Hyper-Spectral/High-Resolution Data fusion: Assessing the Quality of EO1-Hyperion/Spot-Pan & Quickbird-MS Fused Images in Spectral Domain.

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ABSTRACT:

Image fusion is the combination of two or more different images to form a new image by using a certain algorithm (Genderen and Pohl, 1994). Despite the fact that the number and kind of satellite imagery are daily increasing, using fusion techniques, in a proper way, to eliminate the redundancy in data and increasing the quality of them is an important challenge in Remote Sensing Image Processing (RSIP). Data Fusion (DF) techniques can mainly be divided into two specific categories: 1. According to the different processing levels: *Pixel-Based, Feature-Based, and Decision-Based*. 2. According to the domain model: *Spatial-Based, Spectral-Based, and Algebraic-Based.* The object of this study is to examine the quality of fused images in spectral domain models [based on the algorithms have been used in ENVI 4.0.] For this purpose, two different data sets have been examined (EO1-Hyperion\Quickbird-MS and EO1-Hyperion\Spot-Pan). The ability of Principal Component Transform (PCT) and Gram-Schmidt Transformation (GST), as two of the main spectral-based data fusion techniques was examined. The photo interpretive potential and the statistical abilities of them to preserve the spectral quality of fused data, in comparison with original Hyper-spectral image, has been investigated.

1. INTRODUCTION

In the beginning on 21st century we are facing a rapid increase of Geo-Monitoring satellites. Thus the dramatic high amount of Geo-Based satellite images encourages us to get the most efficient methods to process this huge amount of data. Data Fusion can be defined as a set of RSIP techniques for the synergetic use of different datasets for the optimization of the data information potential. The literature of DF shows that an optimal quality for a fused image is defined as having *Minimum Color Distortion* (containing all the spectral property of Multi\Hyper spectral images), *Maximum Spatial Resolution* (containing all the spatial property of high resolution image) and *Maximum Neutrality* (the best integration of spectral and spatial quality of input data). But this ideal situation hardly can be obtained (Zhou, 1998). Based on Vani(2001) and Zhang (2004) getting these optimal results is depending on three necessary conditions for input images as followed:

1. High sophisticated Data Fusion (DF) algorithms.
2. State-of-the-art Remote Sensing Image Processing (RSIP) technology.
3. Simultaneous, fitted to the same range of spectral frequency, optimized Sharpening Factor (SF) and accurate co-registered the set of input data.

The number of DF techniques in RSIP is honestly high but most of them can fall into three classes (Campbell, 2002).

Spectral domain procedures project the multispectral bands into spectral data space, and find the new (transformed) band, that must be closely correlated with the panchromatic image.The spectral content can then be assigned to the high-resolution panchromatic image, e.g. Hue, Intensity, Saturation (HIS), Principal Component Transformation (PCT), Gram Schmidt Transformation (GST). *Spatial domain models* extract the high-frequency variation of a high resolution image and then insert it into the multispectral framework of a corresponding low resolution image, e.g. High-Pass Filter (HPF). *Algebraic Procedures* operate on images at the level of the individual pixel to proportion spectral information among the bands of the multispectral image, so that the replacement (high resolution) image used as a substitute for one of the bands can be assigned correct spectral brightness, e.g. Brovey Transform (BT), Multiplicative Model (MLT). More detailed explanations can be found in (Chavez and Bowell, 1988; Richards, 1999; Schowengerdt, 1997; Ranchin, 2002; Vrabel, 1996 and Samadzadegan, 2002).

The object of this paper is to provide explanations on the pros and cons of two spectral domain image fusion models, Gram-Schmidt Transformation (GST) and Principal Component Transformation (PCT). The core of the idea is the examination of these two algorithms with regard to two different Sharpening Factors (SF).

2. MATERIAL AND METHODS

2.1. Study Area

The study area is located in Central Sulawesi, Indonesia. This area covers approximately 55.31 sq. kilometer and is located between 120° 00´ 51.72´´ – 120º 04´ 16.21´´E longitude and 01° 32´ 18.74´´ – 01° 29´ 08.78´´ S latitude. The land cover in the area is dominated by paddy, perennial crops (cacao), agriculture and forest areas.

2.2. Satellite Imagery

EO-1/Hyperion is the first hyper-spectral satellite in the New Millennium Program and it was launched by NASA on Nov. 21, 2000. Hyperion data can now be acquired from the USGS EROS Data Center. DigitalGlobe's QuickBird was launched on Oct. 18, 2001. A satellite designed to acquire fine-detail imagery collects both multi-spectral and panchromatic imagery. Spot-1 was launched on 1986 and another series of them was launched later. This series of satellite is designed to provide data as a land recourse monitoring vehicle (table. 1; figure1, 2, 3). The images used in this study acquired in three different times as: Hyperion in 5, Jan. 04, Quickbird in 15, Apr. 04 and Spot-Pan in 20, May 03.

Satellite - Sensor	Spatial Resolution (*meter*)	Spectral Range (*nanometer*)	Band Number
EO-1 - hyperion	30	400 - 2500	224
Spot - Panchromatic	10	510 - 730	1
Quickbird - MS	2.4 – 2.8	760-890	4

Table 1: Tabulation of data for used images

Figure 1: Hyperion image

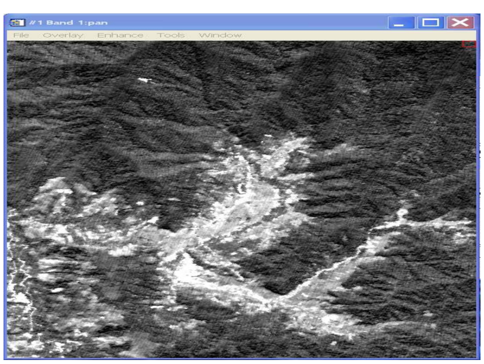

Figure 2: Spot-Pan image

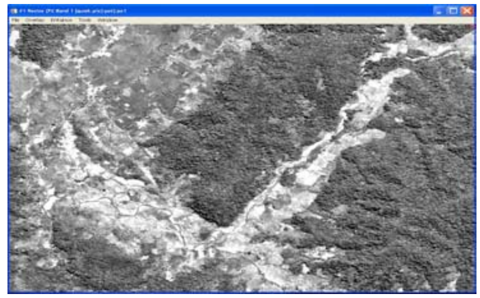
Figure 3: PC1 obtained from Quickbird image

2.3. Algorithms

Multispectral and especially hyperspectral images often show a high correlation between bands. According to Schowengerdt (1997) the correlation between bands mainly depends on three parameters: *Material spectral correlation, Topography, Sensor band overlap.* A plurality of techniques aims at the transformation of a correlated data set into an uncorrelated data set. The main core of these techniques is the protection of useful information during the transformation process. In this study two transformation algorithms used in ENVI 4.0 have been examined.

2.3.1. Gram – Schmidt Transformation (GST)

The GS procedure makes a set of random variables uncorrelated or orthogonal to each other, assuming knowledge of the cross-correlations between them. For instance, with three random variables x_1, x_2 *and* x_3 with known correlations (equation 1)

$$\rho_{ij} = E\left[x_i, x_j\right] ij \in \left[1,2,3\right] \tag{1}$$

We first obtain (equation 2)

$$\begin{bmatrix} v_2^1 \\ v_3^1 \end{bmatrix} = \begin{bmatrix} -q_2^1 & 1 & 0 \\ -q_3^1 & 0 & 1 \end{bmatrix} * \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \tag{2}$$

Where $q_j^1 = \rho_{j1}\rho_{11}, \quad j = 2,3$

This operation produces random variables and v_2^1 and v_3^1

which are orthogonal to x_1 but correlated with x_2 and x_3, respectively. The next step is to find a random variable that is correlated with x_3 but orthogonal to both x_1 and x_2. This is accomplished through defining (equation 3).

$$v_3^2 = v_3^1 - \frac{E\left[v_3^1 v_2^1\right]}{E\left[v_2^1\right]^2} * v_2^1 \qquad (3)$$

The expectations on the right-hand side can be computed from the cross-correlations of the original variables. The variables x_1, v_2^1 and v_3^1 are orthogonal to each other, while spanning the probability space of, x_1, x_2 and x_3 ,and so the task of orthogonalising the inputs is complete. The procedure is easily extended to an arbitrary number of random variables (Gong et al, 2001).

In this method a new Synthetic Low Resolution Panchromatic image (SLRP), using multispectral images, will be incorporated that has a spectral range overlapping with the spectral range of the multispectral image. The SLRP (as the first band), that is combined with the multispectral image, will be transformed using GS transformation. After transformation the Original Low Resolution Panchromatic image (OLRP) will be statistically adopted and substituted with the first band of the transformed data. The new combination will be returned to the new multispectral / high resolution fused image (Zang, 2004)

2.3.2. Principal Component Transformation (PCT)

PCT is a feature space linear transformation, originally known as the Karhunen-Loeve transformation (Loeve, 1955). It is a mathematical operation that applies a linear transformation, based on an image-specific matrix w_{pc} (equation 4).

$$PC = W_{pc} * DN \qquad (4)$$

Where w_{pc} = transformation matrix

PC = transformed data (uncorrelated)

DN = original data

A transformation matrix is applied that consists of weights to diagonalize (uncorrelated) the covariance matrix of the original multispectral images (Schowengerdt, 1997; Richards, 1999). In this technique the multispectral image will be transformed using PC transformation. The panchromatic band will be statistically adopted and substituted with the PC1 and the new combination of $Pan + PC_{2,3,..n}$ will be returned to the new multispectral / high resolution fused image.

3. DATA ANALYSIS

Hyperspectral-based data fusion using the spectral sharpening algorithms in ENVI.4.0 was examined. The visual and statistical analysis of the fused images was restricted to a set of three spectral bands for the two fused datasets respectively (bands no. 18, 25 and 32 of the original Hyperion data set). These processes contain three main parts as follows.

3.1. Data Preparation

Co-registration of three images has been done using the high resolution image (Quickbird / Spot-Pan resp.) as master and Hyperion as slave. The amount of RMS in the registration processes was about 1 pixel. In order to fit the spectral range of images, the bands number 14-33 of the Hyperion image were selected to fit the spectral range of the Quickbird image. Respectively, the bands number 18-38 of the Hyperion image were selected, to fit to the spectral domain of the Spot panchromatic data.

The two generated data sets comprise two different sharpening factors (SF) due to the very different spatial characteristics of the high resolution images (Spot / Quickbird). The SF (ratio of high spectral resolution pixel size to high spatial resolution pixel size) is 3 for Spot-Pan / Hyperion and 11 for Quickbird / Hyperion.

3.2. Visual Interpretation

The visual interpretation of the results shows that the fusion using a high Sharpening Factor (SF=11) for Hyperion \ Quickbird, produces some spectral artifacts (figure 4). This phenomenon is stronger in band 32 than in band 18 of the new, fused image channels.

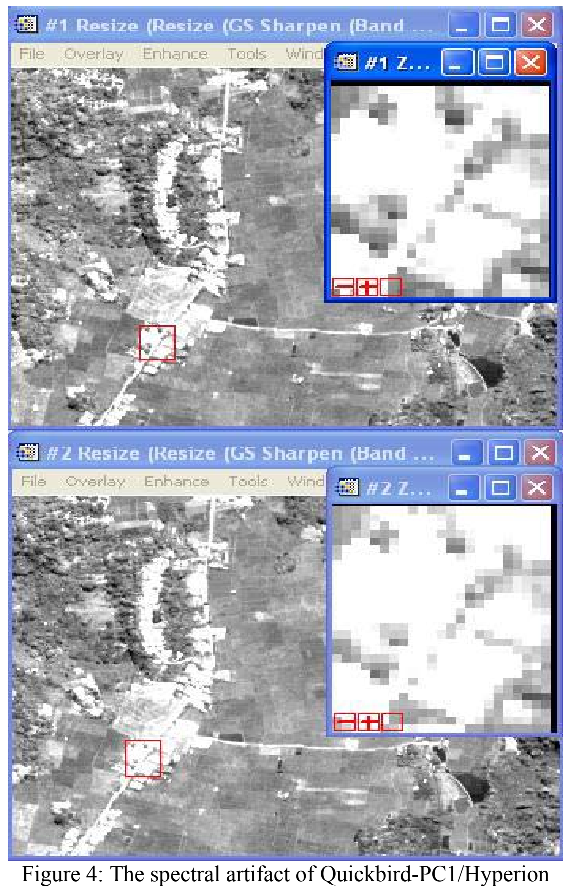

Figure 4: The spectral artifact of Quickbird-PC1/Hyperion fused image bands 18 and 32, respectively

No considerable difference between the two techniques (Gram-Schmidt Transformation and Principal Component Transformation) could be realized from this point of view. The results of Spot-Pan \ Hyperion fusion show that in GST and PCT band no. 18 has better results than band no. 32.

The histogram comparison has been done as another visual parameter and results show that the range of pixel values (min, max) shows a significant increase and consequently the shape of the histogram in the fused images changes compared to the raw Hyperion data (figure 5).

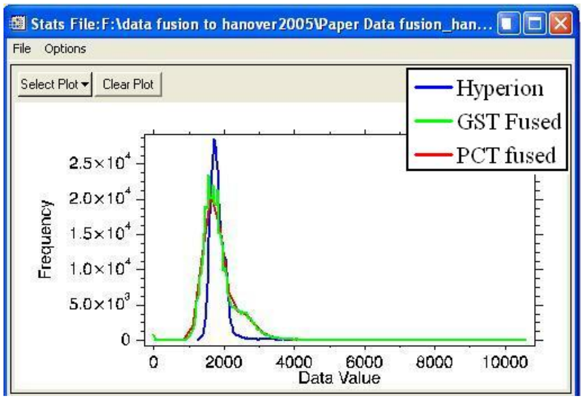

Figure 5: Histogram comparison of Hyperion raw image with GST & PCT fused (Hyperion / Spot pan band 18)

3.3. Statistical Interpretation

In this part, four statistical parameters (Mean, Std. Dev., Mode and Median) and the correlation coefficient (table 2, 3&4) of fused data were chosen and the results were compared with Hyperion raw data. The results (figure 6, 7 & 8) show that:

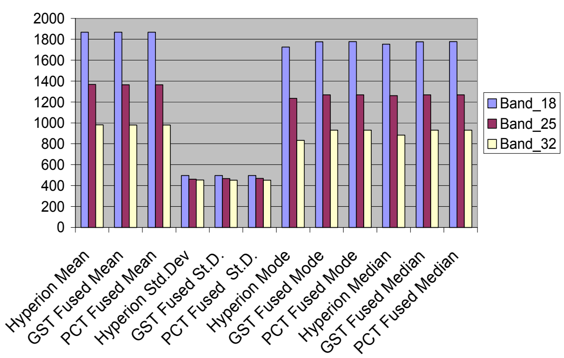

Figure 6: Statistical results of Hyperion / Quickbird -PC1 fused images in comparison with Hyperion raw data

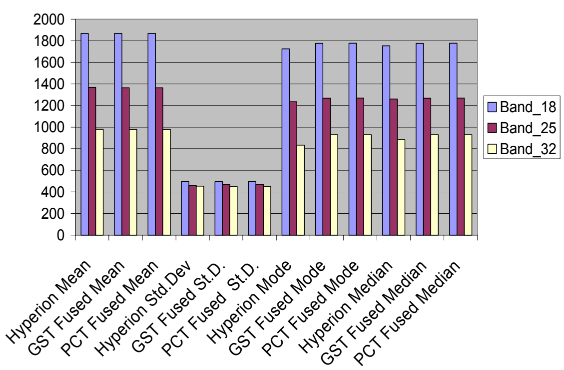

Figure 7: Statistical results of Hyperion/Spot-Pan fused images in comparison with Hyperion raw data

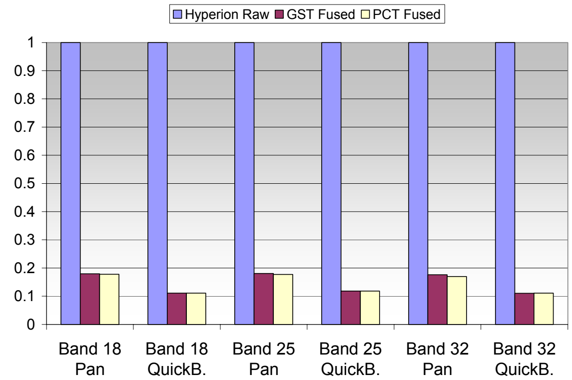

Figure 8: The correlation coefficients between the fused data and the Hyperion raw data (bands 18, 25 & 32)

1. The GST and PCT techniques have almost the same ability in the statistical parameter protection compared to the Hyperion raw image.
2. the results of this comparison show that the bands located in the high frequency area of the spectrum, e.g. band no.18, better preserve the statistics than the bands located in low frequency of the spectrum, e.g. band no. 32.
3. Furthermore, the histogram comparison shows the high amount of shift in maximum and minimum DN values and the changes in the shape of the fused images histograms, compared with hyperspectral raw data (figure 9).
4. The correlation analysis shows only poor correlation between the raw Hyperion data and fused image channels (figure 8).

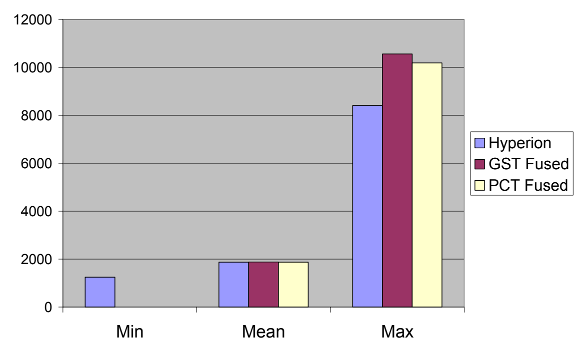

Figure 9: Range comparison of Hyperion raw image with Hyperion/Spot-Pan (band 18) fused images.

4. CONCLUSIONS

In this study two spectral-based data fusion techniques, Gram-Schmidt Transformation (GST) and Principal Component Transformation (PCT), were used in Hyperspectral-based data fusion. The results show that the fusion process in general preserves the image statistics well, considering the mean, standard deviation, mode and median of the histograms taken from the raw data and the fused image channels.
Considering the correlation between the raw and the fused data, the Spot-Pan / Hyperion fused images show better correlation than the Quickbird-PC1 / Hyperion fused data.
The low amount of correlation between the fused images and Hyperion raw data could be explained by the following factors:

1. The different time of data acquisition.
2. The different satellite geometries.

3. The effect of the sharpening factor in the data fusion process.

These three parameters should be considered in more detail in future studies. Finally we can say that the two evaluated techniques have almost the same abilities.

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6. AKNOWLEDGEMENT

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