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Accuracy assessment of an IKONOS derived DSM over urban and suburban area

D. Devriendt
Geography Department, Ghent University, Belgium

R. Goossens
Geography Department, Ghent University, Belgium

M. Binard
S.U.R.F.A.C.E.S. Geography department, University of Liège, Belgium

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ABSTRACT: The availability of IKONOS stereo pairs has made it possible to generate Digital Surface Models of IKONOS data. Though it is possible to obtain a DSM from two images with a different viewing angle on the same area, it is preferred to work with products ordered as stereo. Such stereo pairs have images that are made in the same orbital pass, resulting in a much better geometry of the stereo model. In this paper the accuracy of an IKONOS derived DSM of urban areas is assessed, based on DSMs from aerial photography and laser scanning.

The quality and accuracy of a DSM derived from IKONOS stereo pairs has been assessed for test zones in two cities, Ghent and Liege. The test zones are characterized by a typical urban morphology (city center, residential, industry). The accuracy has been assessed for each of the different types of urban morphology in the study areas. An error surface is obtained by calculating the difference between the generated IKONOS surface models and reference surface models. This surface is used as a measure for the accuracy of the IKONOS surface model. Reference surface models from different origins are used (aerial photography, lidar, large scale 3D database). For the test zones in Liege, the relation between the DSM accuracy and different land cover types is studied in detail. Also the relation between DSM error and the topography will be investigated.

1 INTRODUCTION

The research presented in this paper is part of the SPIDER project of the Belgian Federal Science Policy. This project aims to improve spatial information extraction for local and regional authorities using Very-High-Resolution (VHR) satellite images. On the one hand some technical modules investigate how present-day earth observation technology can support local and regional decision makers, particularly in Belgium. On the other hand the more application-oriented modules develop prototypes of value-added products which fulfill some of the actual information needs of Belgian authorities. The cities of Ghent and Liege were chosen as study areas because of their differences in terrain and urban morphology. One of the technical research modules focuses on the geometrical and 3D aspects of VHR data processing.

The major part of this geometric module deals with the construction and assessment of the accuracy of a digital surface model (DSM) from IKONOS stereo images. Although it is possible to obtain a stereo pair from two images from different orbital passes, it is proved that the stereo pairs, ordered from SpaceImaging or resellers, provide better results (2004, Taillieu *et al.*). In previous papers, we have discussed the accuracy of IKONOS derived DSMs at different scales. Raster surface models with a cell size of one meter and ten meters were constructed and evaluated (one meter for the Ghent area, ten meters for the Liege area). It was observed that the accuracy strongly depends on the type of urban morphology and the land cover type of the study area.

An IKONOS DSM at one meter resolution is created for Liege to validate the accuracy of the Ghent surface model at the same resolution. The accuracy is estimated by subtracting a reference surface model from the IKONOS derived DSM. Since Liege is a more hilly area than Ghent, the influence of terrain morphology (slope, aspect) on the DSM accuracy is investigated only for Liege. The occurrence of occlusion areas in the stereo model is believed to have an influence on the quality. Since for urban areas the ratio of occluded areas can be up to 10% of the whole area (2005 Devriendt *et al.*), the influence of occlusion can be considerable.

2 STUDY AREAS AND DATA

For each of the study areas, an IKONOS stereo couple was ordered in epipolar projection. In both cases, the stereo pairs consist of two components, with each a left and a right image (Table 1). The components were treated as independent stereo pairs, and the surface models were merged in a GIS afterwards. Different surface models were constructed for a number of small test zones, representing a specific type of urban morphology (Table2).

The reference DSM for the Ghent test zones was derived from aerial pictures at a 1:12.000 scale, taken in February 2002. Ground control points (GCPs) were measured with a differential GPS in the test zones and over the whole of the IKONOS stereo pair. Some extra points, not in the test zones, are needed to have an equal distribution of

Table 1. Details of the IKONOS stereo pair components for Ghent and Liege.

	Ghent	Liege
Left		
Acquisition Date	September 18, 2003	September 3, 2004
Acquisition Time	11:08 GMT	10:53 GMT
Nominal Collection Azimuth(degrees)	210,48	50,05
Nominal Collection Elevation(degrees)	68,83	84,60
Right		
Acquisition Date	September 18, 2003	September 3, 2004
Acquisition Time	11:07 GMT	10:53 GMT
Nominal Collection Azimuth(degrees)	346,81	188,52
Nominal Collection Elevation(degrees)	78,87	63,93

Table 2. Details of the test zones in Ghent and Liege.

Study Area Ghent	Test zone id.	Urban morphology	area (km^2)
	TZ1	industrial zone	1,97
	TZ3	high-standing residential housing	1,02
	TZ5	city center	1,55
	TZ6	linear housing	3,81
Liege			
	TZ1	industrial zone	0,54
	TZ5	city center	0,43
	TZ6	linear housing	1,14
	TZ7	building free, slope area	1,59

GCPs in the IKONOS images, whereas the GCPs in the test zones minimise the shift between the reference dataset and the VHR data.

Several data sources were used to construct the reference DSM for the area covered by the IKONOS stereo model of Liege. By order of decreasing accuracy of the source-data, four different datasets were overlaid to generate the reference surface model. The best available source is a LIDAR surface model for the valley of the river Meuse dating from 2001. Secondly, 3D information (points, lines, polygons) are retrieved from the large-scale reference database of the Walloon Region. The remaining gaps were filled with height information of the 1:10.000 and 1:50.000 vector products of the NGI/IGN. These different data layers were used to create one TIN model for the whole area. Finally, this TIN model was rasterized at one meter resolution. A more extensive description of the construction of this reference DSM can be found in Binard *et al.* 2005. The GCPs for the Liege study area were chosen from the large-scale reference database by visual comparison of the database and the IKONOS stereo pair. The accuracy of the GCPs was below 50 cm for both of the study areas.

3 CONSTRUCTION OF THE IKONOS DSM

The two-step method described by Devriendt (2003) is used to create the IKONOS surface models for all the test zones in the two study areas. Step one consists of adding break lines of the built-up area to the stereo model. These break lines are used as input for the matching algorithm, of which the result is improved in step two by contour fitting around buildings. All of the surface models were created on different instances of the same stereo model. Consequently, the surface models of one study area are derived with the same geometric conditions, but they cannot influence each other. The spatial resolution for the surface models is the same as that of the reference model, i.e. one meter.

The accuracy of the DSM is directly related to that of the stereo model, since it is actually a collection of measurements in the stereo model. Table 3 shows the accuracy of the stereo models of Ghent and Liege on all GCP used, indicating the root mean square error (RMSE) for the separate components of each stereo model.

Table 3. Accuracy of the IKONOS stereo models, expressed as the RMSE of the GCP.

	Ghent	Liege
component 1 (rmse in m)		
mx	1,250	0,719
my	1,470	0,793
mxy	1,930	1,071
mz	2,525	0,689
component 2 (rmse in m)		
mx	1,561	0,438
my	1,596	0,602
mxy	2,232	0,744
mz	1,490	0,729

The difference in accuracy of the stereo models between the two components can be explained by the error of measurement of the GCP. The software that was used for the stereo orientation allows pointing up to one fifth of a pixel. With the spatial resolution of the IKONOS images being one meter, we can expect measurement errors of 20 cm on each of the components. However, this does not explain the difference in accuracy between the study areas. The larger off-track angles of the Ghent images probably cause the residuals on the GCP in the stereo model to be twice the size of the Liege images.

Apart from the accuracy of the stereo models, also the accuracy of the digital surface models with regard to the GCP should be discussed. This would not be relevant due to the strategy of working on test zones instead of the whole image. Especially in the Liege area, very few of the ground control points are in one of the test zones. Nevertheless, the GCP are still important in the discussion on the DSM accuracy as they ensure that the shift between the IKONOS derived surface model and the reference DSM is minimal. In the Ghent test zones, the GCPs were used for the aerial pictures from the reference model, and also with the IKONOS stereo pair. The GCPs in the Liege study area were taken from the same data source, which was used to create the reference surface model.

4 DISCUSSION ON THE ACCURACY OF THE IKONOS SURFACE MODELS

4.1 *Urban morphology*

The accuracy of the IKONOS surface models was determined by subtracting the reference DSM separately for all the test zones. In that manner, one error surface per test zone is created. A positive value in this error surface indicates an overestimation in the IKONOS surface model, a negative value indicates an underestimation. The mean and the standard deviation of these error surfaces are shown in Table 4. The accuracy of the surface model is expressed here in terms of mean difference and standard deviation, whereas the accuracy of the stereo model was expressed in terms of RMSE. The accuracy of the Ghent surface models was described in a previous paper (Devriendt *et al.* 2005).

The mean difference and the standard deviation differ greatly from test zone to test zone within one study area. This means that the accuracy of the IKONOS derived surface

Table 4. Mean difference (m.d.) and standard deviation (s.d.) of the error surface for each test zones (IKONOS − reference DSM).

TZ	Ghent		Liege		Type of urban morphology
	m.d. (m)	s.d. (m)	m.d. (m)	s.d. (m)	
1	5,262	3,830−	1,087	6,595	industrial zone
3	3,626	3,874	———	———	high standing residential housing
5	−8,932	10,910	1,841	11,758	city center
6	5,602	8,453	1,528	4,077	linear housing
7	———	———	3,634	6,790	building free, slope area

model depends on the type of urban morphology. On the other hand, test zones from both study areas with similar urban morphology show very different results. For the test zones in the city center and the industrial zones of both study areas, the aspect of stereo occlusion was investigated.

4.2 *Vegetation*

The analysis of the test zones in Ghent had shown that the accuracy strongly varied over different land cover classes. Especially areas with trees and water had a very poor result. The first step in the further analysis was to remove all the water areas from the Liege test zones by a visual interpretation of an orthorectified image. The influence of the vegetation land cover was only investigated for test zones 6 and 7 in Liege, since the other zones had nearly none or very few vegetation (city center and industrial area). Table 5 and Figure 1 show the relative frequency of each value in the error surface. The vegetation is divided into four types: no vegetation, high (e.g. forest), medium (e.g. heath land) and low (lawn, crop fields) vegetation.

The graphs in Figure 1 clearly indicate the influence of the ‘‘high vegetation'' class on the overall accuracy. Low vegetation has the smallest absolute difference and standard deviation, with similar results for the no vegetation and medium vegetation land cover classes. Various explanations are possible for the poor results for the high vegetation class. First of all, it may be possible that the IKONOS stereo pairs are not suited to make DSMs for areas with high vegetation. Secondly, the land cover class of high vegetation is likely to have changed the most in the time gap between the moment of the acquisition of the reference DSM (2001) and the moment of acquisition of the IKONOS stereo pair (2004). More likely, a mixture of the two previous explanations approaches reality. To quantify the proportion of both causes, the acquisition of the reference and the IKONOS surface models should be simultaneous, not only dating from the same year, but also from the same season.

4.3 *Conclusion*

The DSMs of the test zones in the peri-urban area suffer from the influence of a totally different phenomenon, called occlusion. An occlusion zone in a satellite image is the part of the surface that is not visible in the image due to the image displacement of elevated objects. A model to identify and measure the occlusion areas in a satellite image

Table 5. Mean differences (m.d.) and standard deviations (s.d.) per vegetation category for test zones 6 and 7 in the Liege study area.

		vegetation type				
		none	low	medium	high	Full TZ
TZ6	m.d. (m)	1,201	0,990	1,838	8,530	1,528
	s.d. (m)	4,403	3,060	3,613	7,928	4,077
TZ7	m.d. (m)	1,068	0,186	3,5821	2,626	3,634
	s.d. (m)	5,010	2,787	5,363	6,013	6,790

was described in Devriendt (2005). Figure 2 shows a simplified scheme of this occlusion model. The outcome of this model is an occlusion map for one satellite image. Given that there are two images in one stereo pair, there are four possible occlusion combinations (0 = both occlusion zones, 1 = occlusion image one, 2 = occlusion image two, 3 = no occlusion). The influence of occlusion on the DSM lies in the fact that a point has to be visible in both images of the stereo pair to be measured. If no measurement is possible, then the height value for that point will be interpolated between known points in its surroundings. In general, this interpolation leads to an erroneous height value. Application of the occlusion model on test zone 5 in Ghent taught that the total occlusion in the city centre could cover more than 10% of the

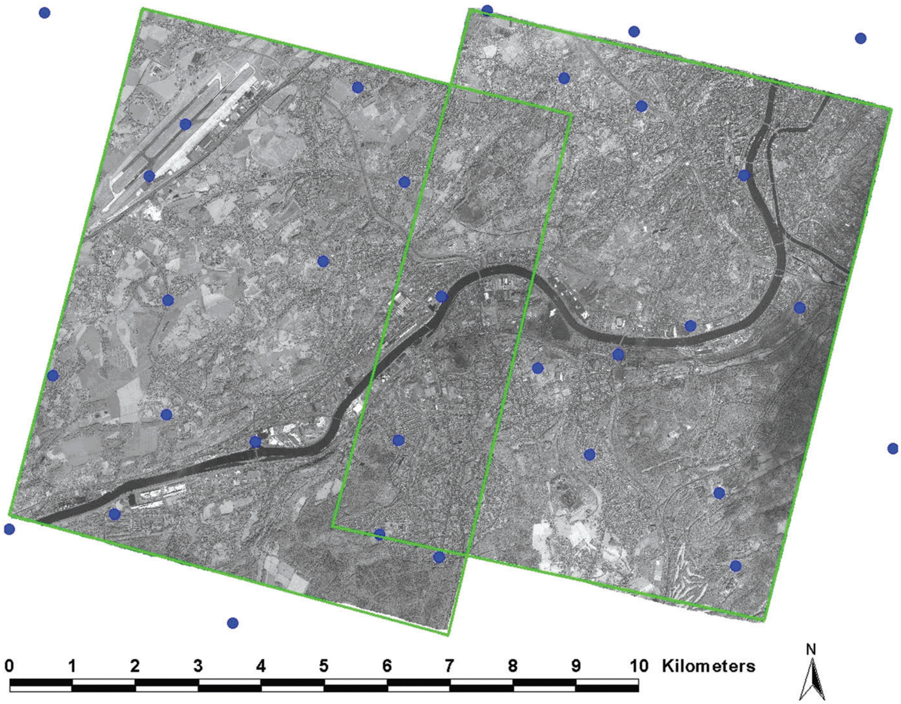

Figure 1. GCP in Liege Study area and orthoimages of the two stereo image components.

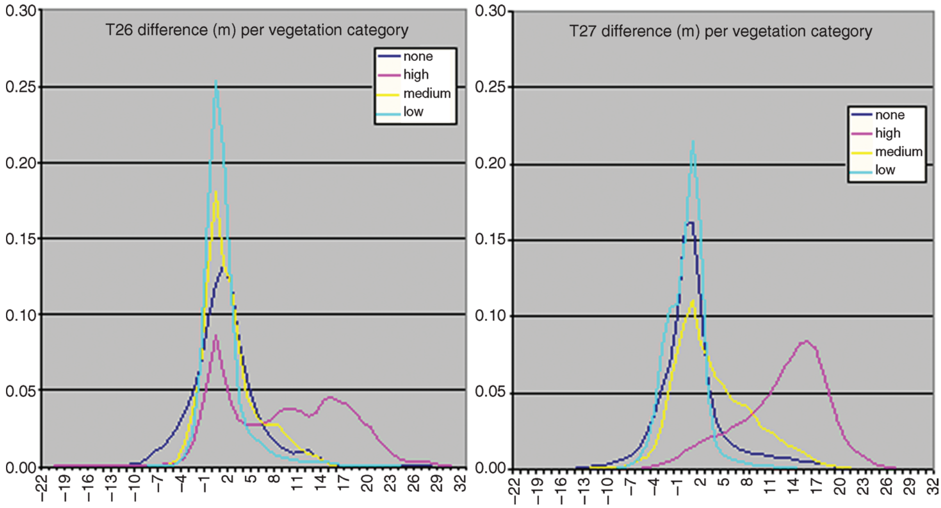

Figure 2. Graphs showing the relative frequency of the differences between the IKONOS surface model and the reference DSM (in meter).

imaged surface, depending on the nominal collection elevation of the image. The closer the satellite elevation is to the azimuth position, the smaller the occlusion area will be.

From Table 6 it becomes clear that the accuracy of the surface model depends on the presence of occlusion zones. The total occlusion area in test zone 1 is rather small. A

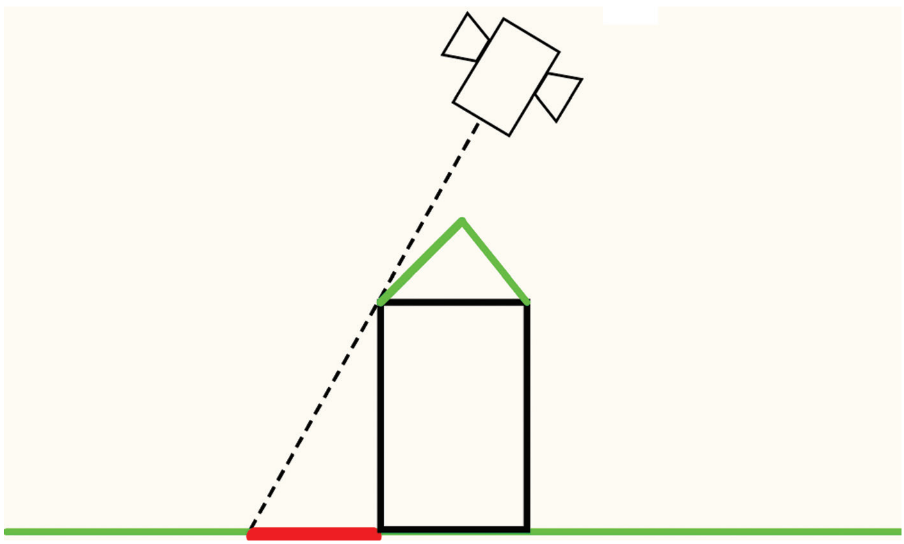

Figure 3. The occlusion zone is the part of the surface that cannot be seen from the satellite's point of view, and is not visible in the satellite image.

Table 6. Mean difference (m.d.) and standard deviation (s.d.) per occlusion category for test zones 1 and 5 in the Liege study area. (0 = both occlusion zones, 1 = occlusion right image, 2 = occlusion left image, 3 = no occlusion).

	occlusion type	0	1	2	3	Full TZ
TZ1	m.d. (m)	5,894	3,983	1,079−	1,396−	1,087
	s.d. (m)	7,720	8,264	9,955	6,344	6,595
	frequency	94	26739	744	446305	6% occlusion
TZ5	m.d. (m)	11,126	11,103	−0,630	−0,423	1,841
	s.d. (m)	12,169	14,090	17,084	9,7471	1,758
	frequency	1559	83494	4563	343005	19% occlusion

visual comparison of the IKONOS and the reference surface model taught that a large building was demolished in the time interval between the acquisitions of both datasets. On the other hand, no large changes could be found in test zone 5. The total occluded area of 19% shows that the aspect of occlusion in the center of the city should not be neglected. The right image, with a nominal collection elevation of 63 degrees, has a much higher mean difference and standard deviation in its occluded zones than the test zone as a whole. The mean value for the occlusion in the left image (nominal collection elevation 84 degrees) is much closer to that of the non-occluded area, but the standard deviation is nearly double. This shows that even with a minimal deviation of the collection elevation from the azimuth, the occlusion still has an important influence on the accuracy of the stereo model.

5 CONCLUSION

It was shown in this paper that the accuracy of IKONOS-derived digital surface models varies according to the type of land cover and the type of urban morphology. The results previously obtained for the Ghent study area were validated by applying identical methods to the test zones in the Liege study area. The vegetation height has a large influence on the DSM accuracy in the peri-urban areas, but further research is needed to quantify this influence. In more densely-built urban areas such as city centers, the occlusion in the stereo pairs has a negative effect on the accuracy of the surface model.

In general, it can be stated that IKONOS stereo pairs are well-suited to create digital surface models for the peri-urban areas. At this moment, an IKONOS stereo pair as such cannot be used to obtain an accurate surface model of a dense urban area. The IKONOS-derived surface model may however be one of the data sources for the integration of different surface models, as was performed to create the reference surface model for this study.

Although the DSM created with IKONOS stereo pairs is less accurate than a similar product of traditional methods (aerial photography, LIDAR), it is still an alternative to be taken into consideration. Especially the shorter production time and the higher update frequency open the road to new applications.

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