

FEATURE COMPILATION FROM HIGH RESOLUTION SATELLITE IMAGERY

V.O. Atak^{a,*} and M.O. Altan^b

^aGeneral Command of Mapping, 06100, Ankara, Turkey - voatak@yahoo.com

^bITU, Civil Engineering Faculty, 80626 Maslak-İstanbul, Turkey - oaltan@itu.edu.tr

Commission IV, WG IV/9

KEY WORDS: High Resolution, Aerial, Digital Elevation Model (DEM), Feature, Production, IKONOS, Quickbird

ABSTRACT:

The high quality level that high resolution satellite images have reached in the last years has proved that these images could be a useful data source for the production of orthophoto and different mapping products. To test the capabilities of high resolution imagery, a study has been implemented in Gölbaşı near Ankara. 12 ground control points were revised and signalized before the recording of images. Stereo-pair Ikonos, mono Quickbird and 1:16.000 scaled stereo aerial images have been provided free of charge. For geometric accuracy assessment; different digital elevation models have been created using photogrammetric and cartographic methods. Using these models, various orthophoto and mosaic images have been produced and besides well-recognized 27 checkpoints have been selected and measured with GPS too. Test of feature compilation was performed in 3 different regions and 1:5.000 scale was selected for compilation processes because of on-going discussions about usage of high resolution space imagery in big scale map productions. Three different experienced operators compiled all features on these regions using mono satellite and stereo aerial images and these map productions have been compared within each other. For the comparison assessment, a field control application has been carried out too. Also the results indicate that the stereo IKONOS image has the best accuracy and allows mapping processes up to 1:6.000 scale. And we can say that high resolution satellite imagery can be used to identify topographic changes for both large- and small-scale mapping, but these images couldn't reach to the accuracy level of aerial imagery in determining and identifying the small features yet and cannot be used as a source of direct topographic feature compilation.

1. INTRODUCTION

The high quality that high resolution satellite images have reached in the last years has proved that these images could be a useful data source for the production of orthophoto images and for different mapping products as well. Specifically, it is very important in areas where aerial photogrammetry is not possible or feasible due to political reasons / restrictions and mapping frequency constrained by the limits of flight planning (Li *et al.*, 2000).

There are two important criteria for quality assessment of the images; geometric accuracy and object definition. When we take the mapping processes into consideration, these criteria are basically dependent on the relation between pixel size and the map scale, contrast information (spectral range and colour), atmosphere and the sun elevation, the printing technology and the resolution of the human eye (Topan *et al.*, 2004).

Research activities about high resolution satellite images have been mainly focusing on the geometric accuracy aspects in ortho-image generation and digital elevation model (DEM) extraction.

In addition to this activities, some researches are increasingly concentrating on feature detection, recognition and reconstruction studies like automated mapping of roads, extraction of trees and 3D buildings, hazard and land/water resource monitoring, coastal/cadastral mapping and updating of topographic maps (Holland *et al.*, 2002; Holland and Marshall, 2004; Holland *et al.*, 2006).

Actually there is nearly a consensus among photogrammetry and remote sensing society that some mapping applications from high resolution space imagery can be realized in 1:6.000-1:10.000 scale (Holland and Marshall, 2004; Volpe, 2003).

Accordingly, in the world literature it is very seldom to see compilation assessments in big scale mapping (e.g. 1:5.000) in which both high resolution satellite images are used and all feature types have been detected. Therefore nowadays, especially with launching the GeoEye satellite which has 50 cm imagery resolution, the discussions about usage of high resolution space imagery in big scale mapping products are growing up again.

2. STUDY AREA AND DATA SETS

2.1 Study Area

The study was carried out in Gölbaşı near Ankara, which has 10 km X 10 km area and a height difference about 440 m. This area has been used in many photogrammetric and geodetic applications by General Command of Mapping. The region has open rural areas with different land cover types, road qualities, water features, communication and electricity transmission lines and small residential areas.

2.2 Ground Control Points (GCP's)

Geometric accuracy depends on the number and distribution of GCP's. However it is not necessary, to collect a very large number of GCP's, since the accuracy doesn't vary in an appreciable way when considering more than 10-15 GCP's

(Volpe, 2003). In fact, the number of GCP's down to 4 / 5 did not decrease the accuracy significantly and sub-meter accuracy can be achieved using only a few GCP's and the RPC models (Baltasvias *et al.*, 2006; Fraser *et al.*, 2006; Michalis and Dowman, 2006). Besides, a well spread distribution of even a few GCP's is more beneficial to accuracy improvement than a dense but poorly spread distribution (Li *et al.*, 2000).

In this study, 12 GCP's were established and marked in May 2002 before recording of images. The coordinates of these GCP's have been measured with Global Positioning System (GPS). These GCP's have been used with different distributions in the orthophoto productions.

2.3 Images

Stereo-pair IKONOS (dated August 4th, 2002), mono Quickbird (dated May 26th, 2002) and 1:16.000 scaled aerial images (dated August 29th, 2002) were provided by Inta Inc. (Turkey), Eurimage (Italy) and General Command of Mapping (Turkey) free of charge. The information about images are in Table 1.

	Nominal Collection Azimuth	Nominal Collection Elevation	Sun Angle Azimuth	Sun Angle Elevation
IKONOS-1	343.397 °	79.1812 °	145.587 °	64.083 °
IKONOS-2	206.640 °	65.7324 °	146.031 °	64.182 °
Quickbird	239.034 °	83.0699 °	139.486 °	67.278 °

Table 1. Azimuth and elevation angles of satellite images

1:16.000 scaled 40 stereo aerial images have been taken in 5 strips (in east-west and west-east direction) using kinematic GPS technique. The overlaps between the images and the strips were % 60 and % 30 respectively.

2.4 Check Points (CP's)

Easily-recognizable and well-distributed 35 CP's such as road junctions and field corners were selected from orthophotos and mosaic images. However, because of the time difference between images and land measurements, the weather conditions and the travel restrictions, only 27 CP's coordinates could be measured with GPS (Figure 1).

The field applications have been realized during two days in March 2003 using two reference points.

2.5 Digital Elevation Models (DEM's)

Photogrammetric, cartographic and Ikonos DEM's are used for different orthophoto productions.

The photogrammetric DEM was produced by collecting data manually from 1:16.000 scaled aerial images in 20 m intervals (İşcan *et al.*, 2004). It is considered that the accuracy of photogrammetric DEM is approximately ± 1 m.

The cartographic DEM has been already produced by General Command of Mapping using printed sheets in 1:25.000 scale. In this production, the printed sheets have been scanned first and then the contour lines have been digitized through semi automatic methods. It can be considered that the accuracy of cartographic DEM is approximately ± 5 m.

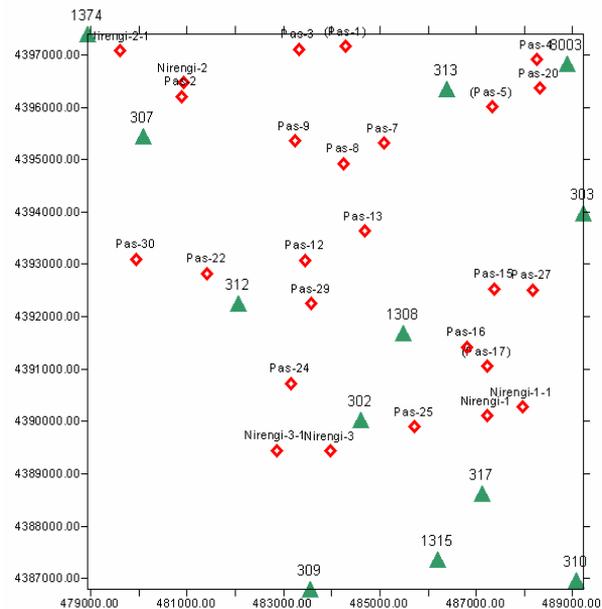


Figure 1. Distribution of GCP's (▲) and CP's (◆)

The last DEM has been produced from IKONOS stereo images. 8 GCP's and 34 tie points were used in this process and a correlation success percent of % 97.2919 was obtained after production. It can be accepted that the accuracy of IKONOS-DEM is approximately ± 2 m (Erdoğan, 2008).

3. GEOMETRIC ACCURACY ASSESSMENT

For geometric accuracy assessment, orthophotos from satellite images and mosaic images from aerial photographs have been produced first. Then, check points (CP's) have been selected from both orthophotos and mosaic images and finally, ground and image coordinates were measured and compared.

3.1 Orthophoto and Mosaic Production

Using photogrammetric, cartographic or Ikonos DEM, various ortho and mosaic images have been produced with different GCP's distributions. Minimum 4/5 GCP's and maximum 7-11 GCP's have been used in ortho and mosaic productions. Furthermore, a stereo IKONOS image (using 7 GCP's and 91 tie points) and orthophotos without GCP's were also produced using direct sensor orientation. In orthophoto productions from satellite images, the rational polynomial coefficients (RPC's) approach has been applied with a polynomial third order refinement.

3.2 Coordinate Measurements

Planimetric coordinates of the CP's have been measured on all orthophoto/mosaic images and stereo IKONOS model. These coordinates have been compared with GPS coordinates. Because of big time difference between images and measurements, some difficulties have been encountered in detection of features on images and in finding the relevant CP's in field. Therefore it has been tried to find the pixels which have the same grey scale values and represent the same features. In this process, it was very beneficial to use the brightness or darkness of adjacent pixels as described in Helder *et al.* (2003).

If the coordinate differences were bigger than 3σ (% 99.73), they were identified as gross errors and re-measured or eliminated. The results are shown in the tables (Table 2-4).

Image	No. Of GCP's	DEM	No. Of CP's	RMSE (m)		
				x	y	x y
Aerial Photo	11	Photog. DEM	23	0.94	0.95	1.33
Aerial Photo	11	Cartog. DEM	22	1.20	0.98	1.55

Table 2. Differences on aerial photographs

Image	No. Of GCP's	DEM	No. Of Check Points	RMSE (m)		
				x	y	x y
Quickbird	4	Photog. DEM	25	1.05	0.85	1.35
Quickbird	5	Photog. DEM	25	1.04	0.84	1.33
Quickbird	9	Photog. DEM	26	1.29	1.01	1.63
Quickbird	9	Cartog. DEM	26	1.56	1.02	1.86
Quickbird	Orient.P ara.	Cartog. DEM	27	38.97	14.89	41.72

Table 3. Differences on Quickbird images

Image	No. Of GCP's	DEM	No. Of Check Points	RMSE (m)		
				x	y	x y
IKONOS	4	Photog. DEM	25	2.25	1.54	2.73
IKONOS	4	Ikonos DEM	25	2.25	1.43	2.67
IKONOS	5	Photog. DEM	25	2.16	1.49	2.62
IKONOS	7	Photog. DEM	26	1.28	1.55	2.01
IKONOS	7	Ikonos DEM	26	1.28	1.54	2.00
IKONOS	7	Cartog. DEM	26	1.37	2.19	2.58
IKONOS	Orient. Para.	Ikonos DEM	27	11.97	11.84	16.84
IKONOS	Orient. Para.	Cartog. DEM	26	11.58	10.66	15.74
IKONOS	7	STEREO	24	0.77	0.89	1.17
				RMSE (z) = 0.94		

Table 4. Differences on IKONOS images

3.3 Geometric Accuracy Assessment Results

The geometric accuracy results show generally that the high resolution satellite images can be used in mid / large scale (1:6.000 to 1:10.000) mapping processes. And we can say that;

- Quickbird ortho-images with 9 GCP's have better accuracy than IKONOS ortho-images with 7 GCP's. And, Quickbird ortho-images having 4 / 5 GCP's have an accuracy

that is very close to aerial photographs (Atak and Altan, 2006). Moreover it has been detected that the accuracy is getting worse in IKONOS and getting better in Quickbird ortho-images if the number of GCP's decreases. The reason of this is the GCP's quality. Likewise the studies using SPOT HRS data by Reinartz *et al.* (2006) and CARTOSAT-1 data by Michalis and Dowman (2006) imply that the same accuracy can be reached with 3/4 GCP's as using 28/39 GCP's.

- Using direct sensor orientation parameters given by the companies (in 2002), IKONOS ortho-images have better accuracy than Quickbird ortho-images. But today, it is possible to reach better accuracy with new orientation parameters. In addition, systematic errors have been observed in the easting/north easting (across track) direction. In most studies it has been noted that the RMS geopositioning accuracy is just below $\frac{1}{4}$ pixel in the cross-track direction and close to $\frac{1}{2}$ pixel in both the along-track direction and in height (Hanley and Fraser, 2004). And a significant portion of the easting errors may have been due to variations in satellite elevation, especially when the IKONOS satellite imaged at low elevation angles (Helder *et al.*, 2003; Yamakawa and Fraser, 2004).

- The results obtained from orthophotos using IKONOS-DEM and photogrammetric DEM are very close. Therefore IKONOS-DEM can be used instead of photogrammetric DEM.

- After evaluating of the gross error positions, it is determined that they are mostly (25 of 27 - % 92.6) located on the edge / outside of GCP network or on rough area where the height differences are very high. In the same way Bouillon *et al.* (2006) determine that the errors are getting bigger if the slope increases (Figure 2).

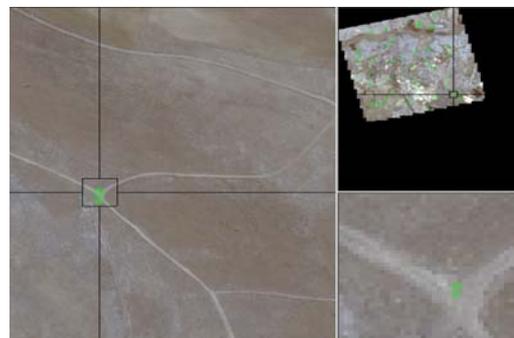


Figure 2. The check point which has the biggest error

- Finally, the results show that the stereo IKONOS image has the best accuracy and stereo IKONOS image allows mapping processes up to 1:6.000 scale. On the other hand, it is possible to realize mapping processes up to 1:7.000 - 1:7.500 scale from mono satellite ortho-images.

4. FEATURE COMPILATION ASSESSMENT

4.1 Mapping Areas and Map Productions

Three regions which have different characteristics have been selected in the study area for feature compilation analyses. Some criteria were taken into consideration in selection of compilation areas (Atak and Altan, 2006). First; the areas have

to be inside of the GCP's/CP's network, second; the areas should have different feature types and a significant height difference, lastly; the areas should be reachable with vehicles for control operations in field.

1:5.000 scale was selected for compilation processes because of on-going discussions about usage of high resolution space imagery in big scale (especially in 1:5.000 or greater scale) map productions. The selected 3 regions have height differences about 110 m, 250 m and 220 m respectively.

In mapping researches it is very seldom to see compilation assessments in which all features have been detected and investigated using detailed layer information. The most comprehensive researches in topographic mapping from high resolution satellite images are applied by the OEEPE (European Organization for Experimental Photogrammetric Research, now renamed EuroSDR) using IKONOS imagery and by Ordnance Survey (UK) using Quickbird imagery (Holland *et al.*, 2002; Holland and Marshall, 2004; Holland *et al.*, 2006). Especially in the project applied by the Ordnance Survey, for each of the features the requirements for capture were broken down into three different levels – high, medium and low. In high level the feature must be identifiable and in medium level it would be desirable to identify the characteristic of the feature while in low level it would be of some minor interest to identify further characteristic of the feature. And for each feature type, the cartographers recorded whether or not the features could be successfully identified from the image (Holland *et al.*, 2006).

From the other side, in our project, three different experienced operators compiled all features on these regions (roads, buildings, water features, forests, hedges, communication and electricity transmission lines etc.) using mono satellite and stereo aerial images for 1:5.000 scaled map productions. In compilation processes, the operators have followed all the standard procedures applied in General Command of Mapping for producing big scale map (Figure 3).

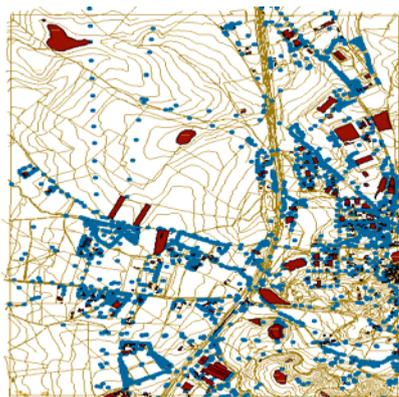


Figure 3. Compilation of first region by stereo aerial images

4.2 Comparison of Compilations

The map productions from different sources (Ikonos, Quickbird and aerial images) have been compared within each other and the compiled features have been controlled in field. In the comparison studies; firstly, the numbers of features in text, line, polygon and point layers have been detected, controlled and compared by using these software. In this stage, aerial photographs have been selected as reference data because the

numbers of features compiled in aerial photographs were more than satellite images (Table 5).

		Line	%	Polygon	%	Point	%	Total	%
1. Sheet	Aerial Photo	1894	100	541	100	2242	100	4677	100
	Ikonos	776	41.0	338	62.5	1189	53.0	2303	49.2
	Quickbird	891	47.0	348	64.3	1068	47.6	2307	49.3
2. Sheet	Aerial Photo	529	100	53	100	242	100	824	100
	Ikonos	295	55.8	26	49.1	186	76.9	507	61.5
	Quickbird	285	53.9	18	34.0	111	45.9	414	50.2
3. Sheet	Aerial Photo	746	100	84	100	384	100	1214	100
	Ikonos	397	53.2	77	91.7	471	122.7	945	77.8
	Quickbird	424	56.8	61	72.6	475	123.7	960	79.1
Total	Aerial Photo	3169	100	678	100	2868	100	6715	100
	Ikonos	1468	46.3	441	65.0	1846	64.4	3755	55.9
	Quickbird	1600	50.5	427	63.0	1654	57.7	3681	54.8

Table 5. The number of details compiled on images

Secondly, the features compiled from different sources have been located one on the top of the other and detected the differences between operators.

4.3 Control of Compilations in Field

It is noted that changes of large features such as those associated with building developments and major road improvements are often detected using established methods (either from local authority planning offices, building developers or bespoke change detection service providers) (Holland *et al.*, 2006). It is due to the fact that small objects or boundaries are unclear and can not be identified properly, some other sources of information like cadastral information or field survey are used (Alexandrov *et al.*, 2004). Therefore, this study has been carried out as control and completion applications in field in October 2005 by two personnel. But because of season conditions and vehicle capabilities, it was not possible to pass over some roads.

And lastly, the feature layers have been evaluated in detail. In compilation processes, 437 features classified in 62 layers have been used. So, every feature layer in every sheet has been compared aerial photographs (Table 6).

Layer No	Feature Names in Layer	Number of Detected Features		Compilation Percentages
		Aerial Photo	Quickbird	%
5	Rocks and stony place	22	-	0.0
31	Water depot	1	-	0.0
42	Telephone/Radio line/station	2	-	0.0
43	Sporting facilities	6	-	0.0
44	Single grave or graveyard	2	-	0.0
49	Pipe line and sewerage	3	-	0.0
51	Ditch, set and tumulus	43	-	0.0
27	Lean-to roof	397	13	3.3
48	Telephone/Electric pole, lamp	321	32	10.0
20	Pavement	183	30	16.4
50	Slope and natural split	183	31	16.9
12	Water well and canal	9	2	22.2
45	Electric line and transformer	53	18	34.0
38	Hedge, wire fence, railing	245	95	38.8
14	Water tower, small lake, winch	10	4	40.0
16	Ownership border	235	99	42.1
11	Stream, spring, marsh	20	9	45.0
26	Building under construction	19	9	47.4
39	Bushes, orchard, tree	1758	1015	57.7
21	Country road, footpath	543	375	69.1
13	Fountain and pool	14	12	85.7
25	Private building	249	225	90.4
36	Factory, chimney, factory hut	41	48	117.1
17	Disapproval ownership border	94	120	127.7
46	Patrol station and pump	6	8	133.3
15	Tunnel, bridge, stop	67	108	161.2
40	Tree, forest area, green house	18	51	283.3
41	Park and garden	-	1	+ 1
22	Under- and top-passage	-	2	+ 2

Table 6. Comparison of feature layers compiled on Quickbird satellite images in 1. sheet

In field control application, the control of outputs of compilations belong to aerial photographs has been carried out firstly because most of the data have been compiled on aerial photographs. While determining an error during the controls, brief notes have been taken on the outputs about the errors and then these errors have been controlled on the outputs of compilations belong to high resolution satellite images. The attributes of features controlled and the errors determined have been investigated on laptop and lastly taking all these data into consideration, it has been tried to evaluate the compilations. Because of long time interval between images and field controls, some difficulties have been encountered in finding and detection of features on Gölbaşı region which is growing very quickly.

4.4 Feature Compilation Assessment Results

Using high resolution satellite data, the feature types that are required for 1:10.000 to 1:50.000 scale mapping could be satisfactorily identified and captured. In some cases, features required for larger scale mapping (e.g. roads and woodland

boundaries) could also be identified. But as may be expected, it is impossible to distinguish the narrow linear features (such as electricity transmission lines, shapes of buildings, boundaries, walls, fences and hedges) on satellite imagery. A combination of panchromatic and multispectral imagery can help to differentiate between vegetation and artificial features (e.g. between hedges and walls) but in general the imagery is unsuitable for the capture of these narrow linear features (Holland and Marshall, 2004; Holland *et al.*, 2006).

Feature compilation assessment results show that high resolution satellite images couldn't reach to the level of aerial photographs in determining/identifying of small features yet. As a result, concerning compilation applications, we can say that;

- The number of features compiled from Quickbird and IKONOS ortho-images was approximately equal and we determined that the nearest values to the aerial photographs was obtained firstly in polygon layer (% 63 - 65), secondly in point layer (% 57 - 64) and lastly in line layer (% 46 - 50).

- Quickbird orthophotos showed better performance in line layer and IKONOS orthophotos have shown better performance in point layer.

- The features which were almost not compiled at all in high resolution satellite images (% 0 - 10) and acquired in aerial photographs are; telephone and electric poles, borders, rocks, stony and sandy places, lean-to roofs and pavements. The features compiled in minimum number (% 10 - % 40) are; slopes, natural splits, telephone and electric poles, water wells, canals, transformers, trees and forest area. The features compiled in number of % 40 - % 70 are; streams, springs, hedges, railings and walls, tunnels, bridges, fountains and bushes. And the features compiled in best number (% 70 - % 100) compared aerial photographs are; country roads, footpaths and single buildings.

As an overall assessment for field control applications, we can say that the operators have had some difficulties in determining and identifying of some features existing in high resolution satellite images. These features are; water wells and transformers taking place in every private country house, communication and electricity transmission lines in dense residence areas, electric/illumination poles, wire hedges, small huts and lean-to roofs. And these results indicate that high resolution satellite imagery can be used to identify topographic changes for both large- and small-scale mapping, even if this imagery cannot be used as a source of direct topographic data capture (Holland *et al.*, 2006).

5. CONCLUSION

In summary, it can be said that;

- IKONOS-DEM can be used instead of photogrammetric DEM produced from 1:16.000 scaled aerial images and the GCP quality which depends on well spread distribution and easy recognition is as important as the number of GCP's.

- When using direct sensor orientation parameters, IKONOS images have better accuracy than Quickbird images. In addition, systematic errors have been observed in the easting/north easting (across track) direction.

▪ The compilation performance of features in Quickbird and IKONOS ortho-images were approximately the same. And the nearest value of compilation to the aerial photographs were obtained in polygon layer. But; Quickbird orthophotos have shown better performance in line layer and IKONOS orthophotos exhibit better performance in point layer.

▪ In compilation of high resolution satellite images, the operators faced difficulties in determining and identifying of some small and complex features available.

Also the geometric accuracy and feature compilation assessment results show that the high resolution satellite images can be used in mid/large scale (1:6.000 to 1:10.000) mapping processes and these images couldn't reach to the level of aerial images in determining and identifying of small features yet. Lastly, in next researches, it is recommended to establish a system of artificially marked points that augment the few existing photo-identifiable man-made features. These panel markers provided clearly identifiable points for which to compare the image pixel locations to the GPS coordinates (Helder *et al.*, 2003).

REFERENCES

- Alexandrov, A., Hristova, T., Ivanova, K., Koeva, M., Madzharova, T., Petrova, V., 2004. Application of Quickbird satellite imagery for updating cadastral information, XX. Congress of International Society for Photogrammetry and Remote Sensing (ISPRS), Commission II, Working Group II/6, 12-23 July 2004, İstanbul-Türkiye.
- Atak, V. O. and Altan, M. O., 2006. Geometric accuracy and feature compilation assessment of high resolution satellite images, Proceedings of the ISPRS Commission IV Symposium on Geospatial Databases for Sustainable Development, 27-30 September 2006, Goa-India, Vol. 36, Part 4, pp. 460-465.
- Baltsavias, E., Li, Z., Eisenbeiss, H., 2006. DSM Generation and Interior Orientation Determination of Ikonos Images Using a Testfield in Switzerland, *Photogrammetrie-Fernerkundung-Geoinformation*, E. Schweizbart'sche Verlagsbuchhandlung, Stuttgart-Germany, 1, 41-54.
- Bouillon, A., Bernard, M., Gigord, P., Orsoni, A., Rudovski, V., Baudoin, A., 2006. Spot 5 HRS Geometric Performances: Using Block Adjustment As a Key Issue to Improve Quality of DEM Generation, *ISPRS Journal of Photogrammetry and Remote Sensing*, 60, 134-146.
- Erdoğan, M., 2008. Investigation of DEM standarts according to data types, quality and production methods. Ph. D. Thesis, İstanbul Technical University, İstanbul-Türkiye.
- Fraser, C. S., Dial, G., Grodecki, J., 2006. Sensor orientation via RPCs. *ISPRS Journal of Photogrammetry & Remote Sensing*, 60, pp. 182-194.
- Hanley, H. B. and Fraser, C. S., 2004. Sensor orientation for high-resolution satellite imagery: Further insights into bias-compensated RPCs. XX. Congress of ISPRS, Commission I, WG I/2, 12-23 July 2004, İstanbul-Türkiye.
- Helder, D., Coan, M., Patrick, K., Gaska, P., 2003. IKONOS geometric characterization. *Remote Sensing of Environment*, No: 88, pp. 69-79.
- Holland, D., Guilford, R., Murray, K., 2002. *OEEPE Official Publication*, No.44, OEEPE Project on Topographic Mapping from High Resolution Space Sensors.
- Holland, D. and Marshall, P., 2004. Updating maps in a well-mapped country using high resolution satellite imagery. XX. Congress of ISPRS, Commission II, WG II/6, 12-23 July 2004, İstanbul-Türkiye.
- Holland, D. A., Boyd, D. S., Marshall, P., 2006. Updating topographic mapping in Great Britain using imagery from high-resolution satellite sensors. *ISPRS Journal of Photogrammetry & Remote Sensing*, 60, pp. 212-223.
- İşcan, L., Aksu, O., Önder, M., Atak, V.O., Lenk, O., Gürdal, M.A., 2004. Accuracy assessment of high resolution satellite images. XX. Congress of ISPRS, Commission IV, Working Group IV/7, 12-23 July 2004, İstanbul-Türkiye.
- Li, R., Zhou, G., Yang, S., Tuell, G., Schmidt, N. J., Fowler, C., 2000. A study of the potential attainable geometric accuracy of IKONOS satellite imagery. IX. Congress of ISPRS, WG IV/6, 16-23 July 2000, Amsterdam-Holland.
- Michalis, P. and Dowman, I., 2006. Sensor model evaluation and DEM generation for CARTOSAT-1, *Proceedings of the ISPRS Commission IV Symposium on Geospatial Databases for Sustainable Development*, 27-30 September 2006, Goa-India, IAPRS&SIS, Vol. 36, Part 4, pp. 1009-1013.
- Reinartz, P., Müller, R., Lehner, M., Schröder, M., 2006. Accuracy analysis for DSM and orthoimages derived from SPOT HRS stereo data using direct georeferencing. *ISPRS Journal of Photogrammetry&Remote Sensing*, 60, pp. 160-169.
- Topan, H., Büyüksalih, G., Jacobsen K., 2004. Comparison of information contents of high resolution space images. XX. Congress of ISPRS, WG IV/7, 12-23 July 2004, Türkiye.
- Volpe, F., 2003. Geometrical processing of Quickbird high resolution satellite data. Joint ISPRS/EARSEL International Workshop 'High Resolution Mapping from Space', 6-8 October 2003, Hannover-Germany.
- Yamakawa, T. and Fraser, C.S., 2004. The affine projection model for sensor orientation: experiences with high-resolution satellite imagery. XX. Congress of ISPRS, Commission I, Working Group IV/5, 12-23 July 2004, İstanbul-Türkiye.

ACKNOWLEDGEMENTS

Thanks to General Command of Mapping for great contributions to this study. And thanks to Inta (Turkey) and Eurimage (Italy) for their data support.