QuickBird Data – experiences with ordering, quality and pan sharpening

BIRGIT KLEINSCHMIT & MICHAEL FÖRSTER, Berlin; ANNETT FRICK, Potsdam & KATJA OEHMICHEN, Hamburg

Keywords: QuickBird, VHR, ordering, pan sharpening, quality, remote sensing

Summary: The QuickBird sensor is one of the first commercial satellites that provides a submeter resolution. This article presents experiences with the ordering, the quality and pan sharpening of QuickBird data, which were acquired for different purposes in various regions of Germany and Asia.

The ordering process and the characteristics of the four offered products are described. The image characteristics depend mainly on the off-nadir view angle. The influence of slant effects and inclination are shown. Other data quality characteristics of QuickBird images are an induced overcharge in the sensor's charge-coupled devices (CCD) for highly reflective materials like metal or glass and "rainbow" pixels which occur along objects with high contrast. A big advantage of the available 11-bit data range is the possibility to differentiate further details in areas overthrown by shadow. Another challenging effect is the high and artificial texturing of areas with low reflection that should be very homogeneous.

Moreover, the quality of seven different pan-sharpening algorithms of three software products was tested. The study introduces the pan-sharpening accuracy assessment, which considers the spectral reliability of the fused data in comparison to the original image and the desired higher spatial frequency of the merged data. The Enhanced IHS fusion proved to be the most successful in pan sharpening QuickBird images.

Zusammenfassung: *QuickBird-Daten – Erfahrungen zu Datenbestellung, Qualität und pan sharpening*. Die Daten des Satelliten QuickBird sind eines der ersten kommerziell verfügbaren Produkte, welche eine geometrische Auflösung im Submeter-Bereich liefern. Der vorliegende Artikel gibt Erfahrungen zur Bestellung, Qualität und Auflösungsverbesserung durch pan sharpening der Daten wieder, die für verschiedene Auswertungen in unterschiedlichen Regionen Deutschlands und Asiens aufgenommen wurden.

Zunächst werden der Bestellprozess und die Charakteristika der vier angebotenen Produkte vorgestellt. Dabei hängt die Bildcharakteristik hauptsächlich vom Aufnahmewinkel (off-nadir) ab. Verzerrungseffekte können die Qualität der Daten erheblich mindern. Auch so genannte „Regenbogen"-Pixel, die an Objekten mit großem Kontrast auftreten, beeinträchtigen die Qualität der Daten. Weitere Artefakte entstehen durch stark reflektierende Materialien, wie Metall oder Glas, die eine Überladung in den lichtempfindlichen Halbleiterdetektoren (CCDs) des Sensors erzeugen. Ein Vorteil der Daten ist die hohe radiometrische Auflösung von 11-bit. Dadurch ist die Möglichkeit der Unterscheidung von Objekten in beschatteten Bereichen gegeben. Problematisch ist hingegen das Auftreten von künstlichen Texturen bei homogenen Gebieten mit geringer Reflektion.

Weiterhin wurde die Qualität von sieben verschiedenen pan sharpening Algorithmen dreier Software-Pakete getestet. Dafür wird eine Methode zur Prüfung der Genauigkeit der pan sharpening Resultate vorgestellt, welche sowohl die spektrale Ähnlichkeit der fusionierten Daten zum Ausgangsbild, als auch die gewünschte höhere räumliche Frequenz des Ergebnisses in die Analyse der Qualität einbezieht. Die Enhanced IHS fusion erwies sich dabei als erfolgreichste pan sharpening Methode für QuickBird Daten.

1432-8364/07/2007/0073 $ 2.75

1 Introduction

The specification "very high resolution" (VHR) is not well-defined but commonly used for a geometric resolution of multispectral sensors with a ground sampling distance (GSD) of up to 4 m (Ehlers 2002). Examples for panchromatic and multispectral sensors operating as VHR systems are QuickBird, OrbView 3, Ikonos 2 or Eros A1 (see Tab. 1). Among these QuickBird, which was launched in October 2001, is one of the first commercial satellites that provides submeter resolution imagery. Its panchromatic band collects data with a 61 cm resolution at nadir while the multispectral ground sampling distance is 2,4 m at nadir. The company DigitalGlobe (Longmont, Colorado, US) offers different types of QuickBird's high resolution imagery products supporting a wide range of applications such as mapping purposes, monitoring of environmental aspects (floods, earthquakes, oil spills), land management forecasting and fire-risk assessment.

WorldView I, the successor of QuickBird, is scheduled for 2007 and will provide a panchromatic resolution of 46 cm at nadir. In 2008 WorldView II is anticipated to launch. It has a multispectral resolution of 1,84 m together with four additional colour bands. (DigitalGlobe 2006a).

2 Ordering data

The distribution of QuickBird satellite data is organised by a world wide network of international resellers. The master distributor for Europe and North Africa is Eurimage, headquartered in Rome, Italy, but there are also several local resellers (Eurimage 2006a).

Tab. 1: Examples for VHR systems (Jacobsen 2006, modified).

System	Launch date	GSD [m] pan/MS	Radiometric Resolution	Swath [km]
IKONOS 2 USA	1999	0,82/3,24	11	11
EROS A1 Israel	2000	1,8 pan	11	12,6
QuickBird-2 USA	2002	0,61/2,44	11	16,5
OrbView 3 USA	2003	1/4	11	8
FORMOSAT-2 Taiwan	2004	2/8	12	24
Cartosat 1 India (stereo)	2005	2,5 pan	10	30
TopSat UK	2005	2,5/5	n. s.	15/10
ALOS Japan (stereo)	2006	2,5/10	8	35
EROS-B1 Israel	2006	0,82 pan	10	7
ResourceSat DK-1 Russia	2006	1/3	n. s.	28
KOMPSAT-2 South Korea	2006	1/4	8	15
WorldView I USA	2007	0,46 pan	11	16
OrbView 5 USA	2007	0,41/1,64	n. s.	n. s.
Pleiades France	2008	0,7/2,8	n. s.	n. s.
WorldView II USA	2008	0,46/1,84	11	16
EROS-C Israel	2009	0,7/2,8	n. s.	n. s.

The period of time between the initial data order and the actual delivery can vary greatly and depends on several factors. The first step in the ordering process is the decision for one of the available QuickBird products. These products mainly differ in the amount of pre-processing that is done prior to delivery. At the moment DigitalGlobe offers the following products (Eurimage 2006b):

- Basic imagery
- Standard and standard ortho-ready imagery
  Ortho-rectified imagery
- DigitalGlobe Digital Ortho Quarter Quad (DG DOQQ: only available for the United States).

Basic imagery is the least processed of the QuickBird Imagery Products. It is radiometrically and sensor corrected, but only geometrically corrected by inner orientation and not mapped to a cartographic projection and ellipsoid. This "quasi" raw data is delivered together with image support data files that provide information about attitude, ephemeris, geometric calibration, camera model, rational polynomial coefficients etc. allowing the customer to perform sophisticated photogrammetric processing such as ortho-rectification and three-dimensional feature extraction.

Standard imagery is delivered with radiometric and sensor corrections. Additionally, it is mapped to a cartographic projection using a coarse digital elevation model (DEM). According to the European data distributor Eurimage it is not suited for producing ortho-images, since the distortion introduced by the coarse DEM cannot be removed later on (Volpe 2003). However, some advances were made in accurate ortho-image generation from QuickBird data (Eisenbeiss et al. 2004). For customers intending to produce ortho-images, a Standard Ortho-ready product can be ordered, which does not use the coarse DEM for geometric correction. In this case further processing with rational polynomial coefficients (RPC) and detailed elevation information is possible in order to achieve good accuracies comparable to those obtained from Basic imagery.

Ortho-rectified imagery is equivalent to the standard imagery, but uses a DEM and ground-control points (GCP) provided by the customer for geometric correction. Therefore the accuracy depends on the number and quality of the provided auxiliary data (DEM and GCPs).

According to the project objectives (e. g. ortho-images, stereo analysis, classifications), the available auxiliary data and the intended data processing steps, the best suited product level and its related options should be chosen. If there is no additional data, the standard product delivering a positional accuracy of 23 m (CE 90 %, RMSE 14 m, excluding terrain distortions) is recommended (DigitalGlobe 2006b). Otherwise the amount and quality of the costumer delivered data defines the achievable accuracy level.

QuickBird data can be ordered either out of the comprehensive DigitalGlobe archive or by submitting a new collection request. When ordering out of archive, there is a rush option available. Otherwise there are three different tasking options, namely standard, priority and rush, which differ in multiple acquisition opportunities (including minimal/maximal order sizes), customer defined tasking parameters and prices.

Data turnaround times depend particularly on the chosen tasking option and product level, e. g. ortho-rectified imagery will need more time than the basic product. The delivery of the data can potentially be delayed for weeks or even months (DigitalGlobe 2006c). For certain applications there may be additional constraints, such as data acquisition during the vegetation period for forestry mapping and agricultural purposes. Furthermore the acceptable cloudiness, off-nadir angle and the size of area and other restrictions will influence the time until delivery as well. So the QuickBird revisit time depends on the latitude of the area of interest and the selected maximum off-nadir angle (see Tab. 2). Orders specifying large areas with a small off-nadir angle range will require multiple passes and several revisits.

Tab. 2: QuickBird revisit time in days as function of geographic latitude and nadir angle (Digital Globe 2005).

Nadir angle / Latitude	0° to 15°	0° to 25°	0° to 45°
0	11	6	3
10	11	6	3
20	9	5	3
30	9	5	2
40	8	5	2
50	7	4	2
60	7	4	1
70	5	3	1
80	3	2	1

Since there are quite a few applications for QuickBird satellite imagery, unexpected events such as natural disasters or military interests may result in a sudden increasing demand for up-to-date QuickBird data that can further prolong the delivery time. In such a situation where the demand exceeds the acquisition capacity, it seems that smaller orders tend to get less priority than bigger ones. To circumvent the delay for research projects intensive communication is necessary, which may be easier when working with a local reseller.

3 Image Quality

The image quality depends mainly on the off-nadir view angle. Larger nadir angles are increasing the pixel size on ground and a longer path through the atmosphere. Scenes captured close to the nadir have a better quality. As soon as the view angle exceeds 15° slant effects occur, which can also affect the classification or interpretation processes.

In Fig. 1 the differences in two subsets from scenes with 5,6° and 20,5° off-nadir are shown, the subsets have the same scale. In urban areas with very high buildings the inclination is another negative effect (see Fig. 4).

Because of the sensors' very high radiometric resolution there is no over-saturation of large areas. Nevertheless, highly reflective materials like metal or glass can induce an over-charge in the sensor's CCDs resulting in white cones (see Fig. 2).

A big advantage of the 11-bit data-range is the possibility to differentiate further details in areas overthrown by shadow. In Fig. 3 trees in a house-shadow can be interpreted after a histogram stretch. It depends of course on the kind of urban structure, in areas with very dense and high buildings no scatter light falls into the shadowed areas

Fig. 1: Subset of a QuickBird-scene with 5,6° off-nadir view angle on the left (Potsdam) and 20,5° on the right (Lieberose), pan-sharpened image (RGB: 4,3,2).

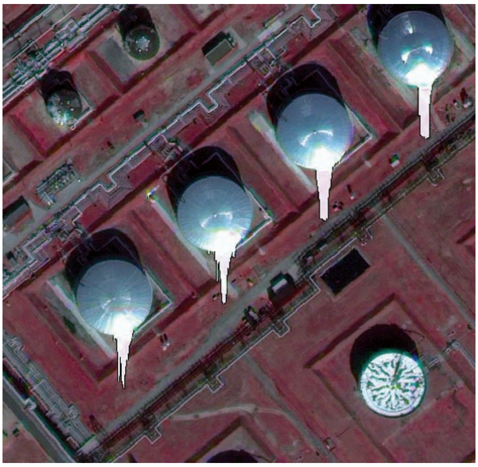

Fig. 2: Over-charged areas, pan-sharpened image (Schwedt, RGB: 4,3,2).

Fig. 4: Problem of shadow and inclination of buildings in very high and dense areas (Seoul, RGB: 3,2,1).

Fig. 3: Shadow-area after a histogram stretch, pan-sharpened image (Potsdam, RGB: 4,3,2).

and no further information can be extracted (see Fig. 4).

A negative characteristic of QuickBird imagery are 'rainbow' pixels that occur along objects with high contrast. This effect is due to the separate processing of the single multispectral bands, slight shifts among the bands lead to the assignment of wrong neighbours during the resampling process[1]. DigitalGlobe suggests the use of other convolution kernels for resampling, but with cubic convolution, for instance, almost every image error can be smoothed over. So this is no solution for imagery that is to be used in digital classification.

Another negative effect is the high and artificial texturing of areas with low reflection that should be very homogeneous. In Fig. 6 a strangely textured water body is shown. DigitalGlobe finds the source of this error in the downlink process from sensor to earth[1].

[1] internal technical Memo, Eurimage

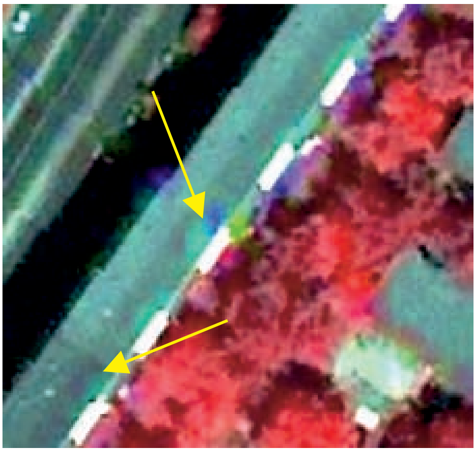

Fig. 5: 'Rainbow' pixels along edges with high contrast, pan-sharpened image (Potsdam, RGB: 4,3,2).

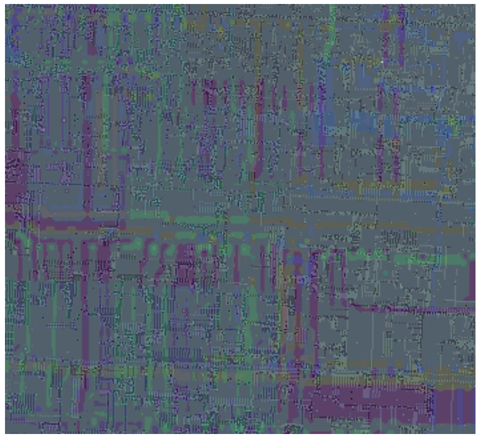

Fig. 6: Artificial texturing in a water body, pan-sharpened image (Falkensee, RGB: 4,3,2).

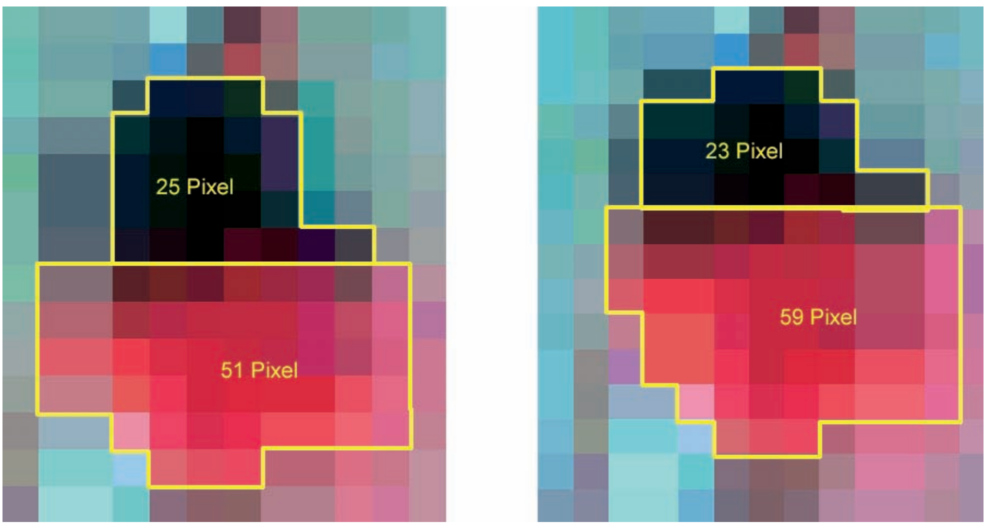

Fig. 7: Differences in the resampling process, left: resampled 2004, right: resampled 2005, multi-spectral image (LIEBEROSE, RGB: 4,3,2).

Since the resampling process and the applied kernels are object of constant research and change within DigitalGlobe it can result in different standard imagery, though captured on the same day, but processed at a later time. This can lead to serious consequences when additional data is ordered. In Fig. 7a subset is shown where the source of both sides is the same scene (captured in September 2004), the left part was ordered in 2004 whereas the right part was ordered in 2005. Both subsets were processed as standard imagery with nearest neighbour resampling. Both shadow area and tree area are not only shifted but also differently sized. This can affect the extraction of quantitative parameters.

One of the big disadvantages is the fact, that up to 20 % of cloud coverage have to be accepted. Under certain circumstances this can render an image useless if the most interesting part of the ordered area is covered by clouds or their shadow.

4 Pan-sharpening algorithms for data fusion

Commercial image-analysis software packages provide standardised algorithms to fuse panchromatic images of high spatial resolution with multispectral images of lower resolution. In some cases, these algorithms are adapted to certain sensor types, such as QuickBird. There are different quality parameters, depending on the purpose of the image analysis. In this study, the aim of the merging tools is defined to preserve the spectral information, while enhancing the spatial variability. Therefore, additive pan-sharpening algorithms, such as the Brovey transform (VRABEL 1996) were not considered here. The pan-sharpening tests were examined on a QuickBird image of a pre-alpine area in Bavaria.

To test the quality of the information fusion the image was separately pan sharpened with seven different merging algorithms of three software packages:

ERDAS IMAGINE 8.7 (Service Pack 2):
- Principal component resolution merge (PCA)
- Wavelet PCA resolution merge
- Modified IHS resolution merge (SIDDIQUI 2003)

PCI 9:
- Enhanced IHS fusion (ZHANG 2002, ZHANG & HONG 2005)

ENVI 4.2
- Gram-Schmidt spectral sharpening (LABEN 2000)
- Principal component spectral sharpening (ENVI PC)
- Colour normalized spectral sharpening (ENVI CN)

To examine the dependency of the pan sharpening algorithms on different spectral and textural materials, the analysis was carried out for subsets of three different land-use types (agricultural, forest, urban).

In a first step, the statistical features (average, median, minimum, maximum) of these algorithms were compared to the original QuickBird image. For two merging tools, PCA and ENVI CN, the average grey values for the subset differ significantly from the multispectral values of the original image, especially in Band 4 (see Tab. 3). If these standard statistical parameters are not adapted to the spectral behaviour of the original scene, a later interpretation is likely to produce misclassifications. Therefore, these algorithms were not used for further investigations.

Tab. 3: Exemplary analysis of average grey values of the test area with predominantly agricultural usage. Similar results were found for other land-use types.

	Band 1	Band 2	Band 3	Band 4
PCA	44,77	40,60	31,41	95,57
Wavelet PCA	44,03	39,90	29,71	101,02
Modified IHS	44,46	40,35	30,08	101,64
Enhanced IHS fusion	44,56	40,43	30,26	101,33
Gram-Schmidt	44,57	40,43	30,26	101,29
ENVI PC	44,57	40,44	30,26	101,36
ENVI CN	56,27	51,04	37,38	132,80
Original	44,57	40,44	30,26	101,28

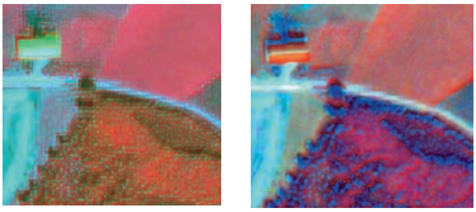

Fig. 8: Pan-sharpening results (Angelberger Forst, Bavaria, RGB 4,2,1) with colour distortions of the Wavelet PCA merge (left) and the ENVI PC merge (right).

The statistical parameters of the ENVI PC and the Wavelet PCA resolution merges achieved statistical results, which were close to the original multispectral image. However, these algorithms had visible colour distortions, which are described especially for wavelet transforms (Zhang 2002). A possible reason for this effect is a poor co-registration of the pan and the multispectral bands, which have a slightly different view angle and recording time when receiving the data (Terhalle 2005). These colour distortions could lead to misclassification in further analyses of the data (see Fig. 8). Consequently, these pan-sharpening tools were not further examined.

The remaining three pan-sharpening tools showed visually and statistically reasonable results (see Fig. 9). Since an objective visual comparison is only possible to a limited degree, an assessment of the pan-sharpening quality had to be found.

Therefore this study introduces the **pan-sharpening accuracy assessment**, which considers the spectral reliability of the fused

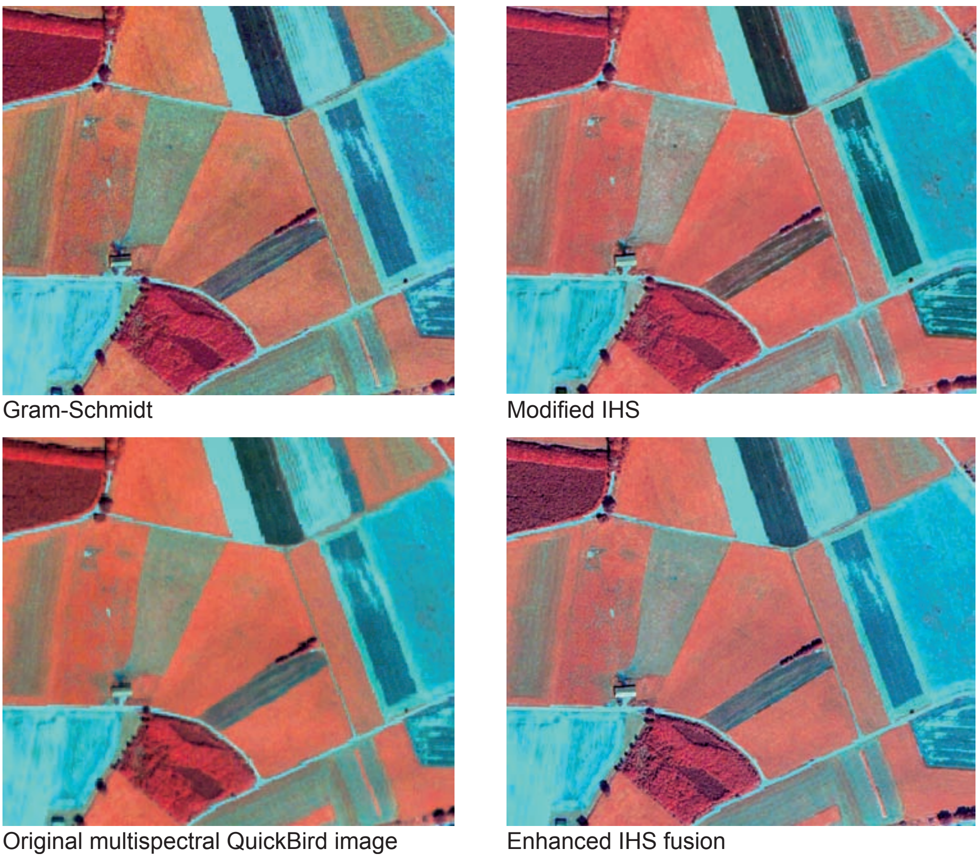

Fig. 9: Pan-sharpening results of the enhanced IHS fusion, the modified IHS and the Gram-Schmidt method for an agricultural subset of the image (pre-Alpine agricultural area, Bavaria, RGB 4,2,1).

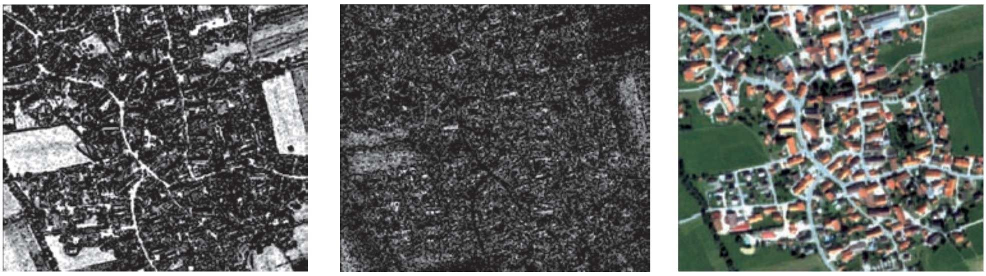

Fig. 10: Pan-sharpening accuracy assessment of band 4 of the Gram-Schmidt algorithm (left) and the Enhanced IHS fusion (middle) of an urban area (original image of Weyarn, Bavaria, right – RGB 3,2,1). The Enhanced IHS fusion shows significantly lower values, which indicates a better fusion result.

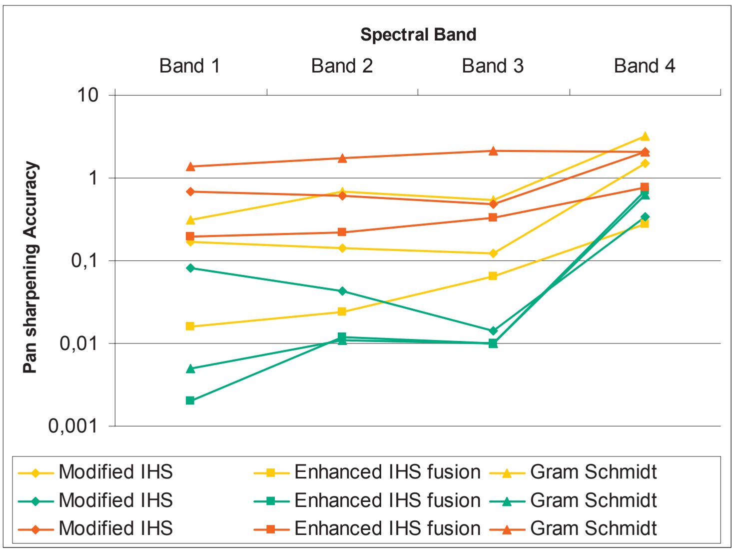

Fig. 11: Average values of the pan-sharpening accuracy assessment of three subsets of different land-use (orange = agriculture, red = urban, green = forest) for the three pan sharpening algorithms under investigation. Lower values indicate a better fusion result.

data in comparison to the original image and the desired higher spatial frequency of the merged data.

Firstly, the pan-sharpened image will be subtracted from the original multispectral image. If a fused pixel has the same value as the original value, the result is zero. Averaged over a scene, a low value shows high spectral reliability.

In a second step, the higher spatial frequency is taken into account. The result of the subtraction is additionally processed with a focal minimum filter (Kernel 5×5). This process is necessary because – although the spectral behaviour of the scene should be constant – a spatial variability of grey values is necessary for a higher resolution image. Therefore, in a surrounding of 5 by 5 pixels the minimum difference value of the pan sharpened and the original image was calculated.

With these two easily processed steps, the pan-sharpening accuracy assessment supplies valuable information on the fusion quality. Additionally, areas of spectral deviation can be visualised. In Fig. 10, two results of the pan-sharpening accuracy assessment are shown. The areas of the image with high differences to the original multispectral image have higher values (shown in brighter tones), and indicate a lower pan-sharpening accuracy. The Gram-Schmidt algorithm shows differences in areas with very high reflectance values as can be seen with sealed surfaces in Fig. 10.

The pan-sharpening accuracy was statistically analysed for average values of different land uses (see Fig. 11). Of the three chosen land covers, forested areas are best pan sharpened with all three algorithms, while urban areas are the most difficult sites to process (see Fig. 11). Nevertheless, for all subsets the Enhanced IHS fusion proved to be the most successful in pan sharpening QuickBird images. Especially in agricultural and urban areas, the average values of the spatial accuracy for all spectral bands had smaller differences compared to the original multispectral image. In spatial terms, high reflectance areas, such as sealed surfaces or fully vegetated areas seem to be constantly overestimated by the Gram-Schmidt and the Modified IHS algorithm.

The analysis of pan-sharpening algorithms can only be an intermediate result. New algorithms are already announced (Ehlers & Klonus 2004, Terhalle 2005) or in a scientific development phase (Su et al. 2004, Tu et al. 2005).

5 References

Breuer, M. & Vollmar, M., 2005: Product level of satellite data and their processing in LPS and Erdas Imagine. – Geosystems User Group Meeting, Fürstenfeldbruck (Germany).

DigitalGlobe, 2005: QuickBird Imagery Products, FAQ, http://www. digitalglobe.com/product/product_docs.shtml (March 2006).

DigitalGlobe, 2006a: product information, imaging systems, ordering and pricing. http://www.digitalglobe.com (March 2006).

DigitalGlobe, 2006b: http://www.digitalglobe.com/product/standard_imagery.shtml (March 2006).

DigitalGlobe, 2006c: http://www.digitalglobe.com/press/FAQ_press.shtml#t11, (June 2006).

Ehlers, M., 2002: Fernerkundung für GIS-Anwender – Sensoren und Methoden zwischen Anspruch und Wirklichkeit. – In: Blaschke, T. (eds.): Fernerkundung und GIS – Neue Sensoren – innovative Methoden, 10–23, Wichmann, Heidelberg.

Ehlers, M. & Klonus, S., 2004: Erhalt der spektralen Charakteristika bei der Bildfusion durch FFT basierte Filterung. – PFG **2004**(6): 495–506.

Eisenbeiss, H., Baltsavias, E., Pateraki, M. & Zhang, L., 2004: Potential of Ikonos and Quickbird imagery for accurate 3D point positioning, orthoimage and DSM generation. – Proc. 20th ISPRS Congress, Istanbul, Turkey, 12–23 July, In: International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXV, Part 3, pp. 522–528.

Eurimage, 2006a: http://www.eurimage.com/reseller/area/germany.html (March 2006).

Eurimage, 2006b: products and services; prices. http://www.eurimage.com (March 2006).

Jacobsen, K., 2006: Very High Resolution Optical Space Sensors – Overview, Accuracy and Information contents. – GORS 15th International Symposium, 2006 Damascus, on CD.

Laben, E. A., 2000: Process for Enhancing the Spatial Resolution of Multispectral Imagery Using Pan-Sharpening (Gram-Schmidt). Eastman Kodak Company, US Patent.

Rossi, L., 2003: New High-Resolution Satellite Applications: QuickBird, proceedings, EFITA2003 Conference Papers, Debrecen-Budapest (Hungary).

Siddiqui, Y., 2003: The modified IHS method for fusing satellite imagery ASPRS 2003 – Annual conference. p. 1–9, Anchorage, Alaska.

Su, Y., Huang, P.S., Lin, C.F., Lin, C.F. & Tu, T.M., 2004: Approach to maximize increased details and minimize color distortion for IKONOS and QuickBird image fusion. – Optical Engineering **43**(12): 3029–3037.

Terhalle, U., 2005: Sensor-Merge in ERDAS IMAGINE "unplugged". – Geosystems, Fürstenfeldbruck.

Tu, T. M., Lee, Y. C., Chang, C. P. & Huang, P. S., 2005: Adjustable intensity-hue-saturation and Brovey transform fusion technique for IKONOS/QuickBird imagery. – Optical Engineering **44**(11).

Volpe, F., 2003: Geometrical Processing of QuickBird High Resolution Satellite Data, proceedings, ISPRS/EARSeL Workshop "High Resolution Mapping from Space 2003", Hannover (Germany).

Vrabel, J., 1996: Multispectral Imagery Band Sharpening Study. – Photogrammetric Engineering & Remote Sensing **62**(9): 1075–1083.

Zhang, Y., 2002: Problems in the fusion of commercial high-resolution satellite images as well as Landsat 7 images and initial solutions. – Int. Arch. Photogram. Remote Sens. **34**(4).

Zhang, Y. & Hong, G., 2005: An IHS and wavelet integrated approach to improve pan-sharpening visual quality of natural colour IKONOS and QuickBird images. – Information Fusion **6**(3): 225–234.

Addresses of the authors:

Prof. Dr. Birgit Kleinschmit
Dipl.-Geoök. Michael Förster
Institute of Landscape Architecture and Environmental Planning
Straße des 17. Juni 145 EB5
D-10623 Berlin
Tel: +49-(0)30-314-72847/72798
e-mail: Birgit.Kleinschmit@TU-Berlin.de
e-mail: Michael.Foerster@TU-Berlin.de

Dipl.-Geoök. Annett Frick
Luftbild und Planung GmbH
Große Weinmeisterstraße 3a
D-14469 Potsdam
Tel: +49-(0)331-2757760
e-mail: Annett.Frick@lup-umwelt.de

Dipl.-Forstw. Katja Oehmichen
University of Hamburg, Department of Woodscience, Institute for World Forestry
Leuschnerstr. 91
D-21031 Hamburg
e-mail: Katja.Oehmichen@online.de

Manuskript eingereicht: Juli 2006
Angenommen: Oktober 2006