

# MULTISCALE FOURIER DOMAIN FUSION TECHNIQUE FOR REMOTELY SENSED SPOT IMAGES

I. Papila\*, Z. D. Uca Avci, M. Karaman, E. Ozelkan, Sedef Kent

Istanbul Technical University, Center for Satellite Communications and Remote Sensing, Maslak, Istanbul Turkey.  
(papila,damla, muhittin, emre)@cscrs.itu.edu.tr

**Abstract** - In this study we examine the use of Multiscale Fourier Transforms (MFT) on the effect of image fusion and segmentation. The proposed method takes SPOT-PAN and SPOT-XS images to register using MFT technique to produce high quality fused image. The algorithm works iteratively from coarsest level of decomposition to the top level. This process applied to the all sub-bands in order to give best choice of transformation. For selecting the fourier coefficients either SPOT-XS band coefficients are replaced by the SPOT-PAN coefficients considering the subband coefficients. After selecting the new fused fourier coefficients, an inverse fourier transform is done to construct the fused image. The technique is first compared respect to the spectral quality assesment with the conventional image fusion techniques such as HSV and Brovey Fusion results. To evaluate the fusion results both visual inspection and segmentation results are used for quality and the degree of similarity with the original image.

**Keywords:** Real Discrete Fourier Transform, multiscale, fusion, Brovey, HSV, SPOT-5.

## 1. INTRODUCTION

Similar to wavelet transform, we build a hierarchical tree model (H. Choi 2001) using multirate real discrete Fourier transform (RDFT) functions. Simply high pass and low pass filters are used to detect singularities and local features so that an object can be easily recognized. The multiscale structure of the transform construct time frequency features at various scales which will be used during fusion process.

In this paper Fourier domain fusion algorithm is proposed for SPOT-5 data. High frequency coefficients of the multispectral band's data are replaced with the panchromatic data's high frequency coefficients at the same scale. To evaluate the Fourier Domain image fusion technique results are compared with HSV and Brovey fusion results either with visually or the segmentation performance of the techniques.

## 2. METHODOLOGY

### 2.1 Multiscale Fourier Transform (MFT)

As explained previously on O. Ersoy 1994 and O Ersoy 1997; Suppose a signal  $x(n)$  is a low pass (LP) and high pass (HP) filtered by using Discrete Fourier Transform (DFT). Zero-phase filtering can be written as follows:

Let  $F$  be the DFT matrix,  $H_L$  and  $H_H$  are low pass and high pass transfer function matrices.

$$x_{LP} = F^{-1} H_L F x \quad x_{HP} = F^{-1} H_H F x$$

$$x_{LP} + x_{HP} = F^{-1} (H_L + H_H) F x = x$$

$$\text{if } H_L + H_H = I \quad x_{HP} = x - x_{LP}$$

In practice,  $x_{LP}$  and  $x_{HP}$  are decimated to  $x'_{LP}$  and  $x'_{HP}$  using decimation by 2 ( $\downarrow 2$ ) to recover  $x$ ,  $x'_{LP}$  and  $x'_{HP}$  must be interpolated back to  $x_{LP}$  and  $x_{HP}$

Low-Pass Filtering and Decimation

DFT of  $x(n)$  is

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-j2\pi nk/N}$$

$x_{LP}(n)$  has DFT given by

$$X_{LP}(k) = X(k) \text{ for } k \in [0, K-1] \text{ and } [N-K+1, N-1]$$

$$X_{LP}(k) = 0 \quad \text{else} \quad , \text{ where } K \text{ is } N/4.$$

$$X_{LP}(k) = \frac{1}{N} \sum_{k=0}^{N-1} X_{LP}(k) e^{j2\pi nk/N}$$

Decimated signal  $X'_{LP}$

$$X'_{LP}(n) = X_{LP}(2n) = \frac{1}{N} \sum_{k=0}^{N-1} X_{LP}(k) e^{j2\pi nk/N/2}$$

$x_{HP}(n)$  has DFT given by

$$X_{HP}(k) = X(k) \quad \text{where } K < k < N-K \quad \text{for } K = n/4$$

$$X_{HP}(k) = 0 \quad \text{else}$$

$$X_{HP}(n) = \frac{1}{N} \sum_{k=0}^{N-1} X_{HP}(k) e^{j2\pi nk/N}$$

Decimated signal  $X'_{HP}$

$$X'_{HP}(n) = x_{HP}(2n) = \frac{1}{N} \sum_{k=0}^{N-1} X_{HP}(k) e^{j2\pi nk/N/2}$$

### 2.2 MFT Algorithm

$X \rightarrow \text{FFT} \rightarrow \text{LP} \rightarrow \text{IFFT} \rightarrow \text{decimate by } 2 \rightarrow X_{LPdec}$  (store  $X_{imag}(N/4+1)$ )

Reconstruction Step for 1-D Low Pass Filtering:

$X_{LPdec} + X_{imag}(N/4+1) \rightarrow \text{FFT} \rightarrow \text{zero-filling} \rightarrow \text{IFFT} \rightarrow X_{reconlow}$

Similarly decomposition Step for 1-D High Pass (HP) Filtering can be showed as:

\*corresponding author

$X \rightarrow \text{FFT} \rightarrow \text{HP} \rightarrow \text{IFFT} \rightarrow \text{decimate by 2} \rightarrow \text{Xhpdec}$  (store  $\text{Ximag}(N/4+1)$ )

Reconstruction Step for 1-D High Pass Filtering:

$\text{Xhpdec} + \text{Ximag}(N/4+1) \rightarrow \text{FFT} \rightarrow \text{zero-filling} \rightarrow \text{IFFT} \rightarrow \text{Xreconhigh}$

For Reconstruction, imaginary value of  $X(N/4+1)$  at the Fourier Domain should be stored. For 2-D signal procedure would be the same by taking the each row as 1-D signal and after performing the algorithm on each row transpose the filtered image and continue filtering for each row again. In this case the imaginary values that are going to be used at reconstruction step should be stored separately for x scale and y scale.

### 2.3 Fusion Algorithm

We perform the multiscale structure on each multispectral SPOT-5 bands. Then we compare each multispectral band's high frequency coefficients with the panchromatic band's fourier coefficients at the same resolution.

High frequency coefficient is chosen according to the corresponding subband's (HL, LH, LL) coefficient values. The one who has relatively bigger values in all subbands is used as the new high frequency coefficient. Then the fused image is reconstructed by using the new high frequency coefficients.

### 2.4 Data Used

To evaluate the performance of the MFT algorithm, SPOT-5 data of the Istanbul Bosphorus image is used. Multispectral SPOT-5 image has 10 m. spatial resolution with 4 bands as processed at level 2A. On the other hand Panchromatic SPOT-5 image has 5 m. spatial resolution and both retrieved on October 2nd 2009



Figure 1. SPOT-5 Multispectral (213 bands are used) and Panchromatic data

Table A. Spectral Properties of SPOT-5 Data

Band Number	Spectral Region
Band 1	0.50 - 0.59 $\mu\text{m}$
Band 2	0.61 - 0.68 $\mu\text{m}$
Band 3	0.78 - 0.89 $\mu\text{m}$
Band 4	1.58 - 1.75 $\mu\text{m}$
Panchromatic	0.48 - 0.71 $\mu\text{m}$

As it is known that the band-4 of the SPOT-5 multispectral data wouldn't give extra information more than band-3 on urban areas and since the segmentation will be performed on the urban

areas, this leads us just to focus on the band 1, 2 and 3 of the multispectral data. So at the end we will have the same image structure to compare with Brovey and HSV fusion results in where both methods also use three bands in the fusion process.

## 3. APPLICATION

Fused image reconstructed by using FMT algorithm is firstly compared with the HSV Sharpening Method and then compared with Brovey Method's fused image.



Figure 2. MFT result using bands 213 combination

### 3.1 HSV Sharpening

A RGB image is transformed into HSV color space, by replacing the value band with the high resolution image, re-sampling the hue and saturation bands to the high-resolution pixel size using a nearest neighbor, bilinear, or cubic convolution technique, and finally transforming the image back to RGB color space. The output RGB images have the pixel size of the input high-resolution data. For re-sampling nearest neighborhood method is used.



Figure 3. HSV fusion result in 213 band combination.

### 3.2 Color Normalized (Brovey) Sharpening

It is a sharpening technique that uses a mathematical combination of the color image and high resolution data. Each

band in the RGB image is multiplied by a ratio of the high resolution data divided by the sum of the color bands. Three color bands are re-sampled to the high-resolution pixel size. The output RGB images will have the pixel size of the input high-resolution data. Similar to HSV nearest neighborhood method is used for re-sampling. (J. Vrabel 1996)



Figure 4. Brovey fusion result in 213 band combination.

### 3.3 Multiresolution Segmentation

In this study, multiresolution segmentation which is a new, patented technique offered by Definiens Software was used for image object extraction test. Segmentation process is the division of whole image into separate image parts according to a homogeneity criterion, which is controlled by color / shape and smoothness / compactness criterion. Color / Shape Criterion parameter controls the color vs. shape homogeneity during object creation. When shape criterion is high weighted, less spectral homogeneity influences the object generation. The smoothness and compactness factor weights are decided to optimize image objects for smoother borders and compact objects, respectively, which at total will sum up to 1. (eCognition User Guide 4)

## 4. RESULTS

### 4.1 Visual Results

Since the algorithm focused on the high frequency components of the Fourier transform, it is expected that the algorithm will have better performance among the regions where the image has edges. On the other hand since the high frequencies are more sensitive to the edges it is possible to expect poor results at the smooth areas.

As it is shown on the Figure 5 HSV has better contrast than the MFT algorithm on the smooth areas where it is all vegetated areas. HSV image gives clear image at the smooth areas where as the MFT fusion result has some blurred effect over the smooth areas.



Figure 5. MFT vs. HSV fusion results



Figure 6. MFT vs. Brovey fusion results

As it is shown on Figure 6 MFT fused image has a better sharpened coastline but the sea image is smoother at the Brovey image. Since MFT is sensitive to the high frequencies it has white shadows on the seaside. In sense of visual inspection again Brovey has better performance at smooth areas.

### 4.2 Segmentation Results

Main purpose of this study is to show the performance of the MFT algorithm on the segmentation of urban areas.

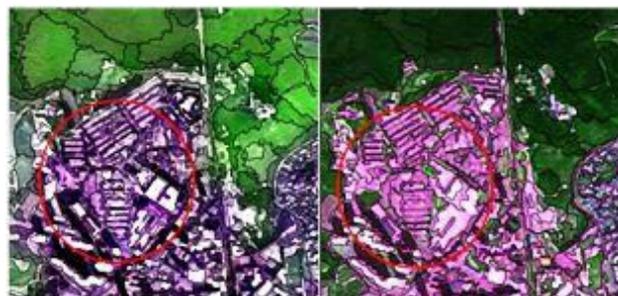


Figure 7. MFT vs. HSV segmentation result

Segmentation parameters that are used during the MFT vs. Brovey comparison: Scale Parameter sets to 45, Color sets to 0.8, Shape sets to 0.2, Compactness sets to 0.5 and Smoothness sets to 0.5 for both. Both algorithms detect the buildings but at the MFT algorithm's result buildings are easily separated from each other where the HSV shows those buildings as a single compact structure.



**Figure 8.** MFT vs. Brovey segmentation result

Segmentation parameters that are used during the MFT vs Brovey comparison: Scale Parameter sets to 25, Color sets to 0.8, Shape sets to 0.2, Compactness sets to 0.5 and Smoothness sets to 0.5 for both. As it is shown at Figure 8 at the lower left of the image MFT successfully detect and separated the buildings where the Brovey segmentation result hardly detects the structure.

It is so obvious that MFT has better segmentation results comparing with both Brovey and HSV fused data. The buildings are more distinguishable at the MFT fusion result and the edges have sharp visualization and have better contrast.

## 5. CONCLUSION

MFT algorithm has significantly better results for segmentation application. It is an expected result since we focused on the high frequency components of the Fourier coefficients. But it is also possible to choose suitable coefficients that can achieve to give better results at the smooth regions of the image. Different criteria can be used as it was mentioned in A. Das 2007 paper: maximizing the mutual information which maximize the marginal entropies of separate images and minimize the entropy of the joint image would lead to a better fusion results. New classifiers as mentioned on both (S. Li 2004) and (S Zheng 2008) papers that; support vector machines can be used while choosing the most valuable Fourier coefficient for the fused image would also improve the fused image performance.

## REFERENCES

- Choi H, Baraniuk RG 2001 Multiscale image segmentation using wavelet-domain hidden Markov models IEEE Transaction on Image Processing 10 (9): 1309-1321 SEP
- Ersoy O., 1994 "A Comparative Review of Real and Complex Fourier-Related Transforms" Proc. IEEE vol. 82 no 3 march
- Ersoy O., 1997 "Fourier-Related Transforms, Fast Algorithms and Applications" Prentice Hall PTR
- Vrabel, Jim, 1996, Multispectral Imagery Band Sharpening Study, Photogrammetric Engineering & Remote Sensing, Vol. 62, No. 9, pp. 1075-1083.
- Das, A and K. Revath,, 2007. Image Fusion Technique for Remote Sensed SPOT Images, International Conference on Computational Intelligence and Multimedia Applications.
- Li S., Kwok J., Tsang I. and Wang Y, Fusing, 2004. Fusing Images with Different Focuses Using Support Vector Machines, IEEE Transactions on Neural Networks Vol.15 No 6. November

Zheng S., Shi W., Liu J. and Tian J. 2008. Remote Sensing Image Fusion Using Multiscale Mapped LS-SVM, IEEE Transactions on Geoscience and remote Sensing Vol 46 No 5 May  
eCognition User Guide 4, Definies Imaging

## ACKNOWLEDGEMENTS

Authors would like to thank to ITU CSCRS and SPOT Image for supplying SPOT-5 Multispectral and Panchromatic data.