QUANTITATIVE EVALUATION FOR THEOS PAN-SHARPENING METHODS

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Abstract: Pan-sharpening is a well-known technique used to fuse the high spatial resolution panchromatic image and the low spatial resolution multispectral image to produce a high spatial resolution multispectral image. This paper will present the quantitative evaluation of THEOS image pan-sharpening methods by means of a Quality Indices (QI). The pan-sharpening methods which consist of Brovey transformation (BT), Multiplicative transformation (MT), Principle Component Analysis (PCA), Intensity-Hue-Saturation (IHS), High Pass Filter (HPF), and Wavelet transformation were here investigated. The QI include Correlation Coefficient (CC), Root Mean Square Error (RMSE), Relative shift of Means (RM), Relative Average Spectral Error (RASE), and Relative dimensionless global error in synthesis (ERGAS) were used to evaluate the pan-sharpening methods. According to the experimental results, it is possible to evaluate the pan-sharpening methods by means of the quantitative measurement and the HPF method seems to be the best method. However, this finding should be tested in other test sites and different condition.

1. INTRODUCTION

Pan-sharpening is a technique used to integrate the geometric detail of a high-resolution panchromatic (PAN) image and the color information of a low-resolution multispectral (MS) image to produce a high-resolution MS image (Zhang, 2004). This technique combines the higher spatial details from a high spatial resolution-low spectral resolution (PAN) image with the low spatial resolution-high spectral resolution (MS) image to create a high spatial and high spectral resolution image (Stathaki, 2008). For remote sensing applications, both high spatial and high spectral resolutions are often desired to achieve more detailed and more accurate information acquisition. Unfortunately, we still have not enough useful information, based on experimental results and scientific research, for selecting and applying an appropriate pan-sharpening method to THEOS imagery.

In principle, evaluation of the pan-sharpening methods can be conducted using several techniques include visual image evaluation, statistical measurement, digital image analysis, quality indices, and effect on classification accuracy. Even though some of those techniques seem to be basic methods for pan-sharpening methods evaluation, the subjective skills of evaluator are still affecting to the evaluation. An application of quantitative evaluation to the quality assessment is an alternative approach which aims to measure the spectral distortion objectively. A main advantage of the approach is to illustrate the deviation among considered pan-sharpening methods using statistical computation.

The main objective in this study is to evaluate selected pan-sharpening methods (BT, MT, PCA, IHS, HPF and Wvlet) using Quality Indices (QI) which include Correlation Coefficient (CC), Root Mean Square Error (RMSE), Relative shift of Means (RM), Relative Average Spectral Error (RASE), and Relative dimensionless global error in synthesis (ERGAS) . Herein a small area of THEOS image (3x3 km.) in Chonburi province was selected as a test site.

DATASETS

Two THEOS datasets acquired on 30 December 2008 included Panchromatic (PAN) image (2x2 m. resolution) and Multispectral (MS) image (15x15 m. resolution) are geometrically corrected products (Level 2A) which granted by the data provider (Geo-Informatics and Space Technology Development Agency, GISTDA) were used in the experiment (Figure 1). Specification of spectral response of THEOS data was summarized in Table 1.

Table 1: THEOS spectral sensor characteristics. (Geo-Informatics and Space Technology Development Agency [GISTDA], 2009).

Spectral sensor Characteristics	Panchromatic (PAN)	Multispectral (MS)
Spatial Resolution at nadir (m)	2	15
Pixel/Line (Number of CCD)	12,000	6,000
Swath width (km.)	22	90
Spectral range (µm)	0.45-0.90	Band 1: 0.62-0.69 (Red) Band 2: 0.53-0.60 (Green) Band 3: 0.45-0.52 (Blue) Band 4: 0.77-0.90 (NIR)
Radiometric resolution	8 bit (256 levels)	8 bit (256 levels)

Figure 1: Original PAN and MS images.

2. METHODS

The pan-sharpening methods which consist of Brovey transformation (BT), Multiplicative transformation (MT), Principle Component Analysis (PCA), Intensity-Hue-Saturation (IHS), High Pass Filtering (HPF), and Wavelet transformation (Wvlet) were here selected in this study. While Quality indices (QI) included Correlation Coefficient (CC), Root Mean Square Error (RMSE), Relative shift of Means (RM), Relative Average Spectral Error (RASE) and Relative dimensionless global error in synthesis (ERGAS) were used to quantify pan-sharpening methods. Detail of pan-sharpening method with specific algorithm and quality indices representing the spectral deviation of pan-sharpening image were briefly summarized as following.

Pan-sharpening methods

Brovey Transformation (BT) BT method is a simple method for combining the values of pixels both PAN and MS images. The MS image is normalized and each band of the fused MS image is obtained by multiplying the normalized MS bands with the PAN image (Vijayaraj, 2004). The method can be expressed as:

$$DNfused(bi) = \frac{DN(bi)}{DN(b1)+DN(b2)+\cdots+DN(bn)} * DN\ (pan) \tag{1}$$

where DN is a digital number of that particular band,
(bi) is a particular band of the MS image,
(pan) is a band of PAN image.

Multiplicative Transformation (MT) MT method is computed by simple multiplication of MS image and PAN image to produce the pan-sharpened image. The advantage of this algorithm is straightforward and simplify by multiplying the same information into all bands (Klonus and Ehlers, 2009). The computation of MT can be expressed as:

$$DNfused(bi) = DN(bi) * DN\ (pan) \tag{2}$$

where DN is a digital number of that particular band,
(bi) is a particular band of the MS image,
(pan) is band of PAN image.

Principal Component Analysis (PCA) PCA method is exercised to compress the information content of several bands of imagery into two or three transformed principal component images. The first principal component of the PCA transform of the MS image is usually replaced by the high resolution PAN image. By a reverse PCA transform, the PAN image can be fused into the low resolution MS bands (Shettigara, 1992).

Intensity-Hue-Saturation (IHS) IHS method converts a color image from the RGB space into the IHS color space. Because the intensity (I) band resembles a PAN image, it is replaced by a high-resolution PAN image in the fusion. A reverse IHS transform is then performed on the PAN image together with the hue (H) and saturation (S) bands, resulting in an IHS fused image (Zhang, 2004). The IHS transformation can be performed by the following steps:

Step 1: To resample the low spatial resolution MS image to the size of the high spatial resolution PAN image.
Step 2: To convert RGB space to IHS space by a following equation:

$$\begin{bmatrix} I \\ v1 \\ v2 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -\sqrt{2}/6 & -\sqrt{2}/6 & \frac{2\sqrt{2}}{6} \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (3)$$

Step 3: To replace intensity image (I) by a PAN image.
Step 4: To revert to RGB space as a following equation:

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} PAN \\ v1 \\ v2 \end{bmatrix} \quad (4)$$

where R, G, B, v1, and v2, represent corresponding values in the original RGB image,
R’, G’, and B’ are corresponding values in the fused images

High Pass Filter (HPF) HPF method involves a convolution using high pass filter on PAN image and merging the result with MS image. The first development of this method aims to reduce data volume and increase the spatial resolution of Landsat MSS data (Carter, 1998). The general process of HPF method can be conducted based on Gangkofner, Pradhan, and Holcomb (2008) by the following steps:

Step 1: To read pixel sizes from image files and calculate scale ratio (R),
Step 2: To apply high-pass filter on the PAN image;
Step 3: To resample the MS image to the pixel size of the high-pass image,
Step 4: To add the HPF image to each MS band. The HPF image is weighted relative to the global standard deviation of the MS band,
Step 5: To stretch the new MS image to match the mean and standard deviation of the original (input) MS image.

The size of the high-pass kernel (HPK) is a function of the relative input pixel sizes as scale ratio (R) as shown Table 2. In addition, all values of the kernel are set to –1 except the center value. There are three possible values for the kernel center value. The lowest of the three values for each kernel size is the default (Table 3).

Table 2: HPK size depends on R value (Leica Geosystems Geospatial Imaging, 2008).

R value	HPK size
1 < R < 2.5	5x5
2.5 <= R < 3.5	7x7
3.5 <= R < 5.5	9x9
5.5 <= R < 7.5	11x11
7.5 <= R < 9.5	13x13
R >= 9.5	15x15

Table 3: Center value options depend on HPK size (Leica Geosystems Geospatial Imaging, 2008).

HPK size	**Center value**		
	Default value	Optional values	
5x5	24	28	32
7x7	48	56	64
9x9	80	93	106
11x11	120	150	180
13x13	168	210	252
15x15	336	392	448

The weighted value of HPF image applied to PAN image relates to global standard deviation of MS band and it also a function of R. The weighting (W) can be determined by the following formula, then

$$W = (SD\ (MS) / SD\ (HPF) * M) \qquad (5)$$

where W is weighting multiplier for HPF image value,
SD (MS) is standard deviation (SD) of the MS band to which the HPF image is being added,
SD (HPF) is standard deviation of the HPF image,
M is modulating factor to determine the crispness of the output image.
This factor is a user-adjustable. The Range and default for M based on R are shown in Table 4.

Table 4: Range and default for M based on R (Leica Geosystems Geospatial Imaging, 2008).

R value	M value		
	Minimum	Default	Maximum
1 < R < 2.5	0.20	0.25	0.30
2.5 <= R < 3.5	0.35	0.50	0.65
3.5 <= R < 5.5	0.35	0.50	0.65
5.5 <= R < 7.5	.050	0.65	1.00
7.5 <= R < 9.5	0.65	1.00	1.40
R >= 9.5	1.00	1.35	2.00

Finally, the calculation for each band of the input image will then be calculated using the following form, then.

$$Pixel\ (out) = [Pixel\ (in)] + [HPF \times W] \qquad (6)$$

Wavelet (Wvlet) transformation Wvlet method is performed the wavelet decomposition of images into four different components which is based on their local frequency content or spatial detail. This method performs the Discrete Wavelet Transforms (DWT) on MS and the PAN images to extract the low frequency data from the MS image and the high frequency data from PAN image. These components are combined to create the Fused Wavelet Coefficient Map. The inverse wavelet transformation is performed on the fused map to create the final pan-sharpened image (Strait, Rahmani, and Markurjev, 2008). The major advantage of the wavelet transformation based method is to provide the minimal distortion of the spectral characteristics of the data. (Garguet-Duport, Girel, Chassery, and Pautou, 1996).

Quality Indices (QI)

Root Mean Square Error (RMSE) RMSE gives an idea of the amount of distortion induced by each method (Parcharidis and Kazi-Tani, 2000). The computation of this index is made on the mean squared error between original MS image and pan-sharpened image, then

$$RMSE = \sqrt{\frac{\sum(fi - f'i)^2}{mn}} \qquad (7)$$

where m and n are number of pixels.
fi and f'i represent the corresponding pixel value of MS image and pan-sharpened image.

Correlation Coefficient (CC) CC is based on Pearson's correlation that expresses the degree to which the DN is related, then

$$CC(fi, \bar{fi}) = \frac{\sum(fi-\bar{fi})(f'i-\bar{f'i})}{\sqrt{(\sum(fi-\bar{fi})^2(f'i-\bar{f'i})^2)}} \tag{8}$$

where fi and $\bar{fi}$ represent the corresponding pixel value of MS image and pan-sharpened image.

Relative shift of the Mean (RM) RM is a statistical comparison method. The simple arithmetic means of each band were calculated in order to represents the spectral deviation of the pan-sharpened images. The RM value is derived from following equation:

$$RM = \frac{OutputMean - OrginalMean}{OrginalMean} \% \tag{9}$$

where OriginalMean is the mean of MS image.
OutputMean is the mean of pan-sharpened image.

Relative Average Spectral Error (RASE) RASE index characterizes the average performance of the method of image fusion in the spectral bands considered (Choi, 2006). Lower value is a better method. The value computation is given by:

$$RASE = \frac{100}{M}\sqrt{\frac{1}{N}\sum_{i=1}^{N} RMSE^2(Bi)} \tag{10}$$

where M is the mean radiance of MS image.
N is the number of bands.
(Bi) is the different between MS image and pan-sharpened image.

Relative dimensionless global error in synthesis (ERGAS) ERGAS is an error index that sensitive to mean shifting and dynamic range change (Du, Younan, King, and Shah, 2007) and offers the global view of the quality of the pan-sharpened image. The value indicates the deviation from the original image. The computation is shown as follow;

$$ERGAS = 100\frac{h}{l}\sqrt{\frac{1}{N}\sum_{N=1}^{N}\left[\frac{RMSE\ (n)}{mean\ (n)}\right]^2} \tag{11}$$

where h and l are spatial resolution of PAN and MS images respectively;
n is the different between MS image and pan-sharpened image;
N is the number of bands.

3. EXPERIMENTAL RESULTS

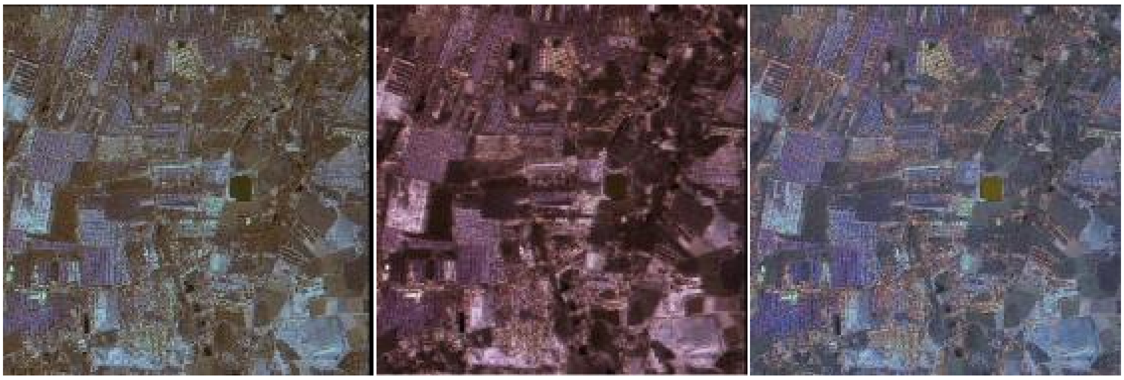
Refer to six selected pan-sharpening methods, IHS method can be applied with only three MS bands and one PAN band at one time. So, selected multispectral bands of THEOS data included Band1 (Red), Band 2 (Green) and Band 3 (Blue) were selected in this study. The spectral range of MS data varies from 0.45 to 0.69 µm while PAN wavelength covers between 0.45 and 0.90 µm. These selected MS bands and a standard nearest neighbor resampling technique were equally applied to all pan-sharpening methods. The result of pan-sharpening image from six selected methods was presented in Figure 2.

In the meantime, quantitative evaluation of pan-sharpening image using five selected quality indices included Correlation Coefficient (CC), Root Mean Square Error (RMSE), Relative shift of Means (RM), Relative Average Spectral Error (RASE) and Relative dimensionless global error in synthesis (ERGAS) were calculated as summary in Table 5. RMSE index represents amount of spectral distortion that varied between 37.1608 (HPF method) and 91.6157 (MT method). RM which illustrates the spectral deviation of the pan-sharpened images from original MS image varied between -10.7482 (HPF method) and -54.4124 (MT method). RASE index which characterizes the average performance of the pan-sharpening method in the considered spectral bands varied between 3.7870 (HPF method) and 5.9701 (MT method) and the ERGAS index which offers the global view of quality of the pan-sharpened data ranged from 3.0029 (HPF method) to 7.5051 (MT method). In contrary, CC which is based on Pearson’s correlation that expresses the correlation between original MS image and pan-sharpened image varied between 0.3789 (PCA method) and 0.7574 (MT method).

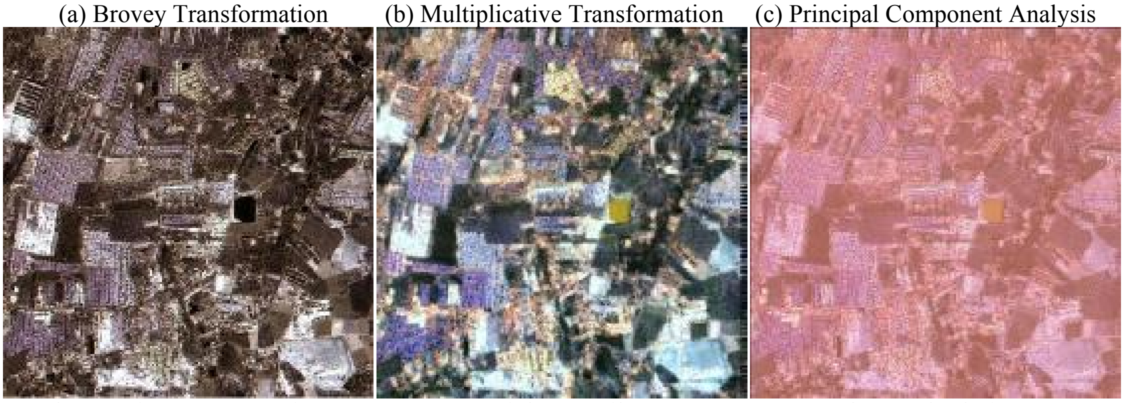
As results, pan-sharpened image from the High Pass Filter (HPF) method provided the best preserve spectral characteristics when it was compared with other pan-sharpening methods. However, this finding should be reconfirmed in another area and different conditions.

Table 5: Quality indices of pan-sharpening methods.

Quality Index	Pan-sharpening method BT	MT	PCA	IHS	HPF	Wvlet
RMSE	78.9755	91.6157	73.4057	85.792	**37.1608**	58.7805
CC	0.5156	**0.7574**	0.3789	0.5402	0.7342	0.6361
RM	-41.418	-54.4124	-34.6702	-39.7706	**-10.7482**	-17.8784
RASE	5.4475	5.9701	5.1754	5.7549	**3.7870**	4.6417
ERGAS	6.1614	7.5051	5.5612	6.9358	**3.0029**	4.4768



(a) Brovey Transformation (b) Multiplicative Transformation (c) Principal Component Analysis



(d) Intensity-Hue-Saturation (e) High Pass Filter (f) Wavelet fusion

Figure 2: Pan-sharpened images.

4. CONCLUSION

This experiment demonstrated a quantitative evaluation of pan-sharpening methods carried out using five selected quality indices. An advantage of this approach is to eliminate the error by human judgment involved to the evaluation process. The results can be objectively used to select an optimum pan-sharpening method. However, quality index is the interesting one among various techniques. Another quantitative evaluation of pan-sharpening methods, digital image analysis and effect on classification accuracy, shall be examined for a comprehensive evaluation. Furthermore, relevant pan-sharpening methods should be added to the future experiment and new pan-sharpening method evaluation with the user-oriented approach will be more investigated.

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REFERENCES:

Carter, D. B., 1998. Analysis of Multiresolution Data Fusion Techniques. Master of Science. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Choi, M., 2006. A new intensity-hue-saturation fusion approach to image fusion with a tradeoff parameter. IEEE Transactions on Geoscience and Remote Sensing. 44(6), pp. 1672-1682.

Du, Q., Younan, N. H., King, R., and Shah, V. P., 2007. On the Performance Evaluation of Pan-Sharpening Techniques. IEEE Geoscience and Remote Sensing Letters, 4(4), pp. 518-522.

Gangkofner, U. G., Pradhan, P. S., and Holcomb, D. W., 2008. Optimizing the High-Pass Filter Addition Technique for Image Fusion. Photogrammetric Engineering & Remote Sensing, 74(9), pp. 1107-1118.

Garguet-Duport, B., Girel, J., Chassery, J.-M., and Pautou, G., 1996. The Use of Multiresolution Analysis and Wavelets Transform for Merging SPOT Panchromatic and Multispectral Image Data. Photogrammetric Engineering & Remote Sensing. 62(9), pp. 1057-1068.

Geo-Informatics and Space Technology Development Agency., 2009. THEOS user guide [On-line]. Available: http://new.gistda.or.th/gistda_n/index.php/dltechnical/doc_download/128-.

Klonus, S., and Ehlers, M., 2009. Performance of evaluation methods in image fusion. Paper presented at the International Conference on Information Fusion - IEEE, Seattle, WA, USA.

Leica Geosystems Geospatial Imaging, L., 2008. ERDAS Field Guide Vol. 2, pp. 354.

Shettigara, V. K., 1992. A generalized component substitution technique for spatial enhacement of multispectral images using a higher resolution data set. Photogrammetric Engineering & Remote Sensing. 58, pp. 561-567.

Siddiqui, Y., 2003. The Modified IHS Method for Fusing Sattellite Imagery. In ASPRS Annual Conference Proceedings. USA.

Stathaki, T. (Ed.)., 2008. Image Fusion: Algorithms and Applications. Academic Press.

Strait, M., Rahmani, S., and Markurjev, D., 2008. Evaluation of Pan-Sharpening Methods [On-line]. Available: http://www.math.ucla.edu/~wittman/reu2008/Reports/pan_report.pdf.

Vijayaraj, V., 2004. A Quantitative Analysis of Pansharpened Images. Master of Science, Mississippi State University, Mississippi.

Zhang, Y., 2004. Understanding Image Fusion. Photogrammetric Engineering & Remote Sensing, 70, pp. 657-659.