



Research paper

Quantitative Assessment of Transformation Based Satellite Image Pan-sharpening Algorithms

F. Tabib Mahmoudi^{*}, A. Karami

Department of Geomatics, Faculty of Civil Engineering, Shahid Rajaei Teacher Training University, Tehran, Iran.

Article Info	Abstract
<p>Article History: Received 03 September 2019 Reviewed 12 November 2019 Revised 17 January 2020 Accepted 21 April 2020</p> <hr/> <p>Keywords: Pan-sharpening Quantitative analysis Spectral deviation Transformation based method Satellite imagery</p>	<p>Background and Objectives: Pan-sharpening algorithms integrate the spectral capabilities of the multispectral imagery with the spatial details of the panchromatic one to obtain a product with confident spectral and spatial resolutions. Due to the large diversities in the utilized pan-sharpening algorithms, occurring spatial and spectral deviations in their results should be recognized by performing the quantitative assessment analysis.</p> <p>Methods: In this research, the pan-sharpened images from PCA, IHS, and Gram-Schmidt transformation based algorithms are evaluated for the multi-spectral and panchromatic images fusion of Landsat-8 OLI sensor (medium scale resolution satellite) and WorldView-2 (high-resolution satellite). Quantitative analysis is performed on the pan-sharpened products based on the Per-Pixel Deviation (PPD) measure for spectral deviation analysis and high-pass filter and edge extraction measures for analyzing the spatial correlations. Moreover, entropy and standard deviation quantitative evaluation measures are also utilized based on the pan-sharpened image content.</p> <p>Results: Quantitative analysis represents that increasing the spatial resolution of the utilized remote sensing data has direct impacts on the spectral, spatial, and content-based characteristics of the generated Pan-sharpened products. Gram-Schmidt transformation based pan-sharpening method has the least spectral deviations in both WorldView-2 and Landsat-8 satellite images. But, the amount of spectral, spatial and content-based quantitative measures of PCA and IHS are changing with various spatial resolutions.</p> <p>Conclusion: it can be said that Gram-Schmidt pan-sharpening method has the best performance in both medium-scale and high-resolution data sets based on the spectral, spatial, and content quantitative evaluation results. The IHS pan-sharpening method has better performance than the PCA method in Landsat-8 OLI data. But, by increasing the spatial resolution of the data, PCA generates pan-sharpened products with better spectral, spatial, and content based quantitative evaluation results.</p>
<p>*Corresponding Author's Email Address: fmahmoudi@sru.ac.ir</p>	<p>©2020 JECEI. All rights reserved.</p>

Introduction

Due to the increasing developments of the sensor technologies along with the modern information acquisition techniques, a large volume of remote sensing data with different spectral, spatial, and temporal

characteristics has been provided to users. Various remotely sensed data has valuable information aspects that together can fully provide the information needed by researchers. Performing remotely sensed data fusion to generate new data that contains all the useful aspects

of information in each of the primary data has received much attention in image processing and pattern recognition [1]-[3]. One of the important applications of remote sensing data fusion is to increase the spatial resolution of multispectral imagery to the spatial details of panchromatic, which is called the pan-sharpening method [4], [5]. Pan-sharpening as a pixel level fusion has a wide variety of methods and algorithms. Therefore, researchers in various fields by categorizing the algorithms analyze the characteristics and advantages of them [2], [6]. Since, pan-sharpening algorithms are rapidly developing in some applications such as object recognition, image classification, and change detection, the efficiency of different integration algorithms can be considered as an essential need. The main necessity in pan-sharpening is that the integration algorithm should maintain as much information as possible in the input images. However, pan-sharpening algorithms usually cause some spatial and spectral distortions in the fused image. Therefore, a quantitative assessment is an essential process for content and distortion evaluation of the pan-sharpened image. Choosing the right pan-sharpening algorithm requires a quantitative evaluation of the results of different integration methods. The main objective of image fusion quantitative assessment is to obtain a quantitative estimate of the quality of the resulting image, which requires the definition of an appropriate metric. According to widely use and rapid developments of pan-sharpening algorithms in the satellite image processing and pattern recognition contributions, quantitative assessment metrics are still important in open research topics [3]-[5], [7]-[11]. Table 1 summarizes the investigated literature review in this research into two categories; pan-sharpening performance analysis, and analyzing the efficiencies of quantitative assessment metrics. In this study, the results of Intensity-Hue-Saturation (IHS), Principal Component Analysis (PCA), and Gram-Schmidt transformation based pan-sharpening methods are evaluated based on spectral and spatial reference-based quantitative assessment measures. Moreover, the results are compared with the quantitative assessment based on entropy and standard deviation measures that don't need reference images. The reason for choosing the above-mentioned transformation based pan-sharpening methods is that these methods are available in most common image processing software and in most cases, researchers perform these pan-sharpening methods to increase the spatial resolution of remote sensing images in various applications as a pre-processing step. On the other hand, various types of remote sensing data with a high variety of spatial resolutions are utilized in different applications.

Table 1: Summarizing the literature review of this paper

Category	Research Topic	Publication Date [Ref]
Pan-sharpening performance analysis	PCA & Wavelet transformation based pan-sharpening assessment (for MRI images).	2010 [3]
	Comparing four pan-sharpening methods with a no-reference assessment (on IKONOS & WV2).	2014 [8]
	Spectral and spatial comparison of twelve pan-sharpening algorithms.	2020 [9]
	Quantitative analysis of a new pan-sharpening algorithm pulse coupled neural network.	2019 [10]
Quantitative assessment efficiency analysis	Quantitative analysis of a new pan-sharpening algorithm based on IHS and wavelet.	2020 [11]
	Introducing a new perceptual quality assessment of pan-sharpened images.	2019 [4]
	Performance comparison of pan-sharpening assessment measures.	2012 [5]
	Critical review of quality assessment protocols in pan-sharpening.	2019 [7]

Therefore, in this study, the results of PCA, IHS, and Gram-Schmidt pan-sharpening algorithms are applied to two types of remote sensing data with different spatial resolutions. Landsat-8 satellite imagery was used as a representative of the medium-scale spatial resolution data, and WordView-2 imagery was used as a representative of high spatial resolution data.

The main objective and novelty of this research with regard to the literature review is on performing assessment in dual aspects;

- 1) Comparing the efficiencies of well-known and common transformation based pan-sharpening algorithms in most of the image processing software.
- 2) Investigating the effects of increasing the spatial resolution of the commercial satellite images in pan-sharpening results.

The other point that can be considered as the novelty of this research is multi-modal conclusion based on the spatial, spectral and content quantitative assessment of the pan-sharpened products. In other words, this study in addition to compare the capabilities of PCA, IHS, and Gram-Schmidt transformation based pan-sharpening methods from spectral, spatial, and content points of

view; also analyze the effect of increasing the spatial resolution of remote sensing data on the generated pan-sharpened products.

Transformation Based Pan-sharpening Algorithms

The use of transformation based pan-sharpening methods is based on the fact that after transforming input images to a new space, by applying the appropriate rules, the images are merged and finally the result is obtained by applying the inverse transformation to the image space [12]-[13]. The important point in such image fusion methods is that to perform pan-sharpening, transformation is usually applied only to the multispectral image and then in the new space, the panchromatic image is replaced with one of its parameters. In this way, a multi-spectral image with the higher spatial resolution is generated, which is returned to the image space by applying the inverse transformation on it. According to the different natures of various transformation based pan-sharpening methods, Intensity-Hue-Saturation (IHS), Principal Component Analysis (PCA), and Gram-Schmidt are described in the following sections of this paper.

A. Principal Component Analysis

In the principal component analysis process, statistically correlated variables are converted to non-correlated variables and a compressed and optimal description of the input data is provided. Assuming an input image with dimensions of $M * N$, PCA method seeks to find a basic orthonormal function $W = (W_1, W_2, \dots, W_d)$ $d \ll MN$ so that the desired image can be displayed by a linear combination of these basic vectors [14], [15]. If the principal components of an image are in descending order in the PCA transformation space, the first component has the highest amount of variance in the image and is considered as the parameter containing the spatial detail of the image. This feature has led to the potential for the use of PCA transformation to integrate images with the aim of pan-sharpening [16], [17]. PCA pan-sharpening method has the following steps:

- **Step 1:** Performing PCA transformation on the multispectral input image.
- **Step 2:** Histogram matching of the panchromatic image with the first principal component of the multispectral image.
- **Step 3:** Replacing the first component of the multispectral image in the PCA transformation space with the panchromatic image after histogram matching.
- **Step 4:** Applying the inverse PCA transformation to the new multispectral image to transform it into the original primary space.

B. HIS

Intensity, Hue, Saturation (IHS) is an image display

system that includes the three main parameters intensity, shape, and saturation. Intensity as the first parameter of the IHS system relates to the overall brightness of a color. The parameter Hue corresponds to the color wavelength and the third parameter Saturation indicates the color purity. Since the display of color images in the IHS display system is based on the parameters of human color perception, the use of image transformation method from RGB to IHS color space in the preliminary stages of image processing is very common. The IHS color transformation method effectively separates the weight of the spatial information of the image (Intensity) from the weight of its spectral information (Hue, Saturation). Therefore, this transformation method is useful for performing pan-sharpening by replacing the panchromatic image with the Intensity parameter of the multispectral image in the IHS color space [18], [19].

C. Gram-Schmidt

Gram-Schmidt (GS) transformation is a common method for having orthogonal basic vectors of a space. A matrix or an image can also be used as input in GS conversion. Assuming that the set $S = \{v_1, v_2, \dots, v_n\}$ are the vectors of the orthogonal base of the interior multiplication space V , each vector $w \in V$ can be shown as the linear combination of the base vectors S .

$$w = \frac{\langle w, v_1 \rangle}{\|v_1\|^2} v_1 + \frac{\langle w, v_2 \rangle}{\|v_2\|^2} v_2 + \dots + \frac{\langle w, v_n \rangle}{\|v_n\|^2} v_n \quad (1)$$

Now, if we assume that $\{u_1, u_2, \dots, u_n\}$ is the desired base in the interior multiplication space of V , then using the Gram-Schmidt algorithm we can form the orthogonal base $\{v_1, v_2, \dots, v_n\}$:

$$Proj_v(u) = \frac{\langle u, v \rangle}{\|v\|^2} v \quad (2)$$

The Gram-Schmidt transformation method has been used successfully to integrate images with the aim of pan-sharpening. In this method, unlike IHS color space transformation, there is no limitation on the number of spectral bands that can be processed in pan-sharpening. Gram-Schmidt pan-sharpening method has the following steps:

- **Step 1:** Restore a panchromatic image with the low spatial resolution
- **Step 2:** Applying the GS conversion on the low spatial resolution panchromatic image and multispectral imagery. Here, the low spatial resolution panchromatic image is the first band of GS.
- **Step 3:** Replacing the main panchromatic image (high spatial resolution) with the first band of GS transformation. For this purpose, it is necessary to first match the mean and standard deviation of the high

spatial resolution panchromatic image with the first band of GS conversion.

Pan-sharpening quantitative assessment analysis

As pan-sharpening quantitative assessment methods are based on suitable metrics, and according to the nature of the designed metrics, these methods can be categorized into one of the following two groups [20]:

- Reference-based quantitative assessment methods. In these methods, the information contained in the input images to the fusion algorithm is used as a reference for quality evaluation of the pan-sharpened image. As the main objective of performing pan-sharpening is to increase the spatial resolution of a multispectral image by combining it with the spatial detail of a panchromatic image, for quantitative assessment of pan-sharpened image, it can be spectrally compared with the input multi-spectral image. Moreover, the spatial characteristic of the pan-sharpened image is also evaluated by the input panchromatic image.
- Quantitative assessment methods those metrics are worked without the need for a reference image and only based on the information contained in the pan-sharpened image.

In this paper, the results of applying the PCA, IHS, and Gram-Schmidt transformation based pan-sharpening methods on the panchromatic and multi-spectral WorldView-2 and Landsat-8 images are evaluated quantitatively. For this purpose, quantitative evaluation methods based on spectral and spatial comparison of the pan-sharpened image with input images to the algorithm are utilized. Also, no-reference based quantitative assessment methods are used for evaluating only based on the information content of the pan-sharpened image. In the following sections, after introducing the data sets used in this research, first, each of the utilized quantitative evaluation metrics will be introduced and then, the quantitative assessment results of the pan-sharpened products will be presented and discussed.

Data Sets

For quantitative assessment of the transformation based pan-sharpening methods, panchromatic and multispectral images of WorldView-2 and Landsat-8 OLI sensor are utilized. The WorldView-2 satellite has a panchromatic image with half a meter spatial resolution. Moreover, the multispectral sensor of the WorlView-2 has 8 spectral bands with 2.4 meters spatial resolution. Thus, the generated pan-sharpened image from WorldView-2 panchromatic and multispectral sensors has 8 spectral bands with half a meter spatial resolution.

Landsat-8 OLI sensor has a panchromatic image with 15 meters spatial resolution and a multispectral image with 7 spectral bands and 30 meters spatial resolution.

The generated pan-sharpened image from the Landsat-8 OLI sensor has 7 spectral bands with 15 meters spatial resolution. Detail characteristics of the WorldView-2 and Landsat-8 OLI data are depicted in Table 2.

Table 2: The characteristics of WorlView-2 and Landsat-8 OLI dat

Landsat-8 OLI			WorldView-2	
No	Band	Wavelength (µm)	Band	Wavelength (µm)
1	Blue	0.45-0.52	Coastal	0.40-0.45
2	Green	0.52-0.60	Blue	0.45-0.51
3	Red	0.63-0.69	Green	0.51-0.58
4	NIR	0.77-0.90	Yellow	0.59-0.63
5	SWIR1	1.55-1.75	Red	0.63-0.69
6	TIR	10.4-12.5	Red Edge	0.70-0.74
7	SWIR2	2.09-2.35	NIR1	0.77-0.895
8	PAN	0.52-1.90	NIR2	0.86-0.95

The main reason for performing a quantitative assessment on the pan-sharpened images of these two types of satellite data is their differences in spatial resolution. The WorldView-2 pan-sharpened image has a high spatial resolution and Landsat-8 OLI pan-sharpened image has a medium-scale spatial resolution. Both of the utilized data are taken from the same urban area in San Francisco. The pan-sharpened WorldView-2 satellite image has 9270*10140 pixels with 0.5*0.5 square meters and the pan-sharpened Landsat-8 satellite image has 348*394 pixels with 15*15 square meters.

Spectral Metrics

As it is mentioned in previous sections, for spectral quantitative assessment of the pan-sharpened image, spectral metrics are described those use the input multispectral image as a reference. Per Pixel Deviation (PPD) is the utilized quantitative measure in this research for evaluating the spectral distortions in the pan-sharpened image.

PPD metric: This metric is used to calculate the amount of spectral deviations between each pixel of the pan-sharpened image and the initial multispectral image to the fusion algorithm. Quantitative assessment based on the PPD metric includes the following steps (see Fig.1):

- Step 1:** Decreasing the spatial resolution of the pan-sharpened image as equal to the spatial resolution of the input multispectral image.
- Step 2:** Pixel by pixel differencing between the original multispectral image and the pan-sharpened image with reduced spatial resolution.
- Step 3:** Determining the average differences for each pixel based on the gray values.

The results of performing the PPD metric as spectral quantitative assessments on the pan-sharpened images of Landsat-8 OLI and WorldView-2 are depicted in Table 3. According to the results, the PPD metric shows the

best spectral matches (the least spectral deviations) between the multispectral image and the pan-sharpened one that is generated by the Gram-Schmidt method. For PCA and IHS pan-sharpening methods, there are more spectral deviations in the generated pan-sharpened images. Since the first principal component in PCA transformation, in addition to spatial details, contains some spectral information, totally replacing it with a panchromatic image causes the loss of some spectral information in the resulting pan-sharpened product.

Table 3: Spectral quantitative assessment of pan-sharpened images based on PPD

Methods	Landsat-8 OLI	WorldView-2
PCA	28.2921	0.0663
IHS	15.1158	0.0766
Gram-Schmidt	0.8971	0.0313

This leads to spectral distortions and variations in the pan-sharpening results from the PCA transformation based fusion method.

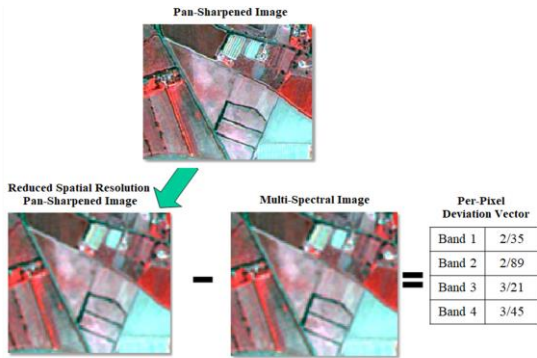


Fig. 1: Per-Pixel Deviation (PPD) quantitative assessment process.

IHS method has the limitation of the number of spectral bands to process. This method applies only to the three spectral bands of the generated pan-sharpened images. Therefore, more spectral deviations may occur.

Spatial Metrics

To spatial quantitative assessments of the pan-sharpened image, some metrics are described those use the input panchromatic image to the fusion algorithm, as reference. The high-pass filter and edge extraction metrics are utilized in this research for the spatially quantitative assessment of the pan-sharpened images from WorldView-2 and Landsat-8 OLI satellite sensors.

High-pass filter metric: As we know, by applying a high-pass filter to the image, its high frequencies can be extracted. Thus, in pan-sharpening algorithms, it is also possible to apply high-pass filters to the panchromatic and the resulting pan-sharpened images for spatially quantitative evaluation of the pan-sharpened algorithm. In this metric, first, a suitable high-pass filter is applied to the input panchromatic image and the generated pan-sharpened image to obtain the high frequencies of these

two images. Then, the correlation coefficient between the filtered panchromatic image and each of the filtered bands of the pan-sharpened image is calculated. The greater correlation between the high frequencies of the pan-sharpened image and the high frequencies of the input panchromatic image means that more spatial details of the panchromatic image have been transferred to the pan-sharpened one.

Edge extraction metric: Another spatially quantitative assessment method of pan-sharpening algorithms is those using edge extraction operators such as Canny for edge extraction from the pan-sharpened image and the panchromatic image entering to the fusion algorithm (Fig. 2).

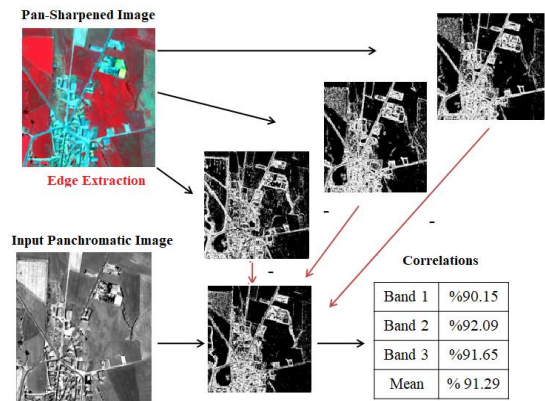


Fig. 2: Edge extraction quantitative assessment process.

The more similar the edge information extracted from the pan-sharpened image is to the edges of the input panchromatic image, the more successful the pan-sharpening algorithm has been in transmitting the spatial detail of the input panchromatic image to the pan-sharpened one. As it is clear in Table 4, both of the edge extraction and high-pass filter metrics indicate the most spatial correlation between Gram-Schmidt pan-sharpened results and the input panchromatic image of Landsat-8 and WorldView-2.

No-reference Metrics

In the group of quantitative assessment methods for evaluating the quality of pan-sharpening algorithms, techniques have also been presented that do not require the use of a reference image in their proposed metrics. In this group of techniques, only using the information extracted from the pan-sharpened image, the quantitative evaluation of the pan-sharpening algorithm can be performed. In the following sub-sections, standard deviation and entropy are described as the well-known no-reference quantitative analysis measures.

Standard Deviation: This criterion performs the quantitative evaluation of the pan-sharpened image without needing reference images and only by obtaining the difference between the pan-sharpened image pixels' gray values and its average value. According to this

evaluation method, the larger the standard deviation, the greater the deviations of the pan-sharpened pixels' gray values from the average, and as a result, the distortion created in the result of the pan-sharpening algorithm is greater. As another description of this criterion, it can be stated that the standard deviation reflects the contrast of the information in the pan-sharpened image.

$$SD = \sqrt{\frac{1}{n-1} \sum_{i=1}^M \sum_{j=1}^N (I_f(i, j) - \mu)^2} \quad (3)$$

In (3), n is the number of spectral bands and μ is the pan-sharpened image average value.

Table 4: Spatial quantitative assessment of pan-sharpened images

Methods	Landsat-8 OLI		WorldView-2	
	Edge	High-Pass	Edge	High-Pass
	Extractio n (%)	Filter (%)	Extraction (%)	Filter (%)
PCA	74.02	29.386	98.18	92.82
IHS	84.89	73.02	89.58	92.89
Gram-Schmidt	86.86	96.72	99.34	92.90

Entropy: The entropy criterion is used to evaluate the information contained in the pan-sharpened image. The greater the information contents in the image, the greater the numerical entropy value. Entropy is sensitive to the noise of the image. In (4), h_{I_f} is the probabilities of the pixels' gray values of the pan-sharpened image I_f .

$$Entropy = - \sum_{i=0}^L h_{I_f}(i) \cdot \text{Log} h_{I_f}(i) \quad (4)$$

The results of entropy and standard deviation quantitative evaluation metrics on the pan-sharpened images are depicted in Table 5 for both Landsat-8 and WorldView-2 satellite images. As it is obvious from no-reference based quantitative evaluation results of Landsat-8 OLI pan-sharpened products, Gram-Schmidt and PCA have fewer amounts of standard deviations, respectively. In WorldView-2 pan-sharpened products also Gram-Schmidt and PCA have the most entropy and the fewer amounts of standard deviations, respectively.

Discussion and Conclusion

In this paper, the pan-sharpened products obtained from PCA, IHS, and Gram-Schmidt transformation based methods are evaluated concerning the five specific spectral, spatial, and content-based measures. In addition to comparing the efficiencies of three different pan-sharpening methods, this study used satellite images with medium and high spatial resolutions those are taken from the same area to determine the impact of increasing the spatial resolution on the quantitative assessment results of pan-sharpened products.

Table 5: No-reference quantitative assessment of pan-sharpened images

Methods	Landsat-8 OLI		WorldView-2	
	Entropy	Standard Deviation	Entropy	Standard Deviation
PCA	4.9996	61.0933	7.3725	53.8688
IHS	6.8784	66.6764	6.6915	62.3462
Gram-Schmidt	5.1032	56.8920	7.3749	51.2074

In the spectral analysis, Gram-Schmidt has the least spectral deviations in both WorldView-2 and Landsat-8 OLI satellite images. The limitation on the number of spectral bands that can be processed in IHS pan-sharpening algorithm (only three spectral bands) is the main reason for more spectral deviations in IHS based pan-sharpened products. Moreover, replacing the first component of the multispectral image in the PCA transformation space with the panchromatic image causes the loss of spectral information of this component. Therefore, the PCA pan-sharpened products have some more spectral deviations than Gram-Schmidt and IHS results (Fig. 3).

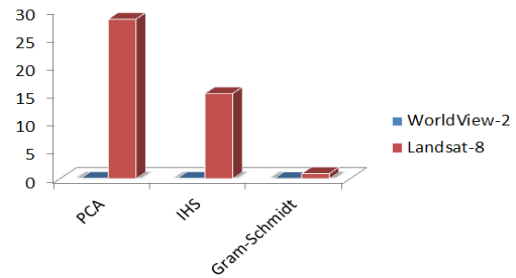


Fig. 3: Spectral quantitative assessment comparison based on PPD measure.

On the other hand, these results confirm the fact that differences in spatial resolution can't affect the Gram-Schmidt pan-sharpening results. However, as it is depicted in Fig. 3, the spectral deviations in the pan-sharpened products of WorldView-2 are less than Landsat-8 pan-sharpened images. The spectral deviations have been reduced for about 0.8658 in Gram-Schmidt, 15.0392 in IHS, and 28.2258 for PCA pan-sharpened products by increasing the spatial resolution of the data from 15 meters to half a meter. Therefore, increasing the spatial resolution can decrease the amounts of spectral deviations in the pan-sharpened images. Spatial analysis of the quantitative assessment results indicates that the most spatial correlations between pan-sharpening products and panchromatic image belong to the Gram-Schmidt pan-sharpening algorithm and PCA and HIS algorithms are in the next grades. According to the spatial analysis results, increasing the spatial resolution of the WorldView-2 pan-sharpened products regarding the Landsat-8 led to increase edge extraction quantitative evaluation results for about 24.16% for PCA, 4.69% for IHS and 12.48% for Gram-Schmidt pan-sharpening algorithms. Moreover,

high-pass filter quantitative assessment results also confirm the advantage of performing pan-sharpening algorithms on the high spatial resolution images. According to the results, most changes in the high-pass filter measure occurred on the PCA pan-sharpening method with 63.43% and then, for the IHS method with 19.96% (Fig. 4).

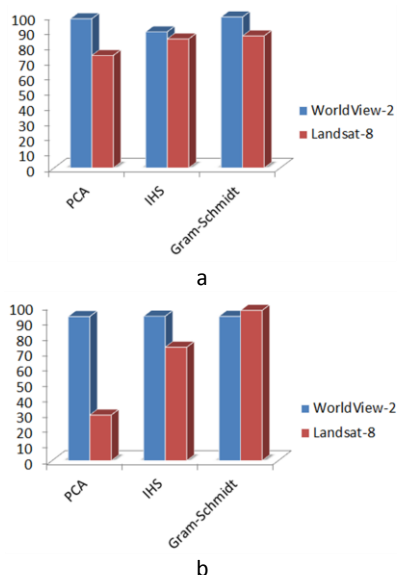


Fig. 4: Spatial quantitative assessment comparison based on a) Edge extraction metric, b) High-pass filter metric.

Content based quantitative assessment measures don't show a significant difference between the efficiencies of Gram-Schmidt, PCA and IHS pan-sharpening algorithms. However, as it is shown in Fig. 5 (a), the amount of entropy is increased with a higher spatial resolution of WordView-2 in PCA (for about 2.3729) and Gram-Schmidt (for about 2.2717) pan-sharpening method. Increasing the spatial resolution almost doesn't have any impact on the IHS pan-sharpening results. Moreover, standard deviations of the PCA, IHS, and Gram-Schmidt pan-sharpened products of WorldView-2 reduced for about 7.2245, 4.3302, and 5.6846, respectively. As a general conclusion, it can be said that Gram-Schmidt pan-sharpening method has the best performance in both medium-scale and high-resolution data sets based on the spectral, spatial, and content quantitative evaluation results. The IHS pan-sharpening method has better performance than the PCA method in Landsat-8 OLI data. But, by increasing the spatial resolution of the data, PCA generates pan-sharpened products with better spectral, spatial, and content based quantitative evaluation results. Therefore, it can be concluded that for medium-scale remote sensing data pan-sharpening, the IHS method can be a good choice. But, for high spatial resolution data such as WorldView-2, the PCA has better pan-sharpening results than the IHS.

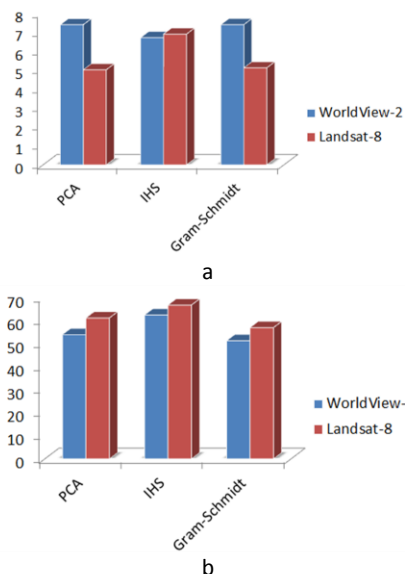


Fig. 5: Quantitative assessment comparison based on a) Entropy, b) Standard deviation

Since, the main objectives of this paper were investigating the efficiencies of transformation based pan-sharpening algorithms based on spectral, spatial and content quantitative assessment metrics, future researches can be conducted in utilizing wavelet algorithm as another transformation based pan-sharpening method. Moreover, applying the capabilities of the Spectral Angle Mapper (SAM) for spectral deviation analysis and Cross Entropy for spatial correlation measurement of the pan-sharpening products should be investigated. Confirming the obtained results in this paper about the well-known pan-sharpening algorithms can eliminate the labor intensive activities for selecting the optimum pan-sharpening algorithm in each image processing or pattern recognition application.

Author Contributions

A. Karami collected the data and applied the quantitative assessment metrics on the pan-sharpened products. F. Tabib Mahmoudi carried out the data analysis, interpreted the results and wrote the manuscript.

Conflict of Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

Aknowledgement

The authors gratefully acknowledges the supports provided by Geomatics department (Remote Sensing branch) of the Civil engineering from Shahid

Rajae Teacher Training University, Tehran, Iran.

Abbreviations

<i>IHS</i>	Intensity-Hue-Saturation
<i>PCA</i>	Principal Component Analysis
<i>GS</i>	Gram-Schmidt
<i>PPD</i>	Per Pixel Deviation
<i>OLI</i>	Operational Land Imager
<i>SAM</i>	Spectral Angle Mapper

References

- [1] G. Vivone, L. Alparone, J. Chanussot, M. Dalla Mura, A. Garzelli, G.A. Licciardi, R. Restaino, L.Wald, "A Critical Comparison Among Pansharpening Algorithms," *IEEE Transactions on Geoscience and Remote Sensing*, 53(5): 2565-2586, 2015.
- [2] S. Yang, M. Wang, L. Jiao, "Fusion of Multispectral and Panchromatic Images Based on Support Value Transform and Adaptive Principal Component Analysis" *Information Fusion*, 13(3): 177-184, 2012.
- [3] M. Deshmukh, U. Behosale, "Image Fusion and Image Quality Assessment of Fused Images" *International Journal of Image Processing (IJIP)*, 4(5): 484-508, 2010.
- [4] O.A. Agudelo-Medina, H. Dario Benitez-Restrepo, G. Vivone, A. Bovik, "Perceptual Quality Assessment of Pan-Sharpned Images," *Remote Sens.* 11(7): 1-19, 2019.
- [5] A. Makarau, G. Palubinskas, P. Reinartz, "Analysis and selection of pan-sharpening assessment measures," *Journal of Applied Remote Sensing*, 6 (1): 1-20, 2012.
- [6] C. Pohl, J.L. Van Jenderen, "Review article Multisensor image fusion in remote sensing: concepts, methods and applications," *International Journal of Remote Sensing*, 19(5): 823 -854, 2010.
- [7] S. Aghapour Maleki, H. Ghassemian, "A critical review of quality assessment protocols in pan-sharpening," in *Proc. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-4/W18, Joint Conferences of SMPR and GI Research: 13-18, 2019.*
- [8] G. Palubinskas, "Quality assessment of pan-sharpening methods," presented at 2014 IEEE Geoscience and Remote Sensing Symposium, Quebec City, QC, Canada, 2014.
- [9] P. Mhangara, W. Mapurisa, N. Mudau, "Comparison of Image Fusion Techniques Using Satellite Pour l'Observation de la Terre (SPOT) 6 Satellite Imagery," *Applied Sciences*, 10(5): 1-13, 2020.
- [10] A.G. Sulaiman, W.H. Elashmawi, G.S. El-Tawel, "A Robust Pan-Sharpning Scheme for Improving Resolution of Satellite Images in the Domain of the Nonsampled Shearlet Transform," *Sensing and Imaging*, 21(3), 2019.
- [11] S.M.A. Wady, Y. Bentoutou, A. Bengermikh, A. Bounoua, N. Taleb, "A new HIS and wavelet based pansharpening algorithm for high

spatial resolution satellite imagery," *Advances in space research*, 66(7): 1507-1521, 2020.

- [12] Y. Choi, E. Sharifahmadian, Sh. Latifi, "Quality Assessment of Image Fusion Methods in Transform Domain," *International Journal on Information Theory (IJIT)*, 3(1): 7-18, 2014.
- [13] S. R. Dammavalam, S. Maddala, K. Prasad MHM, "Quality assessment of pixel-level image fusion using fuzzy logic," *International Journal on Soft Computing (IJSC)*, 3(1): 13-15, 2012.
- [14] H.B. Mitchell, "Image fusion, theories, techniques and applications," Springer-Verlag Berlin Heidelberg, Germany, 2010.
- [15] T. Stathaki, "Image fusion, algorithms and applications," Academic Press is an imprint of Elsevier, Britain, 2008.
- [16] M.R. Metwalli, A.H. Nasr, O.S. Farag Allah, S. El-Rabaie, "Image Fusion Based on Principal Component Analysis and High-Pass Filter," *International Conference on Computer Engineering & Systems*, Cairo: 63-70, 2009.
- [17] V.P.S. Naidu, and J.R. Raol, "Pixel-level Image Fusion using Wavelets and Principal Component Analysis," *Defence Science Journal*, Vol. 58 (3), pp. 338-352, 2008.
- [18] T.M. Tu, S.C. Su, H.C. Shyu, P.S. Huang, "A New Look at IHS- Like Image Fusion Method," *Information Fusion*, 2(2001): 177-186, 2001.
- [19] C. Yang, Q. Zhan, H. Liu, R. Ma, "An IHS-Based Pan-Sharpning Method for Spectral Fidelity Improvement Using Ripplet Transform and Compressed Sensing," *Sensors*, 18(11): 1-20, 2018.
- [20] F. Samadzadegan, F. Tabib Mahmoudi, "Data Fusion in remote sensing concepts and techniques," University of Tehran Press 3316, 2nd Edition, 2014.

Biographies



Fatemeh Tabib Mahmoudi received her B.Sc. degree in civil engineering the branch of Geomatics (Surveying and mapping) from Khajeh Nasireddin Toosi University, Tehran, Iran, in 2004. She received his M.Sc. and PhD degrees in Photogrammetry from Tehran University, Tehran, Iran, in 2009 and 2014, respectively. Since 2016, she has been working as an assistant professor in the Geomatics department of the faculty of Civil Engineering, Shahid Rajae Teacher Training University. She has some publications in the field of remote sensing data analysis, pattern recognition and data fusion.



Adel Karami received his B.Sc. degree in civil engineering the branch of Geomatics (Surveying and mapping) from Tabriz University, Tabriz, Iran, in 2019. Since 2020, he is the M.Sc. student of remote sensing in Geomatics department of the faculty of Civil Engineering, Shahid Rajae Teacher Training University.

Copyrights

©2020 The author(s). This is an open access article distributed under the terms of the Creative Commons Attribution (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, as long as the original authors and source are cited. No permission is required from the authors or the publishers.



How to cite this paper:

F. Tabib Mahmoudi, A. Karami "Quantitative Assessment of Transformation Based Satellite Image Pan-sharpening Algorithms," *Journal of Electrical and Computer Engineering Innovations*, 8(2): 161-168, 2020.

DOI: 10.22061/JECEI.2020.7191.367

URL: http://jecei.sru.ac.ir/article_1458.html

