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ACCURACY ASSESSMENTS OF GÖKTÜRK-1 SATELLITE IMAGERY

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ABSTRACT: Optical satellite imagery has an important place today in terms of responding to the increasing need for geospatial base in many different fields and disciplines, especially because of their availability and temporal resolution. Because all kinds of geospatial information and data production processes such as orthoimages, maps, vector data and etc. in especially for large project areas provide the opportunity to reduce the cost and time required in the field work, so the interest in high resolution satellite imagery. Göktürk-1, an electro-optical satellite that was launched on December 5, 2016 and acquiring 0.50 m spatial resolution imagery, aims to meet the high resolution image requirements of Turkey.

In this study, the horizontal and vertical accuracy of the Digital Surface Model and orthoimages produced by different methods from stereo images obtained from Göktürk-1 satellite in two different regions were investigated. As a result, although the pointing accuracy and the Digital Surface Model accuracy produced from Göktürk-1 satellite imagery, will vary according to the incidence angle of Göktürk-1 satellite, the Digital Terrain Model used in the production of the orthoimage, the selected method for orientation of satellite imagery; a planimetric accuracy of better than ± 2 m RMSE in orthoimage and a height accuracy of better than ± 3 m RMSE is accomplished.

Keywords: *Göktürk-1, Satellite Imagery, Orthoimage, Orthorectification, Digital Surface Model, Geometric Accuracy*

1. INTRODUCTION

Göktürk-1 satellite was launched from French Guiana on December 5, 2016 with the VEGA system of the European Space Agency. Within the scope of the project, 1 Satellite (0,5 m Electro-Optic), 1 Main Ground Station and 1 Mobile Ground Station were provided.

Göktürk-1 has a flexible view direction. The satellite also has the ability of acquiring 902 spot (15 km x15 km) images and downloading and processing 278 frames (spot) images per day. Direct sensor orientation accuracy of the Göktürk-1 satellite is ± 10 m without using a Ground Control Point (GCP) for images up to 10° incidence angle; ± 2 m if sufficient accurate GCPs are provided (Telespazio, 2017, I). The satellite has stereo imaging capability.

The satellite orbits the Earth every 98 minutes, and within 24 hours a total of 14 tours (some days 15). The revisit time of the satellite to display any region of the world is between 2-3 days with an incidence angle of $\pm 30^\circ$. When the incidence angle is $\pm 5^\circ$, the revisit time increases to approximately 11 days. The technical characteristics of the satellite are presented in Table 1 (Telespazio, 2017, II).

Table 1. Technical Specifications of Göktürk-1

Specifications	Göktürk-1 Satellite
Orbit Type	Sun Synchronous
Orbit Altitude	681 km
Inclination Angle	$98,11^\circ$
Period	98 min. 11 sec.
Spot Size	15 km X 15 km
Swath Width	15 km
Strip Length	780 km / 14.300 km
Spatial Resolution	0,5 m PAN – 2 m RGB
Radiometric Resolution	11-Bit
Positional Accuracy	
Horizontal	10 m (without GCP), 2 m (with GCP)
Vertical	20 m (without GCP), 3 m (with GCP)
Spectral Bands	PAN, RGB, NIR
Number of Orbits per Day	14-15 (14,7)
Revisit Time	2-3 days ($\pm 30^\circ$ incidence) 11 days ($\pm 5^\circ$ incidence)
Satellite Life	7 years 3 months

Data processing levels and descriptions of GÖKTÜRK-1 satellite images are given in Table 2 (Telespazio, 2017, III).

Table 2. Göktürk-1 Imagery Levels

Image Levels	Definition
Level-0 (L0)	Raw Image
Level-1 (L1)	Radiometric corrected image
Level-2A (L2A)	Geometrically corrected image
Level -2B (L2B)	The image obtained by the L2A image being georectified according to the WGS84 reference system
Level-3A (L3A)	Orthorectified image using Rational Polynomial Coefficients (RPC)
Level -3B (L3B)	Georeferenced and calibrated orthorectified image using GCPs
Level -4 (L4)	Digital Elevation Model (DEM)
Level -5 (L5)	Mosaic image
Level -6 (L6)	Thematic map (Classification)

Rational Function Model Coefficients instead of the physical sensor parameters of the satellite images are provided to the users in order to orient the satellite images. (Tao and Hu, 2002). Since rational functions are proportions of polynomials, they are also called Rational Polynomial Coefficients (RPC). RPCs provided with satellite images can be improved by using different distribution and number of GCPs (Die et al. 2003).

The geometric orientation accuracy of the satellite images using RPC and/or GCP has been assessed in several studies. Cheng and Chaapel (2010) performed 46 cm resolution Worldview-2 satellite geometric accuracy test. They succeeded 2.6 m and 1.3 m accuracies in X and Y directions respectively without using GCPs; obtained 0.7 m and 1.0 m accuracy in X and Y directions respectively using only one GCP. Yilmaz et al. (2016) used aerial photographs and 46 cm resolution Worldview-2 satellites to compare the geometric orientation accuracy. They obtained 1.9, 1.2 m and 2.2 m in X, Y and Z directions respectively without using any GCP. They also obtained one-pixel accuracy in the X and Y directions using a GCP; it at the level of two pixels was in the Z direction.

Because Göktürk-1 has stereo viewing capability, it is possible to produce Digital Elevation Models (DEMs) from stereo or tri-stereo constellations of the imagery. The method for the DEM production from satellite imagery is matching the conjugate points on the overlapped imagery and then apply coplanarity conditions in photogrammetry.

Numerous studies have been conducted to produce DEMs from high resolution satellite imagery. Among the latest ones is the study conducted by Wang et al. (2019). They produced DEM from Worldview-2 stereo imagery and used for active tectonics. They obtained 1.8 m accuracy without using GCPs and 0.4 m by using GCPs.

Another comprehensive study was held by Perko et al. (2019). In a study by using Pleiades satellite stereo imagery, they reached 1.68 m standard deviation in height

in Innsbruck test site by comparing higher accuracy LIDAR data.

In this study, the orthoimagery and the Digital Surface Model (DSM) accuracy produced from stereo Göktürk-1 satellite images in Serik/Antalya region was examined and results were presented.

2. THE SATELLITE IMAGERY AND STUDY AREA

For the horizontal and vertical position accuracy of Göktürk-1 satellite images, two pairs of stereo satellite images covering Serik district of Antalya province and two mono images covering Etimesgut and Yenimahalle districts of Ankara were used. One of the images used in both regions has a low incidence angle (near nadir) and the other is a high incidence angle (far nadir). Also convergence angle was calculated according to Li et al. (2007). Image properties are presented in Table 3.

Table 3. Göktürk-1 Imagery Specifications

Region	Date Time	Incidence	Convergence	Level
Serik (Antalya)	201803310757	7°	32.08°	L2A
	201803310758	30°		L2A
Etimesgut Yenimahalle (Ankara)	201807060752	28°	35.25°	L2A
	201807270753	6.5°		L2A

The study areas are presented in Figure 1.



Figure 1. Göktürk-1 Image Pairs in Serik/Antalya and Etimesgut-Yenimahalle/Ankara

Serik test area is located on the south Mediterranean coast of Turkey and also on east side of Antalya city. The area is generally flat. The height ranges between 0 and 210 meters. The sea side is mostly built up with hotels.

Serik district center is a medium density built up area. The remaining parts of the test site are agricultural areas. Köprü Stream enters the area from northeast and arrives the sea at southeast. Acısu Stream enters the area from mid-west and arrives the sea at mid-south. The test area has some low hills (~200 meters) in the middle and north parts. The slope in general is between 0° and 5°. The maximum slope on the hilly parts is 30°.

Etimesgut test area is located on the middle of Turkey and also on the west side of Ankara city. The area is generally hilly. The height ranges between 795 and 1305 meters. Etimesgut district center is a high density built up area. The remaining parts of the test site are agricultural areas. There is no stream or lake in the area. The west and south parts are hilly (~1200 meters). The slope in general (%85) is between 0° and 20°. The maximum slope on the hilly parts is 30°.

GCPs and Check Points (CPs) used in the study for both regions are obtained from 30 cm Ground Sampling Distance (GSD) stereo aerial imagery acquired from Vexcel Ultracam Eagle large format digital aerial cameras with 70% forward and 30% side lap. These control points have a horizontal position accuracy of ± 0.5 m and a vertical position accuracy of ± 0.75 m. The aerial imagery acquisition was performed by General Directorate of Mapping (GDM).

In the orthoimage production, 10 m grid spacing Digital Terrain Model (DTM) produced by GDM was used instead of DTM obtained from stereo satellite images. This is because we want to investigate the accuracy of orthoimages produced from Göktürk-1 satellite imagery by external DTMs. As a result of the comparison of DTM with the CPs in Antalya and Ankara test regions, the vertical RMSEs were ± 3.49 m and ± 4.99 m respectively.

The resulting accuracy of orthoimages rely not only the exterior orientation parameters but also the DEM used in orthoimage production and off-nadir angle of the image. The influence of these error sources on orthoimage accuracy was investigated by Yilmaz and Erdogan (2020). They used an empirical model for defining the errors by using the DEM accuracy and off-nadir angle as variables. They found that vertical RMSE of ± 5 m of the DEM and off-nadir angles between 0° and 20° result ± 0.3 m and ± 1.2 m planimetric errors respectively in the orthoimages.

3. ACCURACY ASSESSMENTS OF GÖKTÜRK-1 SATELLITE IMAGERY

3.1 The Method in the Study

In this study, the orthoimages were produced by 7 different arrangements from near nadir images (low incidence angle) and 3 different arrangements from far nadir (high incidence angle) images in both datasets and the accuracy of these orthoimages was investigated.

DSM was produced by two different methods from both stereo data sets and their accuracy was investigated. Table 4 presents a summary of these methods used in the production of orthoimages and DSM.

The Orthoimages and the DSMs were produced by using PCI GXL and Erdas IMAGINE software.

Table 4. Summary for the arrangements in orthoimage and DSM production

Region	Product	Method					
		Direct Sensor Orientation	1 GCP	5 GCP	10 GCP	15 GCP	20 GCP
Antalya Ankara	Near nadir orthoimage	•	•	•	•	•	•
	Far nadir orthoimage	•	•		•		
Antalya	DSM	•	•				

3.2 Accuracy Assessment in Serik/Antalya Region

Three different methods were used for orthorectification of both near and far nadir Göktürk-1 imagery.

3D geopositioning accuracy of stereo Göktürk-1 pair in Serik was assessed with the same configuration stated in 3.2.1.2 section and the results were presented in Table 5. RMSE and CE90 were obtained from CPs.

Table 5. 3D geopositioning accuracy of Serik Göktürk-1 stereo pair

Number of GCPs	0	1	5	10	15	20
Number of CPs	44	43	39	34	29	24
RMSE _{xy} (± m)	7.67	1.33	1.02	0.84	0.82	0.83
CE90 (± m)	13.18	2.02	1.55	1.27	1.25	1.27
RMSE _z (± m)	1.54	1.08	0.75	0.78	0.76	0.75

3.2.1 Accuracy Assessment in Serik/Antalya Region of Near Nadir Imagery

Two L2A satellite images taken on 31 March 2018 were used in the study. Near nadir image has a 7 ° incidence angle, while a far nadir image has a 30 ° incidence angle. In the study area, 44 points were used as GCP or CPs. The distribution of the GCPs and CPs used in the test with the near nadir image is shown in Figure 2.



Figure 2. Near nadir image and the distribution of GCPs and CPs

3.2.1.1 Orthorectification with Direct Sensor Orientation

In the first method, only the provided RPC parameters was used to orient the satellite imagery and to produce orthoimages as direct sensor orientation. 44 GCPs presented in Figure 2 were used as CPs in order to assess the accuracy.

The statistics of the differences obtained as a result of the comparison between the CPs and orthoimage for the accuracy assessment of the orthoimages are presented in Table 6.

Table 6. Accuracy assessment of the orthoimages produced from Direct Sensor Orientation

Number of GCPs	0
Number of CPs	44
RMSE _{xy} (m)	± 8.48
CE90 (m)	± 12.87

3.2.1.2 Orthorectification by Using GCPs

Göktürk-1 imagery was oriented and orthorectified by using different number of GCPs obtained from stereo aerial imagery. 1, 5, 10, 15 and 20 GCPs were used in orthorectification process. In the first GCP arrangement, only GCP# 131 was used. In the second GCP arrangement, GCP# 103, 119, 123, 131 and 134 were used. In the third GCP arrangement, GCP# 103, 104, 119, 121, 123, 124, 125, 131, 134 and 138 were used. In the fourth GCP arrangement, GCP# 103, 104, 110, 111, 118, 121, 123, 125, 130, 131, 133, 134, 138, 139 and 143 were used. In the fourth GCP arrangement, GCP# 103, 104, 106, 108, 110, 111, 116, 118, 119, 121, 123, 124, 125, 130, 131, 133, 134, 138, 139 and 143 were used. The distribution of GCPs can be traced in Figure 2.

The statistics of the differences obtained as a result of the comparison between the GCPs and orthoimages are presented in Table 7.

Table 7. Accuracy assessment of orthoimages produced by using GCPs

Number of GCPs	1	5	10	15	20
Number of CPs	43	39	34	29	24
RMSE _{xy} (m)	± 1.47	± 1.14	± 1.06	± 1.25	± 0.74
CE90 (m)	± 2.23	± 1.73	± 1.61	± 1.90	± 1.12

3.2.2 Accuracy Assessments in Serik/Antalya Region of Far Nadir Imagery

Orthoimages from the far nadir 30 ° incidence angle at L2A level Göktürk-1 satellite images were produced and analyzed using 1 and 10 GCPs obtained from the stereo models generated from aerial photos of Antalya region in 2015 together with RPC parameters. The distribution of the GCPs or CPs used in the assessment is shown in Figure 3.



Figure 3. Distribution of 51 GCPs and CPs with the far nadir image.

3.2.2.1 Orthorectification with Direct Sensor Orientation

In the first method applied to examine the horizontal positional accuracy of the far nadir image, orthorectification was performed using RPC model determined directly from the orbit parameters and the accuracy of the orthoimage was assessed with 51 CPs shown in Figure 3.

The statistics of the differences obtained as a result of the comparison made at the CPs in order to determine the accuracy of the produced orthoimage are presented in Table 8.

Table 8. Accuracy assessment of orthoimages produced by RPC parameters

Number of GCPs	-
Number of CPs	51
RMSE _{xy} (m)	± 11.14
CE90 (m)	± 16.90

3.2.2.2 Orthorectification with GCPs

The orthoimage is produced by using 1 and 10 GCPs. In the first GCP arrangement, only GCP# 142 was used. In the second GCP arrangement, GCP# 103, 104, 119, 122, 134, 135, 136, 143, 150 and 151 were used. The distribution of GCPs can be traced in Figure 2. The accuracy of the orthoimages is assessed by the CPs that were not used as GCP.

The accuracy assessment of the produced orthoimage by using CPs is presented in Table 9.

Table 9. Accuracy assessment of orthoimages produced by using GCPs

Number of GCPs	1	10
Number of CPs	50	41
RMSE _{xy} (m)	± 2.72	± 2.39
CE90 (m)	± 4.13	± 3.63

As a result of the horizontal accuracy assessment performed in Serik/Antalya region; after orthorectifying the image with an incidence angle of 7° only with RPC parameters, the horizontal positional accuracy was ± 12.87 m in 90% confidence interval, and if the orientation parameters were improved using different quality and number of GCPs, the same accuracy value was changed between ± 1.12 m and 2.23 m.

As a result of orthorectifying an image with an incidence angle of 30° only with RPC parameters, the horizontal positional accuracy is ± 16.90 m in the 90% confidence interval, and if the orientation parameters are improved by using 1 and 10 GCPs, the same accuracy value is determined ± 3.63 m to 4.13 m respectively.

Approximately 1.60 m of the decrease in accuracy due to the increase in incidence angle and the DTM used in the production of orthoimages which has an accuracy of approximately 3.50 m in this region.

3.2.3 Accuracy Assessment of DSM

In order to investigate the vertical accuracy, DSM was produced by two different methods. In the first method, DSM was created by using RPC model determined by direct sensor orientation; in the second method, DSM was produced using only 1 GCP. The accuracy of the DEMs produced by both methods was checked with CPs.

3.2.3.1 DSM Production with Direct Sensor Orientation

The accuracy of the DSM produced by direct sensor orientation using only the RPC model was checked by the GCPs presented in Figure 3 as CPs. The statistics on the vertical accuracy statistics of the DSM are presented in Table 10.

Table 10. Accuracy assessment of DSM produced by RPC parameters

Number of GCPs	-
Number of CPs	44
RMSE _z (m)	± 2.84
LE90 (m)	± 4.67

3.2.3.2 DSM Production with GCPs

In the second method, DSM was produced by improving the RPC model by using 1 GCP obtained from the stereo models described in Chapter 2 and presented in

Figure 4. The accuracy of the DSM was checked with the remaining GCPs by using as CPs.

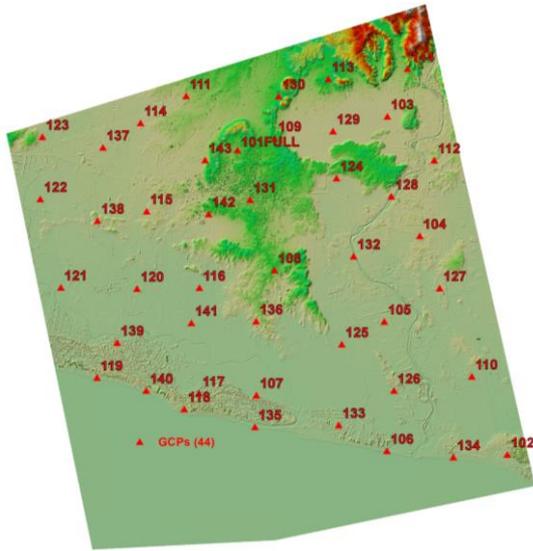


Figure 4. The distribution of CPs

The statistics of the differences obtained as a result of the comparison made at the CPs in order to determine the accuracy of the produced DSM are presented in Table 11.

Table 11. Accuracy assessment of DSM produced by using 1 GCP

Number of GCPs	0	1
Number of CPs	44	43
RMSE _z (m)	± 2.84	± 1.30
LE90 (m)	± 4.67	± 2.14

As a result of the vertical accuracy assessment performed in Serik/Antalya region; it was determined that the accuracy of DSM produced by only RPC parameters from a pair of stereo images was ± 4.67 m in 90% confidence interval and the accuracy of DSM produced by using 1 GCP was ± 2.14 m in 90% confidence interval.

The obtained DSM compared with a superior accuracy reference DSM. This reference DSM is the 5 meters grid spacing DSM produced from 30 cm GSD aerial photos. Detailed information about the reference DSM can be found in Yılmaz and Erdogan (2018). Its' height accuracy is ± 1.3 meter (LE90). Figure 5 shows the difference histogram and accuracy statistics. Even outliers in approximately 50 meters exist, the standard deviation is 1.87 meters.

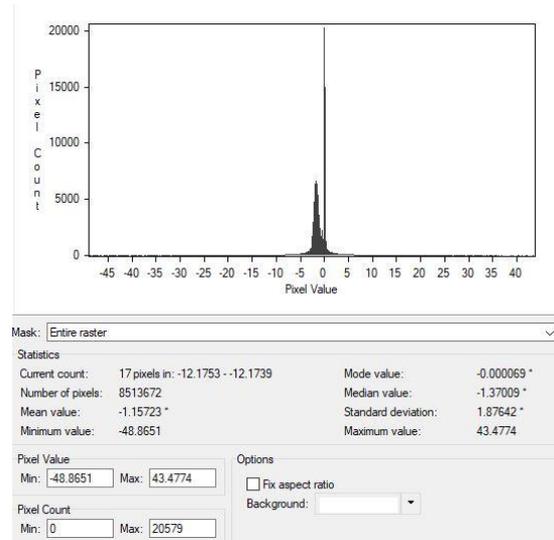


Figure 5. Comparison of Göktürk-1 direct sensor orientation DSM with reference DSM.

3.3 Accuracy Assessment Etimesgut-Yenimahalle/Ankara Region

3.3.1 Accuracy Assessment in Etimesgut-Yenimahalle/Ankara Region of Near Nadir Imagery

L2A level 6.5 ° incidence angle Göktürk-1 satellite image was used to produce orthoimage by using GCPs. 30 GCPs was obtained from the stereo the aerial photos of Ankara region acquired in 2018. The distribution of GCPs is shown in Figure 6.

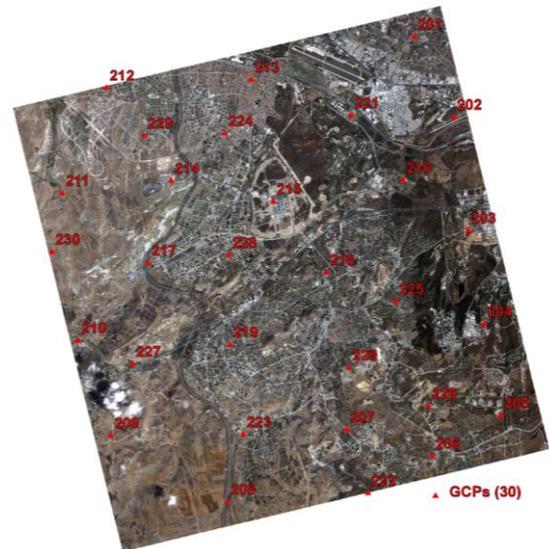


Figure 6. The distribution of 30 GCPs

3.3.1.1 Orthorectification with Direct Sensor Orientation

In the first method to assess the horizontal positional accuracy of the near nadir image, the orthorectification was performed using the RPC model determined directly

from the orbit parameters and the accuracy of the orthoimage was checked with 30 CPs presented in Figure 5.

The statistics of the differences obtained from the comparison at the CPs in order to determine the accuracy of the produced orthoimage are presented in Table 12.

Table 12. Accuracy assessment of the orthoimage produced by using direct sensor orientation

Number of GCPs	-
Number of CPs	30
RMSE _{xy} (m)	± 5.51
CE90 (m)	± 8.36

3.3.1.2 Orthorectification by using GCPs

1,5,10,15 and 20 GCPs obtained from the stereo aerial photos described in Section 2 were used as GCPs and the remaining are as CPs. In the first GCP arrangement, only GCP# 218 was used. In the second GCP arrangement, GCP# 201, 205, 209, 211 and 218 were used. In the third GCP arrangement, GCP# 201, 203, 205, 208, 209, 211, 212, 213, 218 and 222 were used. In the fourth GCP arrangement, GCP# 201, 203, 204, 205, 208, 209, 210, 211, 212, 213, 215, 217, 219, 222 and 225 were used. In the fourth GCP arrangement, GCP# 201, 202, 203, 204, 205, 207, 208, 209, 210, 211, 212, 213, 215, 217, 218, 219, 220, 221, 222 and 225 were used. The distribution of GCPs can be traced in Figure 6. The accuracy of the orthoimages was assessed by the CPs presented in the same figures stated above.

The statistics of the differences obtained from the comparison at the CPs in order to determine the accuracy of the produced orthoimages are presented in Table 13.

Table 13. Accuracy assessment of the orthoimage produced by using different numbers of GCPs

Number of GCPs	1	5	10	15	20
Number of CPs	29	25	20	15	10
RMSE _{xy} (m)	± 0.77	± 0.76	± 0.95	± 0.88	± 0.98
CE90 (m)	± 1.17	± 1.15	± 1.44	± 1.34	± 1.49

3.3.2 Accuracy Assessment in Etimesgut-Yenimahalle/Ankara Region of Far Nadir Imagery

Orthoimages from the far nadir 28 ° incidence angle at L2A level Göktürk-1 satellite images were produced and analyzed using 1 and 10 GCPs obtained from the stereo models generated from aerial photos of Antalya region in 2018 together with RPC parameters. The distribution of the GCPs and CPs used in the assessment is shown in Figure 7.

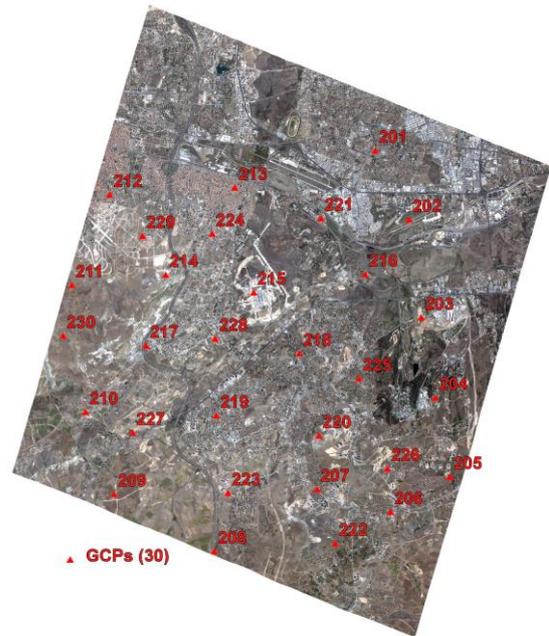


Figure 7. The distribution of 30 GCPs and the far nadir image

3.3.2.1 Orthorectification with Direct Sensor Orientation

In the first method to investigate the horizontal positional accuracy of the far nadir image, orthorectification was performed using the RPC model determined directly from the orbit parameters and the accuracy of the orthoimage was checked with 30 CPs presented in Figure 7.

The statistics of the differences obtained as a result of the comparison of the CPs in order to determine the accuracy of the orthoimage are presented in Table 14.

Table 14. Accuracy assessment of the orthoimage produced by using RPC

Number of GCPs	-
Number of CPs	30
RMSE _{xy} (m)	± 8.35
CE90 (m)	± 12.67

3.3.2.2 Orthorectification by Using GCPs

The orthoimage is produced by using 1 and 10 GCPs. In the first GCP arrangement, only GCP# 218 was used. In the second GCP arrangement, GCP# 201, 203, 206, 208, 210, 212, 213, 217, 218 and 230 were used. The accuracy of the orthoimages is assessed by the CPs that were not used as GCP.

The statistics of the differences obtained as a result of the comparison of the CPs in order to determine the accuracy of the orthoimage are presented in Table 16.

Table 15. Accuracy assessment of orthoimages produced by using GCPs

Number of GCPs	1	10
Number of CPs	29	20
RMSE _{xy} (m)	± 2.75	± 2.11
CE90 (m)	± 4.17	± 3.20

As a result of the horizontal accuracy analysis performed in Etimesgut-Yenimahalle/Ankara region; By the orthorectification of the image with 6.5° incidence angle with only using RPC parameters, the horizontal positional accuracy is ± 8.36 m in 90% confidence interval, and if the orientation parameters are improved using different quality and number of GCPs, the accuracy changes between ± 1.15 m and 1.49 m.

By the orthorectification of the image with 28° angle of incidence with only RPC parameters, the horizontal positional accuracy is ± 16.90 m in 90% confidence interval, and if the orientation parameters are improved by using 1 and 10 GCPs, the accuracy will be ± 3.20 m and 4.17 m respectively.

It is estimated that approximately 2.10 m of the decrease in accuracy due to the increase in incidence angle and also the DTM error, which is used in the production of orthoimages and has an accuracy of approximately 5.00 m in this region.

4. RESULTS AND DISCUSSION

Various arrangements are used in the orthorectification process of the Göktürk-1 satellite images. In this study, the orthoimage and the DSM were produced by using RPC parameters, reference orthoimages and GCPs obtained from the stereo aerial photos. The accuracy of the orthoimages and DSMs were investigated.

The results are summarized in Table 16 and 17.

Table 16. The summary of the accuracy assessment of the orthoimages

Image	Method	ANTALYA				ANKARA			
		Incidence Angle (7°)		Incidence Angle (30°)		Incidence Angle (6.5°)		Incidence Angle (28°)	
		RMSE _{xy} (m)	CE90 (m)						
Orthoimage	Direct Sensor Orientation	±8.48	±12.87	±11.14	±16.90	±5.51	±8.36	±8.35	±12.67
	1 GCP	±1.47	±2.23	±2.72	±4.13	±0.77	±1.17	±2.75	±4.17
	5 GCPs	±1.14	±1.73			±0.76	±1.15		-
	10 GCPs	±1.06	±1.61	±2.39	±3.63	±0.95	±1.44	±2.11	±3.20
	15 GCPs	±1.25	±1.90		-	±0.88	±1.34		-
	20 GCPs	±0.74	±1.12		-	±0.98	±1.49		-

Table 17. The summary of the accuracy assessment of the DSM

IMAGE	Method	ANTALYA	
		RMSE _z (m)	LE90 (m)
DSM	Direct Sensor Orientation	±2.84	±4.67
	1 GCP	±1.30	±2.14

From Göktürk-1 satellite imagery with an incidence angle near nadir (up to 10 °):

- Without using GCP (only with RPC parameters, i.e. direct sensor orientation), in 90% confidence interval, orthoimages better than ± 10 m horizontal accuracy and DSMs better than ± 20 m vertical accuracy can be produced,

- If the orientation parameters are improved by using at least one GCP, it is possible to produce an orthoimage better than ± 2 m horizontal accuracy and DSMs better than ± 3 m vertical accuracy in 90% confidence interval,

- By using only 1 GCP, the accuracy of orthoimage and DSM is improved significantly, and there is no significant improvement in accuracy if more than 1 GCP is used, but it is important to use a large number of evenly distributed GCPs in order to ensure homogeneous accuracy throughout the image,

- Because the convergence angles are very close to each other, the effect of stereo geometry on geopositioning Göktürk-1 imagery cannot be differentiated.

5. CONCLUSIONS

The significant improvement of position by using only one GCP shows that a shift effect exists in both planimetry and vertical positioning of the satellite's RPC. Although using more than one GCP does not reflect meaningful improvement in geopositioning, it is always safe using more than one GCP. Because using one GCP susceptible to the random geopositioning errors of that GCP.

Further studies on Göktürk-1 imagery can be carried out especially about tri-stereo geopositioning accuracies and off-nadir accuracy change on the imagery that can be modelled.

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REFERENCES

Cheng P. and Chaapel C., 2010. Pan-sharpening and geometric correction of WorldView-2 satellite. GEOInformatics 2010:30-33

Di, K., Ma R. and Li R., 2003. Rational functions and potential for rigorous sensor model recovery. *Photogrammetric Engineering and Remote Sensing*, 69(1), 33-41

Li, R., Zhou F., Niu X., and Di K., 2007. Integration of Ikonos and QuickBird Imagery for geopositioning accuracy analysis. *Photogrammetric Engineering & Remote Sensing*, 73 (9):1067–1074.

Perko, R., Raggam, H. and Roth, P.M., 2019. Mapping with Pléiades—End-to-End Workflow. *Remote Sensing* 11 (17) 2052. DOI 10.3390/rs11172052

Tao, V. and Hu, Y. 2002. 3D Reconstruction methods based on the rational function model. *Photogrammetric Engineering Remote Sensing* 68(7):705–714

Telespazio, 2017 I. Göktürk-1 User Guide

Telespazio, 2017 II. Göktürk-1 System Specification Technical Notes

Telespazio, 2017 III. Göktürk-1 Product Specification Definitions Technical Notes

Wang, S., Ren, Z., Wu, C., Lei, Q., Gong, W., Ou, Q., Zhang, H., Ren, G. and Li, C., 2019. DEM generation from Worldview-2 stereo imagery and vertical accuracy assessment for its application in active tectonics. *Geomorphology*. 336:107-118. DOI 10.1016/j.geomorph.2019.03.016.

Yilmaz A., Erdogan M., Maras H.H., Aktug B. and Maras S.S., 2016. Did satellite imagery supersede aerial imagery? A perspective from 3D geopositioning accuracy. *Arabian Journal of Geosciences* (2016) 9: 324 DOI 10.1007/s12517-016-2386-x.

Yilmaz A. and Erdogan M., 2020. Modelling the orthoimage accuracy using DEM accuracy and off-nadir angle. *Geocarto International*, 35 (1), 1-16. DOI: 10.1080/10106049.2018.1493157.

Yilmaz A. and Erdogan M., 2018. Designing High Resolution Countrywide DEM For Turkey. *International Journal of Engineering and Geosciences*, 3 (3), 98-107. DOI: 10.26833/ijeg.384822.