PANSHARPENING OF VHR IMAGES USING WAVELET BASED METHODS

Alper Akoguz, Melih Hayirsever, Sedef Kent Pinar and Serhat Seker

Faculty of Electrical and Electronic Engineering, Istanbul Technical University, Istanbul, Turkey; alper.akoguz@itu.edu.tr

ABSTRACT

Researches on Earth resources using satellite images start with launch of LANDSAT-1 which is the first Earth observation satellite. Many remote sensing satellites had launched with technological developments after LANDSAT-1 satellite has been launched. In spite of the fact that, sensors, which lie inside the satellite, have been improved in time, they are developed in two types due to physical and technological limits. One type gives high spatial resolution images, while other gives high spectral resolution images. Because of that, two types of images which are Panchromatic image having high spatial and low spectral resolutions and Multispectral image having low spatial and high spectral resolution can be supplied from optical remote sensing satellites. It is possible to have an image that has both high spatial and high spectral resolutions by means of using Satellite Image Fusion methods which aim to combine Panchromatic and Multispectral images. Image fusion methods examined in this project is mainly based on Multiresolution Analysis which is also known as Wavelets. Wavelet based pansharpening methods are examined on PLÉIADES 1A co-registered VHR image couple. Wavelet domain methods (which can be categorized as substitution based, addition based and coefficient based) are compared by the fusion quality assessments which have common acceptance in community. Results show that wavelet substitution based method has the best scores.

INTRODUCTION

Since the development of the satellite technology, mankind has a desire to get the information about Earth. In order to provide this, communication satellites, meteorological satellites and remote sensing satellites designed and launched by several countries. The first remote sensing satellite, Landsat 1, launched by USA in 1972, which means that Remote Sensing (RS) satellites are used more than 40 years. These systems have the observation of Earth resources either sending polarized radar to the earth and sense it back mechanism (Active sensing [Radar]) or using sunlight as energy source instead of radar (Passive sensing [Optical]) for generating the RS image.

RS satellites provide various types of resolutions, which shall be listed as:

- Spectral,
- Spatial,
- Radiometric,
- Temporal.

These types of resolutions are provided in order to satisfy different needs in related applications (1).

Spectral resolution is expressed as the electromagnetic (EM) wavelength spectrum sensed by a (optical RS satellite) sensor. Determination of spectral resolution quantity (whether high or low) depends on the recorded interval of EM wavelength spectrum within with inverse proportion. Small intervals mean high spectral resolution, while larger intervals mean lower. According to the spectral distribution and number of spectral intervals, these types of images are classified as:

- Multispectral (MS),

- Hyperspectral (HS).

MS satellites have three to six spectral bands from visible & near-infrared region, while HS typically collect 200 or more spectral bands (2).

Contrary, MS satellites also provide single spectral (monochromatic) or broad band (a so called "Panchromatic" [Pan]) image with higher spatial resolution meaning of having sharper details and provide more spatial information. Optical RS satellites (such as Landsat, SPOT, etc.) acquire Pan images (for better spatial resolution) and MS images (for better spectral resolution) as co-registered when observing a specific territory (3).

Satellite Image Fusion is a process of merging co-registered higher spectral resolution image with higher spatial resolution image, in order to obtain a final image that has both high spatial and spectral resolution together (3). In RS field, it can be thought as lower spatial resolution MS image is getting sharpened by co-registered Pan image. By the community, this concept is also known as "Pansharpening" or simply "Pan+MS".

As mentioned above, in 40 years' time, today's new generation RS satellites supply imagery with better spatial and spectral resolutions than their predecessors. However, the tradeoff, between having higher spectral resolution or higher spatial resolution still remains. Hence, the proposed methods, by the community, are always dealing about two main constraints:

- Keeping the spectral info for MS image with minimum spectral distortion,
- Enhancing spatial details with Pan image.

The object of this project is to examine and compare the performance of Multiresolution Analysis (MRA) based Satellite Image Fusion approaches.

IMAGE FUSION MODEL

Data fusion is defined as a process that deals with data and information from various sources to obtain better information for decision making (4). According to Genderen and Pohl, the combination of two or more different images to form a new image by using a certain algorithm is called image fusion (5).

In RS studies, the image fusion (pansharpening) is dealing about the appropriate combination of MS and Pan Images, so image fusion approach for RS, shall be modelled as a summation of low spatial resolution MS image and extracted spatial details that comes from Pan image.

Satellite Image Fusion process can be divided in four main steps:

- Co-registration of MS and Pan images,
- Interpolation of MS image (aim to have row & column same size as Pan),
- Collection of spatial details from Pan image,
- Insertion of the spatial details to MS image.

If the problem is not examined between cross images (Pan image and MS image from different satellites), optical RS satellites provide co-registered Pan-MS couples, acquired simultaneously (3). Hence, the process can be divided to three main steps, where first step can be skipped under this circumstance.

METHODS

Study Area

In this study, French satellite PLÉIADES 1A is used for VHR image couple, based on an agricultural region in Manisa/Turkey (Figure 1) consists of a Panchromatic (PAN) image with 0.5m spatial resolution and a Multispectral (MS) image with four bands (R,G,B and IR) with 2.0m spatial resolution.

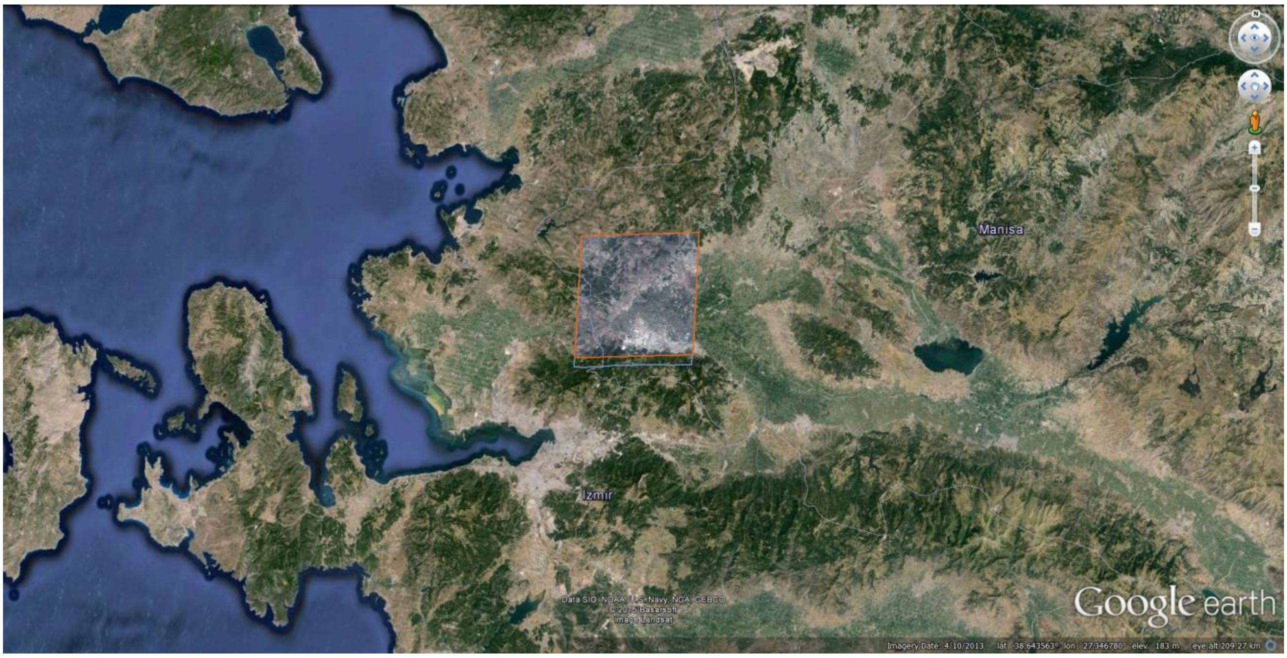

Figure 1: Study region (Manisa/Turkey), which was acquired as co-registered bundle by Pléiades 1A ..

Wavelet decomposition

Multiresolution Analysis (MRA) based on wavelet theory indulges the introduction of the several concepts of details between levels of scale or resolution. Hence, it can be said that a multiresolution decomposition enables to have a scale-invariant interpretation of the image (7). The wavelet transform (WT) provides a framework to decompose images into a number of new images (8). Comparing with the Fourier transform (FT), it can be said that FT deals with the frequency contents in image while WT is an intermediate representation between Fourier and spatial representations, and it can provide good localization in both frequency and space domains (for images two dimensional discrete signal representation leads to have two dimensional space domain for the localization) (6). Continuous Wavelet Transform (CWT) of a one dimensional signal $f(t)$ can be expressed as

$$W(f)(a,b)=|a|^{-\frac{1}{2}}\int_{-\infty}^{+\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt \qquad (1)$$

where a is scaling (reciprocal of the frequency) and b is shifting parameter. Each base function $\psi\left(\frac{t-b}{a}\right)$ is a scaled and shifted version of function ψ, called as *Mother Wavelet*. Supposing if $\psi(t)$ is centered at time zero and have frequency ω_0; $\psi(a^{-1}(t\text{-}b))$ will be centered at time b and have frequency ω_0/a respectively.

Traditionally, CWT is sampled in a dyadic grid, that is to choose $a = 2^{-m}$ and $b = n2^{-m}$ where base functions become

$$\psi_{m,n}(t)=2^{m/2}\psi\left(2^{m}t-n\right) \tag{2}$$

and it is obvious that

$$f(t)=\sum_{m=-\infty}^{+\infty}\sum_{n=-\infty}^{+\infty} d_{m,n}\,\psi_{m,n}(t) \tag{3}$$

where $d_{m,n}$ is the wavelet series coefficients obtained by

$$d_{m,n}=\int f(t)\psi^{*}_{m,n}(t)dt \tag{4}$$

inner production of $f(t)$ and $\psi_{m,n}(t)$.

Wavelet substitution method

In the wavelet merger method, the first wavelet planes of the high-spatial resolution Pan image have spatial information that is not present in MS image. The method involves to wavelet decomposition of these image couples and wavelet planes of MS image are substituted by the planes corresponding to the Pan image as follows (9).

- Co-register the MS image with Pan (if they were acquired simultanously this step can be skipped).
- Interpolate the MS image according to the same size as Pan.
- Perform histogram stretch between Pan image and either,

1. Intensity component (I) of MS image bands,
2. each band of MS image bands,

- Decompose each band of MS image to n wavelet planes.
- Decompose each band of Pan image to n wavelet planes.
- Replace the details from decomposed bands of MS with the corresponding Pan planes.
- Reconstruct the image from the substituted subbands.

Wavelet addition method

In the wavelet additive method, which is represented by Nunes, et al. (10), wavelet decomposition of these image couples are performed and details of MS image are added with details of Pan image, rather than the substitution in previous method.

- Interpolate the MS image according to the same size as Pan,
- Histogram strech the Pan image with either,

1. Intensity component (I) of MS image bands,
2. each band of MS image bands,

- Decompose each band of MS image to n wavelet planes,
- Decompose each band of Pan image to n wavelet planes,
- Add the details from decomposed bands of MS with the corresponding Pan planes,

- Reconstruct the image from the approximation and superposed detail subbands.

Wavelet coefficient method

In the wavelet coefficient method, wavelet decomposition of these image couples are performed and details of Pan Image and original MS image (instead of approximation of upscaled MS) are combined with Inverse Discrete Wavelet Transform. As mentioned previously, histogram stretching can also be applied to Pan Image either by original MS image's Intensity component or each MS band.

RESULTS

Wavelet based Pansharpened images are compared with traditional pansharpening IHS and PCA methods and analysed by common used fusion quality assessments which are SAM (Spectral Angle Mapper), RMSE (Root Mean Square Error), RASE (Relative Average Spectral Error), ERGAS (Erreur Relative Globale Adimensionelle), UIQI (Universal Image Quality Index) and CC (Correlation Coefficients). According to the results, wavelet based methods give better results rather than traditional ones. The most promising wavelet based method is the wavelet substitution based pansharpening method (with band wise histogram stretching) which has the best and second best overall quality scores given in Table 1.

Table 1: Quality assessment results for Pansharpened agricultural region image.

Method	SAM	RMSE	RASE	ERGAS	UIQI	CC
IHS	10.6393	0.0522	4.7859	2.2758	0.6643	0.7640
PCA	8.8718	0.0205	1.9894	0.9773	0.6854	0.6893
DWT Subst.	10.1889	0.0250	2.2996	1.0976	0.7782	0.7978
DWT Subst. (Hist. Strecth-I)	6.6971	0.0170	1.5053	0.6870	0.8809	0.8824
DWT Subst. (Hist. Strecth-B)	6.3818	**0.0169**	**1.4778**	**0.6464**	**0.8967**	0.8974
DWT Add.	7.8509	0.0815	7.1203	3.1339	0.7127	0.8536
DWT Add. (Hist. Strecth-I)	6.4795	0.0793	6.9278	3.0226	0.7775	0.8936
DWT Add. (Hist. Strecth-B)	**6.1768**	0.0791	6.9113	3.0101	0.7883	**0.9035**
DWT Coef.	10.7990	0.0270	2.4543	1.1593	0.7727	0.8026
DWT Coef. (Hist. Strecth-I)	7.6572	0.0198	1.7399	0.7841	0.8644	0.8686
DWT Coef. (Hist. Strecth-B)	7.3443	0.0197	1.7132	0.7479	0.8783	0.8808

CONCLUSIONS

In this study wavelet based pansharpening methods tried to be analyzed and applied to optical VHR multispectral satellite image bundle to obtain fused image in order to have better spectral and spatial resolution at the end.

Several wavelet based methods used with several options and the best case could be determined by fusion quality assessment methods. It can be said that band based histogram stretching has better effect on pansharpening, rather than intensity based.

For future applications, different types of wavelets can be analyzed and for different type of optical satellite images there can be defined the best wavelet methods for related data. Also one can examine the wavelet pansharpening results on different specific cases (forestry, city, etc.).

Post processing on this agriculture case, Pansharpened image shall be used in classification for classification of crop fields, which held upon Turkey's Agricultural Monitoring an Information Systems Project called TARBIL.

In real time applications the images are approximately 1GBs of data, so that parallel processing (on either CPU, or GPU) of these images can be considered as a time constraint problem.

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