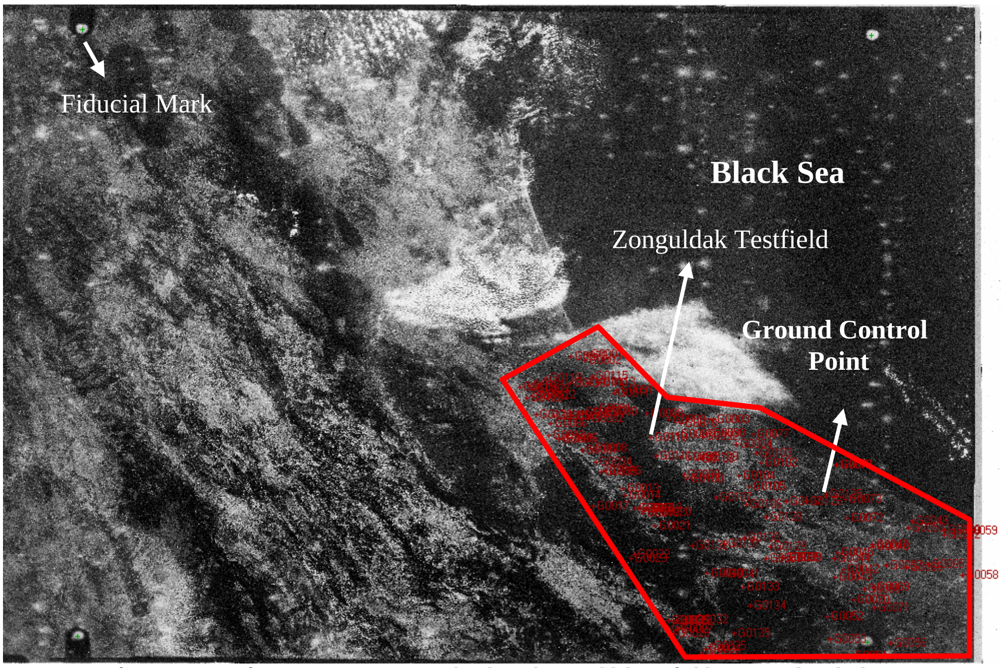

FIG. 3. Left component of TK-350 stereo-pair with selected Zonguldak testfield (upper side, Black Sea is lying)

SENSOR ORIENTATION MODELS

Since the TK-350 images are in perspective geometry, simple mathematical models based on well-known collinearity equations can be implemented for geometric accuracy testing. For this purpose, two commercially available software packages; Hannover University program system BLUH and PCI Geomatica OrthoEngine AE system have been tested. Followings include detailed explanation of the results derived from the experimental works using these systems with TK-350 stereo-images of Zonguldak testfield.

Hannover University Program System BLUH

BLUH (BundLe block adjustment University of Hannover) is a bundle block adjustment program (see Jacobsen, 1997) which is based on the collinearity equations. Observations are photo coordinates, control point coordinates, and if available, coordinates of the projection centers. Unknowns are the photo orientations, object coordinates and additional parameters. In the adjustment with BLUH, the square sum of the image coordinate corrections multiplied with the weight will be minimized. A blunder detection by robust estimators is possible.

Since the collinearity equations are not linear, Newton's method is used for iterative computation.

Table I. Accuracy results derived from the calibration of TK-350 image pairs

Type of analysis	*Root mean square errors (rmse)*		*Systematic part of rmse*		*Rmse without systematic part*	
	x-rmse (μm)	*y-rmse (μm)*	*Syst. x-rmse (μm)*	*Syst. y-rmse (μm)*	*x′-rmse (μm)*	*y′-rmse (μm)*
Planicomp P1 measurements against the nominal values of reseau crosses on TK-350 image 324 (largest discrepancy)	*8·0 (29·8)*	*8·3 (37·3)*	*5·2 (16·0)*	*5·0 (16·1)*	*6·1 (22·4)*	*6·6 (32·1)*
Digital image coordinates against the Planicomp P1 measurements for TK-350 image 324 (largest discrepancy)	*10·7 (36·2)*	*9·7 (38·9)*	*7·3 (21·8)*	*6·4 (22·3)*	*7·8 (28·1)*	*7·2 (30·8)*
Planicomp P1 measurements against the nominal values of reseau crosses on TK-350 image 326 (largest discrepancy)	*7·5 (22·0)*	*7·8 (26·5)*	*3·7 (11·4)*	*4·6 (14·8)*	*6·5 (19·6)*	*6·3 (19·7)*
Digital image coordinates against the Planicomp P1 measurements for TK-350 image 326 (largest discrepancy)	*6·2 (18·7)*	*7·7 (24·1)*	*2·4 (10·0)*	*4·1 (11·1)*	*5·7 (19·3)*	*6·5 (20·5)*

A self-calibration by additional parameters can improve the image geometry which is not exactly corresponding to the mathematical model of perspectivity. The additional parameters have to be checked by statistical tests. In this case, automatic reduction to the specific set of additional parameters or a computation with fixed parameters set would take place. The additional parameters 1-12 are the usual parameter set used for the block adjustment in this program system.

The accuracy results from program BLUH are given in Table II. In this test, out of 135 GCPs, 7 seemed to be erronous and they were taken out. When all remaining 128 points used as GCPs, BLUH produced rmse values of 10·9m in X, 10·0m in Y and 17·3m in Z. Fig. 4 includes the vector plot of the errors. Here, while blue component represents the planimetric error vector, green one corresponds to errors in height. In this case, only 12 points selected as GCPs and others are assigned as independent check points (ICPs). While accuracy values at remaining check points are obtained as 12·4m in X, 13·3m in Y and 19·8m in Z, at 12 GCPs rmse values are found to be 12·1m, 14·1m and 13·2m for X, Y and Z axes respectively. When the systematic components of rmse values at ICPs analyzed, they reached to 4·4m in X, -0·8m in Y and 6·1m in Z. However, random components still have more influence on the accuracy values and systematic error effects were taken out, rmse values only drop to 11·6m in X, 13·3m in Y and 18·8m in Z directions. Furthermore, the accuracy of the image coordinates, σ_0 value, was acquired very close or below to 0·8 pixel at each run and this corresponds to the expectations – the control points could not be identified more precisely than this value in the TK-350 images.

Table II. The accuracy values obtained for X, Y and Z-directions using program BLUH

	rmse			*Maximum residuals*			*Systematic part of rmse*			*rmse without systematic part*		
#GCPs/ ICPs	*X-rmse (m)*	*Y-rmse (m)*	*Z-rmse (m)*	*max. dX (m)*	*max. dY (m)*	*max. dZ (m)*	*Syst. X-rmse (m)*	*Syst. Y-rmse (m)*	*Syst. Z-rmse (m)*	*X´-rmse (m)*	*Y´-rmse (m)*	*Z´-rmse (m)*
128/0	*10·9*	*10·0*	*17·0*	*-32·2*	*19·9*	*-52·3*	*-0·046*	*0·151*	*0·006*	*10·933*	*10·008*	*16·951*
12/116	*12·4*	*13·3*	*19·8*	*35·4*	*30·5*	*-59·1*	*4·411*	*-0·829*	*6·086*	*11·557*	*13·263*	*18·823*

PCI Geomatica OrthoEngine AE System

TK-350 imagery can be handled like an aerial image in this software, thus AE module has been used. This part of OrthoEngine employs the parametric modelling method, based on the collinearity equations, developed by Toutin (1995) at CCRS. This method reflects the physical reality of the complete viewing geometry and the distortions that may occur during the image formation (details may be found at http://www.pcigeomatics.com).

In this case, accuracy values obtained by OrthoEngine AE are given in Table III. In this test, 14 of 135 GCPs were found to be erronous and taken out. Using all remaining 119 points as GCPs gave very similar rmse values to those obtained by the program BLUH. Accuracy results are about 10m in X, 11m in Y and 17m in Z. When only 12 points used as GCPs, rmse values of 11·7m, 12·5m and 18·4m are acquired in X, Y and Z-components respectively at remaining checkpoints. Fig. 5 shows the resulted error vectors at ICPs. As can be seen from this figure, overall representation of error vectors are in random pattern, group of points show locally systematic trends. When number of GCPs decreased to 6 and obtained rmse values at remaining checkpoints compared to those acquired with 12 GCPs, while accuracy value in X stays almost same with 11·8m, it increased to 15·7m in Y and 22·9m in Z.

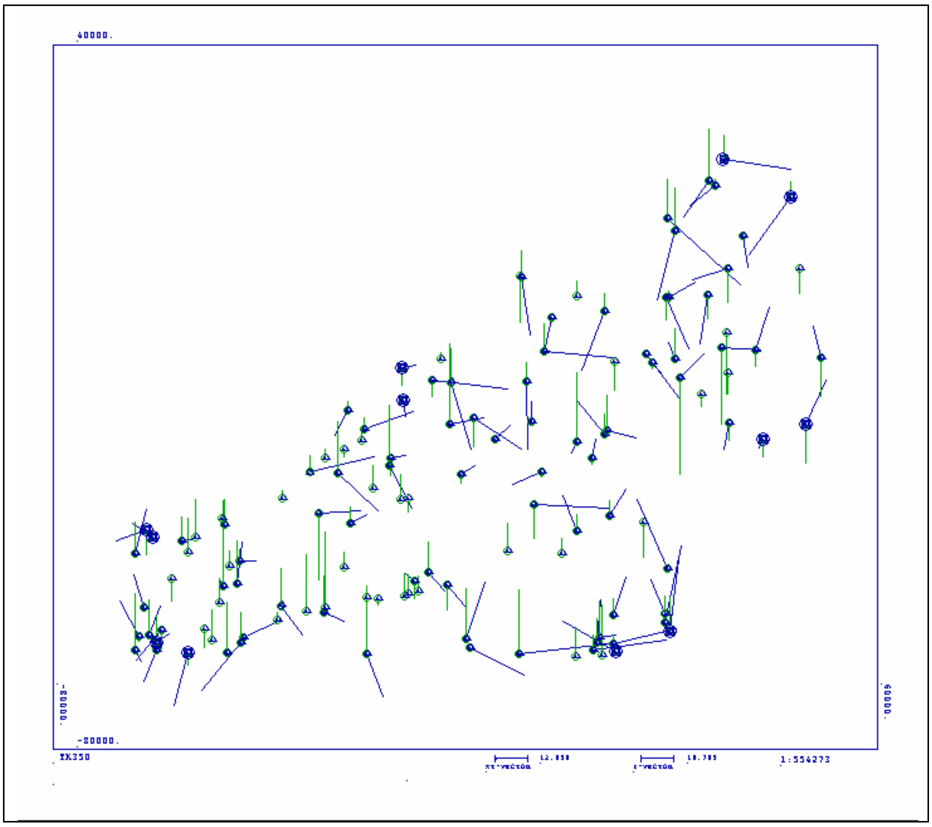

FIG. 4. Vector plot of errors, thick points are showing GCPs and check points with vectors

Table III. The accuracy values resulted from different GCPs/ICPs configurations from TK-350 stereo-scenes using PCI system

	GCPs			*ICPs*		
	X-rmse	*Y-rmse*	*Z-rmse*	*X-rmse*	*Y-rmse*	*Z-rmse*
# GCPs/ICPs	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
119/0	*10·0*	*11·1*	*17·3*	-	-	-
12/107	*7·1*	*12·4*	*15·0*	*11·7*	*12·5*	*18·4*
6/113	*7·1*	*12·1*	*12·5*	*11·8*	*15·7*	*22·9*

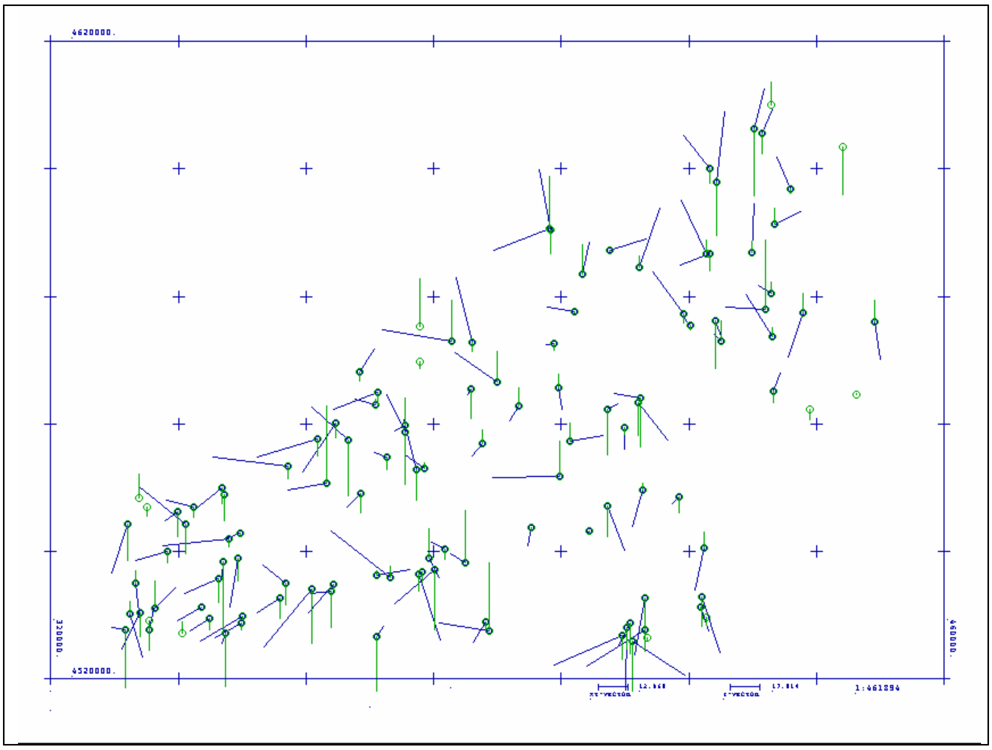

FIG. 5. Vector plot of residual errors obtained by PCI OrthoEngine

DEM GENERATION

The photo quality of the TK350-images is limited. As can be seen from Fig. 6, many scratches are available on the images. In addition, the film grain is visible because of the scanning pixel size only corresponds to a photographic resolution of 31 lp/mm. Automatic image matching was first tried with the original image data using IPI matching program DPCOR and related module of PCI system, but they totally failed or produced too many mismatches. Therefore, scratch removal and lowpass filter were applied to raw TK-350 images using Photoshop program. The final matching was done with the PCI software.

To extract a DEM from a stereo-pair, it is necessary to match points on the one image with the corresponding points on the other image. For this purpose, PCI system employs an area-based image matching technique and produce the DEM through a comparison of the respective grey values on each of these images. This procedure utilizes a mean normalized cross-correlation matching method with a multi-scale strategy to match the image using the statistics collected in defined windows. Matching is performed by considering the neighbourhood surrounding a given pixel in the left quasi-epipolar image (thus forming a template) and moving this template within a search area on the right epipolar image until a position is reached which gives the best match. The actual matching method employed with PCI software generates correlation coefficients between 0 and 1 for each match pixel, where 0 represents a total mismatch and 1 represents a perfect match. A second order surface is then fitted around the maximum correlation coefficients to find the match position to sub-pixel accuracy. The difference in location between the center of the template and the best matched pixel position gives the disparity or parallax arising from the terrain relief, from which the absolute elevation value is then computed. As result of this operation, Fig. 7 shows the 3D-view from Black Sea side to the generated DEM with 40m grid spacing.

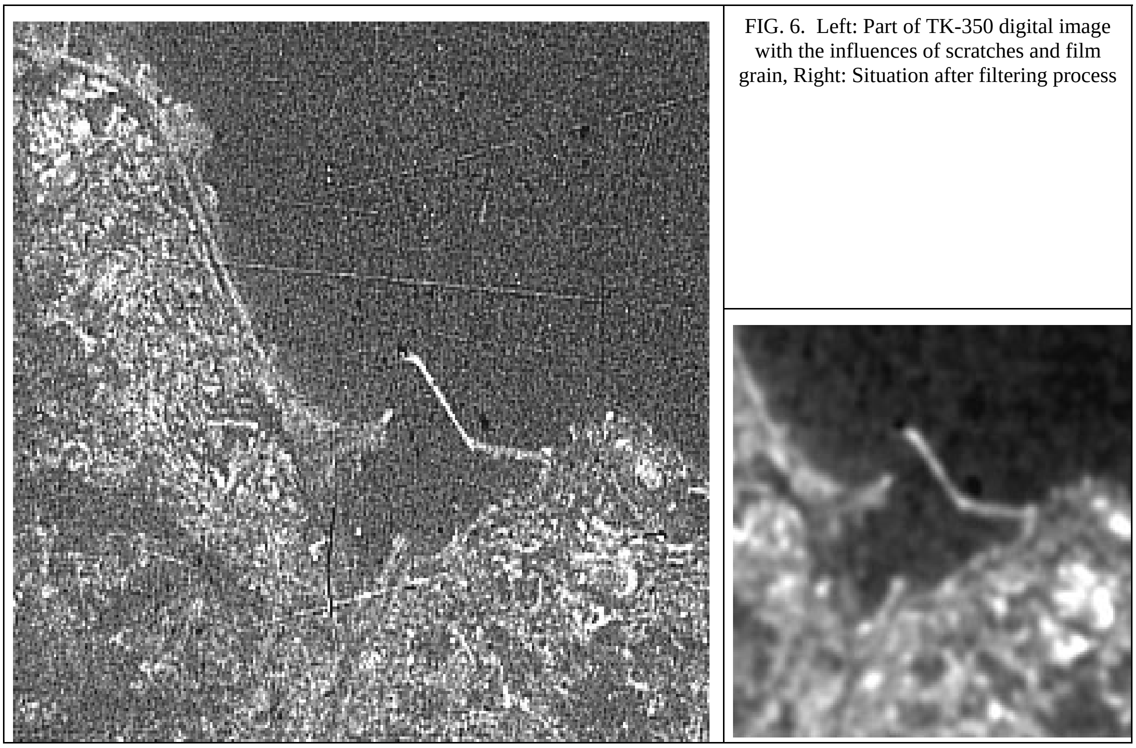

FIG. 6. Left: Part of TK-350 digital image with the influences of scratches and film grain, Right: Situation after filtering process

DEM ANALYSIS

With extracted DEM, PCI system also gives DEM report file which mainly includes elapsed time for extraction process, maximum and minimum elevations for DEM area, DEM cell spacing, height residuals for GCPs and average, maximum residuals with rmse value for height. According to this report file, 2 hours 11 minutes spent for generating the DEM by the program and rmse-Z was found to be 17·00m with the maximum error of 53·7m.

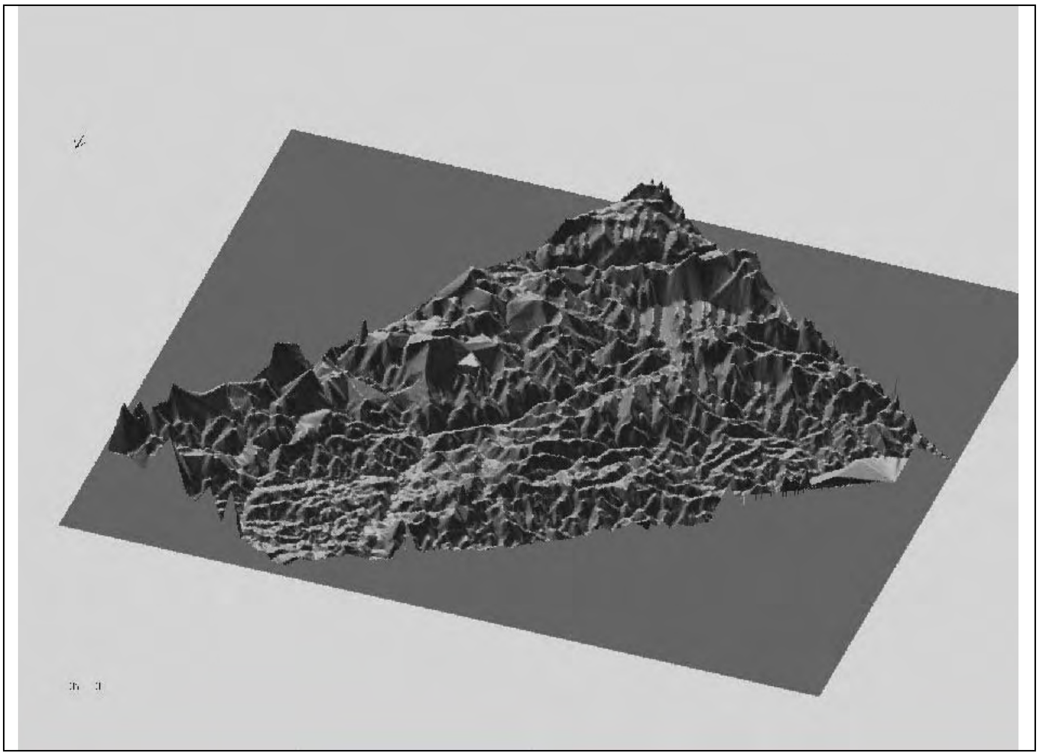

FIG. 7. 3-D view from Black Sea side to the DEM generated using TK-350 stereo-images

For the detailed analysis, the matched DEM was checked by a reference DEM based on digitised contour lines from the 1:25 000 scale topographic maps. Totally, five 1:25 000 sheets reference DEM was available and these were only covering the small part of the DEM generated using TK-350 stereo-pair. Fig. 8(a) and (b) shows the greyvalue-coded forms of reference DEM and its equivalent TK-350 DEM. Although the similarity between two DEMs are quite visible, TK-350 based DEM includes several mismatches and blunders which are represented in the figure as the white areas. Effects of these noisy areas to accuracy analysis is excluded in a computational way. As can be seen from Fig. 9, the major elevations in the test area are in the range up to nearly 600m above sea level with an average altitude of 299m and a maximal height of 847m. Before DEM check, the accuracy of reference DEM was tested by the control points measured with a GPS survey and rmse-Z was obtained as 6·60m. Mean DZ discrepancy was equal to –2·95m. Then, rmse-Z without systematic part was found to be 5·91m. Height differences showed a dependency upon the terrain inclination (see Fig. 10) and can be expressed with an equation of rmse-Z = 4·7 + 22 * tanα.

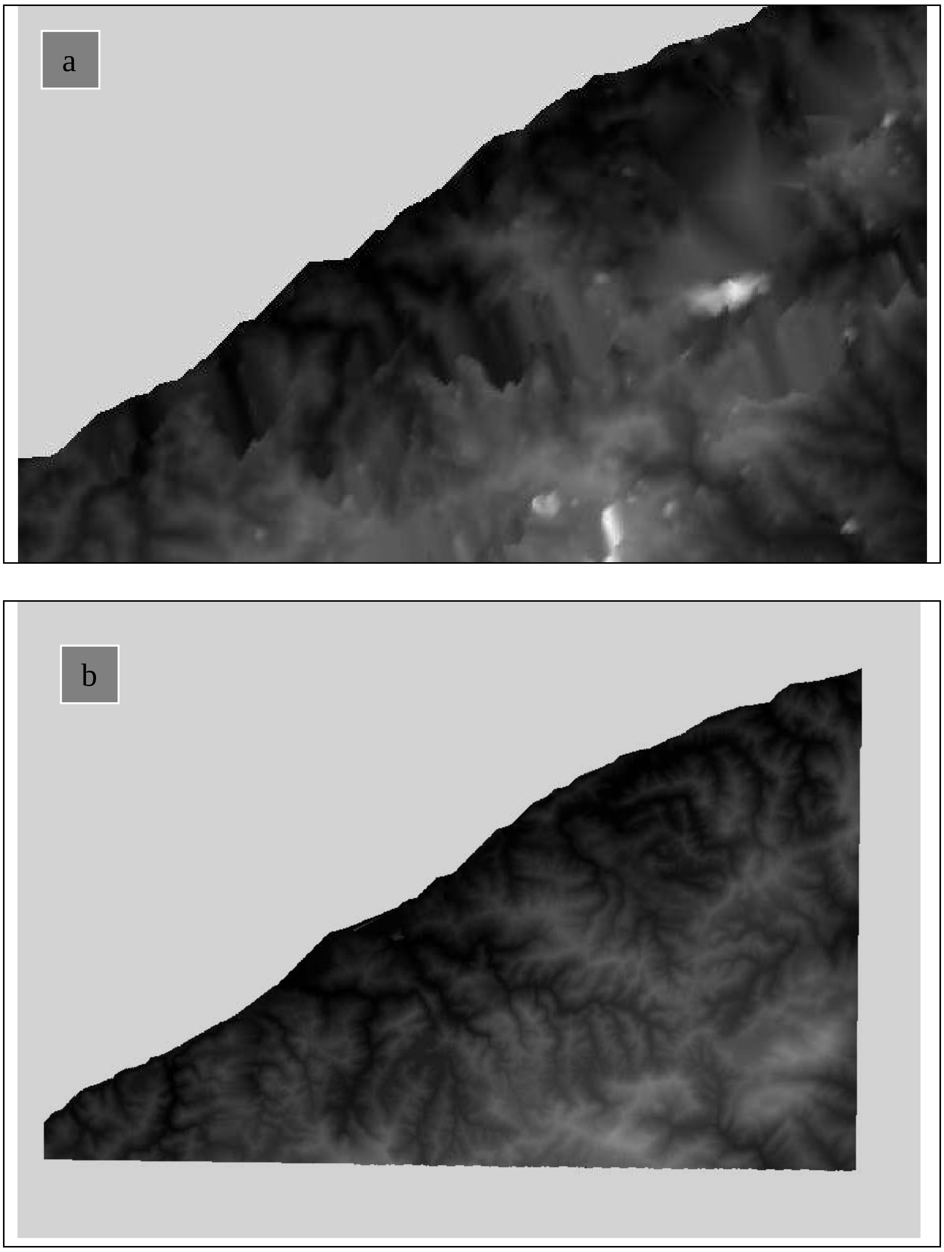

FIG. 8(a) and (b). Greyvalue-coded forms of TK-350 based DEM and reference DEM

For the separation of forest influence from the DEM generation, image classification result (see Fig. 11) acquired using Landsat TM scene of the experimental area was used in the test. The forest layer can be respected by the analysis program DEMANAL which has been developed for comparing the TK-

350 based DEM with the reference dataset. With this program, analysis of DEM can be done for forest covered areas and also for the areas without forest. Furthermore, analysis of DEM can be made for the different height levels separately. The frequency distribution of the discrepancies leads to information about specific problems which can be caused by the vegetation heights. Because reference DEM corresponds directly to the surface while generated DEM with image matching refers to the visible surface of the vegetation and to the roofs of buildings. Obvious mismatching can be excluded by a selectable tolerance limit.

< 47.06	***********
47.06 – 94.11	***************
94.11 –141.17	********************
141.17 –188.22	******************
188.22 –235.28	************************
235.28 –282.33	************************
282.33 –329.39	*********************
329.39 –376.44	*************************
376.44 –423.50	**********************
423.50 –470.56	******************
470.56 –517.61	*************
517.61 –564.67	********
564.67 –611.72	*****
611.72 –658.78	***
>658.78	****

FIG. 9. Frequency distribution of the heights in the reference DEM of experimental area

SLOPE	N	RMSZ	AS FUNCTION OF SLOPE
.00	8	4.73	*******************
.05	12	5.66	***********************
.10	8	7.31	*****************************
.15	4	6.46	**************************
.20	0	.00	
.25	3	9.55	**************************************
.30	0	.00	
.35		112.29	***************************************
.40	0	.00	

FIG. 10. Error values in Z as a function of slope (slope limit=0·2)

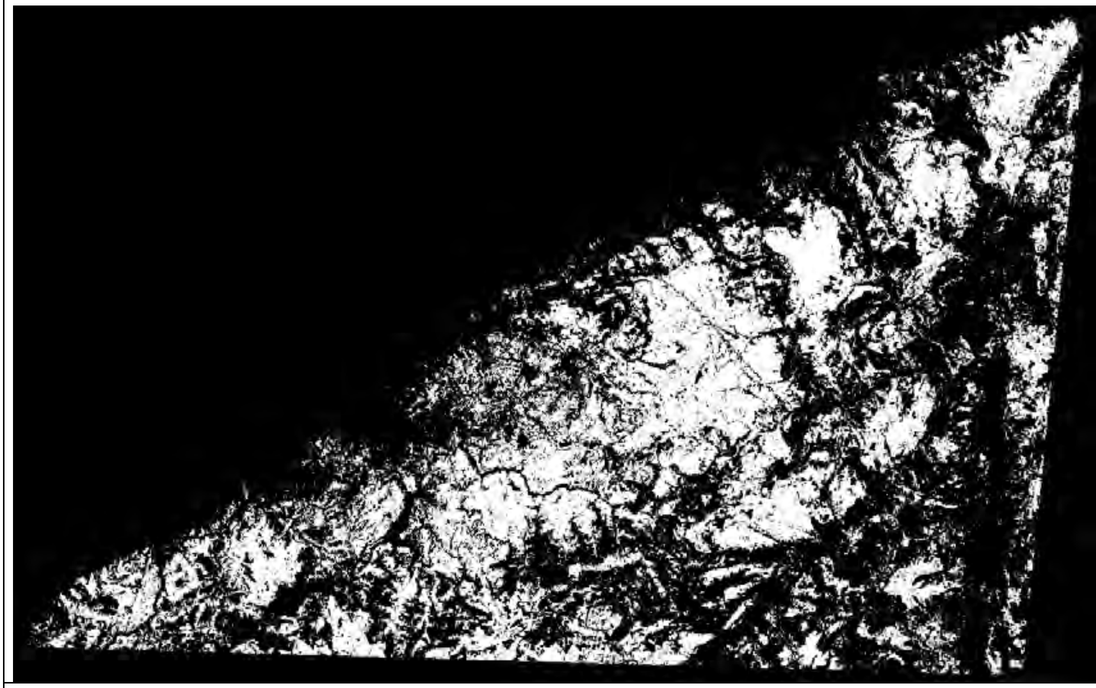

FIG. 11. Forest layer (white parts) of the experimental area

The results achieved in the forest area have not been useful. The contrast of the TK-350 in the forest areas is not sufficient, so many blunders are included and also the accepted observation did not show an acceptable accuracy.

There are some systematic shifts of the matched DEM against the reference DEM, they are reaching up to 7·3m with always positive values (see Table IV). The shifts are also visible in asymmetric shift of the frequency distribution (Figs. 12-13).

The frequency distribution in the forest areas (see Fig. 13) is not well normal-distributed, there are quite more large discrepancies. The justified limit of the accepted height for the computation of the standard distribution can be checked also with the normal distribution. For the TK-350 data the justified limits are 100m outside the forest and 150m inside the forest.

The height discrepancies are also dependent upon the terrain inclination as can be seen in Table V. The slope depending component corresponds to the horizontal accuracy of the height points. The values for the open area are influenced only a little by larger values for the very flat areas (see Table VI). There is no real explanation for the larger values in the very flat areas. The location of the flat areas can be seen in Fig. 14.

Table IV. Discrepancies between the matched DEM and the reference DEM

	Area type	*RMSE-Z [m]*	*shift [m]*	*RMSE-Z without shift [m]*
DZ-limit = 100m	*open area*	*27·5*	*2·2*	*27·5*
	forest	*39·4*	*3·9*	*39·2*
DZ-limit = 150m	*open area*	*33·3*	*2·7*	*33·2*
	forest	*51·3*	*7·3*	*50·7*

```
-150.00
-144.00
-138.00
-132.00
-126.00
-120.00
-114.00
-108.00
-102.00
 -96.00 *
 -90.00 *
 -84.00 *
 -78.00 **
 -72.00 **
 -66.00 **
 -60.00 ***
 -54.00 ***
 -48.00 *****
 -42.00 ********
 -36.00 ************
 -30.00 ****************
 -24.00 *************************
 -18.00 ***********************************
 -12.00 ********************************************
  -6.00 ***********************************************
    .00 **********************************************
   6.00 *******************************************
  12.00 *******************************
  18.00 *********************
  24.00 ***************
  30.00 **********
  36.00 *******
  42.00 *****
  48.00 ****
  54.00 **
  60.00 ***
  66.00 *
  72.00 *
  78.00 *
  84.00 *
  90.00 *
  96.00 *
 102.00 *
 108.00
 114.00
 120.00
 126.00
 132.00
 138.00
 144.00
```

FIG. 12. Frequency distribution of the Z-discrepancies of the TK-350 DEM outside the forest area

```
-150.00 *
-144.00
-138.00 ***
-132.00 *
-126.00 **
-120.00 **
-114.00 ***
-108.00 ***
-102.00 ****
 -96.00 ****
 -90.00 ****
 -84.00 ******
 -78.00 *******
 -72.00 *******
 -66.00 ********
 -60.00 **********
 -54.00 *************
 -48.00 ****************
 -42.00 ********************
 -36.00 ***************************
 -30.00 ****************************
 -24.00 *************************************
 -18.00 ******************************************
 -12.00 *************************************************
  -6.00 **************************************************
    .00 *************************************************
   6.00 *****************************************
  12.00 ************************************
  18.00 *******************************
  24.00 ****************************
  30.00 *********************
  36.00 *******************
  42.00 ***************
  48.00 **************
  54.00 **************
  60.00 **********
  66.00 **********
  72.00 ********
  78.00 ********
  84.00 *****
  90.00 ********
  96.00 *****
 102.00 ******
 108.00 ****
 114.00 *****
 120.00 *****
 126.00 ****
 132.00 ***
 138.00 ****
 144.00 *
```

FIG. 13. Frequency distribution of the Z-discrepancies of the TK-350 DEM inside the forest area

Table V. Standard deviation of height depending upon terrain inclination

TK350 outside forest, DZ up to 100m accepted	*SZ = 21·1m + 18·8 * tan α*
TK350 inside forest, DZ up to 150m accepted	*SZ = 54·4m + 9·4 * tan α*

Table VI. Standard deviation of height depending upon terrain inclination without respecting the larger values in flat areas

TK-350 outside forest, DZ up to 100m accepted	*SZ = 20·0m + 23·9 * tan α*
TK-350 inside forest, DZ up to 150m accepted	*SZ = 53·9m + 11·4 * tan α*

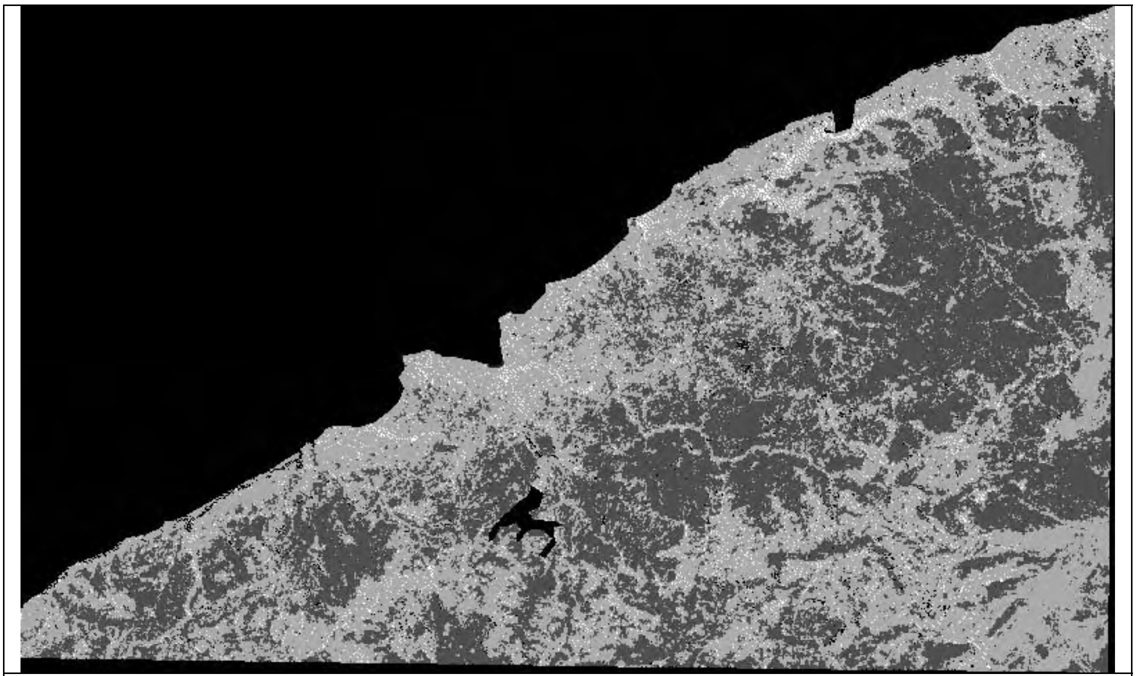

FIG. 14. Location of the flat areas (slope < 0·05) = white

CONCLUSIONS

Based on TK-350 stereo-scenes, with limited effort, a qualified digital elevation model was generated for the overlapped part of the images. For the scene orientation, control points have been taken from a topographic map 1:25 000 were used. The horizontal accuracy that has been achieved within the range of 1 pixel – this is sufficient for mapping. As a rule of thumb, a pixel size of 0·05 to 0·1mm/pixel is necessary for mapping with the required contents (Jacobsen et al., 1998). That means, based on a pixel size of 10m, maps in the scale range of 1:100 000 can be created. However, if the mapping accuracy shall be 0·2mm, a horizontal accuracy of ±20m is required and this is quaranteed by TK-350 images. With a base-to-height-ratio of 0·52, rmse value in Z of approximately ±17m could be reached. These horizontal and vertical accuracy values achieved coincide with those obtained by NIMA results, but not with the ones acquired by the Russian scientists. Based on TK-350 scenes, with the use of automatic image matching, DEM with 40m grid cell was generated. The accuracy was checked against reference DEM based on digitised contour lines from the 1:25 000 scale topographic maps. Analyses were made both for the areas outside and inside forest region. While in the open area, rmse-Z was found to be about 27m, it was equal approximately to the 39m. Height discrepancies are also depend upon the terrain slope and can be expressed as $SZ = 21{\cdot}1m + 18{\cdot}8 * \tan \alpha$. Additionally, some systematic shifts observed between the matched data and reference DEM. These shifts are always positive and can appear as asymmetry in the frequency histogram of height.

ACKNOWLEDGEMENTS

This work was carried out under the international project supported by TUBITAK (Turkey) - JULICH (Germany) cooperation with a code no. 101Y090.

REFERENCES

Chekalin, V.F., Fomtchenko, M.M., 2000. Russian Concept of Space Images Digital Processing, ISPRS Congress, Amsterdam.

Jacobsen, K., 1997. User Manual Program BLUH – BundLe block adjustment University of Hannover, Institute for Photogrammetry and Engineering Surveys University of Hannover.

Jacobsen, K., Konecny, G., Wegmann H., 1998. High Resolution Sensor Test Comparison with SPOT, KFA 1000, KVR 1000, IRS-1C and DPA in Lower Saxony. International Archives of Photogrammetry & Remote Sensing, 32(4), 260-269.

Lavrov, V.N., 1996. Space Survey Photo Cameras for Cartographic Applications, ISPRS Congress, Vienna.

Lavrov, V.N., 2000. Mapping with the Use of Russian Space High Resolution Images, ISPRS Congress, Amsterdam.

Li, Z., 2000. High-Resolution Satellite Images: Past, Present and Future, Journal of Geospatial Engineering, 2(2):21-26.

Petrie, G., 1999. Characteristics and Applications of High-Resolution Space Imagery, Mapping Awareness, 11pp.

Toutin, Th., 1995. Multi-Source Data Fusion with an Integrated and Unified Geometric Modelling. EARSeL-Advances in Remote Sensing, 4(2):118-129.