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An investigation into the spatial accuracy of the IKONOS 2 orthoimagery within an urban environment

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Abstract. This letter reports the results of an orthorectification exercise applied to a panchromatic IKONOS image (GEO format) from the city of Athens, Greece; a region with gentle relief. Seventeen ground control points (GCPs) were collected within the framework of a differential GPS campaign, and were inserted to the orthorectification model together with a 20 m digital elevation model. The root mean square error at the GCPs was less than 0.6 pixels, while the same error at the checkpoints was less than 1 pixel. This shows that in areas where elevation changes are not large, the necessity for large-scale DEMs is diminished. We also show that users can process GEO data to the same standards of accuracy available from the Precision IKONOS data all at a lower cost and in less time.

1. Introduction

The IKONOS 2 satellite launched in September 1999 by Space Imaging Inc. is the world's first commercial satellite offering high spatial resolution imagery. The IKONOS sensor suite is capable of generating 1 m panchromatic images with off-nadir viewing up to 60° in any azimuth for a frequent revisit rate and stereo capabilities (Li 1998). In addition, by acquiring 11-bit data it generates images with a high dynamic range of 2048 grey levels and yields a wealth of contrast information and shadow detail. This is particularly useful in earthquake-hit areas, as in the case of the Athens earthquake ($M = 5.9$, 7 September 1999, Ganas *et al.* 2001) where damage assessment was made using conventional air-photography. Therefore, it is necessary to evaluate the spatial accuracy of the IKONOS products in order to provide post-damage assessment maps rapidly and/or change detection maps to both local governments and civil protection authorities.

2. Methodology

Space Imaging Europe SA provided an IKONOS scene of the New Philadelphia suburb of Athens, acquired on 23 March 2000 (Scene ID po_11 603_pan_0000000.tif; figure 1). This is a residential area of gentle relief with a small river (Kifissos) running in a north–south direction. The ground morphology is smooth and elevation varies

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between 70 and 250 m. The product was delivered in GEO format (UTM projection, WGS84 datum) with a nominal accuracy (90% confidence in circular error) of 50 m on the ground. To orthorectify the product, GCPs were collected with the differential GPS method (DGPS; figure 2) during February 2001. A digital elevation model (DEM) with a pixel size of 20 m, and a commercial software package were also used. Each component of the procedure is described briefly below.

2.1. *The GPS measurements*

We obtained 17 ground control points (GCPs) by performing DGPS measurements under normal weather conditions over Athens. Two dual-frequency geodetic GPS receivers were used (WILD SR 299). The use of two GPS receivers recording simultaneously and observing the same satellites is an effective way to overcome the influence of error and biases and to achieve a positioning accuracy at millimetre level (Mueller 1994). We chose our base to be one of the benchmarks of the Greek first-order geodetic network. This is the benchmark No. 161129 with the following coordinates X, Y: 478025.85, 4211721.35, having an elevation of 158.90 m and being located near G0001 in figure 1 (white, rectangular field; the metric coordinates are in EGSA 87, the Greek projection). The location of the chosen base is near the centre of the IKONOS image, which provides approximately the same distances to GCPs.

The processing and adjustment of the GPS observations were made using the SKI Pro software, which was adequate due to the small distances of the measured baselines (Lagios *et al.* 1998). Then for all GCPs, we acquired the following information: Point ID, image position (pixel, line), elevation, and ground position (X, Y). These data together with uncertainties are reported in table 1. The GCPs were identified on the ground using a laptop computer (see figure 2 for a screen snapshot).

2.2. *The DEM*

The DEM was produced by on-screen digitizing of elevation contours of the 1:50 000 map sheet 'Kifisia', produced by the Hellenic Army Geographical Service (HMGS 1988; contour interval 20 m). In these maps 90% of horizontal rms errors are 25 m, and 90% of vertical rms errors are 10 m, respectively (HMGS 1988). The DEM was constructed at 20 m spacing to minimize interpolation errors in image space between the contours (the procedure is described in Ganas and Athanassiou 2000). The operator's digitizing error is 0.1 mm, i.e. 5 m horizontal rms error. While it was impossible to quantify the contribution of this error during interpolation, we estimate that it is very small. In addition, there is an error regarding the use of the interpolator algorithm. This error is a function of the distance (opening or flatness) between successive contours. We checked this error qualitatively by overlaying the elevation contours on top of the DEM, and examining the elevation values, and the shape of the contours. We found no serious artefacts. Finally, the fact that the DEM type is 32 bit real ensures that no rounding error exists. If the data were 16 bit or 8 bit integers, rounding error of up to 49 cm might occur (for example, pixels with value 3.51 m would become 4 m).

2.3. *The software*

We processed the IKONOS data using the OrthoEngine™ version 7.0 software. This commercial package uses a satellite model developed by Dr Thierry Toutin at the Canadian Centre for Remote Sensing (Toutin and Cheng 2000). The model

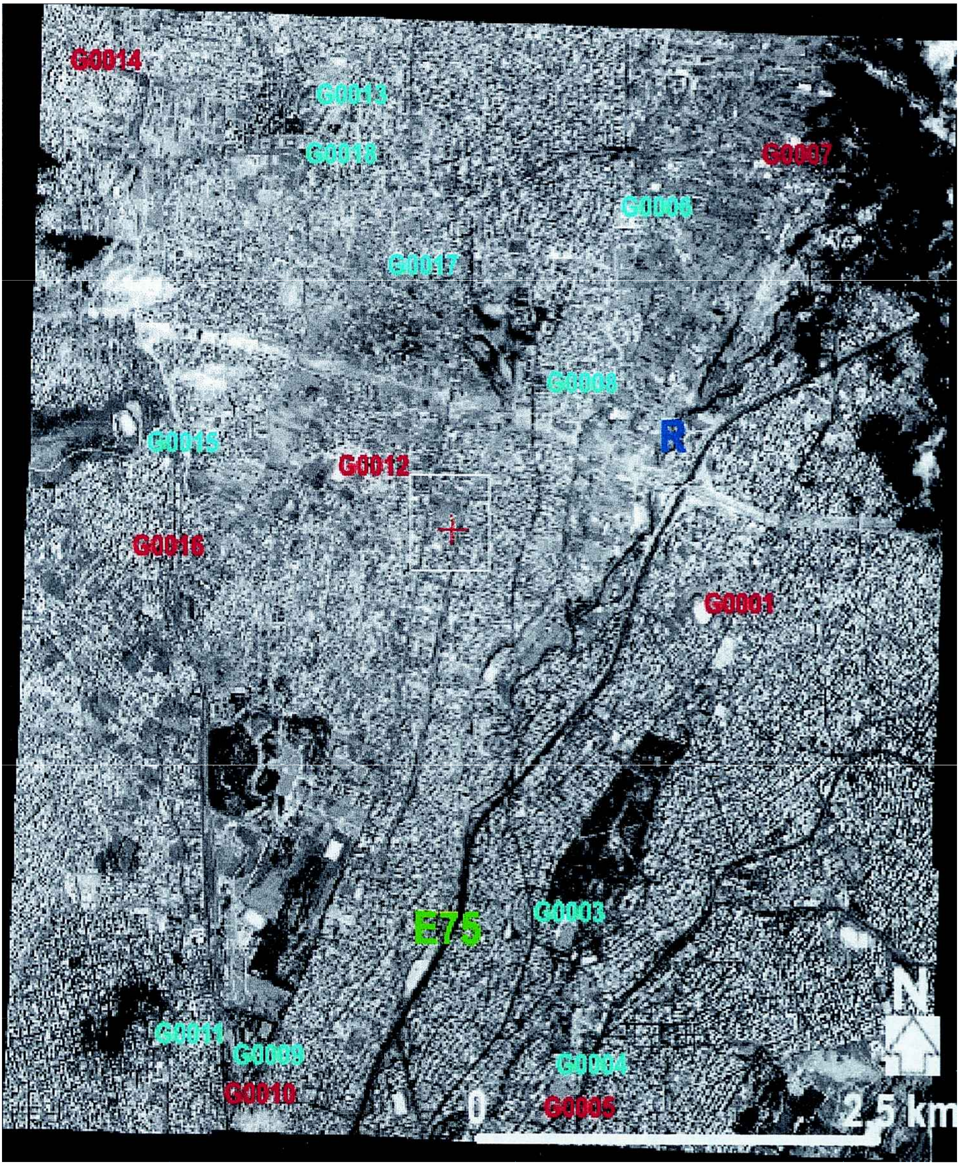

Figure 1. The orthocorrected IKONOS image of the New Philadelphia–Kamatero region, Athens. Scene size: 5680 pixels × 6944 lines. Date image taken: 23 March 2000. Red crosses represent GPS points. Cyan crosses represent checkpoints. R indicates the position of the Kifissos River. E75 indicates a motorway. Processing time was 1 min 52 s and file size was 102 Mb. A PC Pentium III (operating system Windows 2000, 550 MHz clock) was used.

approach used is similar to that used with other optical satellites and has been shown to produce accurate results (Toutin 1995).

3. Results

Our results can be seen in figure 3, and are summarized in tables 2 and 3. We varied the number and distribution of GCPs and checkpoints to characterize the

Table 1. Used GCPs and checkpoints in both image space and in metric coordinates. 3D uncertainties in position are also shown. *X Y* uncertainties are 0.1 of a pixel. Location of points is shown in figure 1 (red crosses). The GCPs are computed in local coordinates (Greek national projection system—EGSA 1987). Point 18 is shown in figure 2. Point 2 was removed from further processing.

			Northing		Easting		Height	
ID	Image pixel	Image line	*Y*	SD	*X*	SD	*Z*	SD
1	3969.5469	3546.5781	4211708.5709	0.0021	477786.6179	0.0013	136.6436	0.0036
2	–	–	4210259.5809	0.0045	477255.3084	0.0013	114.5723	0.0095
3	3211.5313	5513.5313	4209777.9172	0.0020	476960.4980	0.0016	99.8444	0.0107
4	3415.4688	6479.5938	4208806.4428	0.0013	477132.7253	0.0014	99.9526	0.0037
5	3322.5000	6735.5000	4208555.1381	0.0065	477032.4698	0.0034	96.1099	0.0057
6	3575.5313	1141.4688	4214113.4370	0.0026	477473.4839	0.0015	173.0088	0.0041
7	4507.4688	830.5938	4214392.1216	0.0016	478415.2134	0.0012	179.1157	0.0046
8	3197.5000	2300.5000	4212972.9943	0.0033	477056.3582	0.0021	152.8505	0.0072
9	1374.5313	6519.6563	4208840.1509	0.0018	475091.0287	0.0016	76.2708	0.0067
10	1385.5000	6798.7000	4208560.3822	0.0015	475091.6406	0.0016	76.1476	0.0034
11	926.5313	6375.7188	4208996.9566	0.0026	474646.7964	0.0014	76.9302	0.0092
12	1888.4688	2791.4688	4212525.5062	0.0022	475733.6767	0.0014	155.2700	0.0051
13	1719.5000	562.7000	4214747.7217	0.0022	475640.5335	0.0018	186.3038	0.0066
14	249.6563	329.5938	4215034.2785	0.0020	474175.9742	0.0020	159.2296	0.0054
15	688.5000	2656.5000	4212691.1882	0.0012	474542.1217	0.0007	177.6071	0.0014
16	749.4688	3351.5938	4212010.9572	0.0008	474573.6382	0.0004	124.0076	0.0011
17	2228.5313	1588.4688	4213717.0950	0.0024	476111.0369	0.0010	148.1436	0.0032
18	1688.6000	775.5000	4214540.9435	0.0027	475601.1867	0.0008	163.4601	0.0054

spatial distribution of error. Using the minimum distribution of GCPs we orthorectified the image and the result is shown in figure 1. We chose to resample the orthoimage using cubic convolution, because we observed no visible distortion of lines at full spatial resolution. The small, clockwise rotation is attributed to the datum difference between the uncorrected (WGS84) and the orthorectified product (EGSA uses the GRS 1980 ellipsoid).

The variation of the rms error in both *X* and *Y* is shown in figure 3. First, the software needs at least seven GCPs to do the orthorectification. The rms error at the checkpoints is the largest. A reduction of the error is observed as more GCPs are included in the rectification model. The error at the GCPs is maintained below 0.6 pixels after we include 12 points or more in the solution. For the same number of points the error at the checkpoints is maintained below one pixel. This is an increase of a factor of three compared to the horizontal accuracy (rms) of 3 m obtained by Zhou and Li (2000) with simulated IKONOS data.

We also experimented with the asymmetric positioning of the GCPs on the image in the following way. We split the 17 points into two halves (table 3). In table 3, north means all GCPs are concentrated in the north (upper) part of the image with the checkpoints being in the opposite direction. So the checkpoints are not inside the GCPs. We found that the rms error at the GCPs was less than 0.6 pixels, despite their concentration in azimuth. However, the rms error at the checkpoints varied between 15.97 pixels in the case of the southern location of the GCPs to 0.90 pixels in the case of the western location of the GCPs. In general, the *X* error was greater than the *Y* error.

(a)

(b)

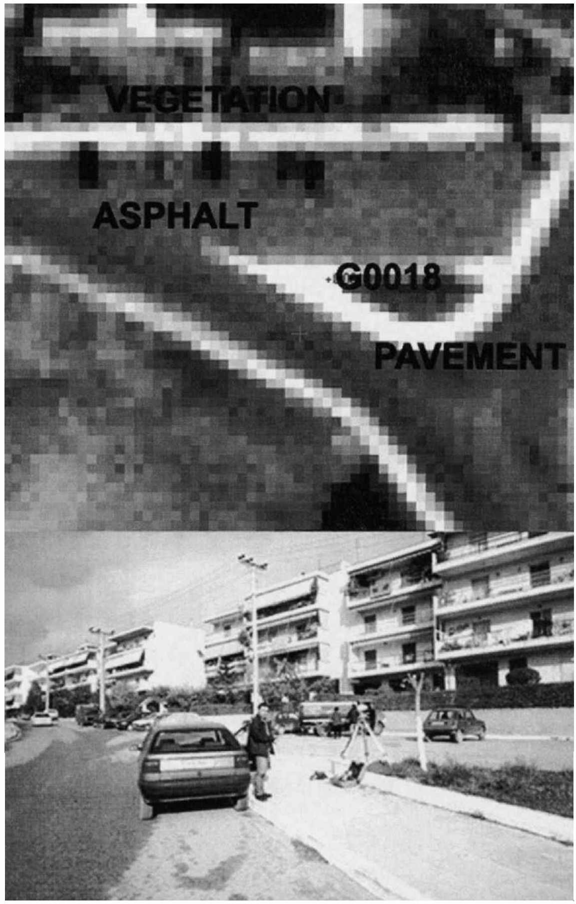

Figure 2. A computer screen snapshot showing the location of checkpoint 18 on the uncorrected IKONOS image. (*a*) IKONOS image, 1 m pixel size. Magnification times seven relative to figure 1. Date image taken: 23 March 2000. (*b*) Field photograph. Date point collected: 2 February 2001. The internal edge of the triangular feature was selected because of the contrast between the pavement and the soil.

4. Conclusions

Our main conclusion is that in areas where elevation changes are not large, the requirement for large-scale (i.e. 1:5000) DEMs is diminished. In such terrain, the critical factor in the orthorectification process is the GPS field campaign, with which we can achieve a much greater accuracy than the size of the IKONOS pixel (1 m). In addition, the skill of the operator is of critical importance, which also influences the accuracy of the solution, because of the difficulty in properly selecting correct pixels within the urban environment. This work also shows that users can process GEO product IKONOS data to the same standards of accuracy available from the Precision IKONOS data at a lower cost and in less time.

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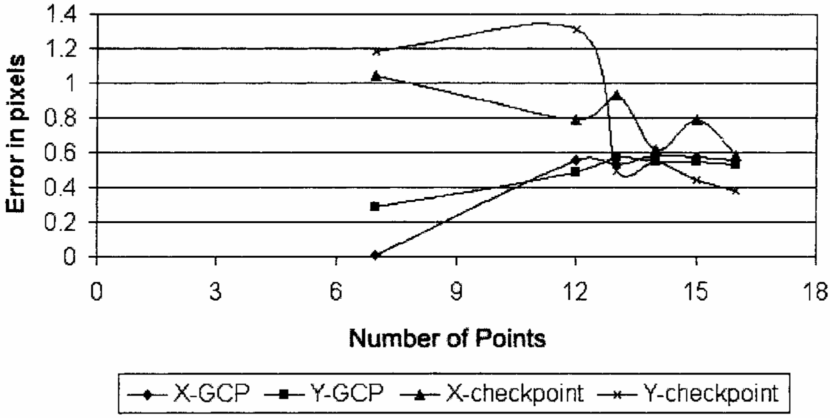

Figure 3. Graph showing the variation of rms error in X (east–west) and in Y (north–south) as a function of the number of control points used. Also shown is the variation of the checkpoint error.

Table 2. Residual error report in image pixel units, arranged in decreasing magnitude of error. GCPs: 7. X rms error = 0.01. Y rms error = 0.29. Check points: 10: X rms = 1.04, Y rms = 1.18. Image X and Image Y are uncorrected point positions. Comp X and Comp Y are orthocorrected point positions.

Point	Residual	Res X	Res Y	Type	Image X	Image Y	Comp X	Comp Y
G0015	3.29	1.26	3.04	check	688.5	2656.5	689.8	2659.5
G0018	1.55	1.15	1.04	check	1688.6	775.5	1689.7	776.5
G0004	1.46	−1.39	0.45	check	3415.5	6479.6	3414.1	6480.0
G0009	1.40	1.12	−0.85	check	1374.5	6519.7	1375.6	6518.8
G0003	1.30	−1.29	−0.05	check	3211.5	5513.5	3210.2	5513.5
G0008	1.00	−0.88	0.47	check	3197.5	2300.5	3196.6	2301.0
G0017	0.84	−0.70	−0.47	check	2228.5	1588.5	2227.8	1588.0
G0013	0.69	0.38	0.57	check	1719.5	562.7	1719.9	563.3
G0006	0.67	−0.66	0.15	check	3575.5	1141.5	3574.9	1141.6
G0011	0.67	0.22	0.63	check	926.5	6375.7	926.8	6376.4
G0001	0.44	−0.01	−0.44	GCP	3969.5	3546.6	3969.5	3546.1
G0016	0.36	0.01	−0.36	GCP	749.5	3351.6	749.5	3351.2
G0007	0.24	0.00	0.24	GCP	4507.5	830.6	4507.5	830.8
G0005	0.21	0.01	0.21	GCP	3322.5	6735.5	3322.5	6735.7
G0014	0.21	0.00	0.21	GCP	249.7	329.6	249.7	329.8
G0010	0.17	−0.01	0.17	GCP	1385.5	6798.7	1385.5	6798.9
G0012	0.03	0.00	−0.03	GCP	1888.5	2791.5	1888.5	2791.4

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Table 3. The influence of azimuthal positioning of GCPs on the quality of orthorectification. rms error is reported in pixels.

Points	GCP *X* rms	GCP *Y* rms	Check *X* rms	Check *Y* rms
South 8gcp-9check	0.41	0.41	15.97	1.15
West 9gcp-8check	0.50	0.61	0.90	2.73
East 7gcp-10check	0.44	0.15	3.99	2.16
North 11gcp-6check	0.45	0.53	7.27	1.30

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