Fusion of Earth Data, Sophia Antipolis, France, 28-30 January 1998.

FUSION OF MULTISPECTRAL AND PANCHROMATIC IMAGES BY LOCAL MEAN AND VARIANCE MATCHING FILTERING TECHNIQUES

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ABSTRACT

Since the advent of high spatial resolution satellite images, the merging of multiresolution images has been an important field of research. Many methods have been developed in the last few years producing good quality merged images characterised by a high spatial information content, but with significantly altered spectral information content. The merging method applied in this case study tends to preserve this spectral information by producing new channels highly correlated with the original ones. The method analyses local image statistics and then matches the local histograms of the two images to be merged by applying mean or mean-variance matching normalisation functions. In this article two different sets of panchromatic and multispectral images with resolution ratios of 4 and 5 are fused and the quality of the result in regard of spectral information preservation is assessed.

1. INTRODUCTION

High resolution (HR) satellite images can now currently be acquired in two different modes : either the panchromatic (PAN) mode with high spatial resolutions of 10 m (SPOT), 5 m (IRS-C) or even 2 m (scanned KOSMOS KVR 1000 photographs), either the multispectral (MS) mode with much lower spatial resolutions of 30 m (LANDSAT TM), 25 m (IRS-C LISS3) or 20 m (SPOT). The PAN images are characterised by a very high spatial information content well-suited for intermediate scale mapping applications and urban analysis. The multispectral images provide the essential spectral information for smaller scale thematic mapping applications such as landuse surveys. In order to take benefit of the high spatial information content of the PAN images and the essential spectral information of lower resolution MS images, fusion of these two types of images can be performed in order to produce pseudo-HR MS images.

The principal interest of merging multiresolution image data is to create composite images of enhanced interpretability (Welch and Ehlers,1987; Kaczynski *et al.*, 1995). The images should have the highest possible spatial information content while still preserving good spectral information quality (Cliche *et al.*, 1985). Some authors stress the idea that the merging method used should not distort the spectral characteristics of the original MS data, ensuring that targets which are spectrally separable in the original data are still separable in the merged data set (Chavez *et al.*, 1991). Such products not only allow a more accurate delineation of ground features, making them more useful for various applications (Vrabel, 1996), but are also more easily interpretable in terms of their original spectral signatures. Garguet-Duport *et al.* (1996) have demonstrated that spectral information preservation is particularly well-suited in the case of vegetation analysis, and our own experience shows its usefulness in urban mapping applications. Going one step further, some authors even suggest that fused products with maximal spectral information preservation could ideally simulate MS images acquired at higher spatial resolutions (Vrabel, 1996; Wald *et al.*, 1997).

Different merging methods have been proposed in the literature, using Principal Component Analysis (PCA), Intensity Hue Saturation (IHS) transforms or High Pass Filters (HPF), and have been mutually compared in regard of spectral information preservation (Chavez *et al.*, 1991). Carper *et al.* (1990) showed, that the IHS transform usually produces reliable results when the Intensity channel of the IHS transform is well-correlated with the PAN image, which is often the case when the PAN and

MS images have been acquired simultaneously. Usually the HPF method introduced by Showengerdt (1980) produces fused images with the least spectral distortion. In all cases however, the results obtained by these methods are scene dependant, and their quality in regard to spectral information preservation is therefore unpredictable. These methods can thus mostly be used to produce good looking colour composites in cases where preservation of spectral information content is not a prerequisite, or when the resolution ratio between PAN and MS channels is clearly too high to expect realistic results.
Recently, new fusion algorithms have been devised to merge multiresolution image data sets with maximal spectral information preservation. Some of these methods are based on multiresolution analysis of the images using wavelet transforms (Ranchin, 1993; Garguet-Duport *et al.*, 1996; Yocky, 1996). Another method based on local mean matching (LMM) or on local mean and variance matching (LMVM) filters in the spatial domain allows to control the amount of spectral information to be preserved (de Béthune *et al.*, 1997).
In this paper three different fusion algorithms (HPF, LMM and LMVM) were applied to two multiresolution data sets in order to assess the quality of the fused products. The first data set corresponds to an IRS-1C PAN image (5 m) and its synchronous highly correlated LISS3 MS channels (25 m). The second data set corresponds to a KOSMOS KVR-1000 PAN image (2 m) to be merged with totally uncorrelated SPOT XS MS channels (20 m).

2. METHODS

Before the data fusion process, the different channels must be very accurately registered. The PAN images are first registered to map coordinates and resampled at 5 meter resolution by cubic convolution. The MS channels are then registered by an image to image procedure directly to their corresponding PAN images and resampled at the same resolution, also by cubic convolution, in order to avoid the blockiness due to the enlargment process (Chavez, 1986). By this process the original spatial resolution ratio of 10 between the KOSMOS and SPOT images has been reduced to a more convenient value of 4, while the original resolution ratio of 5 between the PAN and MS IRS-C images has been maintained.

2.1. HIGH PASS FILTERING (HPF)

The high pass filtering merging method introduced by Showengerdt (1980) extracts edge information of the HR image which is then added to the LR channel on a pixel by pixel basis. The highpass filter of the HR image corresponds to its high frequency component which is mostly related to spatial information. Hence, by adding this filter to the LR channel some of the high spatial information content of the HR image will become apparent in the fused product. The HPF fusion algorithm used in this case study is defined by :

$$F_{i,j} = L_{i,j} + (H_{i,j} - \overline{H}_{i,j(w,h)})$$

where $F_{i,j}$ is the fused image pixel at coordinates (i,j), $L_{i,j}$ and $H_{i,j}$ are the corresponding pixel values in the low (L) and high (H) resolution channels. $\overline{H}_{i,j(w,h)}$ corresponds to the local mean of the HR channel inside a window of w pixels wide and h pixels high centred on the pixel of coordinates (i,j).

2.2. THE LMM AND LMVM FILTERS

These filters were specifically designed in order to minimise the difference between the fused image and the LR MS channels (de Béthune *et al.*, 1997), hence to preserve most of the original spectral information of the LR channels. These filters apply normalisation functions (Joly, 1986) at a local scale within the images in order to match the local mean and/or local mean and variance values of the PAN image with those of the original LR spectral channel. The small residual differences remaining correspond to the high spatial information stemming from the HR PAN image. This type of filtering drastically increases the correlation between the fused product and the LR channel. The amount of spectral information preserved in the fused product can be controlled by adjusting the filtering window sizes.

The LMM algorithm is given by :

$$F_{i,j} = H_{i,j} \cdot \frac{\overline{L}_{i,j(w,h)}}{\overline{H}_{i,j(w,h)}}$$

were $F_{i,j}$ is the fused image, $H_{i,j}$ and $L_{i,j}$ are respectively the high and low spatial resolution images at pixel coordinates *i,j*; $\overline{H}_{i,j(w,h)}$ and $\overline{L}_{i,j(w,h)}$ are the local means calculated inside the window of size (*w*,*h*).

The LMVM algorithm is given by :

$$F_{i,j} = \frac{(H_{i,j} - \overline{H}_{i,j}) \cdot s(L)_{i,j(w,h)}}{s(H)_{i,j(w,h)}} + \overline{L}_{i,j}$$

where *s* is the local standard deviation.

3. QUALITY ASSESSMENT CRITERIA

In order to assess the quality of the merged product in regard of spectral information content by other means than simple visual inspection of the images, some quantitative assessment criteria are to be defined by comparing the radiometry of the merged product and the LR spectral image (Wald *et al.*, 1997). If the two images are made to match each other, then it can be stated that their global statistical parameters such as their means and standard deviations should be very similar. Another useful parameter is the deviation index as defined by Costantini *et al.* (1997), measuring the normalised global absolute difference of the fused image (*F*) with the LR channel (*L*):

$$\textit{Deviation index} = \frac{1}{lc} \sum_{i=1}^{l} \sum_{j=1}^{c} \frac{\left| F_{i,j} - L_{i,j} \right|}{L_{i,j}}$$

Control of the radiometric correspondence of the two images at a local scale, can be performed by measuring the correlation coefficient between the two images.

4. DATA ANALYSIS AND COMPARISON

The principal image characteristics are presented in tabular form (tables 1-3) for the IRS-C images and graphically for the IRS-C (figure 1) and the KOSMOS/SPOT (figure 2) image pairs. For both these image pairs, the three fusion algorithms were applied between the PAN images and an intensity channel corresponding to the sums of the three LISS3 and SPOT XS MS channels respectively. The resulting fused intensity channels can then afterwards be used in an IHS or INR to RGB transform to produce the desired fused MS channels (de Béthune *et al.*, 1997).

The simultaneously acquired IRS-C image pairs are already very close to each other, as expressed by their correlation coefficient of 0.86 and their low deviation index (=0.15). Tables 1 to 3 and figure 1 show the corresponding values of the different assessment criteria measured for the three fusion algorithms applied with varying local window sizes ranging from 5 x 5 to 49 x 49. By construction the three fusion algorithms are mean preserving as confirmed by the reported values. Standard deviation is only well-preserved with the LMVM algorithm and somewhat less with the LMM filter, while the values observed with the HPF filter increase steadily and very rapidly with window size. The three methods clearly improve the already high original correlation between the image pairs, with the highest values obtained for small window sizes. In all cases the deviation index remains smallest with the LMVM algorithm, with a maximum value of 6 %.

In the case of the SPOT-KOSMOS pair, the two images were acquired on different platforms at different times. Their original correlation value of -0.22 and their high deviation index (=1.168) stress the total lack of radiometric correspondence between the images. Despite this fact, figure 2 shows how well the LMVM algorithm performs to match their radiometry, by drastically increasing the correlation between the images even for the largest window sizes tested, and by keeping the deviation index under 5%. The two other algorithms perform poorly compared to the LMVM method, producing much lower correlation values which become rapidly insignificant for large window sizes. In this case, these two filters are also unable to keep the standard deviation within acceptable bounds, resulting in particularly high deviation indexes rising up to 55% in the worst case.

HPF	I	PAN	HPF 5	HPF 7	HPF 11	HPF 15	HPF 25	HPF 35	HPF 49
Mean	78.986	66.768	78.998	79.003	79.006	79.005	79.021	78.977	78.841
Standard deviation	13.545	10.693	14.193	14.751	15.869	16.826	18.516	19.523	20.259
Correlation	1.000	0.859	0.977	0.960	0.939	0.931	0.931	0.936	0.940
Deviation index	0.000	0.152	0.027	0.036	0.049	0.056	0.067	0.074	0.079
Entropy	5.733	5.330	5.800	5.849	5.940	6.016	6.141	6.211	6.266

Table 1. IRS-1C Panchromatic and Multispectral data fusion with the HPF method.

LMM	I	PAN	LMM 5	LMM 7	11	15	25	35	49
Mean	78.986	66.768	78.932	78.955	79.007	79.027	79.030	78.973	78.866
Standard deviation	13.545	10.693	13.913	14.250	14.659	14.699	14.375	14.039	13.679
Correlation	1.000	0.859	0.967	0.944	0.917	0.910	0.900	0.890	0.878
Deviation index	0.000	0.152	0.031	0.041	0.051	0.053	0.056	0.059	0.062
Entropy	5.733	5.330	5.773	5.802	5.832	5.831	5.794	5.760	5.725

Table 2. IRS-1C Panchromatic and Multispectral data fusion with the LMM method.

LMVM	I	PAN	5	7	11	15	25	35	49
Mean	78.986	66.768	78.915	78.892	78.887	78.901	78.925	78.883	78.790
Standard deviation	13.545	10.693	23.479	13.485	13.568	13.644	13.679	13.662	13.589
Correlation	1.000	0.859	0.988	0.977	0.956	0.942	0.919	0.903	0.889
Deviation index	0.000	0.152	0.017	0.025	0.035	0.041	0.049	0.054	0.058
Entropy	5.733	5.330	5.727	5.728	5.737	5.744	5.742	5.738	5.733

Table 3. IRS-1C Panchromatic and Multispectral data fusion with the LMVM method.

5. CONCLUSIONS

Two multiresolution image datasets were merged with the aim of producing spatially enhanced MS channels preserving most of the spectral information content of the original MS channels. In both cases, differing essentially by their initial correlation values, the adaptive intensity matching LMVM filter produced the best results in regard of the quality assessment criteria defined. For small local environments, this filter introduces but minimal changes between the fused product and the LR channel, regardless of the initial correlation of the channels. With increasing filtering window size more and more spatial information of the HR channel is incorporated into the merged product, compensated by more important changes of the spectral information, but always ensuring the maximum possible correlation and minimal deviation compatible with a constant mean and standard deviation constraint. Hence, by adjusting the LMVM filtering window size, one can control the actual amount of spectral information change which is acceptable for the application at hand.

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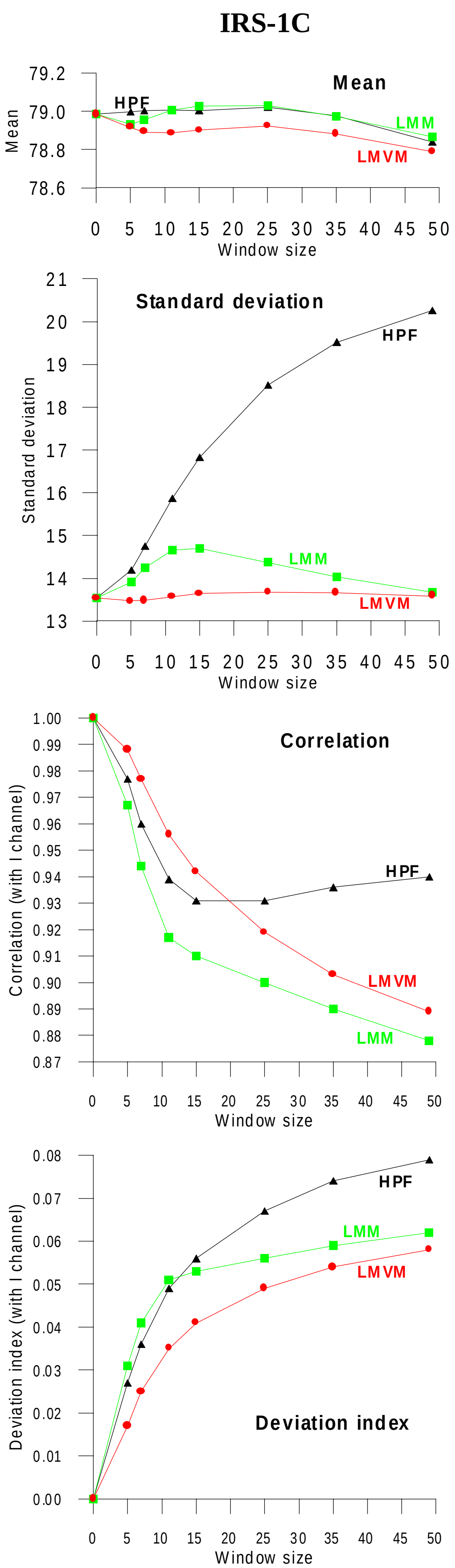

Figure 1. IRS-1C data fusion

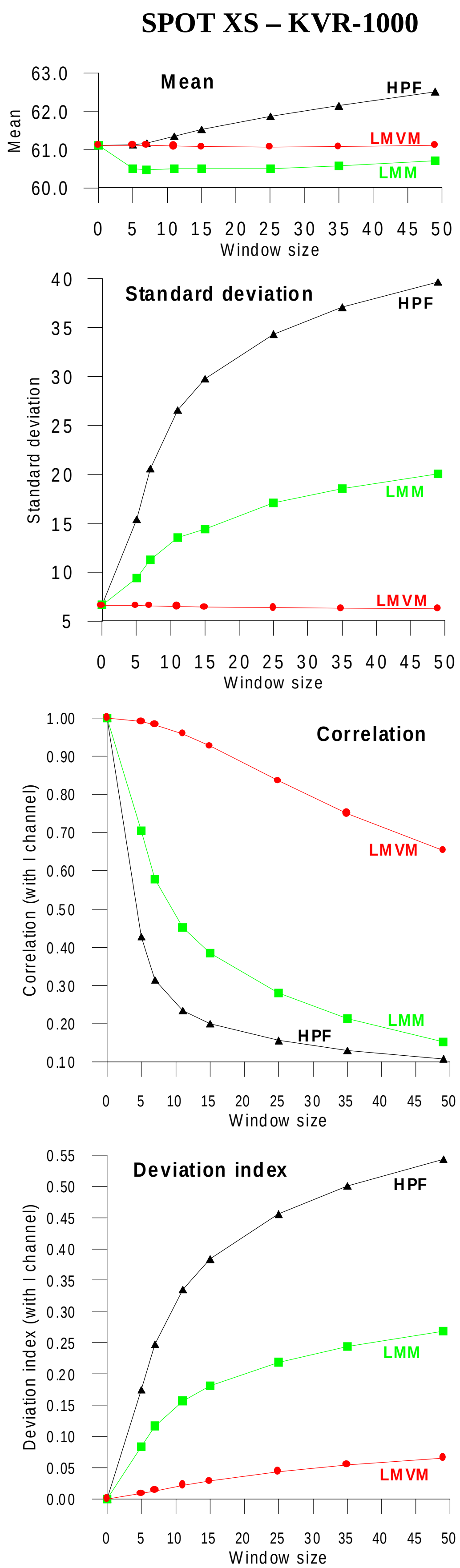

Figure 2. KVR-1000 and SPOT XS data fusion