Weighting Parameters to Improve IHS Transformation in Data Fusion of THEOS Imagery

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ABSTRACT: To efficiently fuse multi-spectral (MS) and panchromatic (PAN) images acquired from THEOS satellite, the authors offer proper parameters to improve IHS fusion technique based on its spectral responsivity. This concept was originally contributed by Tu et al., applied to IKONOS image fusion. Red and NIR bands of THEOS imagery with lower response were adjusted to be higher and close to the response of PAN band using those new proposed parameters. Indexes including the correlation coefficients (CCs), relative dimensionless global error in synthesis (ERGAS), and relative average spectral error (RASE) of the pan-sharpened and MS images were compared to quantitatively evaluate the quality of pan-sharpened images. The resulting indexes indicate that the quality of pan-sharpened images obtained from the study be obviously high. Indexes from images transformed by the method of Tu et al. were compared to the indexes obtained from the study as well. The comparison expresses that indexes resulted from the study are better than ones using the method of Tu et al. It can confirm that the fusion method based on the concept of adjustment on spectral responsivity of specific sensor is valid. The new approach provides a satisfactory result of image fusion, both visually and quantitatively.

Categories and Subject Descriptors
I.4.2 [Compression]; H.3.1 [Content Analysis and Indexing]

General Terms:
Multispectral Images, Image Indexing, Image Quality

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1. Introduction

High spatial resolution and multi-spectral characteristics of remotely sensed imagery are widely known as a powerful tool used to understand phenomena in atmosphere and earth surface. Normally, multi-spectral (MS) images provide less spatial resolution than a panchromatic (PAN) image. Pan-sharpening is thus an image processing technique increasingly used to combine the available high spectral resolution images and high spatial resolution PAN image and result in images with high both spatial and spectral resolutions. Several researchers discovered that pan-sharpening images can be more efficiently used for object clustering and segmentation (Zhang and Wang 2004; Li et al. 2005; Boloorani et al. 2006; Zaveri et al. 2009; Aksoy et el. 2011; Chisense et al. 2010; Johnson et al. 2012; Byun et al. 2013). The image pan-sharpening or fusion technique providing images with more accurately original characteristics is considered very important for their further uses. Recently, there have been several methods of the technique developed by many researchers. The fusion technique synthesizing MS images to obtain higher spatial resolution includes several methods such as Intensity-Hue-Saturation (IHS) transformation (Carper et al. 1990; Koutsias et el. 2000; Tu et el. 2001; Chu and Zhu 2008; El-Mezouar et al. 2011), principal component analysis (PCA) transformation (Zhang 2002; Luo et al. 2008; Metwalli et al. 2009), Brovey transformation (Saroglu 2004; Eshtehardi et al. 2007; Jinghui et al. 2010), and wavelet transformation (Pajares et al. 2004; Guo et al. 2009; Mandhare et al. 2013). The different aspects of data fusion were discussed in more details in (Zhang 1999; Nikolakopoulos 2008; Sahu and Parsai 2012).

This paper is proposed to contribute the IHS transformation method using spectral adjustment of Thailand Earth Observation System (THEOS) imagery. IHS method is among the most popular fusion techniques for pan-sharpening image. IHS fusion uses an RGB image consisting of distinct bands and transforms them into the IHS space. The intensity component in the IHS space is replaced by the PAN image with high spatial resolution and transformed back into the original RGB space with the previous hue and saturation components (Tu et al. 2004). However, the problem of IHS fusion method is the distortion of spectral characteristics of MS images. This means that the variation on hue before and after the fusion process has appeared (Teague, 2001). He found the cause of this variation on hue and realized the influence of spectral response on the fused IKONOS images. Recently, many articles have presented techniques to solve the problem of IHS fusion methods for IKONOS images. For example, Tu et al. (2004) present fast intensity-hue-saturation (FIHS) with spectral response adjustment technique. Zhang and Hong (2005) utilized the IHS transformation to fuse the high-resolution spatial information into low-resolution MS images and used the wavelet transformation to reduce the color distortion. Choi (2006) presents a new IHS fusion approach, based on a concept of Tu et al. (2004) to achieve promising performance by adjusting the related parameters for transformation. Tu et al. (2007) present IHS–Brovey method for image fusion based on Choi's method.

Few researchers have been working on pan-sharpening THEOS images. GISTDA (2009) presents the pan-sharpening techniques for the test, providing by widely used remote sensing software packages such as those from ERDAS imagine, ENVI, and PCI geomatica. The result of IHS fusion methods showed too much Blue in vegetation area. Intajag et al. (2010) present the evaluating results of IHS transformation techniques for pan-sharpened THEOS images using Pradhan algorithm (Pradhan et al. 2006) based on concepts of Tu et al. (2004) and Choi (2006). None considers parameter adjustment method of IHS technique based on THEOS spectral responsivity to improve pan-sharpening image.

Theoretically, the characteristics of high spatial resolution images from different satellite sensors could require different techniques or parameters derivation to achieve better result of pan-sharpening image. For instance, not only spatial resolutions of IKONOS and THEOS images are different but also their spectral responsivity. IKONOS satellite images provide spatial resolution of PAN and MS images as 1 meters and 4 meters, while THEOS images provide 2 meters and 15 meters. Their spectral responsivity of MS and PAN images are also obviously different. This should lead to different proper parameters for HIS transformation of them.

In this article we originally present a set of proper parameters for the IHS fusion method of pan-sharpened THEOS images derived from an adjustment based on its typical spectral responsivity. To examine the quality of resulting pan-sharpened image, the correlation coefficients (CCs) (Zhou et al. 1998; Choi et al. 2005; Shah 2008), relative dimensionless global error in synthesis (ERGAS) (Ranchin and Wald 2000; Du et al. 2007; Khan et al. 2009), and relative average spectral error (RASE) (Gonzalez-Audicana et al. 2004; Basaeed et al. 2013) of the pan-sharpened and MS images were compared. The pan-sharpened images with better quality should contain radiometric characteristics closest to the original MS images. To confirm that the parameters derived are mostly efficient, results from those examination methods operated on the pan-sharpened and MS images generated from the methods of Tu et al. (2004) and from the study were additionally compared.

2. Materials and Methods

2.1 THEOS Satellite Images

THEOS (Thailand Earth Observation System) satellite was first launched on 1 October 2008 into a sun-synchronous orbit. The program was developed by the Geo-Informatics and Space Technology Development Agency (GISTDA), Ministry of Science and Technology, Thailand. The payload of THEOS satellite includes high spatial resolution PAN and MS images. Table 1 describes the characteristics of the THEOS satellite's sensor (GISTDA 2009).

	PAN	MS
Spatial Resolution	2 M	15 M
Imaging Swath	20 KM	90 KM
Spectral Ranges	P : 0.45 – 0.90	B1 (blue) : 0.45 -0.52 B2 (green) : 0.53 – 0.60 B3 (red) : 0.62 – 0.69 B4 (NIR) : 0.77 – 0.90

Table 1. The Characteristics of THEOS

The relative spectral responses of the THEOS PAN and MS wavelengths are shown in Figure 1. It shows the spectral curves for the different bands. The spectral response of the PAN is uniform in the entire wavelength and covers the spectral response of Blue, Green, Red, and NIR bands. It is observable that the responses of Red and NIR are about 5-15% less than that of the PAN. The THEOS relative spectral responsivity is different from IKONOS's reported in Teague (2001).

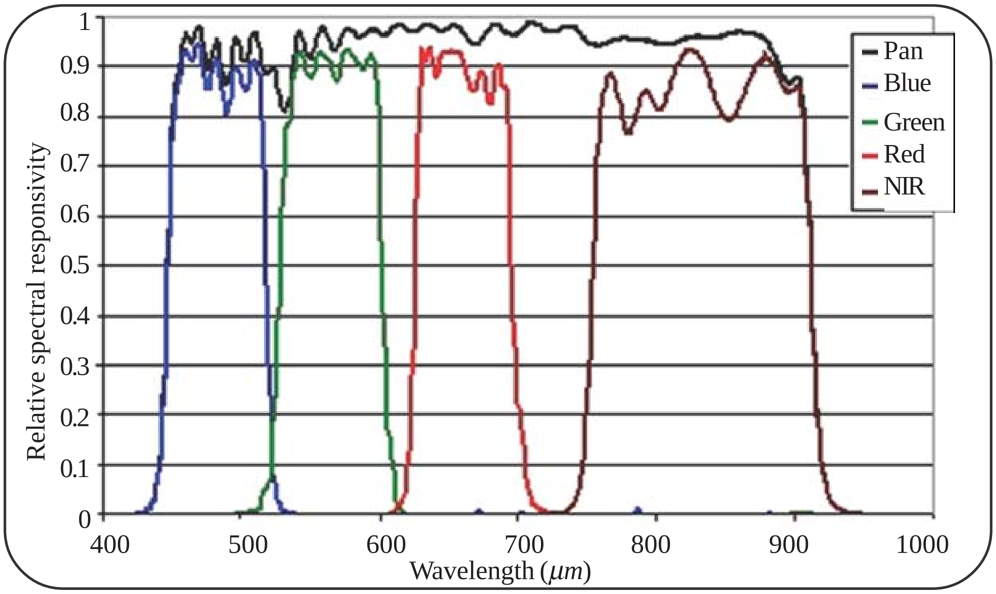

Figure 1. THEOS relative spectral responses (GISTDA 2009)

3. Fast Intensity- Hue- Saturation Fusion Technique

Tu et al. (2004) introduced FIHS with spectral adjustment applied to the "I" image, considering that:

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R + \delta'' \\ G + \delta'' \\ B + \delta'' \\ NIR + \delta'' \end{bmatrix} \qquad (1)$$

when

$$\delta'' = PAN - I'' = PAN - \frac{R + a * G + b * B + NIR}{3} \qquad (2)$$

where "a" and "b" are weighting parameters defined to take into account that the spectral response of the PAN image does not cover that of the Blue and Green bands. The values of these parameters were estimated experimentally after the fusion of 92 IKONOS images, covering different areas. According the experimental results, the best weighting parameters of "a" and "b" for Green and Blue bands are 0.75 and 0.25, respectively.

4. Proper Weighting Parameters Determination in IHS Fusion Technique

The concept of spectral adjustment using proper parameters in IHS fusion method for THEOS imagery follows Tu et al. (2004). To modify the "I" image, the relationship between the relative spectral response of multi-spectral and panchromatic sensors of the THEOS data is considered. In Tu et al. (2004), the parameters "a" and "b" were derived and used to reduce the over values of Blue and Green bands in IHS transformation of IKONOS imagery. In this study we proposed method to improve IHS transformation by increasing values of RED and NIR bands to be close to PAN using two weighting parameters. In other word, the study attempts to find the best parameters, "a" and "b", that best fit to the IHS transformation technique for THEOS data. The best pair of "a" and "b" was selected from 9 THEOS images so that the pan-sharpened images obtained can preserve the most original image characteristics.

The THEOS spectral response (as displayed in Figure 1) is unlike the IKONOS spectral response. Therefore, this study proposes the modification method of IHS pan-sharpening of THEOS images by applying weighting parameters to increase the Red and NIR responses which originally show response lower than of the PAN while the responses of Green and Blue which are about the same as the PAN responses were kept the same as the origin. The proposed method can be expressed as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R + \delta''' \\ G + \delta''' \\ B + \delta''' \\ NIR + \delta''' \end{bmatrix} \qquad (3)$$

when

$$\delta''' = PAN - I''' = PAN - \frac{a * R + G + B + b * NIR}{4} \qquad (4)$$

In this proposed approach, the weighting parameters for the Red and NIR bands were conceptually assumed that combination of "a" and "b" should be equal to 2.22, or "$a + b = 2.22$". Considering the THEOS spectral responses in Figure 1, the responses of Red and NIR can be close to the PAN response when they are multiplied by a weighting parameter ranging from 1 to 1.22, which becomes a value of "a" or "b". To increase the responses of Red and NIR, a value of "a" and "b" should not be less than 1, or "a" and "b" ≥ 1.00. The CCs between the original MS images and the fused images were used as an index to determine the proper values of "a" and "b". The variation of "a" and "b" was operated by increasing and decreasing 0.02 at a time. The varied sets of "a" and "b" were applied to 9 sets of THEOS images and their average CCs were calculated.

The peak of increasing average *CCs* was used to indicate the best set of weighting parameters "*a*" and "*b*".

5. Quantitative Comparison Analyses for Image Quality Examination

The closeness between pan-sharpened and original MS images can be quantified in terms of the correlation function (Veeraraghavan 2004). There are several quantitative indexes employed for pan-sharpened image quality examination. For this study, the *CCs*, *ERGAS*, and *RASE* indexes which express the closeness relationship of the original MS and pan-sharpened images were estimated and used for image quality examination. The quality of pan-sharpened images generated from the methods of Tu et al. (2004) and the proposed were compared by those indexes. The *CC* is computed from:

$$CCs\,(A,B) = \frac{\sum_{i,j}(A_{i,j}-\bar{A})\,(B_{i,j}-\bar{B})}{\sqrt{\left(\sum_{i,j}(A_{i,j}-\bar{A})^2\right)\left(\sum_{i,j}B_{i,j}-\bar{B}\right)^2}} \qquad (5)$$

Where "*A*" and "*B*" are the two images between which the correlation is computed, $\bar{A}$ and $\bar{B}$ are the mean values of the images "*i*" and "*j*", are the number of column and row of the image.

The best spectral information is available in the MS images. The better pan-sharpened image bands should have a correlation closer to those original MS images. It means that the pan-sharpened images have higher quality when *CCs* of each band and their average are higher or closer to 1.

To estimate the global spectral quality of the fused images compared to the original MS images, the index of *ERGAS* and *RASE* were applied. *ERGAS* is used to indicate the overall quality of the fused image (Basaeed et al. 2013). It is defined as (Wald 2000):

$$ERGAS = 100\,\frac{h}{l}\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{RMSE^2(B_i)}{M_i^2}\right)} \qquad (6)$$

Where

h is the resolution of the high spatial resolution image,
l is the resolution of the low spatial resolution image,

M_i is the mean radiance of each spectral band involved in the fusion,

B_i is the original MS bands,

N is the number of spectral bands

RASE expressed as a percentage, it characterizes the average performance of the method in the direct difference of pan-sharpened and original MS images on each spectral band considered. It can be expressed as:

$$RASE = \frac{100}{M}\sqrt{\frac{1}{N}\sum_{i=1}^{N}RMSE^2(B_i)} \qquad (7)$$

Where M is the mean radiance of the N spectral bands (B_i) of the original MS bands. The lower the value of the RASE and ERGAS indexes, the higher the spectral quality of the fused images is considered (Choi, 2006).

6. Result and discussions

The 9 sample sets of THEOS images were employed for determining the proper weighting parameters for pan-sharpening process and examining the quality of pan-sharpened images generated by the use of those parameters. The size of each image set was sampled at 1500 by 1500 pixels. The images cover parts of several land use and land cover types in the west of Mueang district, Nakhon Ratchasima province, Thailand.

6.1 Proper Weighting Parameters Determination

The results of the pan-sharpening process applied to 9 sets of THEOS images using varying sets of weighting parameters (*"a"* and *"b"*) for Red and NIR bands were expressed in term of *CCs* as displayed in Table 2. The increasing average *CCs* of each pair of ""*a"* and "*b"* were calculated and plotted as shown in Table 2 and Figure 2. The best pair of *"a"* and "*b"* which are 1.04 and 1.18 was selected because they indicate the peak of increasing *CC* in the set.

6.2 Quality Examination of Pan-Sharpened Images

The proposed proper weighting parameters ("*a*" = 1.04 and "*b*" = 1.18) were applied to generate pan-sharpened images from 9 sample sets of THEOS images. The parameters of Tu et al. (2004) were also applied to generate pan-sharpened images of the same sets of THEOS images so that the quality of images from both methods could be compared. Two sets of original MS, PAN, and generated images from both methods are displayed as examples in Figure 3.

For quantitative comparison of image quality, the *CCs*, ERGAS, and RASE indexes of each band and set average of 9 sets of pan-sharpened images generated from both methods were estimated and compared in Table 4. From the Table 4, the *CCs* of each band and set average of the proposed method show higher values than of Tu et al. (2004) method for the whole sets of images. Only 3 sets (set 2, set 3, and set 7) of ERGAS show a little lower values of Tu et al. (2004) method than of the proposed while the rest shows considerably lower values of the proposed method than of Tu et al. (2004). For RASE indexes, only 2 sets (set 2 and set 7) of Tu et al. (2004) show a little lower values than of the proposed method while the rest shows considerably lower values of the proposed method than of Tu et al. (2004). By these quantitative comparison analyses, it reveals that pan-sharpened images generated by the proposed method express higher quality.

7. Conclusion

The pan-sharpening process for THEOS images is developed based on the concept of FIHS fusion (Tu et al. 2004) which is operated on IKONOS images. The process

Pairs of Weighting Parameters											
a	1.00	1.02	1.04	1.06	.08	.10	.14	.16	1.18	1.20	1.22
b	1.22	1.20	1.18	1.16	.14	.12	.08	.06	1.04	1.02	1.00
avCCs	0.5999	0.5978	0.5948	0.5922	.5896	.5870	.5816	0.5788	0.5760	0.5732	0.5704
△CCs	0	0.0021	0.00293	0.00258	.00261	.00265	.00272	0.00275	0.00277	0.0028	0.00284

Table 2. Average CCs between original MS and pan-sharpened images and their difference with varying weighting parameters, resulted from pan-sharpening process applied to 9 sets of THEOS images

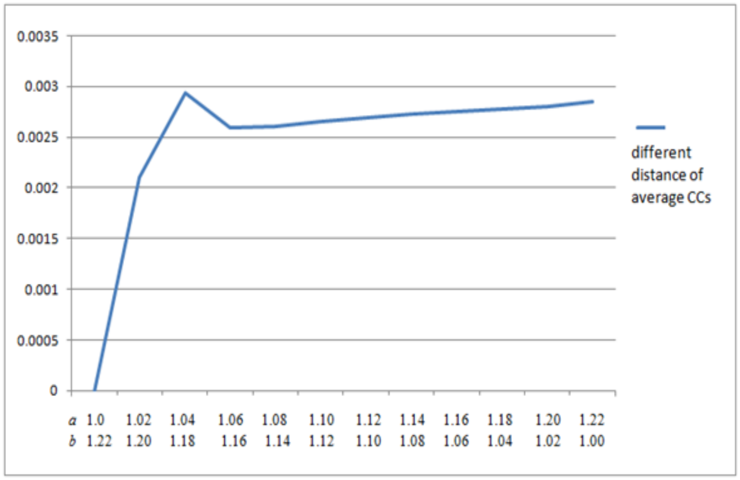

Figure 2. The plot between different distance of average CCs and varying sets of "*a*" and "*b*"

CCs	set 1		set 2		set 3		set 4		set 5	
	Tu	**Proposed**	**Tu**	**Proposed**	**Tu**	**Proposed**	**Tu**	**Proposed**	**Tu**	**Proposed**
Blue	0.1505	0.1481	0.1809	0.1702	0.2336	0.2125	0.0879	0.1039	0.1295	0.1419
Green	0.3945	0.4237	0.4126	0.4354	0.4573	0.463	0.4409	0.4928	0.4949	0.5426
Red	0.7318	0.7592	0.7426	0.7661	0.7332	0.7452	0.8017	0.8327	0.8264	0.8529
NIR	0.7598	0.7889	0.745	0.7745	0.7331	0.7555	0.8468	0.8327	0.8434	0.8679
avCCs	0.5092	0.53	0.5203	0.5366	0.5393	0.5441	0.5443	0.5754	0.5736	0.6013
ERGAS	4.3357	3.8422	4.2114	4.3357	4.1927	4.2087	5.5307	5.3379	5.9461	4.9809
RASE	21.6962	21.3299	23.0521	23.182	23.1367	23.0673	28.51	27.3229	30.3205	26.5128

CCs	set 6		set 7		set 8		set 9		Average	
	Tu	**Proposed**	**Tu**	**Proposed**	**Tu**	**Proposed**	**Tu**	**Proposed**	**Tu**	**Proposed**
Blue	0.1961	0.2071	0.1833	0.2065	0.2326	0.2426	0.2554	0.2701	0.1833	0.1892
Green	0.5199	0.5612	0.5703	0.6208	0.5381	0.5811	0.5546	0.5926	0.4870	0.5237
Red	0.8187	0.8438	0.8803	0.9013	0.8414	0.866	0.8271	0.8516	0.8004	0.8243
NIR	0.7996	0.8283	0.8481	0.8737	0.8831	0.9023	0.9012	0.9166	0.8178	0.8378
avCCs	0.5836	0.6101	0.6205	0.6506	0.6238	0.648	0.6346	0.6577	0.5721	0.5949
ERGAS	5.603	5.0088	3.8139	4.0141	5.9319	5.6966	4.4312	4.1644	4.8885	4.6210
RASE	28.6868	26.0915	15.9833	17.7423	29.7747	28.4769	24.227	22.7627	25.0430	24.0543

Table 4. The comparison of the CCs, ERGAS, and RASE resulted from the methods of Tu et al. (2004) and the proposed

requires proper weighting parameters for spectral adjustment of original MS bands so that their responses are at the same level of PAN appearing in the scheme of THEOS spectral responsivity. Instead of decreasing the responses of Blue and Green bands as operated in Tu et al. (2004), the adjustment of this study aims at increasing

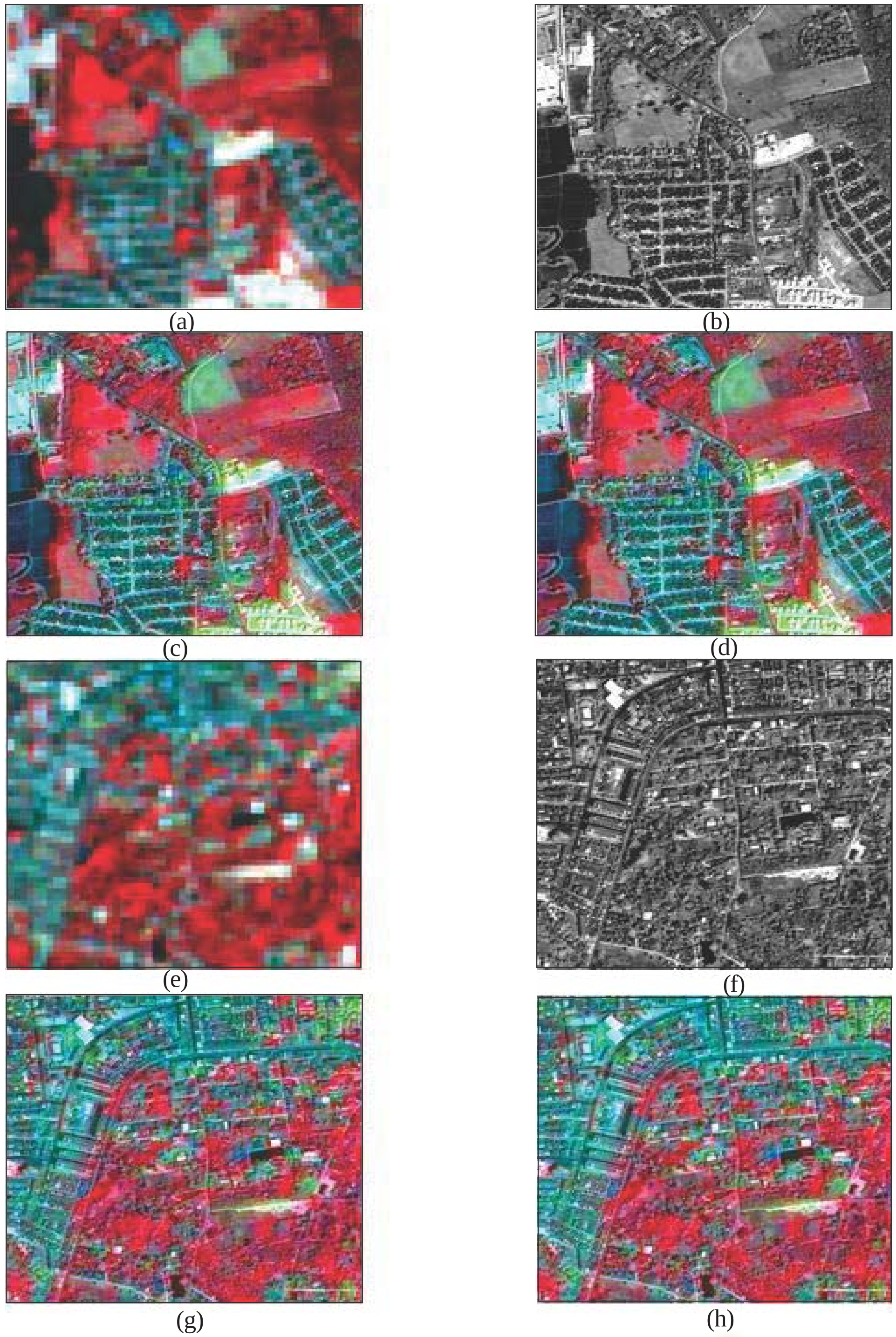

Figure 3 Original images and fused images. (a) Re-sampled original MS images of data set 1. (b) Original PAN image of data set 1. The fused images generated by (c) proposed and (d) Tu et al. (2004) methods of data set 1. (e) Re-sampled original MS images of data set 2. (f) Original PAN image of data set 2. The fused image generated by (g) proposed, and (h) Tu et al. (2004) methods of data set 2

responses of Red and NIR bands while of Blue and Green bands which are about the same level of PAN are kept as the original. To analyze the spatial and spectral quality of the resulting pan-sharpened images from the proposed method, we used indexes i.e. the CCs, ERGAS, and RASE to compare with images fused by the method of Tu et al. (2004). The experimental results show that images fused by the proposed method have a better spectral quality than images fused by the method of Tu et al. (2004). The study results confirm that the fusion method operating based on the concept of spectral adjustment which depends on spectral responsivity of specific sensor is valid. Finally, it can be concluded that the proposed method provides fast computing capability and is very suitable for fusing THEOS images.

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