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Comparison of standard and image-filter fusion techniques

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Abstract

Image fusion in a general sense, can be defined as: " *the combination of two or more different images to form a new image by using a certain algorithm*" [1]. It aims to extract from a set of different images of the same area those properties which are unavailable by the single sensor and which form in a combined way a new image with a higher multispectral resolution. In standard image fusion one multispectral image band is entirely substituted by the panchromatic band. It is not new, however, that due to the incoherence of sensor performances the original multispectral information becomes distorted and hence, the data provides only limited use in the spectral classification of textural image information. In comparison, newly evolved image filter data fusion techniques preserve both spatial and multispectral information. Results of both techniques are shown here using a higher resolution panchromatic image (IRS-1C) and a lower resolution multispectral image (SPOT XS). In detail, this paper discusses on one side the performance of three standard image fusion techniques, Intensity Hue Saturation (IHS), Principle Component Analysis (PCA) and High Pass Filter (HPF) and on the other side the use of a newly evolved image fusion technique, the Adaptive Image Filter (AIF) fusion. Results are visually assessed for image interpretability and statistically for spectral classification of textural data. From this assessment the IHS and PCA fusion achieved similar good results for visual image interpretation. If fused images are used for subsequent image classification, then the AIF fusion is the preferable one, preserving the multispectral information while adding textural and structural detail.

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1 Introduction

Nowadays, almost any application engaged with the study of the earth's surface totally or partially builds on remotely sensed image data. Therefore, one of the most demanding domains is the constant availability of spatial and spectral data of high resolution. Many efforts were made at the end of the last, beginning of this century for the launch of better earth observation systems (EOS). Visible-near infrared EOS detects the intensity of electromagnetic radiation that an object 7reflects at particular wavelength bands. However, due to some sensor specific constellations images are acquired in a higher spatial resolution panchromatic image and a lower spatial resolution multispectral image. In order to improve visual image interpretation the particular advantage of each image can be extracted and combined in a process that is known as image fusion. Various image fusion techniques were developed over recent years: IHS, PCA, HPF, ARSIS, AIF [1][2][3][4]. Some of them have been implemented in commercial software packages and others are still the subject of investigation or improvement. However, there exist considerable differences between these techniques and, in some cases, substantial drawbacks must be accepted in terms of preserving specific sensor properties. In this study an attempt is made to investigate textural and multispectral drawbacks and benefits of three standard image fusion techniques, IHS, PCA and HPF and the AIF fusion technique. Results are visually and statistically correlated.

To obtain a better overview of these different techniques they are divided into two groups. The first group includes image fusion techniques like IHS, PCA or the HPF. These work purely in the spatial image domain and provide a multispectral image with a higher spatial resolution, by substituting one of the multispectral bands with the panchromatic band. The second group of image fusion techniques is a relatively new one applied to the spatial and spectral image domain. The particular advantage of these techniques is the original spectral band information can be preserved while the higher spatial resolution of a panchromatic image is injected into each multispectral band [2][3][4]. The result is an image that not only can be used to increase visual image interpretation, but also for subsequent numerical processing, such as spectral classification of textural image information. Steinnocher [4], for example, has shown how adaptive filter techniques can be successfully applied to the higher resolution panchromatic image extending local object edge into the lower spatial resolution multispectral image. However, due to the well-reported application of standard image fusion techniques in many remote-sensing studies they are the preferable applied ones. The images chosen for this study are taken from two different remote sensing satellites over the city of Madrid. First, a 5.8-m spatial resolution panchromatic image taken by the IRS-1C satellite, dated from 15-03-97, and second a 20-m resolution multispectral image from the SPOT-4 satellite, dated from 04-04-97 was used.

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2 Methodology

A detailed description of the data fusion techniques applied can be found in [1][4]. The following is a brief explanation of the techniques used here.

2.1 Intensity Hue Saturation Fusion

The IHS fusion technique transforms the three bands - RGB - of a multispectral image into IHS space. Whereby intensity (I) refers to the brightness values, or colour of each image band, hue (H) to the dominant or average wavelength of the light contribution to the image colour and saturation (S) to the purity of colour. Since the intensity layer is similar to the higher spatial resolution layer, I can be replaced by the higher spatial resolution panchromatic image band and re-transformed into an RGB file. In this way, the colour information from the multispectral image is added to the better spatial resolution image, providing a synthesised image.

2.2 Principal Component Analysis Fusion

PCA is a decorrelation fusion technique by which spectral information (often correlated) is transformed to orthogonal principle components (PCs), each of which describes successively less observed image variance. Usually the first PC is replaced by the higher spatial resolution panchromatic image, since it contains similar spectral information. The fused image is created applying the inverse of the transformation.

2.3 High Pass Filter Fusion

The HPF deals with the different image channels applying spatial filtering usually to the high spatial resolution image, emphasising high frequency grey scale features, i.e., features showing rapid changes in grey scales. In this way, textural and structural information becomes apparent in the higher resolution image. This enhanced image is then introduced into the multispectral image by simple addition.

2.4 Adaptive Image Filter Fusion

The need for adaptive image processing arises from the need to create more sophisticated image processing algorithms. It is apparent that for a better processing of the inhomogeneous signals inherent in a meaningful visual scene, a more characteristic image model is required. In the AIF fusion object edges, which are most salient in the higher resolution panchromatic image, are extracted averaging all pixels in a local neighbourhood, which could belong to the same distribution as the central pixel. The two unknown variables, window

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size and variance of the distribution must be empirically estimated. To extend the variables to the multispectral bands a particular modified sigma filter programme is used [4]. This programme aims to inject some local variance related to the textural and structural information analysed from the panchromatic image, preserving local mean and standard deviation values of the multispectral channels. This study has shown that the size of the window is very important for the final quality of the fused image.

3 Data preparation and image fusion

Using the above mentioned image fusion techniques, the panchromatic image (IRS-1D, 5.8 m) and the multispectral image (SPOT XS, 20 m), were fused. Prior to the fusion process, images were geometrically aligned to the UTM WGS84 coordinate system. For the IHS and PCA fusion, the images were resampled to the same output cell size of 5-m. A low pass filter was applied in order to reduce the effect of blockiness in the multispectral image. For the HPF fusion, first a fusion appropriate filter kernel of 3x3 window size was defined and applied for filtering textural and structural detail in the high-resolution image. Filters larger than this have considerably distorted detailed image information and therefore were not used.

Image pre-processing for the AIF fusion differed from the other methods through the use of the modified sigma filter. As before, both images were first resampled to the same output cell size. However, instead of resampling the lower resolution image with a convolution filter the image was resampled using the nearest neighbour method. The effect of blockiness was eliminated later during the fusion process using the estimated variance. Based on the empirical analysis of the higher resolution panchromatic image, a local average and a local standard deviation image are computed using an appropriate window size. The minimum window size is determined by the ratio between the higher and the lower spatial resolution image. Finally, a normalised standard deviation image is computed, dividing the standard deviation image by the local average image. It also has to be noted that when dividing standard deviation values by mean values the resulting value range is very small (<1). Therefore, a single float image is used as the output file, which represents values in a continuous range. The mode value of the normalised standard deviation image is the estimated variance for each multispectral band. This variance is applied using the sigma programme. For each band fusion, the sigma filtered panchromatic image and one multispectral band become the input images. The variance used in this study was 0.014 and the window size 9x9. Following this process the output multispectral bands are merged to a 3-band RGB image. Multispectral image information changes very little, since no spectral information from the panchromatic image is transferred.

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4 Results and evaluation [5]

As already mentioned, each fusion technique results in a different image. For a primary visual inspection and assessment of the different fusion results, the fused images were displayed with the corresponding panchromatic and multispectral image in Figures 1 (A), (B), (C), (D), (E) and (F).

For the IHS fusion (C) and the PCA fusion (D), both image fusions show very good results for enhanced structural and textural information. Examining these images and comparing them to the panchromatic image (B) and the multispectral image (A), we can say that fusion has significantly increased visual interpretability, but they both have lost spectral information. For the HPF fusion (E) preservation of textural detail in the urban areas is extended at the expense of losing spectral information. Compared to the two previous used fusion techniques, an increase in feature delineation is visible. For the AIF fusion (F), window sizes ranging from 3x3 up to 15x15 were used. An initial experimental observation is that small window sizes extend less textural and structural information into the output bands, but preserve very well the multispectral information. The reason for less detail is that a small window size is not able to calculate sufficient local averages. Instead, a compromise is needed based on the further use of the fused image. If a detailed image is needed a window size larger than 9x9 achieves good results. If the multispectral information is more important, then a window size of 9x9 is a good compromise. However, in the bright area, in the upper half of the image, it is possible to observe the introduction of structural and textural information. Moreover we can see that the fused image preserves multispectral fidelity. The relatively low effect of enhances detail can be thought of as a result of a poor geometrical alignment of the two images. An effect that was less visible for the standard image fusion techniques. This could probably be harmonised by applying an ortho rectification to the original images.

For the visual analysis of the different image fusions it can be concluded that the fused images had improved visual interpretation compared to the original SPOT multispectral image. The IHS and the PCA fusion techniques achieved similar results. Textural and structural information were well transformed into the multispectral image. The AIF fusion provides more detail compared to the original multispectral image, but less compared to any of the other fusions. It best preserves the original multispectral colours. The HPF adds textural and structural detail but significantly disturbs the original multispectral values. However, due to the limits of human colour perception this type of visual assessment does not withstand standard image quantification. More statistical methods are needed that can be empirically applied in order to apply a quantitative comparison of the fused images.

For this study a method was applied [2] showing the statistical differences, standard deviation and local mean, between the original and fused images. Also, the correlation coefficients for each fused image were calculated and compared

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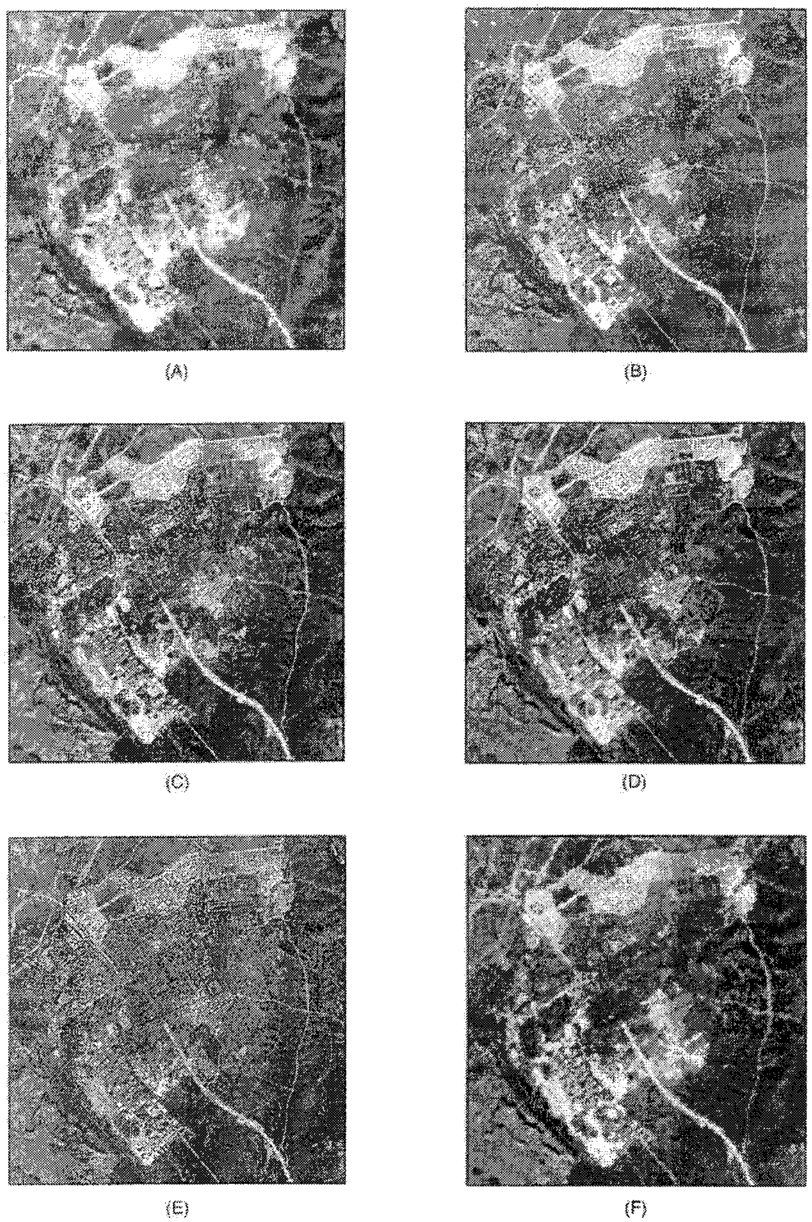

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Figure 1: Input SPOT multispectral image (A) and IRS-1C panchromatic image (B) and the resulting fused images: (C) IHS, (D) PCA, (E) HPF and (F) AIF.

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with the original values. Therefore, equal area subsets were created and the image bands had to be degraded to the original multispectral image cell size of 20 m. Table 1 represents the statistical differences. Column three represents the original multispectral image values as a threshold for the following columns for the fused images.

Table 1. Statistics of image differences.

Image Bands	Parameters	MS	IHS	PCA	HPF	AIF
SPOT Band 1-Blue	Stdv.	97.21	125.28	121.37	124.02	97.19
	Mean	27.70	29.66	30.18	42.32	27.65
SPOT Band 2-Green	Stdv.	75.84	98.78	96.12	100.04	75.87
	Mean	27.66	33.13	29.88	45.46	27.62
SPOT Band 3-Red	Stdv.	108.88	139.67	137.52	137.43	108.85
	Mean	28.81	24.96	24.52	40.49	28.76

The ideal result in this comparison would be that the discrepancies between the parameters, expressed in percentages, should be 0%. Relative to the original multispectral image (MS), the standard deviation for band 1 in the IHS fusion has gained 28%, the PCA fused image has gained 20% and the HPF fused image has gained 22%. The AIF fused image has changed only very little. The original multispectral information has been preserved by 99.97%. Similarly, the mean has also increased, by 7% for the IHS fusion and 8% for the PCA fusion. With 52% distortion, the poorest result was achieved with the HPF fusion. Again, the AIF fusion acquires 99.82%, a very good result. Proportional to the original parameters, these discrepancies are valid also for band 2 and band 3.

Table 2 contains the calculated correlation coefficients between the original multispectral bands and each of the different fused bands. For the calculation of a representative fraction, forty image pixels were measured and analysed. Assuming that the original measured multispectral values have the value one, we can suggest that the value that deviates least from one have best preserved the original multispectral values. Throughout the three bands, the AIF fused bands achieved the best results with values in the middle 0.9. However, the blue and the green band of the IHS and the PCA fusion achieved high correlation values in the lower and middle 0.9. In contrast, the HPF fusion achieved low correlation with values at the high 0.7 and the middle 0.8. The problem of reconstructing the red band in all the standard image fusion techniques is apparent and, of course, has an overall effect of the resulting RGB composition.

Table 2. Correlation coefficients

Image Bands	IHS	PCA	HPF	AIF
SPOT Band 1-Blue	0.8927	0.9137	0.7893	0.9431
SPOT Band 2-Green	0.9408	0.9304	0.8644	0.9586
SPOT Band 3-Red	0.8566	0.8998	0.8086	0.9898

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5 Conclusion

In this study, three standard and one new filter fusion techniques were assessed for their use in image interpretation tasks. From this assessment it can be said that the IHS and PCA fusion achieved a similar good result by creating an image that adds the higher spatial resolution of a panchromatic image while preserving the multispectral image information in an acceptable manner. However, if fused images are used for subsequent image classification, then the IHS and the PCA image fusions may not provide sufficient multispectral information to differentiate textural and structural detail. Instead, the AIF fusion should preferably be used, preserving well the multispectral information while adding some textural and structural detail. The AIF fusion also is flexible since the contribution of the spatial and spectral image information can be tailored using different window sizes.

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