The Influence of DEM Accuracy on Topographic Correction of Ikonos Satellite Images

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Abstract

There is no research which specifically investigates the influence of the Digital Elevation Model (DEM) on topographic correction of satellite images. Such an investigation is necessary in view of the very high resolution (VHR) of recent sensors such as Ikonos and QuickBird and the low availability of accurate height information for the derivation of slope and aspect values. A comparative study of multispectral Ikonos images is presented using eight selected interpolation techniques with contour data. The DEM influence was evaluated by analyzing the variance and classification accuracy of topographically corrected images using the different DEMS. These were found to vary widely, with a 30 percent reduction in variance and a 20 percent improvement in overall classification accuracy between the worst and best performing interpolation techniques. Furthermore, smoothing techniques commonly used for the removal of noise in interpolated contour data or in existing DEMs were found to offer no significant improvement in intra-class variance or classification accuracy, when used with a grid resolution compatible with VHR images. However, a more rigorous planar slope function was found to be more effective, and when combined with the best interpolator, the natural neighbor, or Sibson, method, very high classification accuracy was achieved in the topographically corrected images.

Introduction

The problem of differential terrain illumination on satellite images has been investigated over three decades (Hoffer and Staff, 1975; Holben and Justice, 1980; Shepherd and Dymond, 2003; Xu *et al*., 2003), and a variety of correction techniques have been developed. Recently, models based on correction for both atmospheric and geometric effects of terrain claim to completely eliminate the effect of topography on image radiance (Sandmeier and Itten, 1997; Richter and Schlaepfer, 2002; Shepherd and Dymond, 2003). These models require the input and processing of both atmospheric parameters to account for differential reflectance effects and terrain parameters to account for illumination differences. Potential sources of error in these solutions include inadequate atmospheric data (Shepherd and Dymond, 2003), the non-Lambertian behaviour of the surfaces being corrected (Smith *et al*., 1980; Richter and Schlaepfer, 2002) and inaccuracies caused by the DEM used to generate slope and aspect (Carter, 1992; Ekstrand, 1996; Hale and Rock, 2003). The band ratio technique (Chavez, 1996), which is able to reduce the topographic effect and is the only method not requiring a DEM, results in reduced radiometric resolution. Other techniques which correct image bands individually, require a DEM for the generation of aspect and slope parameters, whereby the inclination of the sun on the terrain can be modeled. These techniques appear to be only partially successful (Ekstrand, 1996; Xu *et al*., 2003) although both Meyer *et al*. (1993) and Hale and Rock (2003) who compared a variety of the available techniques concluded that apart from the Cosine correction, which was unsuitable, any correction was better than none. Riano *et al*. (2003) give an overview of existing techniques for correction of topographically induced radiometric distortion.

Recent research in slope modeling has developed techniques for better surface orientation than is available from traditional interpolation techniques. These techniques are especially important since modern very high spatial resolution (VHR) sensors such as Ikonos and QuickBird require a more accurate DEM than can be obtained using standard interpolators. There has been no specific attempt to evaluate the effect of the DEM on the accuracy of topographic correction. Furthermore, most previous research on topographic correction has been concerned with medium resolution sensors such as Landsat and SPOT. Therefore, the main objective of this study is to evaluate the influence of the DEM on topographic correction of Ikonos VHR images. It compares DEMs from different interpolation techniques using two well-known topographic correction algorithms. The project concentrates on the interpolation of DEMs from contour data because, despite modern techniques, contour maps remain the most available form of elevation data.

DEM Quality

DEM Resolution

It is generally considered appropriate to use a DEM with a grid size of the same order of magnitude as the resolution of the imagery being corrected (Kawata *et al*., 1988; Goyal *et al*., 1988). Thus, DEMs of 30 m grid size, commonly available from USGS 1:24 000 quad sheets (contour interval, commonly 20 m),

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Photogrammetric Engineering & Remote Sensing
Vol. 74, No. 1, January 2008, pp. 47–53.

0099-1112/08/7401–0047/$3.00/0

have been used for topographic correction of 30 m resolution Landsat TM images (Itten and Meyer, 1993; Civco, 1989; Colby 1991; Riano *et al.*, 2003). Shepherd and Dymond (2003), on the other hand used a DEM of 20 m with 20 m resolution SPOT image. Richter (1998) demonstrates that even when the grid size matches the image resolution, slope facets at sub-pixel scale or slope errors due to sub-pixel registration error may introduce reflectance errors of 20 to 80 percent in steep areas (incidence angles of 60° to 90°).

However, the present generation of high-resolution sensors such as Ikonos and QuickBird is adversely affected by the lack of elevation data of sufficient resolution. A grid resolution lower than that of the images being corrected would both omit some important topographic features, as well as create pronounced edges in the dataset that would propagate through to slope and aspect values. In cases where only a lower resolution DEM is available, resampling the original DEM to a higher resolution may give more accurate slope and aspect values (Ekstrand, 1996). However, since such resampling merely reduces errors caused by overshooting of grid values beyond the edge of the current pixel, its ability to improve the derived slope and aspect values is limited.

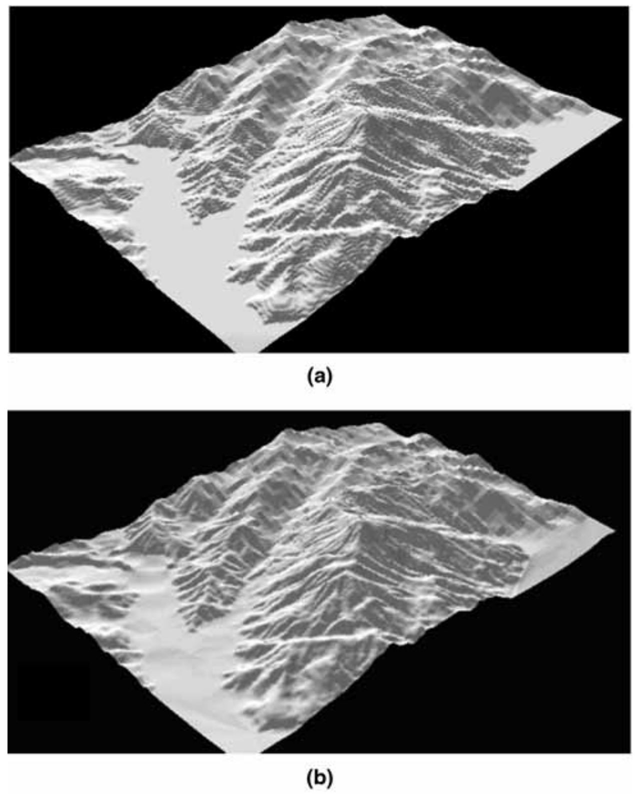

Figure 1. Terrain model of 5*5 km image subset comparing two selected interpolators: (a) NN showing the stepped surface resulting from contour artifacts in the DEM, and (b) Sibson with slope showing a smooth surface resulting from more rigorous surface interpolation techniques.

DEM Interpolation Methods

A further source of inaccuracy in DEMs is the interpolation technique used. Errors in DEMs usually result from the interpolation of contour data using nearest neighbor (NN) interpolators. Height values are clustered at the contour level, because many of the nearest surrounding data points belong to the same contour, giving a stepped appearance to slopes (Figure 1a). Over- and under-shoots in spline interpolators also create spurious data points especially in steep terrain. Therefore, some kind of post-processing of grid values is usually required to remove various types of *noise* due to interpolation. Civco (1989) used two iterations of a 3*3 low pass, smoothing filter to "eliminate spurious data points" in the USGS DEM used for the study, Hale and Rock (2003) used the same filter "to remove systematic errors from the DEM," and Shepherd and Dymond (2003) used it "to minimize contour artifacts in the DEM." Although smoothing is able to correct some of the systematic error of interpolation, its effectiveness is dependent on the grid resolution and kernel size in relation to terrain steepness, since if there is only one height value within a kernel, no smoothing will be achieved. Smoothing also loses the original height values. Thus, following topographic correction the image may be smoother, but detailed terrain features are not accurately represented, resulting in many under- or over-corrected pixels. A localized patchy (or noisy) appearance of the topographically corrected image is commonly observed.

This project evaluates DEMs created from sixteen different weighted average interpolators in addition to the Triangulation Irregular Netwotk (TIN) model. These interpolators are available in three terrain modeling software, ArcGIS®, Arc/GRID®, and Hong Kong Terrain modeling (HKTM; techniques described in Dakowicz and Gold, 2003) (Table 1). The NN, spline, and TIN methods are readily available in commercial software and often used. They were tested here to provide a benchmark for accuracy testing of more rigorous interpolators, such as the natural neighbor (Sibson) model (Sibson, 1982), the triangle-based interpolator (Dakowicz and Gold, 2003), the natural element method (Sukumar *et al.*, 1998), and ArcGRID® TOPOGRID (Hutchinson, 1989). The Sibson and natural element models are particularly useful as they use Voronoi cells to calculate weighting factors by volume and by distance, respectively, thus redistributing height values away from the contour levels. For example, the Sibson method inserts each grid point temporarily into a Voronoi diagram constructed from the data points, then measures the volume stolen from its set of neighbors. These volumes are then used for weighted averaging of the grid cell height. This method is appropriate for poor data distribution as it defines the neighbors objectively, but it produces angularity at ridges and valleys since slopes are discontinuous at all data points (Gold and Dakowicz, 2002). TOPOGRID, available in ArcGRID® is a thin-plate spline interpolator which uses contour data to build a generalized drainage model. By identifying areas of local maximum curvature in each contour, the areas of steepest slope are identified, and a network of streams and ridges created (Hutchinson, 1989). After the general morphology of the surface has been determined, contour data are also used in the interpolation of elevation values at each cell, resulting in a hydrologically correct grid.

The Slope Factor

Slope accuracy is sometimes more important than elevation accuracy. This is especially true for topographic correction, which is based on the slope and aspect of the terrain. Dakowicz and Gold (2003) proposed a method to extract meaningful slope values. In the weighted-average operation of the interpolation, they replace the height of a neighboring data value by the value of a function defined at that data point. This is a planar function involving the data

Table 1. Methods for DEM Construction Tested in this Study, Software Used, and Accuracy Assessment Using 32 Spot Heights

Interpolation Method	Software	RMS Error of Spot Height Checking (m)
NN (radius 30 m) *	ArcView®	4.6
NN (radius 30 m) with smoothing (3*3 kernel)*	ArcView® (smooth in ErMapper®)	3.7
NN (radius 30 m) with smoothing (5*5 kernel)	ArcView® (smooth in ErMapper®)	3.5
NN (radius 30 m) with smoothing (7*7 kernel)*	ArcView® (smooth in ErMapper®)	3.2
NN (radius 30 m) with smoothing (9*9 kernel)	ArcView® (smooth in ErMapper®)	3.3
NN (radius 30 m), with slope*	ArcView®(slope in HKTM)	1.9
NN (nearest 12 neighbor)	ArcView®	4.5
NN (Voronoi cell-based)	HKTM	2.6
Spline	ArcView®	3.6
Sibson (Sibson)*	ArcView®/HKTM	4.1
Sibson (Sibson) with slope*	HKTM	1.8
Triangle-based interpolator	HKTM	4.1
Triangle-based with slope	HKTM	1.8
Natural Element	HKTM	4.1
Natural Element with slope	HKTM	1.8
TIN*	ArcView®	4.0
TOPOGRID*	ArcInfo® GRID	2.4

*selected for comparison in topographic correction

point height and local slopes derived from surrounding points. Thus, at any grid point (P) the planar function of the neighboring points (Pi) is calculated for the (x, y) of the grid point. These new z estimates for neighboring points (z_i) are then weighted and averaged as in normal distance weighted interpolators, to give z' (Equation 1, Dacowicz and Gold, 2003). The *slope* function was added to some of the weighted average interpolators, as an alternative to smoothing, as a means of reducing the systematic errors of interpolation discussed above.

$$z' = z_i + \frac{a}{c}(x_i - x) + \frac{b}{c}(y_i - y) \tag{1}$$

where a, b, and c are the coefficients of interpolation.

Study Area and Image Details

This project investigates an Ikonos image of 10 km × 10 km. with a inclination angle of 69° acquired on 07 September 2002 having a sun azimuth of 128.7°, and sun elevation 65.2°. The image covers extremely mountainous terrain with a relative relief of over 900 m in three country parks of the central and northern part of the New Territories in Hong Kong. Vegetation cover comprises mainly forest on lowland and lower slopes with grassland on upper slopes, ridges, and summits. The recognition of distinct forest stands is difficult even on the ground due to the relatively young age of all forestland in Hong Kong which is post WWII, combined with the intermingling of forest and plantation species. Precise registration of the image to the DEM is vital to obtain correct slope and aspect values for each image pixel. Therefore, three different methods of orthorectification, the Simple Polynomial, Rational Function, and Rigorous model were tested. The height information for the GCPs was extracted from the DEM generated by the most accurate DEM, the Sibson interpolation with slope function. The Rigorous model (Toutin, 1983), using forty 3D GCPs gave the best result, with x and y RMS errors of 0.60 pixel and 0.78 pixel, respectively.

Methods

First, a comparative study of DEMs from sixteen different terrain modelling techniques (Table 1) was carried out in order to select those with sufficient difference to test in topographic correction. For this, a 5 km × 5 km subset of the Ikonos image in Shing Mun Country Park was selected. Height information was derived from contours, spot heights, and shorelines on digital maps of 1:5 000 scale, with stated accuracy of not more than 10 percent of elevations tested being in error of greater than 5 m. A grid size of 2 m was chosen for interpolating the DEM to resemble the 4 m resolution of the multispectral Ikonos images. Three methods were used to evaluate the quality of the twelve DEMs created, namely Visual Interpretation, Independent Spot Height Checking, and Relative Height Histograms.

Second, three different methodologies for topographic correction were tested in the study area. These were the cosine (Smith *et al.*, 1980), Minnaert (Minnaert, 1941), and two-stage normalization (Civco, 1989) methods. The Minnaert constant and the correction coefficients for use in two-stage normalization were derived from the main cover type, forest, because such semi-empirical corrections are cover-type dependent, and general corrections based on more than one cover type appear to be unsuccessful (Teillet *et al.*, 1980). The quality of the corrections was evaluated by visual analysis and evaluation of training area statistics.

Third, slope and aspect values derived from eight different interpolators selected in the first stage were applied to the two best performing topographic correction methods selected in the second stage. These were the Minnaert and two-stage normalization corrections. The results of topographic correction using the different DEMs were evaluated by three methods: visual analysis, analysis of training area statistics, and supervised classification. The classes evaluated were forest, herbaceous cover, soil, and urban areas. Training areas were located with reference to large scale digital orthophotos, and no distinction was made between slopes facing to, and away from the sun for each cover type. Four hundred sample points were used for construction of the error matrices.

Results

DEM Quality

Visual inspection of the terrain models from the different DEMs (Figure 1a and 1b) showed that those generated from basic NN interpolators and NN with smoothing using kernel sizes of 3*3 and 5*5 (Figure 1a) were not realistically smooth, and appeared to have *steps* on the surface. Thus, the smoothing function using small kernel sizes was unable to remove the underlying noise in the data. However, smoothing with a kernel size of 7*7 and above, as well as the addition of the slope function produced a smoother, more visually acceptable model with no steps on the surface (Figure 1b). All the other four interpolators tested produced visually smooth terrain models.

Independent Spot Height Checking was used at 32 randomly selected points to test the height accuracy of the DEMs. Interpolation methods with slope function appeared to have approximately 2 to 3 m higher accuracy than those without slope function, independently of the interpolation technique (Table 1). For example, the slope function with NN was able to reduce the RMS error by 2.8 m (to 1.9 m) and for Sibson a reduction of 2.3 m (to 1.8 m) was achieved. There was only a small difference between the interpolation models themselves e.g., NN 4.6, Sibson 4.1, TIN 4.0, and TOPOGRID 4.2.

Relative Height Histograms represent the summation of the number of points whose height values lie within each of ten equal intervals from the height at each contour. The frequency of points in each class is shown on the *Y* axis (Figure 2). Height values clustered near the contour level suggests that the interpolator is unable to distribute height values away from the contour. All interpolators without the slope function exhibited some clustering of height values in classes 1 and 10 near the contour (Figure 2a, 2b, and 2c). For those with the slope function (Figure 2d) as well as the TIN model, the distribution of height values was much more even due to smoother slopes.

The above evaluations resulted in eight interpolation techniques being selected for use in topographic correction. These were NN, NN with smoothing using kernel sizes of 3*3 and 7*7, NN with slope, Sibson, Sibson with slope, TIN and TOPOGRID. These eight were selected because they resulted in very different quality DEMs, as well as in order to compare the commonly used NN model and smoothing function with more rigorous interpolation techniques.

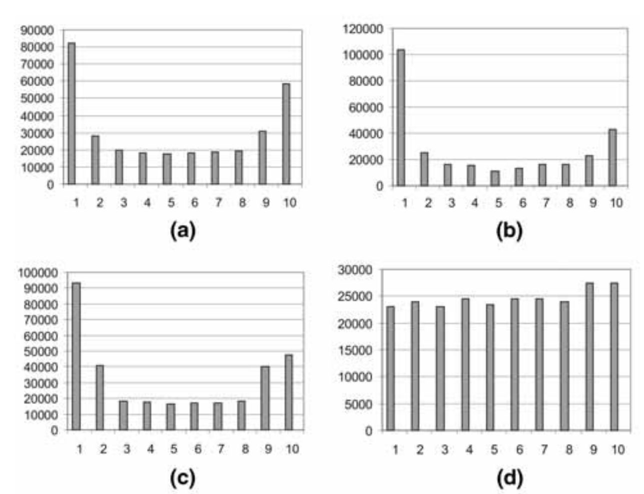

Figure 2. Relative height histograms for selected interpolators showing the frequency of points (*Y* axis) in 10 classes by height distance from contour (*X* axis): (a) NN, (b) NN with 3*3 smoothing kernel, (c) NN with 7*7 smoothing kernel, and (d) Sibson with slope.

Comparison of Topographic Correction Techniques

A successful correction should decrease the variability (SD) within individual cover types, and additionally, large changes in the mean radiance would imply under-or over-correction. Thus, the two-stage normalization method, was judged overall to be the most successful in preserving the image mean values and reducing the standard deviations for the entire image as well as for forest and herbaceous classes individually (Table 2). The Minnaert correction was somewhat less successful, since in some cases variability of the whole image, as well as that of individual classes actually increased, due to over-correction on shady slopes. As in other studies (Holben and Justice, 1980; Smith *et al.*, 1980; Teillet *et al.*, 1982; Meyer *et al.* 1993), the cosine correction was found to be unsuitable for further use due to its over-correction of shady slopes. In this study, over-correction resulted in somewhat higher mean values for the Minnaert, and much higher mean for the cosine correction.

Evaluation of DEMs in Topographic Correction

Both the Minnaert and two-stage normalization methods were used for testing the different DEMs, and since the results were generally similar, but with somewhat greater success for two-stage normalization, detailed results are only given for this method.

Visual Analysis

Figures 3a through 3h show extracts of the two-stage normalized images using various DEMs. These visual results match the quality of the terrain models (Figure 1), such that the smoother the surface of the terrain model, the smoother the corrected image. Thus, "steps" were found on the corrected image using NN and NN with 3*3-kernel smoothing, but these were removed with the 7*7-kernel smoothing, as well as by adding the slope function to the NN interpolator. However, both the NN with 3*3 and NN with 7*7 smoothed images (Figure 3c and 3d) indicate a severe loss of image detail such that roads and gravesites (white patches) have been lost. The 7*7 smoothed DEM (Figure 3d) additionally produces an image lacking in contrast compared with the other corrected images. The image using Sibson (Figure 3g) also showed some "steps," but the effect was reduced. Sibson interpolation with slope function (Figure 3h), TIN (Figure 3f), and TOPOGRID (not shown) gave the smoothest normalized images, while retaining the details and contrast of the original. Due to the more detailed texture of VHR images, the corrected images appear more noisy than medium resolution images, e.g., note the patchy appearance of the results for the un-smoothed DEMs (Figures 3e through 3h), of which the Sibson with slope DEM is the least noisy.

Image Statistics: Mean and Standard Deviation

The results for herbaceous and forest cover types using different DEMs are given in Table 3. There was no significant difference in mean values for the herbaceous category between the original, and the normalized images for the four bands. However, while none of the four NN interpolated DEMs was able to reduce the variance (SD) much more than the original image, the variance of the three corrected images using Sibson, Sibson with slope function, and TIN was considerably reduced. Furthermore, for NN, NN with 3*3, and NN with 7*7-kernel smoothing, the variance for band 4 was considerably greater than for the original image. The forest category gave similar results to the herbaceous class, in that only the Sibson, Sibson with slope, and TIN-corrected images gave considerable reduction in variance (Table 3).

Table 2. Comparison of Three Methods of Topographic Correction in the Study Area Showing Means and Standard Deviations for the Herbaceous and Forest Cover Types Following Topographic Correction. Training Areas on Sunny and Shady Slopes were Combined

	Original Image		Cosine Correction		Minnaert Correction		Two-stage Normalization	
	Herbaceous							
Band	μ	σ	μ	σ	μ	σ	μ	σ
1	72.60	1.62	91.44	27.44	76.42	3.50	72.96	1.22
2	62.62	2.69	78.54	22.50	66.26	3.04	63.45	1.89
3	40.41	2.86	50.40	13.49	42.77	2.21	41.24	1.98
4	89.27	8.21	111.72	32.21	98.07	9.44	92.32	6.69
	Forest							
Band	μ	σ	μ	σ	μ	σ	μ	σ
1	68.82	1.66	87.87	30.61	72.52	4.21	69.15	1.48
2	54.72	2.40	69.50	23.05	57.97	3.09	55.42	1.83
3	33.40	2.00	39.27	13.67	35.41	2.00	34.07	1.60
4	84.20	11.75	96.39	31.06	92.20	9.84	86.54	8.25

Table 3. Radiance Values of Herbaceous and Forest Cover Types for the Two-Stage Normalized Image

	Original		NN		NN with smoothing 3*3		NN with smoothing 7*7		NN with slope		Sibson with Sibson		slope		TIN		Topo Grid	
	Herbaceous																	
Band	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
1	72.60	1.62	72.93	1.34	72.79	1.54	73.59	1.26	72.77	1.53	72.86	1.26	72.83	1.28	72.96	1.22	72.8	1.4
2	62.62	2.69	63.50	2.45	63.72	2.57	65.33	2.45	63.53	2.45	63.41	1.88	63.32	1.87	63.45	1.89	63.2	2
3	40.41	2.86	41.36	2.60	41.36	2.72	43.36	2.64	41.19	2.61	41.21	1.99	41.11	2.01	41.24	1.98	41	2
4	89.27	7.21	92.25	8.44	95.72	11.28	98.37	9.80	92.03	7.30	92.20	6.64	91.84	6.27	92.32	6.69	91.5	6.6
	Forest																	
Band	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
1	68.82	1.66	69.11	1.56	68.89	1.60	69.78	1.64	68.87	1.59	69.07	1.47	69.05	1.46	69.15	1.48	70	1.6
2	54.72	2.40	55.44	2.22	55.09	2.19	57.13	2.57	54.97	2.07	55.40	1.83	55.35	1.80	55.42	1.83	55.1	2
3	33.40	2.00	34.15	2.11	33.70	1.83	35.91	2.70	33.60	1.72	34.07	1.59	34.01	1.55	34.07	1.60	33.8	1.7
4	84.20	11.75	86.44	9.31	86.08	11.30	92.32	9.55	84.79	9.32	86.53	8.17	86.37	8.31	86.54	8.25	85.2	9

Supervised Classification

All corrections achieved higher classification accuracy than the 72 percent for the original image (Table 4). However, all four NN interpolators produced lower accuracy than the Sibson, Sibson with slope, TIN, and TOPOGRID models. Surprisingly, smoothing of the NN interpolated DEM using both a 3*3 and 7*7 kernel actually reduced the classification accuracy, giving 79 percent and 78 percent, compared with 82 percent for NN alone whereas the slope function with NN achieved the highest accuracy among the NN interpolators of 87 percent. The classification accuracy using Sibson interpolation was higher than that using all three NN interpolators. However, the Sibson interpolation with slope function gave the highest overall accuracy of 98.75 percent, which was 5 percent better than the second most accurate, Sibson interpolated DEM.

Although the TIN and TOPOGRID models were able to reduce the variance within forest and herbaceous cover types, the class accuracies at 92 percent and 91 percent, respectively, were not particularly high. Examination of the misclassified pixels for both models showed that many corresponded to grassland wrongly classified as soil, both of which occur on summits and ridges, which corresponded to flat triangles in the TIN.

Discussion

The results suggest that DEM quality is highly significant in topographic correction, and support observations from previous studies (Teillet *et al.*, 1980; Itten *et al.*, 1993; Ekstrand, 1996; Hale and Rock, 2003) that disappointing results may be partially attributable to deficiencies in the DEM. Notably, in this study, the intra-class variance due to the topographic effect was not reduced by some interpolators, while others achieved a reduction of approximately 30 percent. Furthermore, a difference of 20 percent in overall classification accuracy was observed between the lowest and the highest performing interpolation techniques. The overall classification accuracy of 98.7 percent using the Sibson with slope DEM is considerably higher than that obtained for forest versus non-forest by Meyer *et al.* (1993), whose highest accuracy among four correction techniques tested was 90 percent. The high-resolution, 2 m grid used for correcting Ikonos VHR images in this study was well below the frequency of systematic noise in the DEM derived from a contour interval of 10 m. This rendered the commonly used 3*3 smoothing filter ineffective for removing interpolation errors. Increasing the kernel size did not offer much improvement, as it resulted in loss of height accuracy due to averaging within a larger kernel. Thus, although the 7*7 smoothing

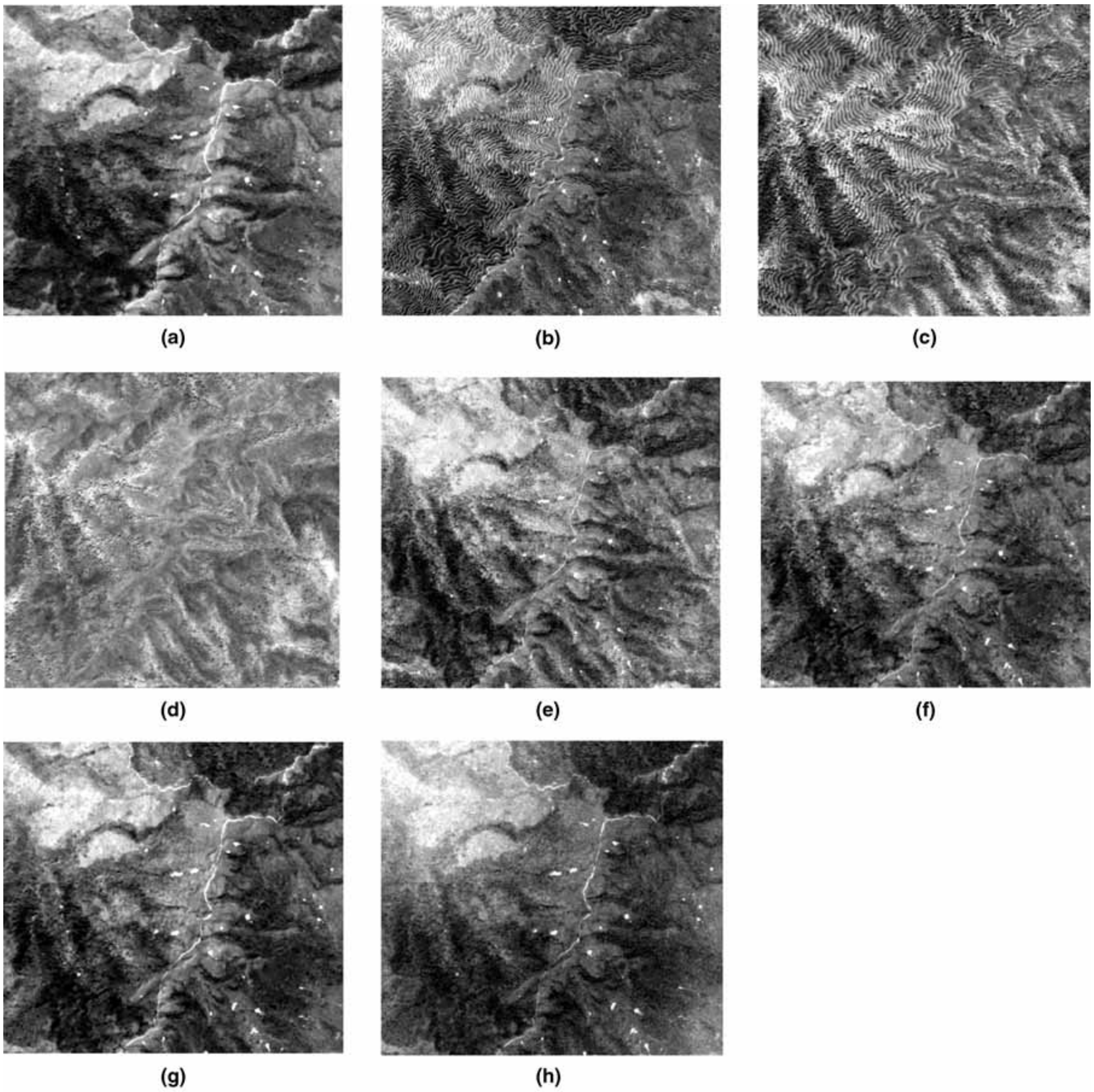

Figure 3. Extracts showing the NIR band of the topographically corrected images: (a) original image, (b) NN (radius 30 m), (c) NN with 3*3 smoothing kernel, (d) NN with 7*7 smoothing kernel, (e) NN with slope, (f) TIN, (g) Sibson, and (h) Sibson with slope. The dark curvilinear features on the corrected images (e.g., Figure 3h) represent forest which is more likely to occupy valley bottoms and north-facing slopes than grassland, and is not due to any remaining 3D relief effect.

filter used in this study produced a visually smoother DEM than the 3*3 filter, it did not achieve a significant reduction in variance, or increase in classification accuracy of the corrected image.

A better option is to use an interpolator more suitable for use with contour data such as the Sibson, TIN, or TOPOGRID model, or to remove noise with a slope, rather than smoothing function. Thus, classification accuracy due to the interpolation technique used increased by 11 percent (from 82 to 93 percent) when the Sibson, as opposed to NN interpolator was used. Accuracy due to adding the slope function to each of these two interpolators increased by 5 percent (from 82 to 87 percent) for NN, and by 6 percent (from 93 to 99 percent) using Sibson. On the other hand, the smoothing function added to the NN with both 3*3- and 7*7-kernel sizes resulted in a slight decrease in class accuracy. Visually, many of the corrected images appeared noisier, an effect also noted by Teillet *et al*. (1980). The best overall combined technique, the Sibson with slope function achieved 17 percent higher accuracy over the lowest: the NN interpolator, and no dark patches (or noise) were present in the image. Unless the problem of flat triangles in the TIN model can be removed by the addition of break lines and a skeleton, this model is only moderately effective in topographic correction. Although TOPOGRID is theoretically capable of computing accurate drainage models based on contour shape, it performed only moderately. This may be attributed to the generally poor contour definition for drainage lines on steep slopes, a well as the extremely rugged nature of the study area for which a spline-based interpolator would not be optimal.

Table 4. Accuracy of Supervised Classification for Four Land-cover Classes Based on 400 Sample Points

	Minnaert		Two-stage Normalization	
	Overall (%)	Kappa	Overall (%)	Kappa
Original image	72	0.49	72	0.49
NN	84	0.73	82	0.67
NN with smoothing 3*3	80	0.65	79	0.63
NN with smoothing 7*7	77	0.57	78	0.59
NN with slope function	86	0.76	87	0.76
Sibson	94	0.90	93	0.88
Sibson with slope function	98	0.97	99	0.98
TIN	91	0.85	92	0.86
TOPOGRID			91	0.84

Conclusions

This study has demonstrated the importance of DEM quality on topographic correction of images, showing a difference of 20 percent in overall class accuracy between the least and most effective interpolation techniques. The results also suggest that the new generation of very high-resolution sensors present special problems in topographic correction due to the need for higher resolution DEMs to match the pixel size. Thus, the commonly used 3*3 smoothing filter may be ineffective for a high-resolution grid if the kernel size in relation to terrain steepness is not considered. Even though a larger kernel size may give a smooth DEM and resulting image, loss of image detail and contrast may result. Therefore, smoothing as a means of removing noise is only moderately effective compared to the slope function, which achieved approximately 6 percent higher class accuracy than smoothing in the present study. When the slope function is used in combination with the most effective, Sibson interpolation technique, very high classification accuracy may be obtained from the topographically corrected image.

Acknowledgments

The authors would like to thank Chris Gold and Maciek Dakowicz for the use of HKTM software used in this study, a well as funding received from CERG Grant PolyU5166.03E from the Hong Kong government.

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(Received 10 January 2006; accepted 27 March 2006; revised 07 June 2006)