Application of Satellite Imagery for Revision of Topographic Map of Sofia

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ABSTRACT

In this paper application of satellite imagery for producing of orthoimagery and revision of the topographic map of City of Sofia are described. Single panchromatic imagery from QuickBird satellite with 61 cm resolution in nadir is processed. Orthorectification by use of geodetical points and DEM generate from contours at 5 m is performed. The different approaches of geometric correction of the imagery are examined. The obtained accuracy for the check points is as follows: RMS ± 0.82 m, maximal 1.64 m.
The orthoimage is used for revision of the map at 1:5000 scale of a part of Capital Sofia.
Due to the limitation, imposed by the resolution of the satellite image, the information from the digital cadastral model of Sofia is used.
A comparative analysis of accuracy between orthoimagery and orthomosaic from aerial photographs is made.

1. Introduction

GIS SOFIA Ltd. belongs to the Municipality of Sofia, which main activity is creation and maintenance of the information system and digital models of cadastre and revision of maps in digital format. It incorporates nine departments, one of them is the Photogrammetry Department.

One of the assigned to the company tasks is revision of the topographic map of Sofia at 1:5000 scale. For this purpose information from the following sources has been used:
- Existing topographic map at 1:5000 scale.
- Satellite image obtained from QuickBird.
- Digital cadastral model of Sofia.

2. Large-scale topographic map

For the highly intensive activity regions of Bulgaria the large scale topographic map is produced at 1:5000 scale, and for the less intensive ones – high mountain and forest regions – at 1:10000 scale. For production as well for revision of the large-scale topographic map aerial sterephotogrammetry is in use.

The aim of large-scale topographic map is to represent the location, form, dimensions and crops of the separate units. All situation details and objects visible within the map scale, all hydrographic and transport object and structure, as well as the terrain relief have also to be shown.

The large-scale topographic map is intended for the investigation, designing and planning of economic activities, for the solutions of research problems, as well as for defense purposes. The content and scale of the topographic map is determined according to the purpose of its use in: agriculture, forestry, geological surveys, hydrographic and hydro-melioration activities, rural cadastre, etc.

The large-scale topographic maps for the territory of Bulgaria have been produced in 1970 Coordinate System and Baltic Sea Level Datum. Each map sheet with dimensions 50 x 50 cm of the map at 1:5000 scale covers 2.50 x 2.50 km = 6.25 km^2 from the Earth's surface. The graphical accuracy is not less than 0.4 mm in the scale of the map (1:5000) or 2 m on the terrain.

The large-scale topographic map is subject to periodic revisions depending on the respective needs. Due to the rapid change of the Capital Sofia infrastructure, it was necessary to revise the topographic map at 1:5000 scale for a part of the city. Main source of information for revision of the map was the orthorectified QuickBird satellite image.

3. Advantages of the satellite images

Setting out in orbit of the new generation of satellites, providing images with high resolution, which are available for civil purposes, widens considerably the areas of application of the satellite images. In some respects they compete with the aerial pictures, especially for small-scale mapping.

The use of satellite images has certain advantages, such as:

- The process of photographing of the land surface is continuous lasting for a period of 4 days. Owing to this the most appropriate image was chosen.
- The formalities for aerial photography and flight arrangement are avoided.
- The use of satellite images is less expensive than the aerial pictures.

Due to the above mentioned reasons GIS SOFIA Ltd. decided to use satellite imagery for revision of the topographic map at 1:5000 scale for a part of the territory of the Capital Sofia.

4. Main characteristics of QuickBird satellite imagery

4.1. Geometric resolution. Because of the large scale of the map an image, obtained by QuickBird is selected, which for the time being is with highest resolution – 61 cm in nadir for panchromatic image.

4.2. Radiometric resolution. Data obtained by QuickBird, have 11-bit dynamic range, which improves visualisation and makes them appropriate for use in urban territories.

4.3. Spectral range. According to the spectral range, the delivered images are grouped as follows:

- Panchromatic – with range of 450-900 nm.
- Multispectral – four channels with different spectral range:
    - Blue (450-520 nm).
    - Green (520-600 nm).
    - Red (630-690 nm).
    - Near-Infrared (760-900 nm).

4.4. Main products. QuickBird offers satellite images in three basic products depending on the level of processing of the rough image: Basic, Standard and Orthorectified.

- <u>Basic Imagery</u> appears to be the product with least additional processing. Just corrections for elimination of the radiometric and sensor distortion are made, and no other geometric corrections. It is delivered with additional files with information for efemerides, sensor position, etc. These data are needed for setting up of an rigorous sensor model. Basic Imagery is considered as most appropriate for further photogrammetric processing. Minimum order is a full scene 270-300 km^2.
- <u>Standard Imagery</u> is an image, which is corrected with respect to the radiometric, sensor, and platform-induced distortions and the topographic distortion, using the GTOPO30 digital elevation model. The image is georeferenced and is made in a pre-set cartographic projection. It is possible to order parts of the scene (minimum area of 25 km^2). A variety of this product is Ortho Ready Standard Imagery. It is appropriate for orthorectifying when using a ready digital elevation model.
- <u>Orthorectified Imagery</u> is a product, corrected for radiometric, sensor and topographic distortion. Usually for its orthorectification, digital elevation model and geodetic points are used, provided by the user. It is georeferenced and transformed into pre-defined cartographic projection.

4.5. Basic data about the selected image. The image is panchromatic Basic Imagery, which covers the central part of Sofia. It is an archive image, taken on 27 March 2003 at 09:17 hours GMT. The period, when the image was made, was very appropriate in view of vegetation of plants – hardly any leaves, which could stand in the way of important features. Although that early spring is characterized by unstable weather conditions, in this case they are extremely appropriate – 0 % clouds. The time interval between acquisition of the image and the time of its purchase and start of further processing for orthorectification and deriving the vector information is within a period of four months, which is completely satisfactory.

5. Geometric corrections

5.1. Use of 3D polynomial transformation in the range of entire image. The digital photogrammetric software PHOTOMOD 3.51 of RACURS Co. is used for processing of the image. However, the software package does not contain QuickBird sensor model. Hence transformation of the image is performed by 3D – polynomial transformations, derived on the basis of geodetically defined points.
A special feature of such transformations is that the polynomial coefficients have no physical meaning, in other words do not correspond to any geometric model. They are empirically obtained relations, which makes the result very much influenced by the number, location and accuracy of the ground control points in use.

Because of the nature of activity of GIS SOFIA Ltd. sufficient number of geodetically determined points is provided. Specific elements from the terrain, which are clearly visible on the image and defined at earlier geodetic surveys, are used. Despite the large number of ground control points the achieved accuracy is insufficient in the range of the entire image. In some areas the deviations are up to 4 – 5 m.

5.2. Use of 3D polynomial transformation in the range of a part of the image. The central part of the image, where the terrain is relatively flat (high differences of less than 250 m) is selected. There are 16 control and 19 check points used. The obtained maximum and RMS errors in position of the check points are 1.64 and ±0.82 m respectively. The residuals in X and Y directions, as well as the location of points are given in Table 1 and Figure 1.

Orthorectification by use of DEM, which is generated from contours at 5 m is performed. The obtained maximal displacement and RMS error in position of the check points are 1.74 and ±0.91 m respectively.

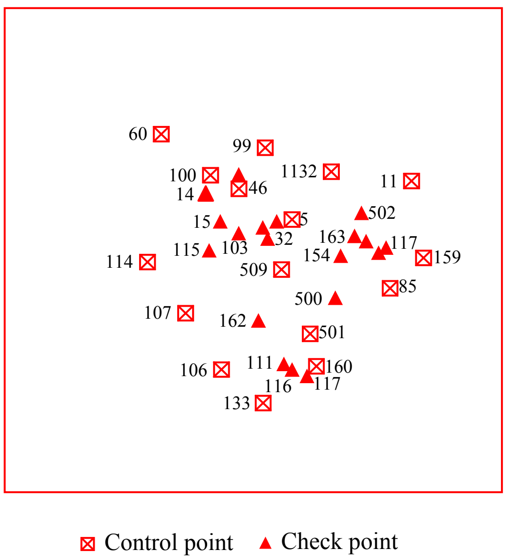

Figure 1. Points location within the imagery

Residuals in control points				Residuals in check points			
№	Point	Dx Pixels	dy Pixels	№	Point	dx Pixels	dy Pixels
1.	11	-0.456	-0.755	1.	14	-0.287	-0.813
2.	5	-0.104	0.306	2.	15	1.043	-1.081
3.	60	-0.003	-2.708	3.	152	0.297	1.405
4.	1132	0.102	1.918	4.	32	0.442	-0.771
5.	99	0.722	2.741	5.	33	1.992	0.209
6.	114	-0.268	-1.301	6.	154	2.035	-0.519
7.	46	0.466	0.322	7.	92	0.808	-0.548
8.	501	0.443	-0.164	8.	500	0.250	-1.612
9.	509	-0.855	0.750	9.	502	0.175	-0.743
10.	159	0.007	-0.849	10.	508	0.767	-0.296
11.	160	0.598	-0.126	11.	156	0.706	0.848
12.	85	0.044	-1.580	12.	162	1.044	-1.451
13.	100	-0.495	-0.641	13.	163	0.981	1.375
14.	106	0.681	-0.774	14.	165	-0.019	0.947
15.	107	-0.016	2.337	15.	103	-0.012	0.918
16.	133	-0.863	0.525	16.	111	0.318	1.005
				17.	115	0.177	1.700
				18.	116	-0.898	-0.404
				19.	117	-0.087	-0.825
RMS:		±0.49	±1.40	RMS:		±0.80	±1.01
MAX:		0.86	2.74	MAX:		2.04	1.70
Approximate ground displacement **[m]**				Approximate ground displacement **[m]**			
RMS:	±0.92			RMS:	±0.82		
MAX:	1.78			MAX:	1.64		

Table 1. The residuals in control and check points

The accuracy is verified also by superimposition of vector objects from the available cadastral information over the orthorectified image. The differences are within the obtained maximal displacement and RMS error.

The results show that, the use of 3D polynomial transformations, obtained on the basis of ground survey points, appears to be an unreliable approach, especially when applied for large territories. Its use for smaller regions with insignificant relief variations, when having sufficient number of control and check points, gives considerably better results.

5.3. Use of Rational Polynomial Coefficients (RPC), supplied by QuickBird, with further polynomial transformations. With the cooperation by RACURS Co. relatively good results in the range of the entire image are obtained. The software was upgraded, which gives the opportunity to include RPC, submitted together with the satellite image. They are such an empirical coefficients that, the obtained functions represent approximation of the rigorous sensor model. Their use is an alternative to application of accurate physical model of the sensor, especially for relatively flat terrain.

The following approach is used:

- Transformation by use of the RPC is made.
- The precision of the obtained result is increased by means of 3D polynomial transformations of the basis of points, measured by GPS.

For the experiment 8 control and 15 check points, normally distributed within the range of the image, are used. The obtained maximal displacement and RMS error in position of the check points are 2.56 and ±1.40 m, respectively. The errors in X and Y directions, as well as the location of points are given in Table 2 and Figure 2.

Residuals in control points				Residuals in check points			
№	**Point**	**dx Pixels**	**dy Pixels**	**№**	**Point**	**dx Pixels**	**dy Pixels**
1.	01	-0.030	-1.464	1.	04	-1.205	-2.700
2.	02	0.086	0.835	2.	07	-0.555	-0.598
3.	03	0.044	-1.555	3.	08	0.040	-1.328
4.	05	0.014	-0.561	4.	09	-0.559	-0.402
5.	06	-0.065	1.323	5.	13	0.772	0979
6.	11	-0.028	1.025	6.	14	-0.258	-2.342
7.	15	-0.181	0.072	7.	16	-1.101	-0.369
8.	22	0.160	0.325	8.	17	1.350	-3.238
				9.	19	0.542	-0.820
				10.	20	-2.052	1.334
				11.	21	2.316	-1.521
				12.	23	0.290	-2.606
				13.	24	-2.605	2.388
				14.	25	-0.389	2.010
				15.	26	0.997	-2.387
RMS:		0.10	1.03	RMS:		1.26	1.89
MAX:		0.18	1.56	MAX:		2.61	3.24
Approximate ground displacement **[m]**				Approximate ground displacement **[m]**			
RMS:		0.64		RMS:		1.40	
MAX:		0.97		MAX:		2.56	

Table 2. The residuals in control and check points

After the orthorectification the obtained maximal displacement and RMS error in position of the check points are 2.30 and ±1.54 m, respectively. The analysis of the results shows that this approach ensures the needed accuracy for scale 1:5000 in the range of the entire image.

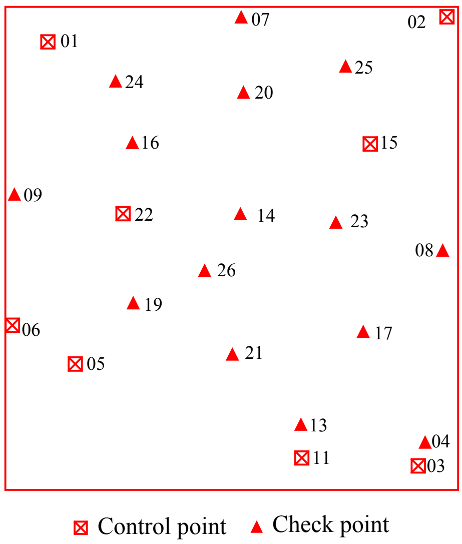

Figure 2. Points location within the imagery

Since these models do not correspond to the geometric relations it is better to be applied in cases, when sufficient additional information is available (points and vector objects), which information could be used for control of the orthorectified image.

6. Revision of the topographic map

The obtained orthoimage is used for revision of the map at 1:5000 scale. Due to the limitation, imposed by the resolution of the satellite image, not all objects can be identified with sufficient accuracy and clearness.

- The boundaries between separate properties are clearly visible, but hardly classified. The basic information about them is taken from the available digital model.
- Large residential and industrial buildings of a similar type are clearly visible on the image and can be plotted in accordance with the required accuracy.
- The small buildings and buildings with complex outline are not well recognised. In order to secure their accurate and proper representation, information from the digital model of cadastre and additional check (interpretation) and field surveys, are made.
- The streets, roads and separation strips are easy to be identified.
- Single train and tram rails are not clearly recognisable. The stations, however, are clearly visible.
- Water areas – lakes, swimming pools, dams, as well as their facilities are easily and accurately identifiable.
- Some of the water flows can be identified indirectly, while corrected river beds are clearly visible.
- It is impossible to identify the terrain elevation by a single scene (without a stereo-pair). In order to depict the relief contours, spot heights and break lines from the cadastre are used.

When object boundaries are unclear and can not be identified properly, other sources of information are used:

- Data from the cadastral information.
- Field interpretation of the image.
- Field survey.

7. Comparative analysis of accuracy of orthophoto images, obtained from aerophoto and satellite images

The rapid development of sensor technologies and decrease of the pixel size on the earth's surface lead to the following questions:

* Up to what scales and for what purposes the use of aerial photographs or satellite images is justified?
* Is it justifiable to involve more expensive activities for the topographic maps at 1:5000 scale?

In respect to this a comparative analysis of accuracy of an orthophotoimage obtained from satellite image and one from aerial photographs is performed.

An aerial photography of a part of Sofia with area 4.5 km^2 is used. This is a region, having relatively high buildings and rapidly changing infrastructure. It is covered by 3 strips with 18 aerial photographs in total.

Data about the photography:

- Aerial survey camera RMK A 15/23.
- Approximate image scale 1:4500.
- Average flight height above the terrain 690 m.

The aerial triangulation is based on 8 control points, pre-marked on the terrain. The achieved accuracy is established by 9 check points. The results are compared in Tables 3 and 4, where Xm, Ym, Zm are average coordinates calculated from all models, and Xg, Yg, Zg are geodetically determinated coordinates, as well as dXY is the ground displacement of the points. Unacceptable residuals are marked with an asterisk (*).

An orthophotomosaic on the basis of the DEM, generated from 3D vector objects and points, for the entire territory is produced. The situation including roads and buildings over the orthoimages were digitized and superimposed. The result is well done coincidence of outlines and completeness of visible information. The maximum deviation with linear objects is 1.20 m, which is within the graphical accuracy for the corresponding map scale. For topographic and cadastral maps at 1:5000 scale the satellite imagery meets the requirements for accuracy of information.

№	Xm-Xg [m]	Ym-Yg [m]	Zm-Zg [m]	dXY [m]
11	-0.06	-0.06	-0.26*	0.08
13	-0.01	0.07	0.14	0.07
24	0.02	0.03	0.19	0.04
16	-0.08	-0.07	-0.22*	0.10
31	0.09	0.05	-0.22*	0.11
26	-0.01	0.01	-0.19	0.02
44	0.00	-0.06	0.18	0.06
46	-0.02	-0.07	-0.22*	0.08
RMS:	±0.05	±0.06	±0.20*	±0.08
MAX:	0.09	0.07	0.26*	0.11

Table 3. Ground control points residuals

№	Xm-Xg [m]	Ym-Yg [m]	Zm-Zg [m]	dXY [m]
12	-0.06	-0.00	0.25*	0.06
23	-0.01	-0.06	0.17	0.06
14	0.07	0.02	0.18	0.08
15	0.01	-0.05	0.17	0.05
25	0.03	0.08	0.07	0.09
32	0.00	-0.00	0.11	0.01
35	0.05	0.03	0.34*	0.05
36	-0.02	0.06	0.15	0.06
45	0.04	-0.07	0.12	0.08
RMS:	±0.04	±0.05	±0.19	±0.06
MAX:	0.07	0.08	0.34*	0.09

Table 4. Check points residuals

8. Conclusions

- The geometrical accuracy of the orthorectification of high resolution satellite images meets the requirements for topographic map at 1:5000 scale.

- The outlines of a part of the objects can not be defined within the accuracy requirement of the scale. In this case it is necessary to use other sources of information. The use of aeral pictures provides higher completeness of information, but is more expensive**.**

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