Photogrammetric Week '07 Dieter Fritsch (Ed.) Wichmann Verlag, Heidelberg, 2007

New Approaches to Generating and Processing High Resolution Elevation Data with Imagery

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ABSTRACT

Automatic determination of heights from imagery is a difficult problem. BAE Systems has offered the Automatic Terrain Extraction (ATE) and Interactive Terrain Editing (ITE) modules of its photogrammetric software suite SOCET SET® for many years and these represent a best-in-industry solution, though errors can occur in certain circumstances. Now BAE Systems has introduced Next-Generation Automatic Terrain Extraction (NGATE), a new approach to the problem. NGATE is easy to use and offers significant improvements in accuracy to ATE, resulting in a reduction in the amount of editing required in the ITE phase. Tests indicate that *this reduction is in excess of 30%*, which represents considerable progress in terms of productivity and cost savings sufficient to provide ample return on investment on the cost of ownership of NGATE.

1. INTRODUCTION

The automatic derivation of elevation data from imagery is a challenge with which photogrammetrists have grappled for half a century. The problem is that the underlying image matching process may fail or give incorrect results, not because the algorithms are erroneous, but because the overlapping images are simply different owing to different viewpoints and perhaps temporal disparity. It is straightforward for a human to understand what is being viewed, but daunting for an automated software process. A second problem is that, especially on large-scale imagery, automated algorithms often encounter problems with trees and buildings. The discontinuities at the edges of roofs of buildings are particularly troublesome, added to the fact that often the side of a building appears in one image but not another.

2. ELEVATION GENERATION IN SOCET SET

The approach taken with ATE and ITE in SOCET SET has been a reasoned solution to the practical problems. ATE has a long history, originating in work done in the 1980s on U.S. government programs (1,2). It is based on area-matching, i.e., a small window in one image is matched against a moving window in another image to find the best match using two-dimensional cross-correlation. This method is a refinement of possibly the most popular method of image matching. ATE includes certain special algorithms to increase its effectiveness, for example different strategies for different kinds of terrain, so that in the event of failed or very poor matching, for example, a slope constraint parameter ensures that the algorithm does not stray unrealistically far from the true terrain. The parameters for the different strategies can be specified by the user, but this demands a deeper knowledge of SOCET SET than should be expected of most users. Consequently, in 1997 Adaptive ATE was introduced, enabling the parameters to start in accordance with one of a limited range of strategies then vary according to the nature of the terrain (4).

2.1. Improvements in elevation generation in SOCET SET in recent years

Development work has continued (3,5) and the following summarizes the advances aimed at more reliable terrain from the automated process. Numerous improvements have been made to the interactive editing functions and the speed of drawing terrain over the stereomodel. A “bare earth” filter to remove trees and buildings, i.e., change the digital surface model (DSM) derived from the image matching into a digital elevation model (DEM), has been added. Existing terrain models or feature files may be used to "seed" the ATE process, i.e., provide it with reasonable starting values to reduce computing time and increase the probability of the correlation algorithm finding the true optimum for each point. It is possible to merge different DTMs into a single output, taking into account the precision of each component DTM and any biases (systematic vertical shifts) between them. Work has been done to increase compatibility in switching between grid and TIN (triangulated irregular network) representations of the terrain and the provision of equivalent functionality for both representations. Multi-image matching, whereby the optimum stereo pair is selected for each area based on the nature of the terrain and the overall geometry of the sensor positions and orientations with respect to it, has been a powerful new tool in blunder detection: if different image pairs give dissimilar results for a point, then that point can be rejected as erroneous; back-matching too, whereby a fixed window in one image is correlated with a moving one in the other, then the process is reversed and any discrepancies between the results are evidence of an erroneous point, empowers blunder detection (5). Recently, it has been necessary to redesign the architecture of the underlying terrain database to accommodate the massive point clouds being acquired by the airborne LIDAR systems that are central in current mapping operations.

3. NGATE

Despite the above tremendous progress in ATE and ITE, which, it is contended, has resulted in a best-in-industry software product, further improvement remains desirable, especially in view of the high labor costs of interactive editing. In 2005, BAE Systems began to work on some ground-breaking ideas for a new approach.

3.1. Principles

The theory behind NGATE and the algorithms associated with it have been described in a series of published papers (3,5). Earlier algorithms were based on the principle that the terrain within the window being matched is level. This is clearly not the case and, indeed, elevation differences within the window reduce the correlation. Thus NGATE was built with the capability of allowing terrain variation within the window and the window size is related to the elevation difference. Secondly, most image matching algorithms perform correlation at specific points, usually spaced out according to the choice of the user. In ATE, for example, the user selects the point spacing as a function of the resolution of the imagery, i.e., some multiple of the ground sample distance (GSD) of the imagery. In NGATE, however, matching takes place for every pixel. Previously, this approach was regarded as too slow owing to the intimidating computational effort of matching at each of the hundreds of millions of pixels in a stereo overlap, but NGATE's innovative computational algorithms are sufficiently fast that this has ceased to be a stumbling-block. Thirdly, ATE and similar solutions employ area-matching, usually based on a form of the two-dimensional cross-correlation function. The problem of discontinuities at the edges of roofs has already been highlighted. Furthermore, edges are lines rather than areas, so in this situation it is probably better to match edges rather than areas. Edge-matching is more robust for buildings: elevation discontinuities such as building edges usually generate image edges; and edge-matching "masks" out pixels that are not edge pixels, which are likely to have significant elevation differences. NGATE, therefore, uses a hybrid of both edge-matching and area-matching: results from area-matching are used to guide and constrain edge-matching; results from edge-matching are used to guide and constrain area-matching; and the final results are the combined results from both approaches together with blunder detection and inconsistency checking.

Criterion	NGATE	ATE
Computation of image matching	Every pixel	Each post
Type of matching	Combines results optimally from area-matching and edge-matching	Uses only area-matching
Basis of accuracy and speed	Minification level at which to stop	Post spacing or number of posts
Back-matching	On by default	User can turn on/off via GUI
Multi-pair matching	User-selectable	User-selectable
Multi-CPU enabled	User-selectable	User-selectable
Performance	Better than ATE with large-scale imagery in urban areas	
Editing time	Less than ATE, resulting from highly accurate DTMs	

Table 1: Comparison of NGATE and ATE

A comparison of NGATE and ATE is provided in table 1. These principles are the basis of a complex body of algorithms and efficient code, resulting in accurate, very dense terrain models. NGATE is designed not only to be robust and fast, but also to be easy to use, with rather few choices to be made by the user. It functions with all the sensor models and image types available in SOCET SET.

3.2. User experience

The user typically initiates NGATE from the top-level SOCET SET menu, chooses to create a DTM and is presented with a tabbed user interface. The first tab, Images, provides for the selection of the imagery. The second, DTM Properties, enables the user to define the extent of the required DTM, the representation of the output (grid or TIN), and the X and Y spacing. In the case of a TIN, NGATE populates cells of the size specified in the spacing where good quality matches are achieved, giving the raw data to be triangulated into the TIN. NGATE computes an elevation for every pixel, but the user may not want such a huge DTM, so the spacing is used to resample the internal NGATE DTM to the desired density. The third tab, NGATE Properties, enables the user to decide how NGATE will run. Two strategies are available, one for small- to medium-scale imagery, mostly natural terrain; and one for larger-scale imagery, as commonly acquired over urban areas. These can be customized for difficult areas. The number of image pairs per point has a default value of one, but two to three is recommended if available. If the computer has more than one CPU and the user has more than one NGATE license, more than one NGATE can execute simultaneously. Each NGATE generates a section of the whole DTM and, after completing all sections, NGATE merges them into one DTM. The Eliminate Trees/Buildings/Other option determines whether NGATE generates a DSM or DEM: if this option is checked, buildings or trees with heights above ground greater than a specified minimum height and width less than a specified maximum width are eliminated. The Precision/Speed selection has a default value of high precision and low speed (High/Slow). For high speed and less precision, select Low/Fast. High/Slow causes NGATE to perform area- and edge-matching all the way to minification level 1:1, whereas Medium/Medium stops it at 2:1, and Low/Fast, 4:1. Remember that the speed of NGATE does not depend on the post spacing: it always performs matching on every image pixel regardless of the post spacing. Finally, the user can choose whether thinning is performed to create sparser TINs, thus reducing the data volume and the amount of detail. The fourth tab, Seed DTM, is the means of providing starting values. The user defines the minification level at which NGATE will no longer hold the seed points fixed. At one extreme, the seed points will not change at all throughout the whole process. At the other, NGATE will determine when to let the seed points move, based on the estimated relative vertical accuracy of the points in the seed DTM file specified by the user.

4. RESULTS

BAE Systems has carried out a series of case studies using a variety of image sources and terrain types. The goals have been to examine the accuracy of NGATE terrain models in terms of vertical root mean square error (rmse) and to assess the quality of these models subjectively via criteria such as amount of detail, sharpness of edges and realism. In each case, the comparison has been with results from ATE using the same imagery and orientation parameters.

4.1. Case study 1: large-scale film imagery, urban area

This case study is summarized in table 2. The richness of detail captured by NGATE is apparent, for example the air-conditioning and elevator hardware on the tops of industrial buildings, the cars in the parking lot and the superior quality of the edges of the buildings.

Location	San Diego, California
Type of terrain	Urban
Coordinate system	UTM
Imagery	Film, scanned at 12.5 µm
Image scale	Large
Spectral characteristics	Color, 3 bands, 8 bits per pixel per band
Number of images	21
GSD (m)	0.05
DTM representation	Grid
DTM spacing (m)	0.25 in both X and Y
Number of points	52,200,024

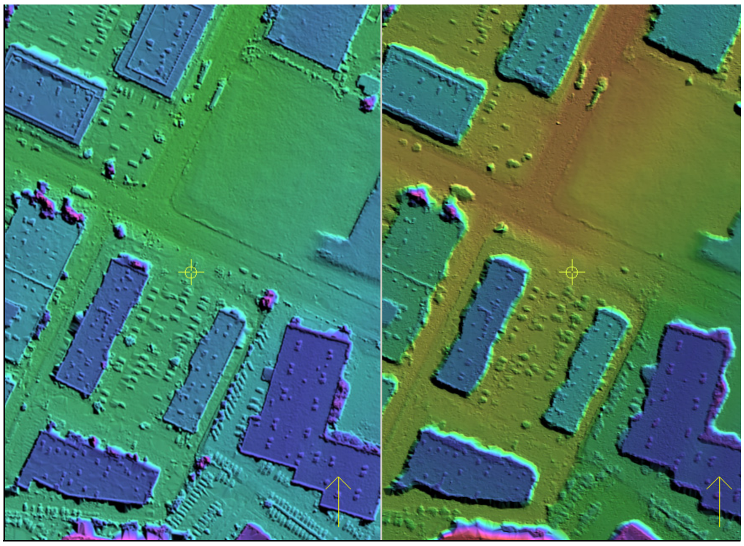


Table 2: Case study 1 – summary (left), NGATE result (center) and ATE result (right)

Points	% points removed	RMSE (m)	Bias (m)
NGATE			
204	0.0	0.18	-0.03
201	1.5	0.13	-0.04
195	4.6	0.11	-0.03
192	6.3	0.10	-0.03
ATE			
204	0.0	0.76	0.03
197	3.6	0.33	-0.00
191	6.8	0.19	-0.03
188	8.5	0.16	-0.01

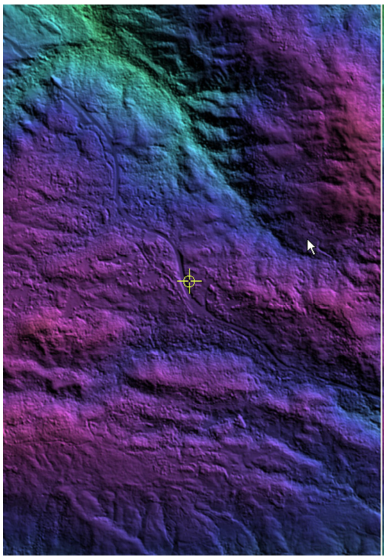
Table 3: Case study 1 – comparison of NGATE and ATE DSMs and ground truth

Table 3 shows statistics from 204 manually edited, regularly spaced grid points, measured by two engineers to ensure their accuracy. These were used to estimate the accuracy of the DSM of 52 million points generated from NGATE. With no editing whatsoever, the rmse was 0.18 m, i.e., 3.5 pixels (3.5 times GSD – a simple comparator to provide perspective) or 0.08‰ of the flying height. When only 1.5% of the points were removed by editing, these values dropped to 0.13 m, 2.5 pixels, and 0.05‰ respectively. The unedited ATE values were 0.76 m, 15 pixels and 0.33‰. If 6.8% of the ATE points were edited, the quality of the results was similar to the unedited NGATE points. 6.8% of 52 million points is 3.5 million points - NGATE delivers a significant reduction in editing time!
This case study was also analyzed with respect to

the orthorectified imagery that can be generated from the NGATE TIN. If insufficient attention is paid to the elevation data, the positional error of orthorectified imagery can be 100 times greater than its ground sample distance (GSD). The imagery was used to assess the positional errors due to elevation errors in the DEM. Two orthoimages were generated, the first using the DSM from NGATE and the second, an SRTM DEM from USGS. The largest positional error in the orthoimage generated using the SRTM DEM, based on 20 test points measured, was 5.35 m, 107 times the imagery GSD. The largest positional error in the orthoimage generated using the NGATE DEM was 0.40 m, 13 times more accurate. For NGATE, rmse in X was 0.17 m, Y, 0.13 m and XY, 0.21 m. The corresponding values for the SRTM orthoimage were 1.80 m, 1.99 m and 2.68 m. Thus the planimetric error measured by rmse for the orthoimage generated using NGATE was 13 times more accurate.

4.2. Case study 2: medium-scale film imagery, mixed terrain

Location	Santa Barbara, California
Type of terrain	Urban, rural, lakes, airport, mountains
Coordinate system	Geographic
Imagery	Film, scanned at 14 μm
Image scale	Medium
Spectral characteristics	Color, 3 bands, 8 bits per pixel per band
Number of images	90
GSD (m)	0.35
DTM representation	Grid
DTM spacing (m)	3 in both X and Y
Number of points	56,981,100



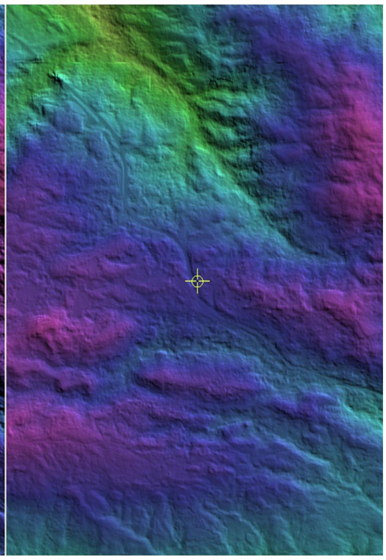


Table 4: Case study 2 – summary (left), NGATE result (center) and ATE result (right)

Points	% points removed	RMSE (m)	Bias (m)
NGATE			
347	0.0	1.12	-0.28
344	0.9	1.06	-0.27
ATE			
347	0.0	1.83	0.06
340	2.16	1.40	-0.06
336	3.3	1.32	-0.06
331	4.8	1.24	-0.12

Table 5: Case study 2 – comparison of NGATE and ATE DSMs and ground truth

This case study is summarized in table 4. Once again, the superior, more detailed representation of the terrain displayed by the NGATE DSM is apparent. The quantitative measures of accuracy are given in table 5, based on 347 manually edited, regularly spaced grid points (edited twice by two engineers to ensure their accuracy). With no editing, the rmse from NGATE was 1.12 m, 3 pixels or 0.29‰ of the flying height. The unedited ATE values were 1.83 m, 5 pixels or 0.48‰. When 4.8% of the ATE sample points were edited, the quality of the results was similar to the unedited NGATE points. 4.8% of 57 million points is 2.7 million points - another significant reduction in editing time! Finally, a small test was performed over an airport in the area of the case study, which we would expect to present fewer challenges than the often mountainous and wooded terrain of the case study as a whole. 96 sample points in the airport area were measured manually in a stereo pair and compared with the NGATE results, giving an rmse of 0.31 m, 0.9 pixels and 0.08‰ of the flying height.

4.3. Case study 3: medium-scale Intergraph DMC imagery, suburban and rural

Location	Sussex, UK
Type of terrain	Suburban and rural
Coordinate system	LSR
Imagery	Intergraph DMC
Image scale	Medium
Spectral characteristics	Color, 3 bands, 8 bits per pixel per band
Number of images	320
GSD (m)	0.25
DTM representation	Grid
DTM spacing (m)	1.5 in both X and Y
Number of points	55,823,460

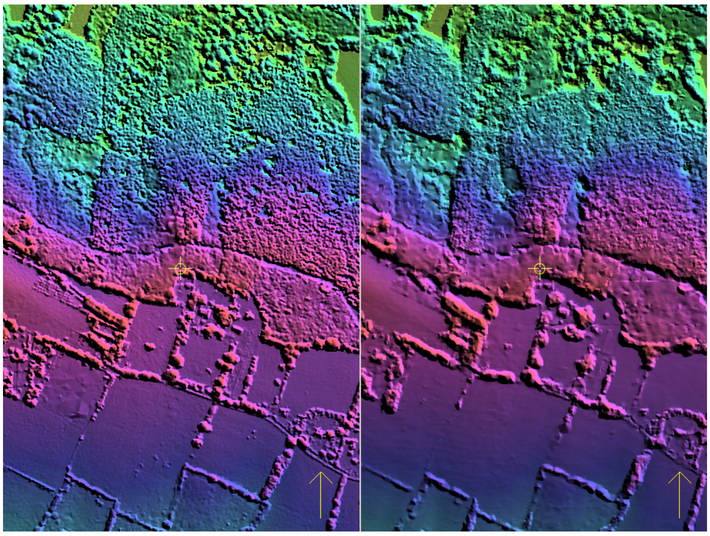


Table 6: Case study 3 – summary (left), NGATE result (center) and ATE result (right)

Points	% points removed	RMSE (m)	Bias (m)
NGATE			
522	0.0	0.56	-0.24
513	1.8	0.41	-0.20
504	4.2	0.35	-0.17
ATE			
522	0.0	1.76	0.07
508	2.8	0.89	-0.15
492	6.1	0.61	-0.23
479	9.0	0.50	-0.21

Table 7: Case study 3 – comparison of NGATE and ATE DSMs and ground truth

The third case study is summarized in table 6, where the greater detail in the trees, the sharper nature of some of the field boundaries and more small details in the fields in the lower half of the image are evident in the NGATE image in the center. Table 7 gives statistics from 522 manually edited, regularly spaced grid points (edited twice by two engineers to ensure their accuracy), used to estimate the accuracy of the DSM of 56 million points generated from NGATE. With no editing, the rmse was 0.56 m, 2 pixels or 0.22‰ of the flying height. Substantial improvements were available with some editing: 0.41 m, 1.6 pixels and 0.16‰ with 1.75% of points removed and 0.35 m, 1.4 and 0.14‰ with 4.2% removed. The unedited ATE values were 1.76 m, 7 pixels or 0.70‰. When 6.1% of the ATE sample points were edited, the quality of the results was similar to the unedited NGATE points. 6.1% of 56 million points is 3.4 million points - a significant reduction in editing time!

4.4. Case study 4: medium-scale Intergraph DMC imagery, urban

The fourth case study is summarized in table 8. The red dots in the image are points measured manually in SOCET SET using the same image support data referenced by NGATE. Table 9 is a comparison of the Z coordinates of the measured points and the values interpolated from the NGATE point cloud. A small number of blunders was then removed sequentially. It is seen that with no editing NGATE gave an rmse of 0.73 m, i.e. 5 pixels or 0.49‰ of the flying height. With only 1.7% of points edited these values improved to 0.35 m, 2 pixels and 0.23‰ respectively. The lower part of table 9 shows a variant of the information: all points on trees were removed from the data set to give an estimate of what could be obtained if photogrammetrically derived heights were used in treeless areas only. With no editing, the values were 0.57 m, 4 pixels and 0.38‰ respectively. With only 1% of points edited, these values improved to be almost the same as those from the data set without trees removed and 1.7% edited.

Location	Bournemouth, UK
Type of terrain	Urban
Coordinate system	LSR
Imagery	Intergraph DMC
Image scale	Large
Spectral characteristics	Panchromatic, 12 bits
Number of images	12
GSD (m)	0.15
DTM representation	TIN
DTM spacing (m)	0.5 in X and Y
Number of points	34,933,605

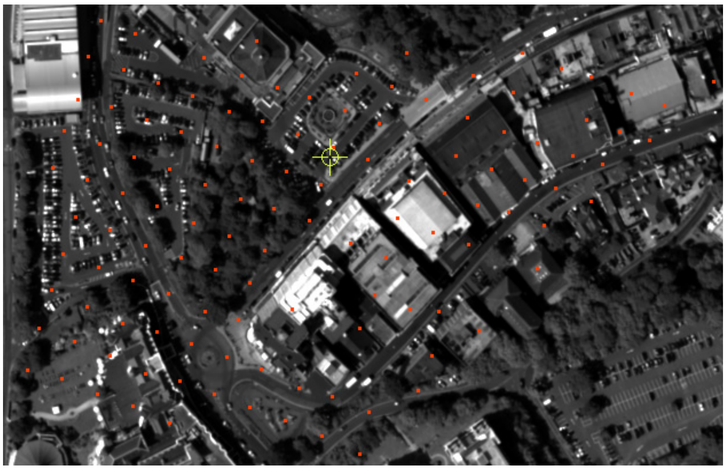


Table 8: Case study 4 – summary (left) and imagery with test points (right)

Points	% blunders removed	RMSE (m)	Bias (m)
All points			
121	0.0	0.73	-0.02
119	1.7	0.35	0.00
115	5.0	0.32	0.01
112	7.4	0.28	0.02
Points on trees removed			
104	0.0	0.57	-0.06
103	1.0	0.35	-0.01
101	2.9	0.29	0.02
99	4.8	0.25	0.04

Table 9: Case study 4 – comparison of NGATE and ground truth

To complement case studies 3 and 4, which were based on digital airborne imagery from Intergraph DMC cameras, test imagery was obtained for further case studies using Microsoft UltraCam$_D$ and Leica ADS40 imagery. NGATE performed well, but there is insufficient space here to provide the results, though the UltraCam$_D$ study has been reported elsewhere (6). The remaining case studies involve satellite rather than airborne imagery.

4.5. Case study 5: IKONOS panchromatic imagery, mixed terrain

Case study 5, based on IKONOS 1 m panchromatic imagery, is summarized in table 10 and fig. 1. Both NGATE (graphic in center of table 10) and ATE (right hand side) performed very well, with just a little more detail in the NGATE representation. The top row of illustrations in fig. 1 is overlaid with 3 m contours. Those in the upper left illustration show how well the buildings are modeled, for example the corners shown by the arrows. The contours in the upper center and upper right illustrations show how well the DSM follows the surface, sloping down sharply from the decks of bridges and finding the ground in the narrow gap between the two bridges shown by the central arrow in the center illustration (the process has not been confused by the moving vehicles on the freeway). The contours follow the very steep slopes of the construction site closely, shown by the arrows in the upper right illustration. The 5 m contours in red in the lower left illustration are from NGATE, whereas those in green are from ATE with back matching: the NGATE data needs no editing and the contours follow the terrain slightly better than those from ATE, for example in the ditch at the left center. The red dots in the lower right illustration are the NGATE DSM: the water body is flat, with no spurious points, and an object on it has been correctly detected.

Location	San Diego, California
Type of terrain	Urban, rural, highways, water bodies, construction sites, forest
Coordinate system	UTM
Imagery	GeoEye™ IKONOS®
Image scale	Very high-resolution satellite
Spectral characteristics	Panchromatic
Number of images	2
GSD (m)	1.0
DTM representation	Grid
DTM spacing (m)	5
Number of points	8,206,380

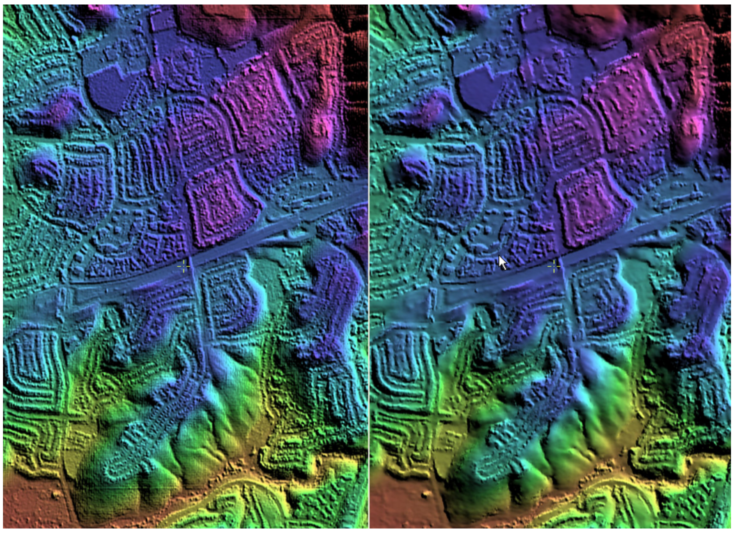


Table 10: Case study 5 – summary (left), NGATE result (center) and ATE result (right)

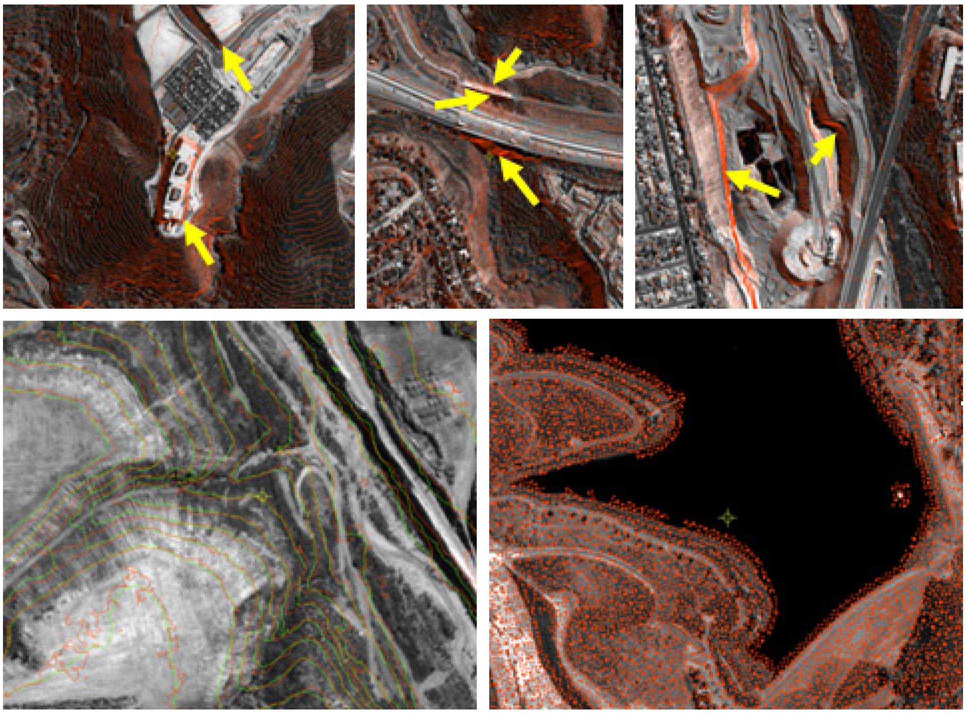


Fig. 1: Case study 5 – samples of imagery

A sample of 221 check points was measured manually and compared to the NGATE DSM. The resultant rmse was 0.98 m (1 pixel). These results were remarkably good and it was concluded that no editing was needed with NGATE, whereas minimal editing was needed with ATE.

4.6. Case study 6: Cartosat-1 panchromatic imagery, desert terrain

Location	Great Salt Lake Desert, Utah
Type of terrain	Mountains, desert
Coordinate system	UTM
Imagery	Cartosat-1
Image scale	High-resolution satellite
Spectral characteristics	Panchromatic, 12 bits
Number of images	4
GSD (m)	2.4
DTM representation	TIN
DTM spacing (m)	10
Number of points	18,660,246

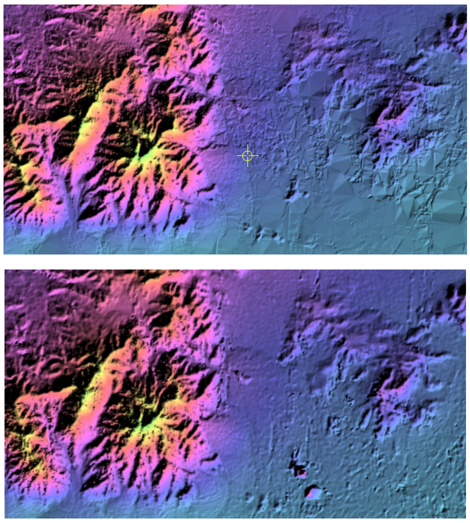


Table 11: Case study 6 – summary (left), NGATE result (upper right) and ATE result (lower right)

BAE Systems was provided with early Cartosat-1 panchromatic imagery for evaluation. The RPC coefficients provided with the imagery were used for the case study, but Cartosat-1 processing is not yet part of the standard SOCET SET product. The case study, summarized in table 11, is still in progress, but it is already clear that NGATE is outperforming ATE, as illustrated by the greater detail in the terrain shaded relief view from NGATE at the top right of table 11, and the absence of the artifacts visible in the lower center of the ATE image at the bottom right. An engineer measured 419 points manually. With no editing, NGATE gave an rmse of 5.7 m or 2.4 pixels, while the corresponding values for ATE were 27.4 m and 11.4 pixels. This difference between NGATE and ATE is astonishing and is being investigated. For example, discrepancies were found between the two stereopairs covering the test areas, so these stereopairs are also being analyzed individually. Further ongoing work includes an experiment with the special strategy developed for the martian imagery discussed below, since this is designed to cope with image phenomena that may also be encountered in desert areas on Earth.

4.7. Case study 7: Mars Express HRSC, Mars

Work has begun on a case study based on imagery from Mars obtained courtesy of the Astrogeology Team of U.S. Geological Survey (USGS) in Flagstaff, Arizona. The imagery was taken by the High Resolution Stereo Camera on board the European Space Agency's Mars Express. This is a line scanner and is accommodated in SOCET SET by a customized sensor model written by USGS and not included in the standard product. Moreover, a special NGATE strategy suited to imagery with high noise-to-signal characteristics was created. It is evident from the figure at the right hand side of the graphic in table 12 that the ATE terrain model contains many blunders, as indicated by the rough, blocky nature of the terrain shaded relief, whereas NGATE, on the left hand side, has produced a smoother, more accurate representation of the martian surface. Work, including the computation of quality statistics, is continuing on this project by both BAE Systems and USGS. The success of the new strategy is encouraging and experiments will be designed to try it on terrestrial imagery of deserts and other areas of low texture.

Location	Vallis Marineris, Mars
Type of terrain	Mountains, craters, smooth plains
Coordinate system	Mars_VM_sinusoidal
Imagery	Mars Express HRSC
Image scale	Medium-resolution satellite
Spectral characteristics	Panchromatic, 8 bits
Number of images	2
GSD (m)	26.8
DTM representation	Grid
DTM spacing (m)	100
Number of points	4,251,156

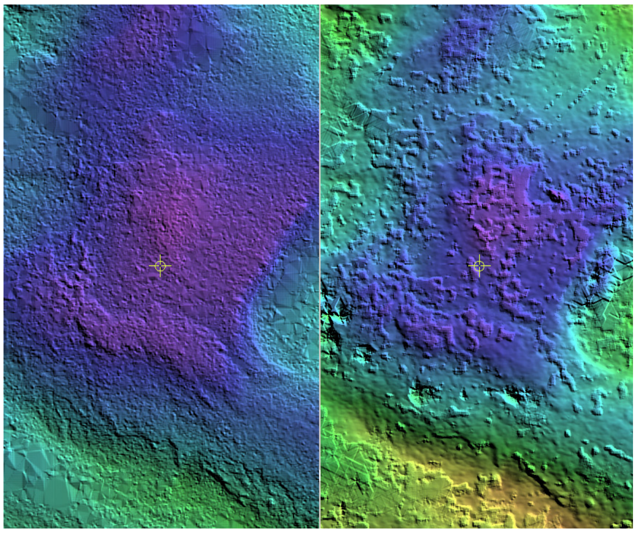


Table 12: Case study 7 – summary (left), NGATE result (center) and ATE result (right)

4.8. Experience in production

BAE Systems includes a business area called Geospatial Products and Services (GP&S), which operates as a commercial photogrammetric service company, competing in the private sector for both commercial and government business. GP&S began using NGATE in the autumn of 2006 and at the time of writing this paper had accumulated eight months of experience with it, covering a wide range of image sources and scales and terrain types. The production managers' conclusion is that the editing time spent with the ITE module has been reduced by 30%. This is a most important statistic and represents substantial cost savings. Given that GP&S started with a very early version of the production module of NGATE and that significant improvements have been made in the intervening time, it is reasonable to expect that this figure of 30% has now been exceeded.

5. CONCLUSIONS FROM THE VARIOUS RESULTS

Having acquired extensive experience and conducted a brace of tests, BAE Systems feels able to state the following with confidence with respect to NGATE:

- On small- to medium-scale imagery, DTM editing is minimal
- On large-scale imagery in urban areas, DTM editing is significantly reduced
- On large-scale imagery in natural terrain, DTM editing is minimal
- Building edges are preserved
- Water bodies are flattened
- Streets and featureless areas are precisely modeled
- The main cost of DTM generation is manual editing, which is significantly reduced, by more than 30%.

6. AVAILABILITY OF NGATE AND ONGOING DEVELOPMENT WORK

After an extensive, worldwide beta testing program, NGATE began shipping with SOCET SET v5.4 in July 2007. It is an add-on module for SOCET SET and requires the Core module to run (and Advanced Sensor Models or DataThruWay® modules if sensor models other than those in Core are required). Each NGATE license consists of a main GUI NGATE license that controls the main window, plus two NGATE processing licenses, which permit distributed processing of the application or running the application with two separate batch mode executions at one time on the license server network.

Though NGATE is now part of the standard product, development is continuing. Work in progress includes the following improvements:

- Hough Transform to match edges that are parallel to epipolar lines and improve edge-matching for non-epipolar-parallel edges
- Computation of two DTMs (DSM and bare earth DEM) from NGATE simultaneously; this should result in a much better bare earth DEM, improve sharpness of the DSM at building edges, and provide users with three options - DSM; DEM; or both DSM and DEM
- Enhancement of bare earth algorithm especially for hilly areas to remove trees; the current bare earth algorithm works reasonably well in relatively flat areas with dense DSMs, but is rather slow and needs improvement to work with hilly areas, especially to remove trees from the DSM
- Flatten water body for Grid format - though NGATE typically generates no elevation points on water when the TIN format is used, the Grid representation is not perfectly flat on water and this must be rectified
- Extension of the Condor distributed processing capabilities in SOCET SET to include NGATE.

7. A NOTE ON LIDAR

SOCET SET handles point clouds regardless of origin. Its LIDAR import enables multiple returns and intensity values to be imported, in ASCII or the industry standard LAS format. The design of the terrain database enables more than two billion points to be accommodated. LIDAR data can be viewed on its own or with imagery, monoscopically or stereoscopically, using the same terrain representations that are available for photogrammetrically derived elevation data. The intensity values can be used to create an intensity image, which is in fact an orthophoto, during input. The functionality in the Ortho module of SOCET SET enables the user to create a stereomate and uses this, together with the intensity image, to extract features stereoscopically, a process sometimes known as “LIDARgrammetry.” Monoscopic extraction from the intensity image is also possible — SOCET SET adds Z coordinates from the underlying LIDAR DTM — but the lack of stereoscopic visualization makes the interpretation of the scene more difficult. SOCET SET is a photogrammetric software package and is not designed for automatic classification of LIDAR point clouds, but the bare earth filter and powerful range of ITE tools enable much to be done with this data. Finally, SOCET SET’s terrain shaded relief is a very effective way of viewing LIDAR data monoscopically, stereoscopically, or as perspective scenes, and results may be exported in OpenFlight format to third-party visualization packages.

Extensive experience working with LIDAR and NGATE data sets at BAE Systems has led to the conclusion that a LIDAR DSM has advantages over an NGATE DSM in shadow areas, in narrow alleys between buildings and in forest areas. Typically, an NGATE DSM has fewer blunders because of embedded blunder detection and removal. For natural terrain, photogrammetry and LIDAR DSMs have similar accuracy, though of course this depends on the relative flying heights of the imagery and LIDAR acquisition missions.

Since high-density photogrammetric DTMs and LIDAR data are so similar, certain operations can be applied equally to either data set, as noted above. Both data sets contain huge numbers of points that define the terrain surface but are not accompanied by attributes providing any qualitative information about that surface. Bare earth filtering is one way to divide the data sets into the “bald earth” surface and the buildings, trees and other structures upon it. BAE Systems, however, has gone beyond that and is working on automatic extraction of buildings from point clouds, with straight edges that are accurate, appealing representations of reality. It is anticipated that this work will be incorporated into the SOCET SET and SOCET GXP® products in 2008.

8. CONCLUSIONS AND FUTURE WORK

NGATE is an innovative module for SOCET SET that can create terrain models automatically from imagery. The results are more accurate than those from the earlier ATE module and require significantly less human editing, resulting in remarkable cost savings. Furthermore, the terrain models generated by NGATE are denser and represent the terrain, including small features and details, better than those from ATE. Using NGATE, together with rather modest interactive editing in the ITE module, the resultant photogrammetrically derived DTMs are first-rate deliverables on their own, or a superb basis from which to create orthorectified imagery and other products. Photogrammetry and LIDAR should be regarded as complementary rather than competing technologies with respect to the cost-effective acquisition of high-quality terrain elevation data.

9. REFERENCES

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