URBAN REMOTE SENSING: NEW DEVELOPMENTS AND TRENDS

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ABSTRACT:

Due to the high spatial resolution requirements for urban information systems, aerial photography has been used as standard imaging input. The advent of new satellites with a resolution of better than 1m (e.g., IKONOS, Quickbird) and digital airborne scanners with excellent geometric fidelity and high spatial resolutions in the cm range (e.g., HRSC, ADS, DMC), however, challenges the analog airphoto techniques. These airborne and spaceborne high resolution sensors offer an advanced potential for generating and updating GIS databases especially for urban areas. Moreover, digital airborne stereo sensors are capable of producing digital surface models (DSM) by automated techniques. Coupled with differential GPS and inertial navigation systems (INS), these sensors generate georeferenced ultra high resolution multispectral image data together with their accompanying DSM. Another source of 3D information for city modeling are laser scanning (LIDAR) sensors which produce accurate height information of high and very high resolution. This paper presents an overview of the new sensor developments and examples of integrated processing. Highest resolution for all sensors is obtained in their panchromatic mode whereas the multispectral information is acquired at lower resolutions. The ratio between the panchromatic and the multispectral resolution is usually in the order of 1:2 to 1:8. Especially for vegetation analyses and urban sprawl quantification, multispectral information is a mandatory requirement. To obtain multispectral image data with high spatial resolution, multispectral and panchromatic images have to be merged (pansharpening). Image transforms such as the Intensity-Hue-Saturation (IHS) or Principal Component (PC) transforms are widely used to fuse panchromatic images of high spatial resolution with multispectral images of lower resolution. These techniques create multispectral images of higher spatial resolution but usually at the cost that these transforms do not preserve the original color or spectral characteristics of the input image data. The FZG has developed a new method for image fusion that is based on the standard IHS transform combined with filtering in the Fourier domain. This method preserves the spectral characteristics of the lower resolution images. Using this spectral characteristics preserving fusion method, multispectral images can be pansharpened without changing their spectral characteristics.

1 INTRODUCTION

1.1 Very High Resolution Satellite Systems

The availability of remote sensing data that are applicable for global, regional and local environmental monitoring has greatly increased over the recent years. New technologies such as global positioning system (GPS), digital photogrammetry, and multi-source satellite integration are opening new application fields for remote sensing. With the advent of new commercial satellite programs such as IKONOS or Quickbird and, in addition, digital airborne cameras, data are created at higher spatial, spectral and temporal resolution than have been collected at any other time on earth (see table 1). Figure 1 shows a pansharpened multispectral Quickbird image at 70-cm resolution. The potential of these sensors for urban application is demonstrated by individual buildings that are clearly discernible in the image.
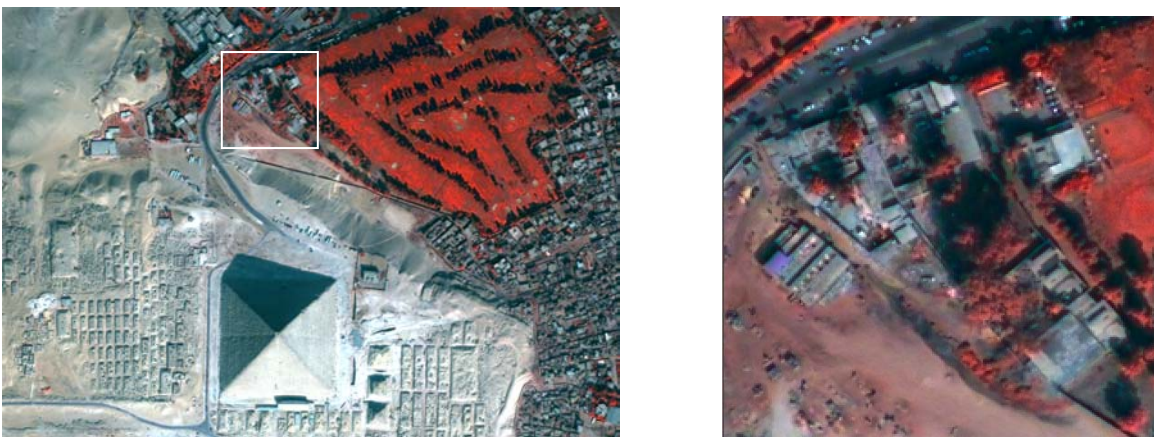

Figure 1 Pansharpened multispectral Quickbird image (Egypt) with enlarged subset (right).

Company	Space Imaging		Digital Globe		Orbimage		Imagesat
System	Ikonos II launch 9/99		QuickBird 2 launch 11/01		OrbView-3 launch 6/03		EROS A1 launch 12/00
URL	www.spaceimaging.com		www.digitalglobe.com		www.orbimage.com		www.imagesat.com
Modus	Pan 11 bit	multispectral 11 bit	pan 11 bit	multispectral 11 bit	pan 11 bit	multispectral 11 bit	pan 11 bit
Geometric Resolution	1 m	4 m	0.61 m	2.44 m	1 m	4 m	1.8 m (hypersampling 1 m)
Spectral Resolution (nm)	525-929	445-516 (b) 506-595 (g) 632-698 (r) 767-853 (nir)	450-900	450-520 (b) 520-600 (g) 630-690 (r) 760-900 (nir)	450-900	450-520 (b) 520-600 (g) 630-690 (r) 760-900 (nir)	500-900
Scale for Applications			1 : 5 000 – 1 : 25 000				
Swath Width	11 km		16.5 km		8 km		13.5 km
Image Scene Size	11 x 11 km^2		16.5 x 16.5 km^2 strip: 16.5 x 165 km^2		8 x 8 km^2		13.5 x 13.5 km^2 vector scene: 13.5 x 40 km^2
Orbit Altitude	681 km		450 km		470 km		480 km
Inclination	98.1 sun synchronous		97.2 sun synchronous		97 sun synchronous		97.3 sun synchronous

Table 1 Selected satellite missions of very high resolution (after Ehlers 2004a)

1.2 Digital Airborne Sensors

After a long period of development, we have seen the emergence of operational digital camera systems which challenge aerial frame cameras. Advanced technologies such as GPS coupled navigation systems and advanced digital sensor technologies have overcome the strongest impediment of aircraft scanners: the lack of geometric stability. Public and private research has concentrated on the development of digital line array or matrix scanners that will serve as successors to the 'classical' aerial cameras. Companies such as Leica Geosystems, Z/I Imaging or Vexcel offer commercial systems, research centers such as the German Space Center (DLR) fly their own prototypes. Such systems have to establish their market somewhere between the satellite image user seeking higher resolution and the airphoto user seeking digital input and GIS compatibility. Consequently, airborne scanner systems have to offer stereo capability and multispectral recording (Fig. 2).

2 TECHNICAL PARAMETERS OF ULTRA HIGH RESOLUTION AIRBORNE SYSTEMS

2.1 Imaging Sensors

Two different technologies are being employed to accomplish an airborne digital recording system. Z/I Imaging and Vexcel make use of twodimensional arrays and a set of coupled nadir-looking lenses to emulate a standard frame camera's central perspective. Leica Geosystems and the DLR employ triplet scanner technology with onedimensional line arrays arranged in fore, nadir, and aft looking modes. The advantage of a 2D matrix camera is that all standard photogrammetric techniques can be used in a digital environment.

Figure 2: 3D perspective view of a subset of the nature protection area Heuckenlock near Hamburg, Germany. The HRSC-AX image has a ground resolution of 25 cm. The perspective view is a computer generated drape of the RGB image data over the 50 cm resolution digital surface model (DSM) also generated by the HRSC AX.

The advantage of a stereo triplet solution is that photogrammetric preprocessing (i.e. DSM and ortho image generation) is performed before the user receives the data thus alleviating the need to run sophisticated software at the users' organization. The image data are provided in the required coordinate system and can be easily integrated into an existing GIS database. Which of the two approaches is more suitable will largely depend on the user demands and the price-performance ratios of the respective systems. Table 2 presents five selected ultra high resolution airborne digital camera systems.

Sensor	HRSC-AX	DSS		ADS 40	UltraCam-D	DMC
Company	DLR	Applanix (Emerge)		Leica Geosystems	Vexcel Corp.	Z/I Imaging
URL	www.dlr.de	www.emergedss.com		www.gis.leica-geosystems.com/	www.vexcel.com	www.ziimaging.com
Sensor Type	Line CCD	Area CCD		Line CCD	Area CCD	Area CCD
Introduction	2000	2004		2000	2003	2002
Focal Length	151 mm	55 mm (color & CIR) 35 mm (only color)		62.7 mm	100 mm (28 mm multispectral)	120 mm (25 mm multispectral)
Field-of-view	29°	37° x 55.4°		64°	55° x 37°	74° x 44°
# CCD- Lines /- Matrix Camera	9	1		7	9	8
# CCDs across track	12 172	4077		2 x 12 000 (pan) 12 000 (ms)	11 500 (pan) 4008 (ms.)	13 824 (pan) 3 000 (msl)
# CCDs along track	-	4092		-	7 500 (pan) 2 672 (ms)	7 680 (pan) 2 000 (ms)
Sensor Size	6.5 µm	9 µm		6.5 µm	9 µm	12 µm
Radiometric Resolution	12 bit	12 bit		12 bit	> 12 bit	12 bit
Spectral Resolution (nm)	520–760 (pan) 450–510 (blue) 530–576 (green) 642–682 (red) 770–814 (NIR)	**RGB MODUS** 400-500 (blue) 500-600 (green) 600-680 (red)	**CIR MODUS** 510-600 (green) 600-720 (nor/NIR) 720-920 (NIR)	465-680 (pan) 428-492 (blue) 533-587 (green) 608-662 (red) 703-757 (NIR) or 833-887 (NIR opt.)	390-690 (pan) 390-470 (blue) 420-580 (green) 620-690 (red) 690-900 (NIR)	400-580 (pan) 400-580 (blue) 500-650 (green) 590-675 (red) 675-850 (NIR)
Readout Frequency	1640 lines/s	0.25 images/s		800 lines/s	0.75 images/s	0.5 images/s
Stabilisation	Zeiss T-AS platform	own platform		LH platform	own platform	Zeiss T-AS platform
Data Recording	High speed recorded	80 GB exchangeable hard disk		MM40 mass storage	RAID disk system	SCU (> 1 TB)
Georeferencing	Applanix POS/DG	Applanix POS IMU		Applanix POS IMU	POS Z/I 510	Not specified
Estim. Costs incl. Pos. system	-	425.000 $		1.200.000 $	700.000 $	1.600.000 $

Table 2 Selected digital airborne sensors (based on Schiewe & Ehlers 2004)

The advantages of digital cameras are widely understood: no film, no photo processing, no scanning, better radiometric quality through direct sensing, 'non-aging' storage and direct integration into GIS and image processing systems. The disadvantages of digital scanners, most notable its geometric distortions and monoscopic imaging mode, no longer exist due to the stereo capabilities of the new sensors and the use of integrated INS and differential GPS technology during image acquisition.

2.2 Multisensor Systems

The progress of GPS and inertial navigation systems for direct orientation is also responsible for the development of operational laser scanning or LIDAR systems (Lemmens 2004). The simultaneous use of LIDAR and imaging technology creates multisensor systems which produce accurate digital surface models and image data at the same time. Table 3 presents a selection of multisensor systems which have increasingly been used in Europe.

The acquisition of elevation data can be achieved by different techniques: For area CCD sensors, such as DMC or Ultracam, standard digital photogrammetric techniques (stereocorrelation) can be employed to create digital elevation models from overlapping frame images (see, for example, Spiller 2000). The line CCD sensors, such as ADS or HRSC, make use of a triplet along-track stereo geometry for 3D information extraction which requires specific software for preprocessing (see, for example, Fricker et al. 2000, Ehlers *et al.*, 2003). Combined laser scanners and imaging sensors create a very accurate and dense digital surface model which can be easily co-registered with the image data. All techniques allow the creation of orthophotos that can be readily interfaced with GIS and digital map data. Figure 3 demonstrates the geometric differences between the central perspective for the area CCDs (left) and the line CCDs cameras (right). The differences in elevation determination for stereocorrelation and LIDAR sensors are presented in Figure 4. The higher density and the direct distance measurements of the laser scanners produce more accurate digital surface models with sharper edges. Window based correlation, on the other hand, tends to create 'hills' in areas of distinct discontinuities (i.e. house walls, trees etc.). For more details, see Schiewe & Ehlers (2004).

System	FALCON	ALTM 3033, 3070		ALS 50
Company	TopoSys	Optech		Leica Geosystems
URL	www.toposys.de	www.optech.on.ca		www.gis.leica-geosystems.com
Recording Principle	Glasfiber Array	Rotating mirror		Rotating mirror
Multiple Reflections	Max. 2 echoes	Max. 4 echoes		Max. 4 echoes
Image Sensor	Line scanner (pixel size 0.5 m)	DSS		ADS 40
(Spectral Resolution in nm)	450-490 (blue) 500-580 (green) 580-660 (red) 770-890 (NIR)	**RGB MODUS** 400-500 (blue) 500-600 (green) 600-680 (red)	**CIR MODUS** 510-600 (green) 600-720 (nor/NIR) 720-920 (NIR)	465-680 (pan) 428-492 (blue) 533-587 (green) 608-662 (red) 703-757 (NIR) or 833-887 (NIR opt.)
Pulse Frequency	83 kHz	up to 70 kHz		up to 83 kHz
Scanning Frequency	653 Hz	70 Hz		412.33 x FOV$^{-0.6548}$ (max. 51°)
Max. Flying Height	1600 m	3000 m		4000 m
Scan Angle (FOV)	± 7°	± 0... 25°		± 10... 37.5°
Swath Width (h=1000 m)	245 m	930 m		1530 m
Resolution	0.02 m	0.01 m		0.01 m
Vertical Accuracy	± 0.15 m	± 0.15 m (h=1200 m)		± 0.15 m ... ± 0.50 m
Horizontal Accuracy	-	± 0.50 m (h=1000 m)		± 0.15 m ... ± 0.75 m

Table 3 Selected LIDAR systems with optional imaging sensors (after Schiewe & Ehlers 2004)

Figure 3 Comparison of the different recording geometries: central perspective DMC (left) and the line scanner ADS (right) with central perspective distortion only in cross-track direction. Digital cadastral data (houses) are overlaid for better clarification.
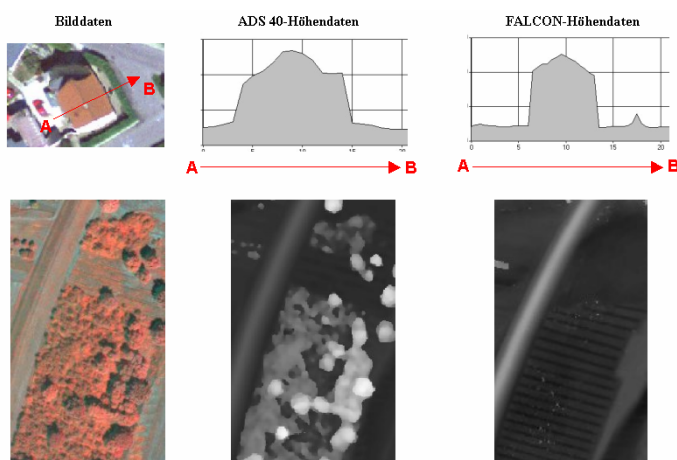
Figure 4 Derivation of elevation models: The laser scanner (here: Falcon) displays a better edge preservation than image based correlation for the ADS 40 (top). The other advantage of laser scanners is the ability to use last echoes for retrieving ground elevation even under trees (bottom)

3 IMAGE FUSION

3.1 Fusion Techniques

Fusion techniques for remotely sensed data (image fusion) can be classified into three levels: pixel level (ikonic), feature level (symbolic) and knowledge or decision level (Pohl and van Genderen 1998). Of highest relevance for remote sensing data are techniques for ikonic image fusion to merge panchromatic images of high spatial resolution with multispectral data of lower resolution (see Cliche *et al.* 1985, Welch & Ehlers 1987, and Zhang 2002). However, existing techniques hardly satisfy conditions for successful fusion for

the new generation of high-resolution satellite images such as IKONOS, Landsat-7, SPOT-5 and QuickBird or ultra high resolution airborne data (Zhang 2002). All of the new generation satellite sensors provide high-resolution information only in their panchromatic mode whereas the multispectral images are of lower spatial resolution. The ratios between high resolution panchromatic and low resolution multispectral images vary between 1:2 and 1:8 (Ehlers 2004b). For high resolution multispectral datasets, the panchromatic information has to be merged with the multispectral images. The most significant problem with image fusion techniques is the color distortion of the fused image.

3.2 Spectral Characteristics Preserving Image Fusion

The principal idea behind a spectral characteristics preserving image fusion is that the high resolution image has to sharpen the multispectral image without adding new information to the spectral components. As basic image fusion technique, we will make use of the Intensity-Hue-Saturation (IHS) transform. This technique will be extended to include more than the standard 3 bands (red, green, blue color transform) from color theory. In addition, filter functions for the multispectral and panchromatic images have to be developed. The filters have to be designed in a way that the effect of color change from the high resolution component is minimized. The ideal fusion function would add the high resolution spatial components of the panchromatic image (i.e. edges, object changes) but disregard its actual gray values. For a thorough analysis of the information distribution along the spatial frequencies of an image we make use of Fourier transform (FT) theory (Gonzalez & Woods 2001). An overview flowchart of the method is presented in Fig. 5 (see Ehlers & Klonus 2004 for complete description). Results of the FFT based fusion are shown in figures 6 and 7.
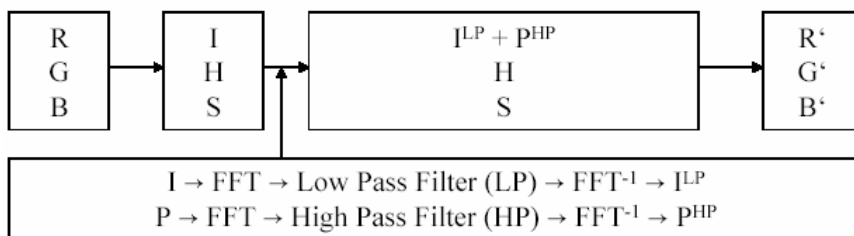
Figure 5   FFT based filter fusion using a standard IHS transform. Three selected bands (RGB) of the low resolution multispectral image are transformed into the IHS domain. Intensity component and the high resolution panchromatic image are transformed into the Fourier domain using a twodimensional Fast Fourier Transform (FFT). The power spectrum of both images is used to design the appropriate low pass filter (LP) for the intensity component and high pass filter (HP) for the high resolution panchromatic image. An inverse FFT transforms both components back into the spatial domain. The low pass filtered intensity (I^{LP}) and the high pass filtered panchromatic band (P^{HP}) are added and matched to the original intensity histogram. At the end, an inverse IHS transform converts the fused image back into the RGB domain (after Ehlers & Klonus 2004).
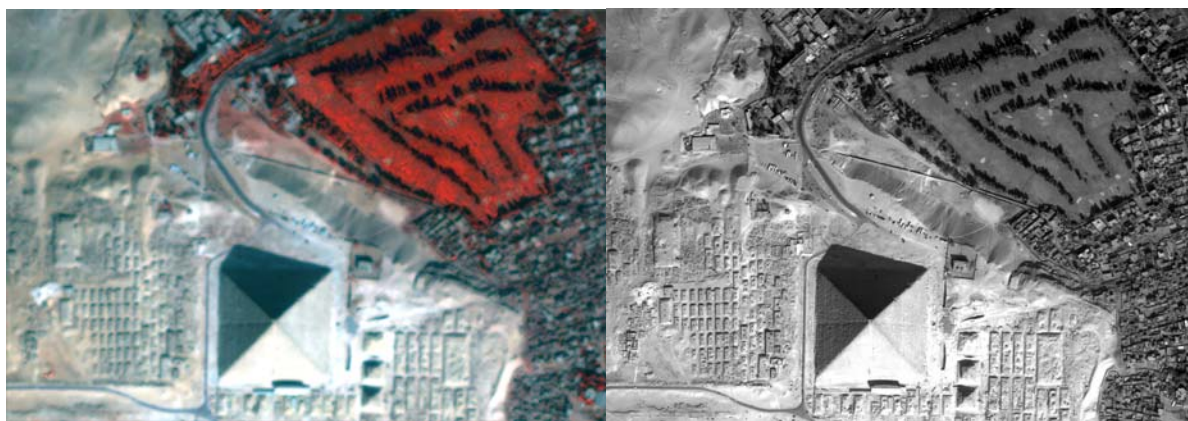
Figure 6 FFT based image fusion: The Quickbird multispectral image (left) is merged with the panchromatic image (right).
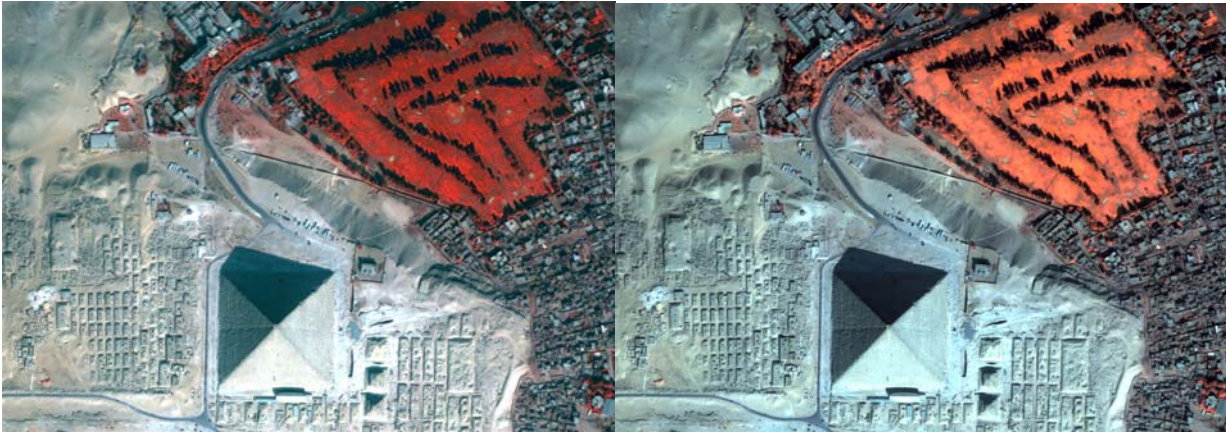
Figure 7   Pansharpened Quickbird image: The FFT based fusion (left) shows no color distortions whereas the Brovey transform (right) sharpens the image but changes the spectral characteristics although both image were recorded simultaneously.

4   CONCLUSION

It could be shown that the new very high and ultra high resolution sensors offer a tremendous potential for urban applications. Especially the 3D capability of the airborne sensors is a great advantage for applications such as city modeling. As almost all sensors have the highest resolution only for their panchromatic mode, image fusion for pansharpening is an essential for the image analysis. FFT based filtering prior to the application of an IHS transform produces fused images of improved spatial resolution without changing the spectral characteristics. First experiments prove also that this technique works well for the fusion of hyperspectral images with ultra high resolution airborne scanner data. Next tests will involve more rigid comparison (e.g., image profiles, selected objects analysis). Other image fusion techniques to be included in our research are single band and multi band wavelet transforms (Na et al.2004). Due to its complexity, the filter design should be as automated and user friendly as possible. Consequently, we will try to develop meaningful default values for the fusion of multispectral and hyperspectral datasets. Based on these results, we attempt to develop a flowchart modeler which will allow the occasional user to apply standard values and standard procedures. First steps to incorporate our method into the ERDAS Modeler show encouraging results.

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