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Image fusion of multitemporal and multisensoral data

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ABSTRACT: Several definitions for data fusion can be found in the literature. Data fusion exists in different forms in different scientific communities. The remote sensing community defines data fusion as "… a formal framework in which are expressed means and tools for the alliance of data originating from different sources. It aims at obtaining information of greater quality; the exact definition of greater quality will depend upon the application" (Wald 1999). Image fusion forms a subgroup within this definition, with the objective to generate a single image from multiple image data for the extraction of information of higher quality (Pohl 1999). Image fusion can be classified into three levels: pixel level (iconic), feature level (symbolic) and knowledge or decision level (Pohl & van Genderen 1998). In this paper, we focus on iconic fusion.

Iconic image fusion is a technique that is used to combine the spatial structure of a high resolution panchromatic image with the spectral information of a low resolution multispectral image to produce a high resolution multispectral image. Currently, widely used methods are the Intensity-Hue-Saturation (IHS), Principal Component (PC) or the Brovey method which are implemented in a number of commercial image processing systems. In most cases, these techniques provide very good results, i.e. they retain the high spatial resolution of the panchromatic image and the spectral information from the multispectral image. These techniques, when applied to multitemporal or multisensoral image data, still create spatially enhanced datasets but usually at the cost of the spectral characteristics. In this study it is shown that the Ehlers fusion, an IHS based fusion with adaptive filtering in the Fourier domain, can preserve the spectral characteristics of the multispectral image also for multidate and multisensor data. One multispectral FORMOSAT scene and seven multispectral SPOT scenes from different dates are fused with a panchromatic Ikonos image. The fused images are compared visually and quantitatively to evaluate the spectral preservation and spatial improvement in the images. It can be shown that only the Ehlers Fusion can improve the spatial resolution while retaining the spectral characteristics of the multitemporal and multisensoral data.

1 INTRODUCTION

Image fusion is used in many fields like military, medical imaging, computer vision, robotic industry and remote sensing. The goals of the fusion process are manyfold: to sharpen multispectral images, to improve geometric corrections, to provide stereo viewing capabilities for stereophotogrammetry, to enhance certain features not visible in either of the single datasets alone, to complement data sets for improved classification, to detect changes using multitemporal data and to replace defective data (Pohl & van Genderen 1998). In this paper, we will concentrate on the image sharpening process and the question of quality assessment.

Generally, image fusion methods can be differentiated into three levels: pixel level (iconic), feature level (symbolic) and knowledge or decision level. Of highest relevance for remote sensing are techniques for iconic image fusion, for which many different methods have been developed (see, for example, Welch & Ehlers 1987; Pohl & van Genderen 1998).

2 DATA AND METHODOLOGY

2.1 *Study area and datasets*

The study area is located in the North of Spain, southwest of the town Vitoria Gasteiz. It represents the region around Santo Domingo de la Calzada. This area was used as a control site of the JRC (Joint Research Centre of the European Commission) in the project "Control with Remote Sensing of Area-Based Subsidies" (CwRS) (Åstrand *et al.* 2007). Eight different multispectral SPOT and Formosat images were used for this investigation. These multispectral images cover a time frame of almost 2 years and virtually all seasons and thus pose an excellent challenge for a spectral characteristics preserving data fusion. All images were merged with a panchromatic Ikonos image from 30 May 2005 (1 m GSD) using seven different fusion algorithms (see chapter 2.2.). To ensure that the images are in perfect registration a differential registration procedure is necessary, especially for areas with terrain relief. Otherwise the quality of the fused image will decrease significantly.

2.2 *Fusion methods*

We employed seven different algorithms for fusion of the images. All eight images were fused with the panchromatic Ikonos image resulting in a dataset of 56 fused images. All images were evaluated visually and statistically for color preservation and spatial improvement. We made use of standard techniques and a number of recently developed algorithms. We are aware that other methods are being proposed but most are still in an experimental stage and some have not been published. We concentrated on those that are already available in remote sensing image analysis packages that we had access to. The modified IHS fusion from Siddiqui (2003), the color normalization (CN) spectral sharpening (Vrabel *et al.* 2002), the Gram Schmidt spectral sharpening (Laben *et al.* 2000), the Brovey Transform (Hallada & Cox 1983), the PCA (Chavez *et al.* 1991), the Ehlers Fusion (see below) and a Wavelet based method.

The Ehlers fusion was developed specifically for a spectral characteristics preserving image merging (Ehlers 2004; Ehlers & Klonus 2004). It is based on an IHS transform coupled with a Fourier domain filtering. For optimal color separation, use is made of an IHS transform. This technique is extended to include more than 3 bands by using multiple IHS transforms until the number of bands is exhausted. A subsequent Fourier transform of the intensity component and the panchromatic image allows an adaptive filter design in the frequency domain. Using fast Fourier transform (FFT) techniques, the spatial components to be enhanced or suppressed can be directly accessed. The intensity spectrum is filtered with a low pass filter (LP) whereas the panchromatic spectrum is filtered with a reverse high pass filter (HP). After filtering, the images are transformed back into the spatial domain with an inverse FFT and added together to form a fused intensity component with the low-frequency information from the low resolution multispectral image and the high-frequency information from the high resolution panchromatic image. This new intensity component and the original hue and saturation components of the multispectral image form a new IHS image. As the last step, an inverse IHS transformation produces a fused RGB image that contains the spatial resolution of the panchromatic image and the spectral characteristics of the multispectral image. These steps can be repeated with successive 3-band selections until all bands are fused with the panchromatic image (for a complete description of the method see Klonus & Ehlers 2007).

3 PERFORMANCE EVALUATION

For the visual analysis, we concentrated on the issue of color preservation. The results were grouped into six categories ranging from "almost no color changes visible" (+++) to "complete color change" (—). The disadvantage of this analysis is that it is very subjective and depends heavily on the interpreter. Therefore, we also subjected the fusion results to a thorough statistical analysis using a number of quality parameters. From the results, however, it was clearly visible that some fusion methods failed miserably or were inconsistent, a fact that did not really need a quantitative analysis.

Statistical evaluation procedures have the advantage that they are objective, quantitative, and repeatable. Two different statistical evaluation methods from the literature were chosen:

- Correlation coefficients between the original multispectral bands and the equivalent fused bands.
- Per-pixel deviation (see Wald 2002, pp. 147–160).

In most analyses, emphasis has been placed on the spectral evaluation. It is, however, also mandatory to investigate the performance of the pansharpening algorithms as far as the spatial improvement is concerned. Otherwise, the original image with no spatial improvement will produce the best results. The objective is to find the fused image with the optimal combination of preserving spectral characteristics and spatial improvement. To quantitatively measure the quality of the spatial improvement, two different methods are chosen:

- Correlation between the original panchromatic band and the fused bands after high pass filtering. by Zhou *et al.* (1998).
- Edge detection in the panchromatic image and the fused multispectral bands. For this, we chose a Sobel filter (Jensen 2005) and performed a visual analysis of the correspondence of edge detected in the panchromatic and the fused multispectral images for each band.

4 RESULTS AND DISCUSSION

All eight images were visually and statistically analyzed for all seven fusion methods. Our comprehensive analysis is based on all 56 single results. For demonstration purposes the SPOT 5 image of July 2004 was selected, because it is very representative for the encountered fusion effects. Figure 1 shows the original multispectral SPOT 5 (bands 1 – green, 2 – red, and 3 – near infrared) as a standard false color infrared display as well as the seven different fusion results. The Ehlers (Figure 1d) and the wavelet fusions (Figure 1h) show almost no color distortions and achieved the best results for all images as far as spectral characteristics preservation is concerned. While the wavelet fusion generates an image that preserves the original colors very well, it is also evident that it does not produce a spatially improved image. The fused image shows only sketchy spatial improvement in some parts of the image. The overall impression is that of a very blurred image (similar to the original resampled one) with some overlaid sketch lines on top (Figure 1h). Brovey (Figure 1c), CN (Figure 1b) and IHS (Figure 1e) fusion show sometimes acceptable results, but were never without serious color changes. The best results for IHS and Brovey were achieved for the SPOT image which was recorded in April 2005, i.e. the closest to the acquisition date of the panchromatic Ikonos image. PC (Figure 1g) and Gram Schmidt fusion (Figure 1f) have the most serious color deficiencies and should therefore not be used for multitemporal and/or multisensoral image fusion.

The quantitative analyses for the spectral characteristics confirmed the visual inspection findings. Ehlers and wavelet fusion were always the best for all employed spectral quality measurements. Again, it is evident that the spectral fidelity of the wavelet fusion comes at the expense of the spatial improvement. The point score in the last column was calculated from the rank of the method (ordered from the best to the worst value), i.e. lower point scores mean better results.

The lowest (and best) values are associated with the Ehlers fusion. The wavelet fusion shows the second best results with very small values. The worst results were produced by the PC, CN and Brovey methods (Table 1).

The second statistical analysis, the calculation of the correlation coefficient between the fused and original image bands confirms the previous findings. Best results were obtained by the Ehlers and wavelet methods. The wavelet function showed a higher coefficient only for one date (10 December 2004). Brovey, IHS and PC fusion present their best results for the image of 10 April 2005 which is the closest to the acquisition time of the panchromatic Ikonos image. CN, IHS, Brovey, PC, and Gram Schmidt had very low

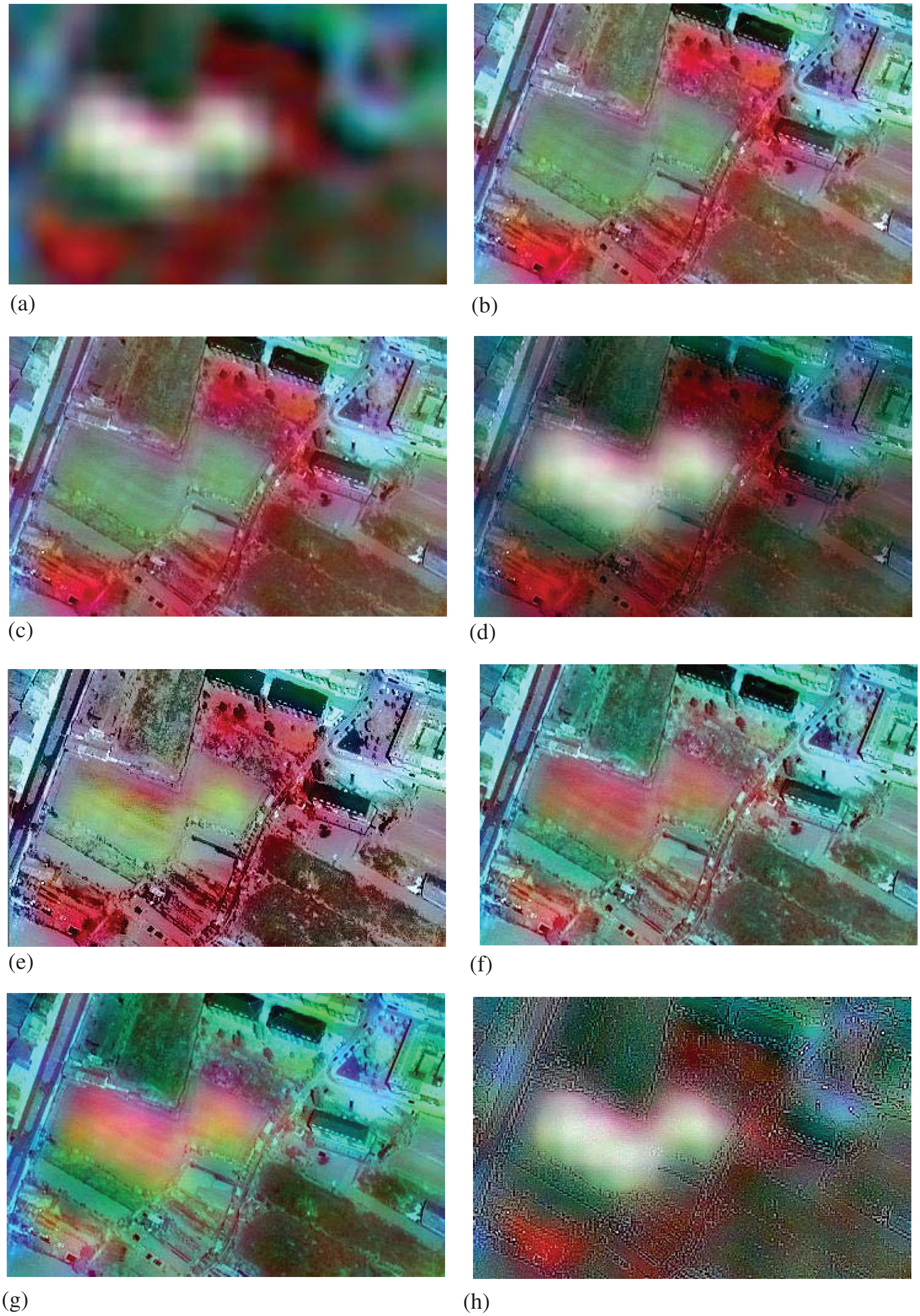

Figure 1. a) Original multispectral Spot 5 image recorded on 24 July 2004; b) CN spectral sharpening; c) Brovey fusion; d) Ehlers fusion; e) IHS fusion; f) Gram Schmidt fusion; g) PC fusion; h) Wavelet fusion.

Table 1. Per-pixel deviation between the fused and the original images.

	03.11.2003	24.04.2004	15.05.2004	24.07.2004	10.12.2004	10.04.2005	20.07.2005	12.08.2005	Points
Ehlers	1,30	0,62	0,55	0,72	0,35	0,68	0,62	1,02	**10**
Wavelet	0,91	1,46	1,71	0,84	0,34	1,53	2,92	1,39	**14**
HIS	11,60	10,22	18,20	6,68	5,55	7,19	23,76	12,96	**28**
Gram	9,99	20,75	29,23	6,58	4,15	12,86	32,02	13,72	**33**
CN	11,51	12,08	24,62	7,27	64,95	8,34	38,92	21,82	**40**
PC	11,74	46,70	26,26	7,09	8,10	18,30	46,70	19,71	**44**
Brovey	58,26	64,65	95,98	65,31	8,19	74,02	130,43	84,45	**55**

Table 2. Correlation coefficients between fused and original multispectral bands.

	03.11.2003	24.04.2004	15.05.2004	24.07.2004	10.12.2004	10.04.2005	20.07.2005	12.08.2005	Points
Ehlers	0,9644	0,9825	0,9860	0,9501	0,9282	0,9866	0,9908	0,9486	**9**
Wavelet	0,9540	0,9545	0,9583	0,9415	0,9532	0,9566	0,9327	0,9350	**15**
CN	0,6918	0,8559	0,7273	0,6412	0,3009	0,9315	0,6486	0,4483	**30**
HIS	0,5593	0,7762	0,7029	0,7064	0,2381	0,8937	0,5320	0,4805	**36**
Brovey	0,5938	0,6471	0,5720	0,4970	0,3227	0,8890	0,4329	0,4500	**41**
PC	0,6316	0,2982	0,3191	0,5129	0,3377	0,6858	0,2632	0,3022	**46**
Gram	0,6273	0,5694	0,2908	0,5694	0,3122	0,7476	0,2021	0,4031	**47**

correlation coefficients (with the exception of the April 2005 image). Table 2 presents the correlation results. The correlation coefficient represents the average value for all bands.

Considering the spatial enhancement in the fused images, all methods proved to be sufficient with the exception of the wavelet function which did not pansharpen the images. Often only stripes instead of spatial enhancement were visible in the fused images. Particularly in homogeneous areas, no spatial improvement could be found at all. This was true for all multitemporal images. These results were confirmed by both statistical analyses in which the wavelet fusion shows the worst results (see Tables 3 and 4).

Visually, Brovey, Ehlers, IHS, and CN spectral sharpening showed good to very good spatial sharpening results in all images. PCA and Gram Schmidt showed some improvement in spatial resolution but never as much as the other methods. In some cases, the fused images still looked blurred. For the first quantitative analyses, the correlation coefficients between the high pass filtered panchromatic and the high pass filtered fused images were computed. Brovey, Ehlers and the modified IHS provided the best results. The Gram-Schmidt fusion showed also acceptable results, the only exceptions were the images which were recorded in April and May. CN sharpening and PC fusion showed unacceptable results with only few positive exceptions.

For the edge detection evaluation most of the methods show acceptable results with more than 80% correspondence (PC and CN had a lower result for one image each). As expected, the wavelet fusion was last, with less than 80% correspondence in four images.

5 CONCLUSIONS AND OUTLOOK

The results of this research show that most fusion methods that are implemented in commercial image processing systems cannot cope with the demands that are placed on them by multisensor/multitemporal fusion, thus confirming our previous findings (Klonus & Ehlers 2007). The color distortions in this study range from brightness differences to a complete change of spectral characteristics. Most of the fusion methods like principal component, CN spectral sharpening or Gram Schmidt fusion should only be used for single-sensor, single-date fusion. Wavelet based fusion retains most of the spectral characteristics but at the cost of spatial improvement whereas the Brovey fusion produces the best results for spatial enhancement at the cost of spectral fidelity. In our study, only the Ehlers fusion technique delivers pansharpened images with almost no spectral change. This fusion method has been made available to the public within the latest release of the ERDAS Imagine image processing software. Recently developed fusion algorithms that we have not yet tested will be compared in future research. Examples of these include the methods proposed by Alparone *et al.* (2005), or Gungor & Shan (2006). First tests were already performed with the Zhang (or UNB) fusion implemented in PCI‘s Geomatica software which revealed spectral distortions when applied to multi-date and multi-sensor images (Klonus 2006). Other tests with a predecessor of the Ehlers fusion with less flexibility proved to be superior to a combined IHS/wavelet fusion (Ling *et al.* 2007). Future work will also consider a combined method for a quantitative assessment of spatial improvement and spectral preservation because

Table 3. Correlation coefficients between the high pass filtered fused images and the high pass filtered panchromatic Ikonos image.

	03.11.2003	24.04.2004	15.05.2004	24.07.2004	10.12.2004	10.04.2005	20.07.2005	12.08.2005	Points
Brovey	0,9827	0,9781	0,9798	0,9951	0,9634	0,9776	0,9850	0,9899	**9**
Ehlers	0,9718	0,9587	0,9395	0,9397	0,9291	0,9609	0,9280	0,9652	**22**
Mod. HIS	0,9355	0,9413	0,8835	0,8761	0,8832	0,8947	0,8592	0,8409	**30**
Gram	0,9847	0,5840	0,5892	0,8730	0,9397	0,5252	0,9406	0,9761	**33**
CN	0,7650	0,6970	0,7600	0,7913	0,8707	0,7713	0,6970	0,9693	**37**
PC	0,5466	0,6193	0,6795	0,5937	0,9480	0,5923	0,7988	0,7295	**44**
Wavelet	0,6777	0,6565	0,6674	0,6460	0,6594	0,6685	0,6368	0,6400	**49**

Table 4. Percent of edges which are detected in the fused images and the panchromatic Ikonos image.

	03.11.2003	24.04.2004	15.05.2004	24.07.2004	10.12.2004	10.04.2005	20.07.2005	12.08.2005	Points
Brovey	93,89	91,84	92,69	96,57	89,23	89,75	94,04	94,46	**13**
Gram	93,28	92,86	92,60	85,64	90,65	95,31	94,42	92,47	**15**
PC	91,54	89,99	86,45	79,92	91,02	89,19	82,71	88,47	**30**
Ehlers	89,76	85,54	84,38	89,95	85,46	83,91	83,27	86,21	**35**
Mod. IHS	87,39	87,69	86,49	83,64	83,17	83,17	85,48	80,53	**37**
CN	82,73	81,27	83,91	86,41	89,23	79,24	85,25	92,05	**38**
Wavelet	80,12	79,46	80,34	77,51	73,78	80,81	80,72	79,64	**55**

otherwise the best color preservation is observed if no pansharpening is performed which – of course – makes the fusion obsolete. Only a combined assessment of spatial improvement and spectral characteristics preservation can be used as a quality measure for image fusion. Based on our results, however, we can conclude that techniques exist to fuse multitemporal and multisensoral images with sufficient spatial enhancement and spectral fidelity.

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