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Adaptive fusion of ETM+ Landsat imagery in the Fourier domain

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RESUMEN

Se propone una nueva metodología para la fusión de imágenes multiespectrales, basada en el filtrado adaptado de las imágenes fuente, en el dominio de Fourier. Para esto, se han sintonizado filtros tipo FIR (Finite-duration Impulse Response) que extraen la información de alta y baja frecuencia contenida en una imagen de alta resolución espacial (*PAN*) y otra de baja resolución espacial (*MULTI*), respectivamente. Se ha establecido un criterio objetivo, que depende solamente de las imágenes fuente, para determinar el orden y la frecuencia de corte de los filtro de tipo FIR. El método propuesto ha sido evaluado para imágenes ETM+, y los resultados comparados con los métodos de fusión de imágenes Wavelet e IHS. De los resultados obtenidos se puede concluir que las imágenes fusionadas por el método propuesto se caracterizan por tener una alta calidad espacial y espectral.

PALABRAS CLAVE: entropía, filtros FIR, Transformada de Fourier, fusión de imágenes, potencia de una imagen.

ABSTRACT

This work proposes a new methodology for fusing multispectral images, based on the a tailored filtering in the Fourier domain. FIR (Finite-duration Impulse Response) filters have been designed to fuse the high and low frequencies information contained in a high spatial resolution image (*PAN*) and in a multispectral image (*MULTI*), respectively. An objective criterion, which depends only on source images characteristics, has been established for determining the order and the cut-off frequency of the FIR filters. The proposed method has been tested with ETM+ images, and its performances have been compared with those of Wavelet and IHS. From obtained results, it can be concluded, that the fused images by the proposed method are characterized by a high spatial and spectral quality.

KEY WORDS: entropy, FIR filters, Fourier Transform, image fusion, image power.

INTRODUCCIÓN

The remote sensing field has a constant development concerning new products and techniques offered in the market. The increasing number of applications where the classification quality should be improved, presents two possible solutions. First, the development of new sensors that detect better quality imagery, providing high spectral and spatial resolutions; and second, the investigation of new techniques that improve the quality of images supplied by sensors operating currently. The main advantage of this last solution is that it makes the information more affordable to the users.

In the remote sensing field, the image fusion techniques attempt this last goal, combining information from images with low spatial and high spectral resolutions and information from images with high spatial and low spectral resolutions.

There is a wide variety of these techniques described in the literature that approach this problem, some of them are: IHS (Intensity, Hue, Saturation), Principal Components Analysis (PCA), Wavelet decomposition (Pohl 1999, Pohl 2000, Chavez 1991, Nuñez et al. 1999).

Another image fusion technique is the fusion through filters applied in Fourier's domain

(Ghassemian 2001). The fusion procedure is formally stated in equation (1):

$$FUS = DFT^{-1}\{LPF\{DFT(MULTI)\} + HPF\{DFT(PAN)\}\} \quad (1)$$

Where *DFT* represents the Discrete Fourier Transform, *LPF* a low pass filter and *HPF* a high pass filter; and *FUS* corresponds to the fused image.

The basic idea of the technique modelled according to the equation (1), is that the low frequency information contained in a *MULTI* image will provide the necessary information to generate the background of a final fused image, while the high frequency information contained in the *PAN* image will provide information about its details. In this way, it is possible to obtain a multispectral image that integrates the best features of the two source images. This technique presents two principal problems: false edges in the fused images and spectral degradation. Both problems have the same origin: the cut-off frequencies of the filters are determined independently of the spatial quality and the spectral one desired for the fused image, with respect to the information provided by the source images . It can be expected that the application of a criterion of maximum quality would allow avoiding, or at least, minimizing these pernicious effects. In this sense. The main goal of this work is to propose an objective criterion for FIR filters design used in the image fusion process (Proakis and Manolakis 1995), applied to panchromatic (*PAN*) and multispectral (*MULTI*) images. The parameters of the FIR filters, the order (*M*) and the cut-off frequency (w_c), will be determined through the power and the entropy of the source images.

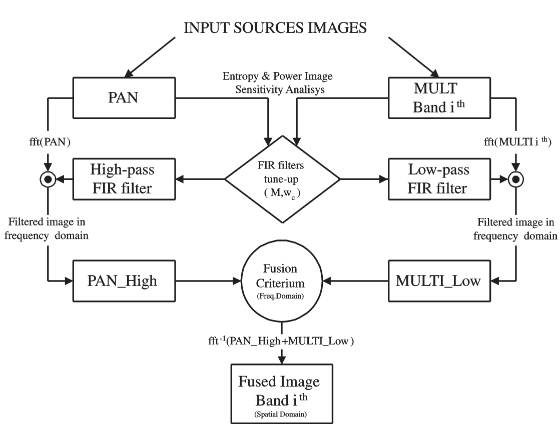


Figura 1. Sinopsys

FUSION METHOD

The aim of the fusion method proposed in this work is to avoid the disadvantages, already mentioned, of a previous fusion method based on the filtering in the Fourier domain (eq. 1). In this sense, here it is proposed an objective criterion to determine the FIR filters parameters: the order of the filter (*M*) and the cut-off frequency (w_c). This criterion depends exclusively on the source images characteristics.

Figure 1 shows a schematic diagram of the proposed fusion methodology. Initially the multispectral image must be resized to the panchromatic image size by an interpolation method. Both images must be radiometrically corrected and spatially referenced (Price, 1999). In order to perform the fusion of the images in the Fourier domain, the *DFT* of source images should be carried out. A critical aspect that guarantees the good spatial and spectral quality of the fused images is the quality and quantity of the information provided by each one of the filtered images.

An analysis of the power sensitivity of the source images, with respect to the variation of w_c, has been carried out to determine the parameter *M*. For that, a different filtered image has been obtained for each pair of values (*M*, w_c) and its power calculated. Low pass filters are applied to all spectral bands of *MULTI* and high pass filters to *PAN*.

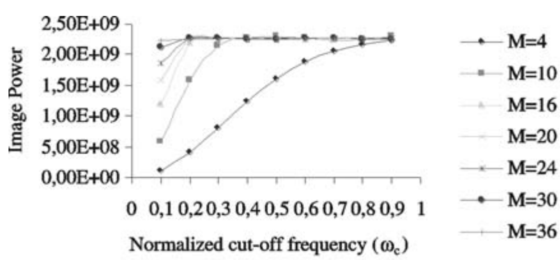


Figure 2. Sensitivity analysis for determining the low pass filter order

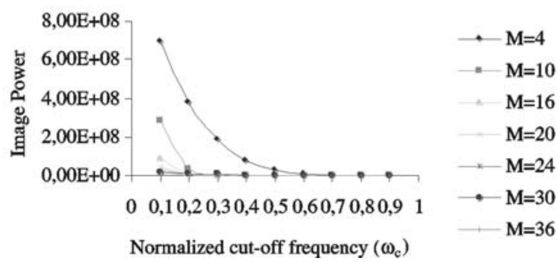


Figure 3. Sensitivity analysis for determining the high pass filter order

Figures 2 and 3 show the sensitivity curves (Image Power vs. w_c) obtained for the i^{th} spectral band of a particular *MULTI* scene and the corresponding panchromatic scene. It can be observed in these figures, that for both cases, sensitivity increases as *M* diminishes. In this sense a value of *M*=4, will be used to filters design.

Once the parameter (*M*) has been specified, the cut-off frequency, w_c, of the FIR filters must be determined. For that, it has been analysed how the amount of filtered image information varies with the cut-off frequency of the used filter. In this work, the amount of information that every source image gives to the fused image has been evaluated through the corresponding entropies, according to equation (2) (Price, 1987):

$$H = -\sum_{j=0}^{DN_{max}} p_j \log_2 p_j \qquad (2)$$

Where the p_j represents the probability of the digital numbers (DN) in the image.

Figure 4 shows a set of sensitivity curves, where the entropy of the *MULTI* (ETM1, ETM2, ETM3, ETM4, ETM5 and ETM7) and *PAN* (ETM8) filtered images has been obtained for different values of w_c, and *M*= 4.

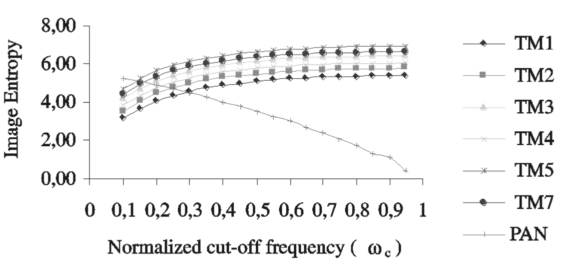


Figure 4. Sensitivity analysis for determining ω_c

The intersection points of the curves in figure 4 give a value of w_c for each spectral band, which assures that both source images contribute with the same amount of information to the fused image.

In order to continue the process of images fusion, a high pass filter for the *PAN* image, and a low pass filter for each one of the spectral bands implied in the fusion process, for the *MULTI* image, should be implemented with the parameters specified by the method described above (Figures 3 and 4). Applying these filters to the *DFT* of the *PAN* and of the *MULTI*, filtered *PAN* (*PAN_High*) and *MULTI* ($MULTI\_Low_i$) images are obtained in the Fourier domain.

The image fused is obtained in the frequencies domain by summing up both the real and the complex part of the *MULTI_Low* and *PAN_High* images according to equation (1). An inverse *DFT* gives the final fused image in the spatial domain.

RESULTS

The data used for the evaluation of the proposed method were two 4.5km x 4.5km scenes located in Madrid, Spain. The images *MULTI* and *PAN* were collected by the sensor ETM+ (Landsat 7) on 20th August, 1999. The ETM1, ETM2, ETM3, ETM4, ETM5 and ETM7 bands of the Thematic Mapper ETM+ sensor, with a common 30m spatial resolution, were fused with the Panchromatic (ETM8) image, with a 15m spatial resolution, obtaining a new multiespectral image distinguished by a high spatial (15m) and spectral (6 bands) quality.

The evaluation of both spatial and spectral quality of the fused images has been carried out by means of a visual evaluation and the ERGAS index calculation (Wald. 2000). The results have been compared with other fusion methods (IHS and Wavelet).

The order of the filters, *M*, and the cut-off frequency value, w_c expressed as normalised frequency, required to implement the high and low pass filters, have been calculated for the scene used in this work by ther method described in the last section. Their values are summarized at Table 1.

	TM1	TM2	TM3	TM4	TM5	TM7
M	4	4	4	4	4	4
ω_C	0.30	0.25	0.18	0.22	0.14	0.16

Table 1. Values of *M* and ω_c for designing the FIR filters

Figure 5 shows RGB colour compositions (R=ETM3, G=ETM2 and B=ETM1) of the *MULTI* image (Figure 5(a)), and the fused images by the proposed methodology (Figure 5(b)) and by the IHS (Figure 5(c)) and Wavelet (Figure 5(d)) methods.

A visual analysis of Figure 5 shows that images fusion carried out by the Wavelet and the proposed method present a clear improvement in the spatial resolution and preserve the RGB composition colours of the *MULTI* image. In other words, the spectral degradation is visually negligible. Moreover, it can be observed at Figure 4 that the IHS method provides a high spatial quality, but a poor spectral quality.

The ERGAS index has been extensively used to quantify the spectral quality of the different fused images. This index was defined by Wald (2000), according to equation (3).

$$ERGAS = 100\frac{h}{l}\sqrt{\frac{1}{N}\sum_{i=1}^{n}\left[\frac{RMSE^2(B_i)}{M_i^2}\right]} \quad (3)$$

Where h and l represent the spatial resolution of the PAN and MULTI images, respectively; M_i is the average radiance of the i^{th} spectral band (B_i); and $RMSE^2$ is defined as:

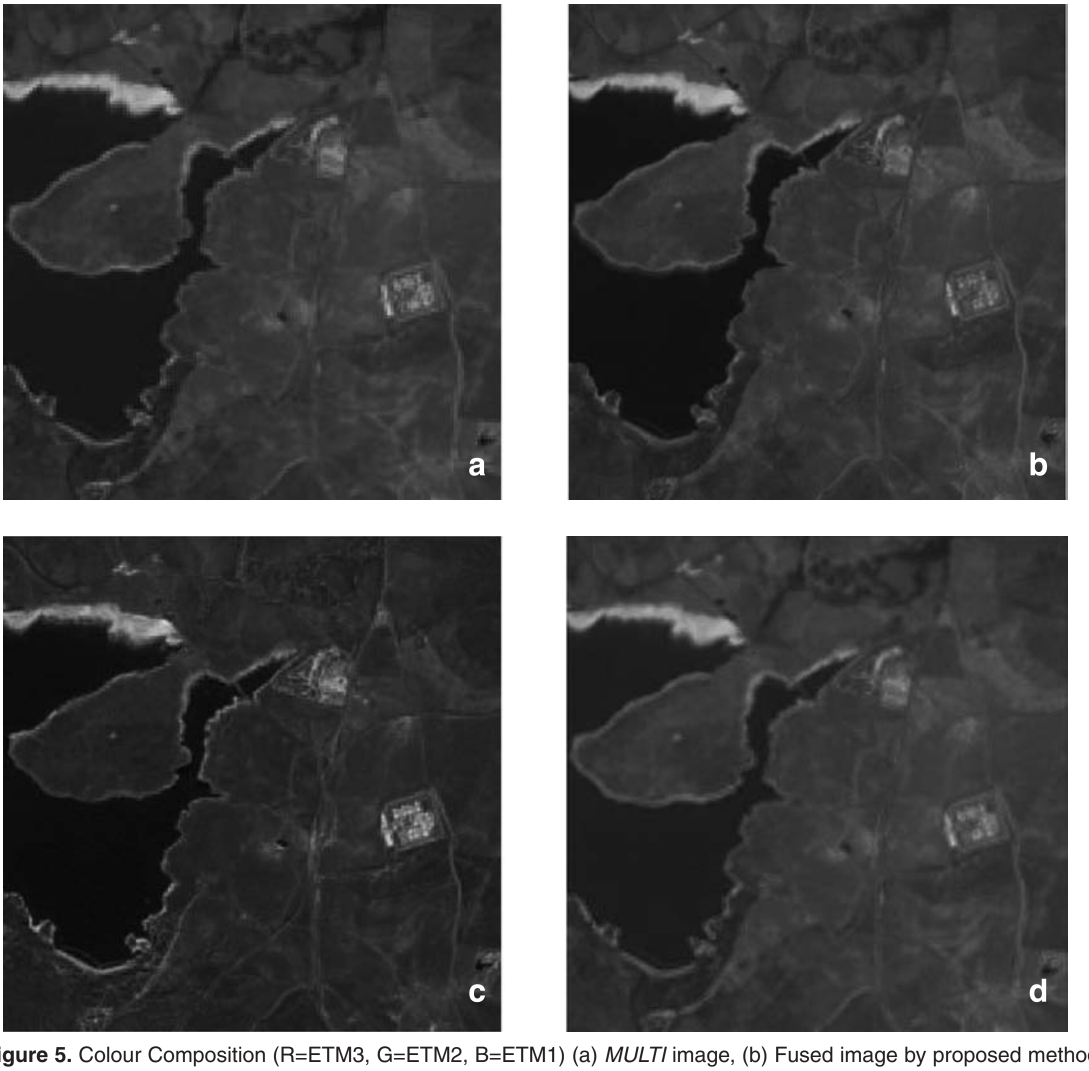
$$RMSE^2(B_i) = \left(M_i^{Original} - M_i^{Fused}\right)^2 + \left(\sigma_i^{Original-Fused}\right)^2,$$

being $\sigma_i^{Original-Fused}$ the standard deviation of the difference between the original image and the fused one. From equation (3), it is obvious that a high global spectral quality of the fused image corresponds to a small value of ERGAS index.

Table 2 summarizes the index values calculated for the six bands of the fused image. The low ERGAS value given by the proposed method, evidence the high spectral quality of the images fused by it.

Methods	IHS	Wavelet	Proposed Method
ERGAS	14.72	4.18	1.69

Table 2. ERGAS index



*** Figure 5.** Colour Composition (R=ETM3, G=ETM2, B=ETM1) (a) *MULTI* image, (b) Fused image by proposed method, (c) Fused image by IHS, (d) Fused image by Wavelet.

Todas las figuras precedidas de asterisco se incluyen en el cuadernillo anexo de color

CONCLUSIONS

In this work, a new methodology for fusing multispectral images, based on tailored filtering in the Fourier domain, has been proposed. An objective criterion, which depends only on the source images characteristics, has been established for designing the FIR filters. From obtained results, it can be concluded, that the fused images by the proposed method are characterized by a high spatial and spectral quality.

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