

ASPECTS OF THE STANDARDIZATION OF SENSOR AND DATA FUSION OF REMOTE SENSING DATA

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ABSTRACT:

Owing to continuous developments in technology and new requirements single sensor measurements are faced with constraints in their accuracy and thus in the applicability of their results. An innovative method of improving the geometric and radiometric data quality is the fusion of data obtained from different digital sensors. Sensor fusion means merging data obtained from different individual physical sensors to provide more comprehensive information from a single 'logical' or 'virtual' sensor. Airborne and spaceborne high-resolution digital cameras, laser scanners, hyperspectral systems, radar and InSAR systems have been considered in this context. Common fusion methods are resolution improvement, fusion of altitude or distance information and texture information (orthophoto generation), pan-sharpening and tracking. The derivation of orientation information from fusion of different sensors is not regarded in this paper. Assessment criteria for fusion results of data obtained from different sources have so far only been established in a few cases. Within the INS project (German Institute for Standardization DIN, 2008) the scientific bases for standardization has been developed to provide manufacturers and users with rules for the quality of the end products – also with regard to the international market. Therefore sensors and methods for achieving possible fusion products were introduced and discussed. This formed the basis for the development of a working document for a draft standard for requirements for geometric fusion methods.

KURZFASSUNG:

Messungen mit einzelnen Sensoren kommen durch die ständige technologische Entwicklung und neue Anforderungen an die Grenzen ihrer Genauigkeit und damit auch der Verwendbarkeit dieser Ergebnisse. Eine innovative Methode zur Verbesserung der geometrischen und radiometrischen Datenqualität ist die Fusion von Daten unterschiedlicher digitaler Sensoren. Dabei werden die Daten von verschiedenen individuellen physikalischen Sensoren zu einer umfassenderen Information eines „logischen“ oder „virtuellen“ Sensors zusammengefügt. In diesem Zusammenhang wurden flugzeug- und satellitengetragene hochauflösende Kameras, Laserscanner, Hyperspektralscanner, Radar- und InSAR-Systeme berücksichtigt. Typische Fusionsverfahren sind die Auflösungsverbesserung, die Verbindung von Höheninformation und bildhafter Information (mit Parallelen zur Orthophotoerstellung), Pan-sharpening sowie Objektverfolgung. Die Ableitung von Orientierungsinformationen aus der Fusion unterschiedlicher Sensoren wird hier nicht betrachtet. Bislang existieren nur in wenigen Fällen Kriterien, die eine Beurteilung der Ergebnisse der Fusion von Daten unterschiedlicher Quellen erlauben. Im INS-Projekt (German Institute for Standardization DIN, 2008) sollten die wissenschaftlichen Grundlagen erarbeitet werden, um Herstellern und Anwendern – auch in Hinblick auf den internationalen Markt – Festlegungen über die Qualität der Endprodukte an die Hand geben zu können. Deshalb wurden Sensoren und Verfahren für potenzielle Fusionsprodukte vorgestellt und diskutiert, um auf dieser Grundlage einen Norm-Entwurf für Anforderungen an geometrische Fusionsverfahren zu erarbeiten.

1. INTRODUCTION

In order to improve measurement accuracy and therefore also to extend the applicability of sensors it is advisable to merge data obtained from different individual physical sensors so that more comprehensive information is provided by a single "logical" sensor. The measurement data of a virtual sensor is already calibrated and has a well-known spatial and temporal relation between each single dataset. Currently many sensors, applications and techniques exist. Scientific literature has been reporting on it for more than 25 years (Haydn et al., 1982). One of the first applications was the integration of the low-resolution multispectral bands of Landsat data with the high-resolution panchromatic band of SPOT data (pan-sharpening). This

opened up new possibilities for simultaneous processing of remote sensing data. With the introduction of digital photogrammetric airborne cameras different applications, which were only discussed in the scientific community, are becoming economically important. Especially the simultaneous measurements with multispectral bands also open up possibilities for remote sensing applications apart from photogrammetric products. Thus, fusion products are already available and integrated into a workflow for higher level photogrammetric and remote sensing products. So this new generation of digital cameras with multispectral bands is leading towards integration between photogrammetry and remote sensing. At the same time, high resolution multispectral data pose a new challenge for the remote sensing community.

However, assessment criteria of fusion results obtained from different sources have so far only been established in a few cases. Therefore, it is necessary to develop quality standards to facilitate the comparability of the derived fusion products. Thus, the aim of this work was to provide an overview of systems, techniques and applications of sensor and data fusion as well as to identify algorithms and products for sensor fusion. Moreover, it had to be investigated whether such approaches are suitable for standardisation. At the same time, the scientific basis for the development of a working document for a draft standard for requirements for geometric fusion methods had to be established.

This paper results from the standardization of digital photogrammetric cameras within Germany (German Institute for Standardization DIN, 2007). However, research into fusion products needs to be extended with respect to the number of different sensor types. This is why a comprehensive research into current photogrammetric and remote sensing sensors was conducted. The sensors under investigation were systematized according to their supporting platform (airborne or spaceborne) as well as subdivided in active and passive systems to facilitate their comparability (see table 1-4). Moreover, the sensor types were described and their technical specifications were outlined. Concerning the objective – to extract the information relevant for standardization - fundamental sensor systems and approaches were juxtaposed to aid comparison at the end.

The paper is organized as follows. The second chapter contains an overview of common sensor systems. After a brief introduction of fusion principles a number of applications for data fusion obtained from different sensors are considered in chapter three. Furthermore, some examples of techniques, methods and procedures for the fusion of geometric data have been identified, correspondingly arranged and differentiated. In the fourth chapter some important requirements for fusion products are derived. Finally, the paper ends with some conclusions and an outlook.

2. SENSORS

The tables below show an overview of selected sensors (see table 1-4). The sensors are highly sophisticated and deployed for production tasks in photogrammetry and remote sensing. They can be divided into passive and active sensor systems. Active sensors are able to operate at night. Depending on the platform (aircraft or satellite) these sensors are classified as digital cameras, laser scanners, multi- and hyperspectral scanners and radar systems. This list is not exhaustive. However, the most relevant sensors from the photogrammetric point of view are specified. A more comprehensive overview of high-resolution satellite imaging systems can be found in (Jacobson, 2005).

airborne		spaceborne	
system	manufacturer	system	manufacturer
ADS40	Leica Geosystems	IKONOS	GeoEye
DMC	Intergraph	QuickBird-2	Digital Globe
UltraCam X TM	Microsoft Photogrammetry	RapidEye	RapidEye AG

Table 1. Passive systems – digital cameras

airborne		spaceborne	
system	manufacturer	system	manufacturer
AVIRIS	NASA	EnMap	Kayser-Threde, GFZ, DLR
HyMap	Integr. Spectronics	Landsat	NASA, USGS
ARES	DLR	GeoEye1	GeoEye
CASI	ITRES		

Table 2. Passive systems – multi- and hyperspectral scanner

airborne	
system	manufacturer
ALTM	Optech
ALS50	Leica
LMS	Riegl
LiteMapper	IGI

Table 3. Active systems – laser scanner

airborne		spaceborne	
system	manufacturer	system	manufacturer
E-SAR	DLR	A-SAR	ESA
ARTINO	FGAN	SAR-Lupe	OHB
PAMIR	FHR/FGAN	TerraSAR-X	DLR
AIRSAR	JPL	X-SAR/SRTM	NGA, NASA
EMISAR	DCRS		
PiSAR	NICT/JAXA		
RAMSES	ONERA		

Table 4. Active sensor systems - radar

2.1 Digital optical high-resolution sensors

The following approach was taken for quantitative sensor classification: High-resolution spaceborne sensors have a spatial resolution better than 1 m to 2 m, high-resolution airborne sensors better than 10 cm to 20 cm. Thus, a resolution about ten times higher with reference to the Ground Sample Distance (GSD) is assumed. This is related to typical applications and sensors deployed in the past. The number of measured pixels per image exceeds 100 mega pixels. They have a radiometric dynamic of 12 bit to 14 bit and a signal-to-noise ratio (SNR) better than 8 bit. Apart from the high-resolution panchromatic band, optical airborne and spaceborne sensors have another four (mostly lower-resolution) multispectral bands.

2.2 Laserscanner (LIDAR)

The surface is sampled by a scanning laser beam and the period of time between the emission of the laser impulse and the receiving of the reflected beams is measured (Time of flight - TOF). A more accurate approach is based on evaluation of the phase shift between the emitted and received modulated light beam. A disadvantage of this approach is the phase unwrapping procedure (Wehr, 2005).

The laser distance measurement enables the distance between the reflective surface and aircraft to be derived. The elevation of reflective locations can be calculated very exactly in the geodetic framework. This is because the exact position and flight direction of the aircraft can be determined by a Global Positioning System (GPS) and an Inertial Navigation System (INS) (Wehr and Lohr, 1999). Additional alignment parameters are needed to calculate the coordinates in a laser scanner relevant coordinate system.

2.3 Multi- and Hyperspectral Scanner

Measurements depend on illumination conditions, topography and angle-dependent surface reflection features.

The aim of using these sensors is to derive special objects (plant cover, crop) and object features of the surveyed areas by analysing spectral surface reflection. For this purpose, common remote sensing and image processing techniques (e.g. segmentation and classification) are applied.

Multispectral scanners possess 10 bands to 12 bands (e.g. Landsat TM); hyperspectral scanners possess more than 100 bands (e.g. HyMap). Hyperspectral scanners (imaging spectrometer) measure object-specific signatures with high spectral resolution. It permits the recording of an almost continuous spectrum for every image element. Thus, objects detected on the earth's surface are separable and thus classifiable. These objects exhibit characteristic absorption and reflection features in very narrow spectral bands which cannot be resolved by conventional sensors. However, the spatial resolution is restricted for energetic reasons.

2.4 Radar sensors

Based on the spectral range used these sensors also work in cloudy conditions. With the aid of radar sensors reasonable information can also be obtained from territories with extremely low contrast such as the ice areas of the Arctic.

Interactions between radar signals and researched objects (reflection features and penetration depth) are determined by the used frequency and polarisation of the radar signal. Interferometric Synthetic Apertur Radar systems (InSAR) are based on the analysis of phase differences between two SAR-datasets taken from different positions. Because of the reference from phase difference to ground level high-resolution digital elevation models (DEM) can be generated (TSGC, 2004).

3. FUSION METHODS AND TECHNIQUES

In the following some fundamentals about fusion in relation to photogrammetry and remote sensing as well as relevant methods and applications are described.

3.1 Fusion

Within data processing various different algorithm or special software are applied to obtain derived information from raw sensor data. So objects and their features can be derived from image data by segmentation algorithms, and the behaviour of these objects in the surveyed area can be described. Based on this information, decisions can be made. Each processing step is equivalent to an increasing information extraction level. Fusion with other sensors is possible on each level.

In this paper, pixel-, feature- or decision-level techniques are subdivided (Klein, 2004) (see figure 1).

- Pixel-level fusion: combination of raw data of different sensors, or sensor channels within a common sensor to one single image (e.g. pan-sharpening of Landsat imagery).
- Feature-level fusion: requires extraction of different single features from each sensor or sensor channel before merging them into a composite feature, representative of the object in the common field of view of the sensors (e.g. Tracking).
- Decision-level/information-Level fusion: combination of the initial object detection and classification results by the individual sensors to obtain a merged product or even a decision by a fusion algorithm.

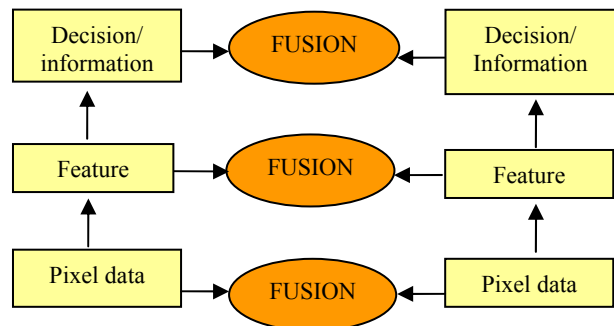


Figure 1. Pixel level, feature level and decision level fusion

The merged dataset has higher information content than each individual source image of the considered scene. Due to the competing or complementary information the result will necessarily possess a greater richness in detail. The images are to be co-registered prior to the fusion. This applies to both to the spatial and the temporal aspects. Image fusion of multi-sensor images is of great importance for earth and space observation, especially for mapping in the fields of environment, agriculture and oceanography.

3.2 Applications and methods

Applications for sensor and data fusion are environmental monitoring, object recognition and detection as well as change detection (e.g. Sault et al., 2005; Hill et al., 1999; Duong, 2002; Schatten et al., 2006; Bujor et al., 2001; Madhavan et al., 2006). Most of the applications and methods in photogrammetry and remote sensing are based on pixel level fusion. Only tracking can also be carried out at feature level.

Typical methods and techniques concern the improvement of data (resolution enhancement, bridging data gaps of other sensors), the combination of image data and elevation or distance data (orthophoto generation), the combination of high-resolution panchromatic and lower-resolution multispectral data (pan-sharpening) as well as detection and tracking within observed areas.

Initially, pan-sharpening (e.g. the integration of high-resolution SPOT data and multispectral Landsat data) took centre stage. Vijayaraj performed a quantitative analysis of pansharpened images and presented a review of common pan-sharpening algorithms (Vijayaraj et al., 2006). High-resolution

panchromatic and multispectral data of current digital photogrammetric cameras pose completely new challenges to analysis and especially to accuracy requirements on previous co-registration of image data, which need to be (object-related) in the centimetre range (see figure 2). For remote sensing tasks one of the true colour bands is replaced by the NIR band (CIR-image).

Integration of image and elevation data is in principle resolved by orthophoto generation in photogrammetry and has been standardized in Germany (German Institute for Standardization DIN, 2003). Modern technologies (Laserscanner and InSAR-systems) also permit the generation of high-resolution DEMs in complicated observation conditions (e.g. in forests, in urban areas, in conditions with poor contrast and in bad weather conditions). However, formal approaches remain the same as already defined. Merely co-registration becomes more



Figure 2. Panchromatic (top), RGB (middle) and CIR (bottom) images (image data by DMC/Intergraph)

complicated because of different observation conditions (e.g. SAR-systems).

Latest key research developments are towards true orthophotos. Moreover, texture and 3D information can be obtained by airborne cameras (e.g. MFC). This is applied for 3D city models from stereo image data, with a remarkable sharpness of the edges of the 3D objects (Boerner et al., 2008) (see figure 3-4).

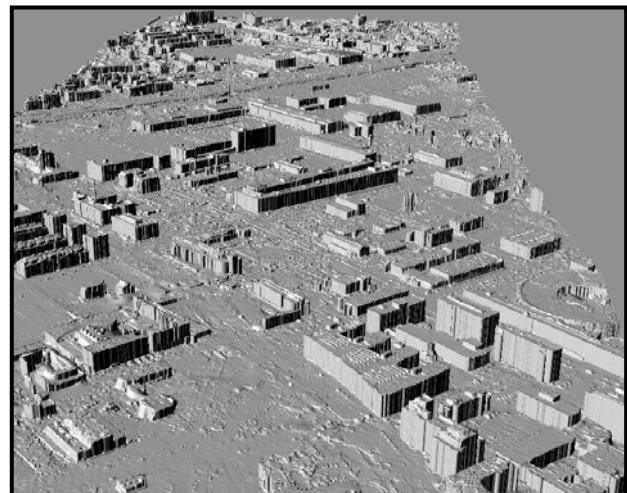


Figure 3. Digital Elevation Model (DEM) (image data by MFC)

Methods for resolution enhancement have been established in research for many years and also employed in production. Keywords are linked to SPOT HR band and ADS40, which are equipped with what is known as a “staggered array” (Reulke et al. 2004) and also with Superresolution (SR).

SR algorithms can be divided in frequency and spatial domain algorithms. Through SR enhanced-resolution images are created by merging lower-resolution images together. Reulke et al. showed an improved resolution by a factor of 2 using a combination of staggered data and image restoration. A resolution potential in the sub-decimetres range was

demonstrated for the ADS40 (Reulke et al. 2006). Based on the sampling theorem, the optical system has to provide the necessary spatial frequency for Superresolution.



Figure 4. Textured DEM (image data by MFC/DLR)

Object detection and tracking are methods which are not only employed in the fields of photogrammetry and remote sensing. Typical applications refer to the integration of optical and distance sensors, which are applied in the automobile industry (e.g. vehicle sensors) (Catalá-Prat et al., 2008), to tracking of objects provided by multiple camera systems for observing tasks and to traffic monitoring (Meffert et al., 2005). Related approaches are interesting as they also contain synchronization aspects between datasets (beside the classic spatial co-registration).

4. DERIVATION OF REQUIREMENTS FOR FUSION PRODUCTS

Aspects of relevance to standardization and to the quality assessment of fusion results irrespective of which algorithm is applied do not appear in many published papers. The following fields of requirements can be determined:

- Requirements for utilised sensors
- Requirements for methods and quality of co-registration
- Requirements for spatial image quality (e.g. from point spread function analyses) and
- Requirements for radiometric and colour quality (for true colour image data).

The above requirements have to be specified and explained more exactly for individual approaches.

As for the requirements for image and elevation data reference can be made to the German standard 'Requirements for the orthophoto' (German Institute for Standardization DIN, 2003).

As for pan-sharpening methods the requirements correspond exemplarily to following aspects:

- The utilized sensors have to fulfil both remote sensing tasks and true colour demands.
- The quality of co-registration refers to low-resolution multispectral data in comparison to the high-resolution band.
- The spatial image quality (e.g. from point spread function analysis) has to correspond with the image

quality of the high-resolution band after the pan-sharpening process.

- The radiometric and colour quality (for true colour image data) has to correspondent with the multispectral products.

The quality aspects of pan-sharpened images are described in greater detail below.

Requirements for data fusion

- Enhancement of spatial resolution
A quality criterion for pan-sharpening methods is the preservation of the spatial resolution of the panchromatic image in the end product. This can be evaluated by analysis of the point spread function by means of distinctive image structures.
- Preservation of spectral features
Spectral features of the original low-resolution image need to be preserved in the generated high-resolution multispectral image in order to be in the position to adopt e.g. classification algorithms successfully. A modification of the colour distribution in the end product compared to the reference image can be roughly endorsed by comparison of the histograms of the red, green and blue proportions of the individual images. More differentiated assessment of the preservation of true colour features in the original and the pan-sharpened images can be carried out by applying colour-distance in Lab-space (Wyszecki and Stiles, 2000).

Another quality criterion for the pan-sharpening process performance is the number of visible artefacts. Especially problematic are object edges, if the red, green and blue bands are not accurately co-registered.

5. CONCLUSIONS AND OUTLOOK

A small number of fusion methods have been well implemented (e.g. orthophoto generation, pan-sharpening).

Data fusion is not only an issue in remote sensing research. It has become of operational importance. Many civilian and defence applications are enhanced through sensor and data fusion (e.g. transportation management, tracking, and automotive).

The quality assessment of fusion is still difficult. Corresponding fundamental scientific research is necessary.

From our point of view, new applications based on higher levels (feature and decision level) are to develop in the future. An outstanding challenge is the handling of ambiguities if different sensors come to different fusion results on decision-level.

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