

EVALUATION OF SPOT-5 IMAGE FUSION USING MODIFIED PAN-SHARPENING METHODS

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Abstract. Image fusion, commonly known as pan-sharpening, is a method that combines two data: a panchromatic image that has geometric detail information with the highest spatial resolution and multi-spectral image that has the highest color information but with the lowest resolution. *Pan-sharpening* is very important for various remote sensing applications, such as to improve the image classification, to change the detection using temporal data, to increase the geometric, image segmentation, and to improve the visibility of certain object that does not appear on certain data. This study aims to compare the existing pan-sharpening methods such as Brovey, Brovey modification using green and red band, Gram-Schmidt, HPF, Multiplicative, and SFIM. The quality of the pan-sharpening result should be evaluated, this study used Universal Image Quality Index (UIQI/Q index); this evaluation method gives the opportunity to choose which method is best to provide the most similar spectral information with the original multispectral image. A pan-sharpening qualitative analysis shows that there has been a sharpening process on all pan-sharpening images. Based on spectral visualization (color display), several pan-sharpening methods such as HPF multiplicative method provides brighter colors and Brovey transformation method displays dark colors. Gram-Schmidt method also provides a different color from the original multispectral image. A pan-sharpening quantitative analysis shows that the best pan-sharpening method with UIQI value > 0.9 is Brovey modification using green and red band. This is due to the green band (500-590 nm) and the red band (610-680 nm) wavelength are in the panchromatic band (480-710 nm) of the SPOT-5 Data.

Keywords: *Image Fusion, Pan-sharpening method, SPOT-5, UIQI*

1 INTRODUCTION

Image fusion or commonly known as *pan-sharpening* is a method that combines the geometric detail of a panchromatic image with high spatial resolution and the color information of the multi-spectral image but with lower spatial resolution to produce multi-spectral image with high spatial resolution (Zhang, 2004). *Pan-sharpening* is very important for various remote sensing applications, such as to improve the image classification, change detection using temporal data, to increase the geometric, image segmentation, and improve the visibility of certain object that do not appear on certain data (Jawak *et al.*, 2013; Vijayaraj, 2004).

Optical remote sensing data SPOT-5 has a panchromatic image with 2.5 meters of spatial resolution and 10 meters of multi-spectral image. In every attempt to combine both data, the question on what the best image fusion method always arises in order to get the fusion result with similar color as the original multi-spectral image and also with the same detail as the panchromatic image.

Many scientific publications have discussed the pan-sharpening method such as Brovey, Gram-Schmidt, Multiplicative, IHS, Wavelet, HPF, SFIM, PCA, (Vrabel, 1996; Gangkofner *et al.*, 2008; Bovolo *et al.*, 2010; Helmy *et al.*, 2010; Chandra, 2013; Maurer, 2013; Sarp, 2014; Sivi, 2014).

According to Zhang (2008), there are two evaluation approaches that can be used to assess the pan-sharpening quality: [1] a qualitative approach, by visual comparison between the color of the original multi-spectral image and the color of pan-sharpening and also the spatial detail comparison between the original panchromatic image and the pan-sharpening image; [2] The quantitative approach, which involves a set of quality standard indicators for measuring spectral and spatial similarity between the pan-sharpening image and the multi-spectral or panchromatic image.

The qualitative approach (visual evaluation) usually contains subjective factors and it is influenced by a person's preference (Siwi, 2014), while the quantitative approach is needed to prove the truth of the visual evaluation.

A quantitative approach used to evaluate the pan-sharpening quality is Universal Image Quality Index (UIQI/Q index) method. This method proposed by Wang and Bovik (2002), in which the calculation is easy and applicable to various image processing applications. The proposed index is designed by image distortion modeling as a combination of three factors namely the correlation degree, the lighting distortion, and the distortion contrast.

This study aims to compare the existing methods of pan-sharpening (Brovey, Gram-Schmidt, HPF, Multiplicative, and SFIM), and the modification of Brovey method using green band and red band. It also evaluates the pan-sharpening quality using Universal Image Quality Index (UIQI/Q index); thus, this study can show which method produces the most similar spectral information with the original multi-spectral images. The hypothesis of this study is Brovey modification method using green band and red band on the SPOT-5 data provides the best quality of spectral information compared to other methods.

2 METHOD

The flow diagram of this study is shown in Figure 2-1.

2.1 Location and Data

The data used in this research is SPOT-5 Bundle which consists of (SPOT Image, 2014): [1] multi-spectral image consisting of four (4) bands, the green band (500-590 nm), the red band (610 - 680 nm), the NIR band (780-890 nm), and the SWIR/MIR band (1.580 to 1.750 nm) with the spatial resolution of 10 meters (green, red, and NIR) and 20 meters (SWIR/MIR); [2] The single-channel-panchromatic image (480-710 nm) in black and white with 2.5 meters spatial resolution (Figure 2-2 and Figure 2-3). The SPOT-5 data with *ortho* level were obtained from LAPAN institution located in K/J 311/348 recorded at March 2, 2013.

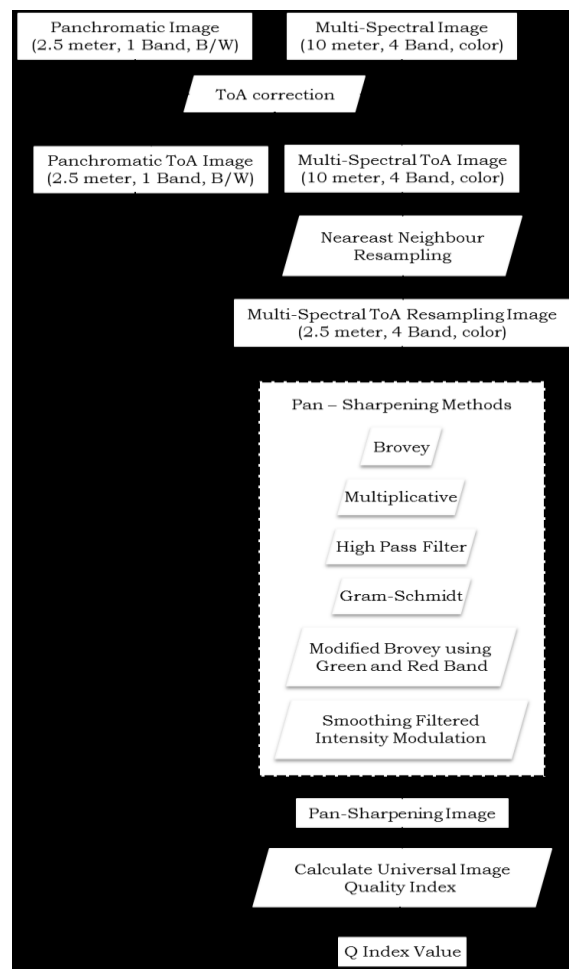


Figure 2-1: Flow Chart

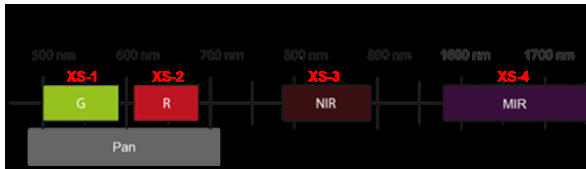


Figure 2-2: SPOT-5 spectral band

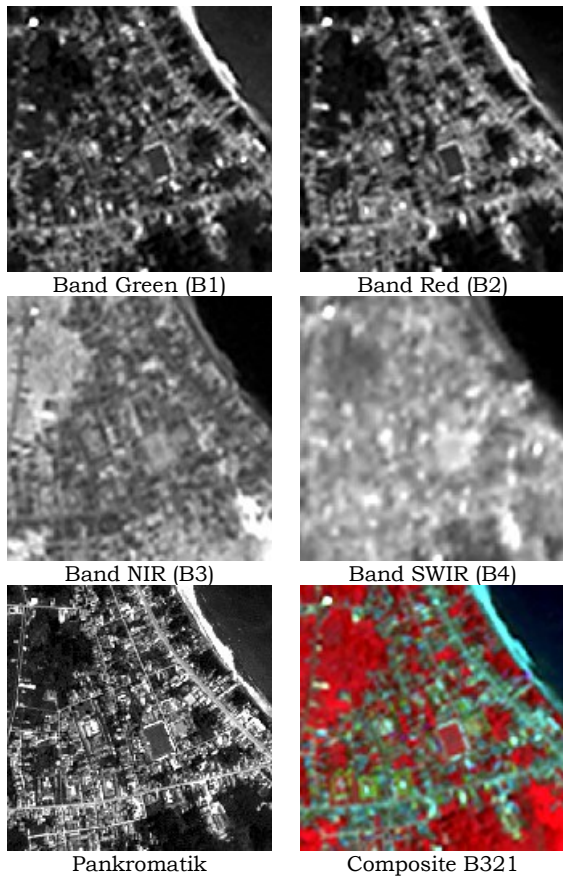


Figure 2-3: Multi-spectral and panchromatic SPOT-5 image

2.2 Research Method
Top of Atmosphere (TOA)

Radiometric correction was conducted to correct pixel values by considering atmospheric disturbance factors as the main source of error. Atmospheric effects cause the value of the object surface’s reflection on earth recorded by the sensors, different from their original value, resulting in greater digital value because of the scattering or smaller digital value because of absorption process (Danoedoro, 2012). SPOT-5 Data obtained from LAPAN has not been proceed with radiometric correction. This study uses Top of Atmosphere (TOA) radiometric correction

to reduce the effects of the sun position and the different satellites by the following formula (El-Hajj *et al.*, 2008):

$$Reflektan_i = \frac{\pi \times \left(\frac{DN_i}{G_i} + B_i \right) \times d^2}{ESUN_i \times \cos \theta} \quad (2-1)$$

where

- i : Greenband (B1), Red (B2), NIR (B3), SWIR (B4),
- Pan; DNI : digital number on the band i;
- Gi: gain on band i; Bi: Bias on band i; d: distance of the sun to the earth at a particular time, which is calculated using the following formula:

$$d = 1 - [0.0168 \times \left(\cos \left(\left(\frac{julian\ day}{365} \right) \times 360 \right) \right)] \quad (2-2)$$

ESUNi: exoatmosferik irradiant ON band i;
Cos θ: sudut zenith, (θ = 90 – angle of elevation).

Resampling

Resampling process is a mathematical technique used to create a new image with height and width pixel numbers differ from those of the original image (Sachs, 2001). *Nearest neighbor* resampling method is a simple method by taking the color pixel of the original image and apply to the newly created pixel of the original image. The result obtained from this method is a new image with larger size while maintaining all the details of the original image. Resampling is done to change the spatial resolution from 10 meters to 2.5 meters, so the multispectral image has a spatial resolution that is similar to the panchromatic image.

Pan-Sharpening Methods

This study used six different pan-sharpening algorithms to fuse images that can produce multispectral images with a spatial resolution of 2.5 meters, those algorithms are:

- Brovey transformation

Brovey transformation uses a mathematical combination between multispectral and panchromatic images with high resolutions. In this process, each Multispectral band is multiplied by the ratio of the high-resolution panchromatic band, then is divided by the number of Multispectral band. The output of this transformation is a pixel size from data input with high resolution (Bovolo *et al.*, 2010; Sarp, 2014; Siwi, 2014). Brovey transformation is defined as equation (3)

$$DN_{pan-sharpening_{bi}} = \frac{DN_{bi}}{DN_{b1} + DN_{b2} + \dots + DN_{bn}} \times DN_{pan} \quad (2-3)$$

Where DN is the digital number of a particular band, *bi* is a particular band of a Multi-Spektal image (green band, red, NIR and SWIR), *pan* is a panchromatic image.

- Modified Brovey

The modification of Brovey transformation is done by replacing the total number of bands on Multispectral SPOT-5 images with bands that has panchromatic image wavelength (480-710 nm), the green band (500-590 nm) and the red band (610-680 nm) with the following formula (Siwi, 2014):

$$DN_{modified_{bi}} = DN_{bi} \times \frac{DN_{pan}}{\frac{1}{2} \times (DN_{green} + DN_{red})} \quad (2-4)$$

Where DN is the digital value of a particular band, *bi* is a particular band of the Multispectral image (green, red, NIR and SWIR band), *pan* is a panchromatic image.

- Multiplicative

This method is calculated by simple multiplication of Multi-Spektal image and panchromatic image to produce a pan-sharpening image, where the result has the same number of bands with the image of the original multispektal (Seetha *et al.*,

2007; Siwi, 2014) based on the following formula:

$$DN_{pan-sharpening_{bi}} = DN_{bi} \times DN_{pan} \quad (2-5)$$

Where DN is the digital value of a particular band, *bi* is a particular band of Multi-Spectral image (green, red, NIR and SWIR band), *pan* is a panchromatic image.

- High Pass Filter

This method combines the high frequency information of the panchromatic image (Pan_{HPF}) with the low resolution of the Multi-Spectral image to obtain Multispectral images with high resolution (Chaves *et al.*, 1991; Rajendran *et al.*, 2012). High-frequency information of panchromatic image (Pan_{HPF}) is calculated by giving a high pass filter with an average of simple local pixels, in this case is a filter box (Al-Wassai *et al.*, 2011; Siwi, 2014). The filter box size functions as the relative size of the input pixel with ratio scale 5x5, 7x7, 9x9 or 11x11 (Pohl, 1998; Han *et al.*, 2008) with the following formula:

$$HPF_{i,j,k} = 1/2(MS_{i,j,k} + FP_{i,j}) \quad (2-6)$$

Where HPF is the *pan-sharpening* image; *i*, *j* is the pixel of band *k*; FP is filter image using *High-Pass* Filter.

- Gram-Schmidt

Gram-Schmidt method simulates a panchromatic band of a multispectral image with lower spatial resolution. In general, this is achieved by calculating the average of multispectral bands. The next step, the Gram-Schmidt transformation is performed for simulating panchromatic band and multispectral bands with the simulated panchromatic band employed as the first band. The panchromatic band replaces the first Gram-Schmidt band (simulated panchromatic band). Finally, the Gram-Schmidt inverse transformation

is conducted to create the pansharpened Multispectral band. This method usually produces good results for pansharpening image from one sensor, the statistical procedures such as *Pdetilpal Componentis* needed in order to vary the fusion product which depends on the dataset chosen (Laben *et al.*, 2000; Clonus *et al.*, 2009).

- *Smoothing Filtered Intensity Modulation (SFIM)*

SFIM is a method where the ratio of high-resolution panchromatic image is divided by simulated image of a low resolution panchromatic image, the results are then multiplied by the Multispectral image with low resolution. The method process is simply taking the panchromatic detail without touching the spectral attributes and contrast of the Multispectral image. Thus, the spectral value of Multispectral image remains undistorted (Han *et al.*, 2013), the formula as follows:

$$SFIM_{i,j,k} = (MS_{i,j,k} \times Pan_{i,j}) / Mean_{i,j} \quad (2-7)$$

Where SFIM is the pan-sharpening image; i, j is the pixel of band k; Mean is the simulation of low resolution pixel derived from high-resolution panchromatic image using the filter averaging; MS is a multispectral image; Pan is a panchromatic image.

Quality Evaluation of Pan-Sharpning

The purpose of the image fusion is to improve the spatial and spectral resolution of the low resolution image. This study used Q index method to evaluate pansharpening quality (Wang and Bovik, 2002), the formula is as follows:

$$Q = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \cdot \frac{2 \bar{x} \bar{y}}{(\bar{x})^2 + (\bar{y})^2} \cdot \frac{2 \sigma_x \sigma_y}{\sigma_x^2 + \sigma_y^2} \quad (2-8)$$

Where σ is the standard deviation; x is the

original Multispectral image; y is the pansharpening image.

3 RESULTS AND DISCUSSIONS

The multispectral and panchromatic remote sensing images are important data sources for obtaining large-scale information and geospatial detail to various remote sensing applications. Interpretation, digital classification, and image color visualization are the widely used approaches to obtain the detailed geospatial information (Zhang, 2004).

In this paper, six methods of *pan-sharpening*, Brovey Transformation, Modified Brovey using green and red band, High Pass Filter, SFIM, and Gram-Schmidt, were used to process the image fusion between the multispectral and panchromatic image of SPOT-5 data. The results of *Pan-sharpening* process show that the sharpening process occurred on all the image objects. Although there is visual sharpening, the color display differs on each result. The visual results can be seen in Figure 3-1 to Figure 3-3. Figure 3-1 is the result of image fusion using six pansharpening methods for settlement object. Figure 3-2 is the result of image fusion using six pansharpening methods for forest object. Figure 3-3 is the result of image fusion using six pansharpening methods for pond object.

The result of the image fusion process between the low resolution multispectral image with the high resolution panchromatic image shows that all the six methods which were tested on three land cover objects succeed in sharpening the objects in term of multispectral image. In term of spectral visualization (color display) several pansharpening methods such as multiplicative method and HPF produces bright color while Brovey transformation tends to produce dark colors. Gram-Schmidt produces different color from the original multispectral image.

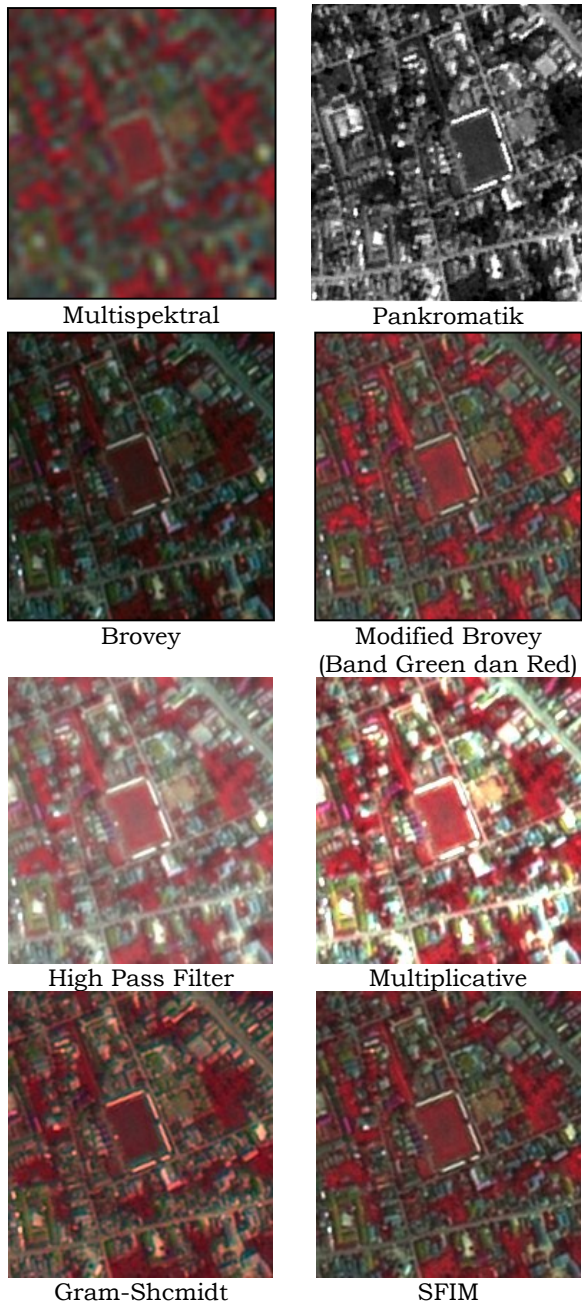


Figure 3-1: Pan-Sharpning of SPOT-5 imagery for settlements objects

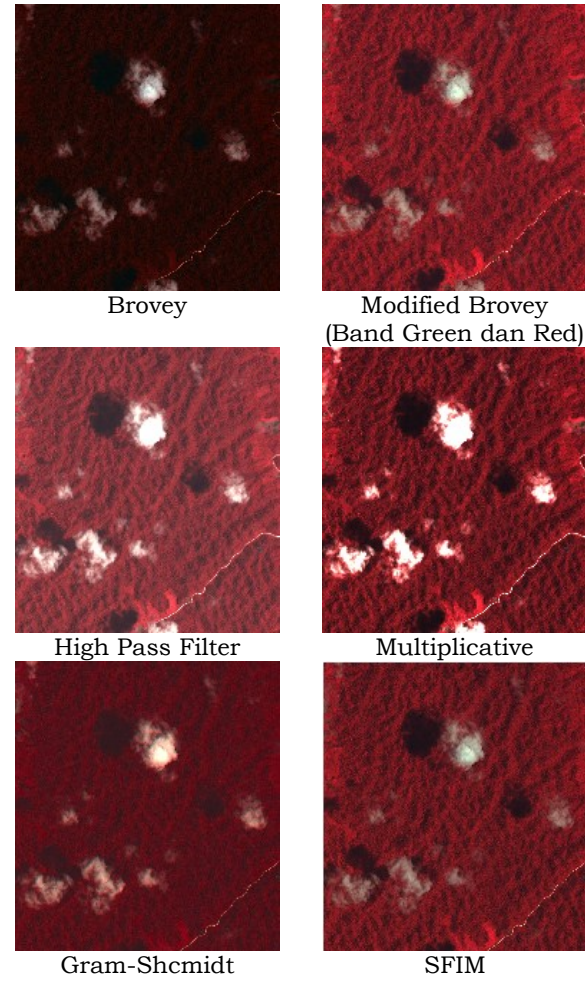
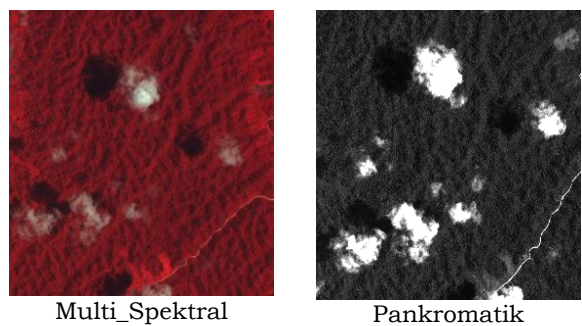


Figure 3-2: Pan-Sharpning of SPOT-5 imagery for forest object

It is necessary to test the quality of pan-sharpening results; the quality test gives the opportunity to choose which method is best for image fusion on SPOT-5 data. This study examined the quality of the pan-sharpening using six methods, it aimed to see to what extent the pan-sharpening results providing the similar spectral information as the original multi-spectral images for settlement objects representing developed land/open land, the forest objects products representing vegetation, and pond object representing water.

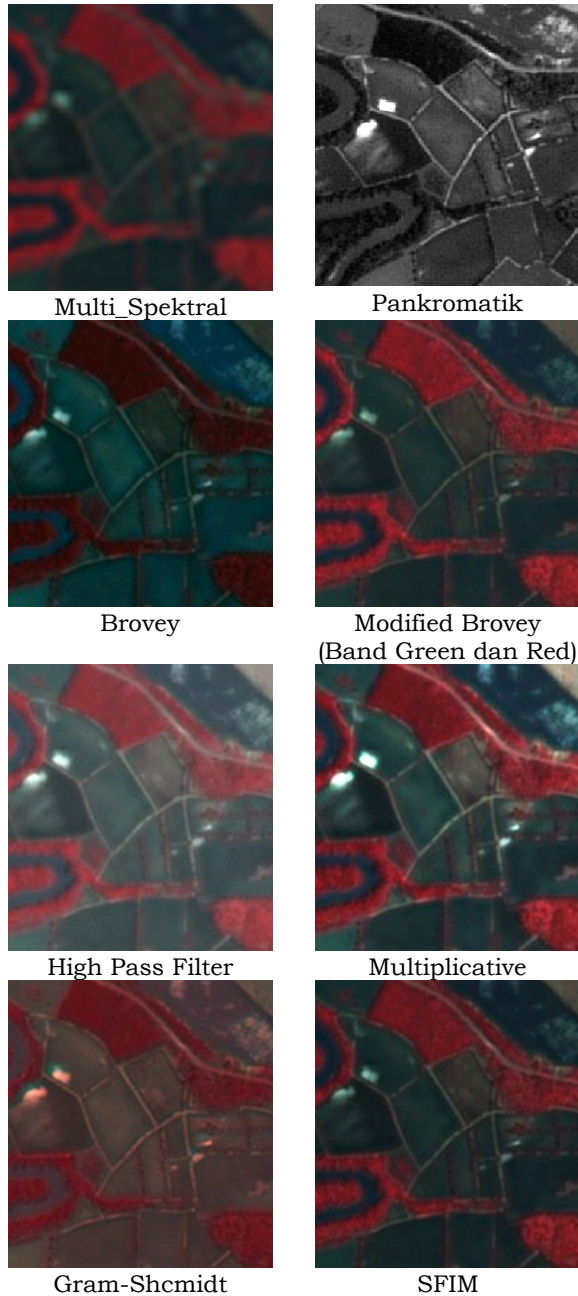


Figure 3-3: Pan-Sharpener of SPOT-5 imagery for pond object

Universal Image Quality Index Method (Q index) combines three factors to assess the quality of the pan-sharpening image (y) on the original multispectral image (x), the factors are as follows [1] correlation coefficient component which measures the degree of linear correlation between the x and y image; [2] The lighting distortion component by measuring how close the mean value between the x and y image; and [3] the contrast distortion component by measuring the similarity between the x and y image (Wang and Bovik, 2002). Q index calculation results can be seen in Table 3-1.

Q index value ranging from -1 to 1, wherein if the Q value index approaches 1, then the spectral information generated from pan-sharpening process has similarities with the original multispectral image. Conversely, if the Q index value is close to -1, then there is no resemblance between the spectral information with the original multispectral image. Thus, the chosen pan-sharpening method is the method that sharpened the objects without changing the spectral values.

Tabel 3-1: Evaluation of the quality of the pan-sharpening

No	Pan-Sharpener Method	Q Index		
		Settlement	Forest	Fishpond
1	Brovey transformation	0.200	0.119	0.150
2	Modified Brovey (band green dan band red)	0.905	0.937	0.902
3	Gram-Schmidt	0.621	0.838	0.564
4	High Pass Filter	0.686	0.742	0.712
5	Multiplicative	0.578	0.668	0.660
6	Smoothing Filtered Intensity Modulation (SFIM)	0.933	0.771	0.714

The result of the Q index calculation of the six pan-sharpening methods (Table 3-1) on land cover objects is as follows: [1] Q index for settlements with value of > 0.9 is produced by modified Brovey (0905) and SFIM (0933), while value close to -1 is produced by Brovey transformation method (0200); [2] Q index for forest with value > 0.9 is produced by modified Brovey (0937), while value close to -1 is produced by Brovey transformation method (0199); [3] Q index for forest with value > 0.9 is produced by modified Brovey (0902), while value close to -1 is produced by Brovey transformation method (0150).

Q index calculation results show that the Brovey method that has been modified using green and red band has similarities with the original multispectral image compared to other methods of pan-sharpening. This is due to the green band (500-590 nm) and the red band (610-680 nm) wavelength are in the panchromatic band (480-710 nm) of the SPOT-5 Data or in other words panchromatic band, green band and red band are at the visible wavelengths.

The pan-sharpening results using modified Brovey method do not decrease the spectral information and show clear objects. While the Brovey transformation method significantly decrease the spectral information so that the visualization result looks darker and does not guarantee having a clear objects in the image. This is indicated by the lower value of Q index than other methods of pan-sharpening.

4 CONCLUSION

The fusion of Multispectral and Pakromatik image of SPOT-5 data shows that the best method of pan-sharpening that can provide similar image as the

original multispectral image is modified Brovey method using green and red band. This can be seen from the calculation result of Q index value > 0.9 for all cover land objects.

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