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Measurement of Quality Preservation of Pan-sharpened Image

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Abstract—In real time remote sensing it is necessary to know the quality of images obtained from the different satellite sensors. Pan-sharpening enhances the spatial information of input raw multispectral images. This paper focuses on the evaluation and analysis of eight frequently used image quality assessment methods to determine the preservation of spectral and spatial integrity in the pan-sharpened images. The eight indexes are entropy, correlation coefficient, mean gradient, standard deviation mean, normalized root mean square error, peak signal to noise ratio, relative average spectral error. Experimental results show that the gamma corrected IHSNSCT pan-sharpening scheme can effectively preserve spectral information while improving the spatial quality, and outperforms the general IHS based pan-sharpening methods.

Keywords—NSCT, RASE, pan-sharpening, gradient

I. INTRODUCTION

The purpose of image pan sharpening is to produce a single image which contains more information about a scene than any of the individual source images [1]. The image fusion between low resolution input raw multispectral (MS) and high resolution panchromatic image is important for a variety of remote sensing applications. Pan-sharpened image should be more helpful for enhancing spectral and spatial information like urban and rural areas of each image. Recently several image quality measurement parameters have been introduced [3]-[5]. In research publications the widely used image fusion quality evolution approaches can be included into two main categories.

The demand for high spatial and spectral resolutions imagery in applications like change analysis, environmental monitoring, cartography, and geology is increasing rapidly. A number of different pan-sharpening algorithms are used to produce images with both high spatial and spectral resolutions [Zhang 2004]. The suitability of these images for various applications depends on the spectral and spatial quality of the pan-sharpened images. Hence, there is a need to quantitatively access the quality of different pan-sharpened or fused images. Quantitative assessment is not easy as the images to be compared are at different spatial and spectral resolutions. This study uses statistical, changes in classification, and feature level change measures to assess the quality of the images. The statistical measures are the spectral mean square error, root mean square error, entropy, correlation coefficients, and histogram based metrics. This paper emphasizes on the assessment and analysis of image pan-sharpening method by measuring the spectral, spatial quality and quantity of enhanced information in different pan-sharpened images. It is evident from the available literature that considerable work has been carried out with respect to image pan-sharpening methods and applications. There are many methods available for image quality evaluation, which include visual comparison, statistical comparison, least mean square deviation computation and variance tabulation. Quantitative assessment is carried out using statistical parameters on IRS ID LISS III images. Therefore there is a need to take up a comprehensive analysis of all the parameters for evaluating the image pan-sharpening methods. The different image quality matrices like entropy, mean, standard deviation, correlation coefficient between a raw multispectral image and pan-sharpened image, correlation coefficient between a pan image and pan-sharpened image, peak signal to noise ratio, normalized root mean square error, mean gradient, relative average spectral error (RASE) are employed on the five image pan-sharpening methods such as Brovey transformation, Principal Component Analysis, Adaptive Intensity Hue Saturation transformation, Intensity Hue Saturation Wavelet Transform (IHSWT) and gamma corrected IHSNSCT pan-sharpening method. The results are compared with the Intensity Hue Saturation Non Sub-sampled Contourlet Transform (IHSNSCT) based image pan-sharpening method.

II. QUALITATIVE /QUANTITATIVE PARAMETERS

2.1 Entropy in the Image Context

To quantify the information of an image (the digital numbers of the pixels) is similar to quantify the information of communication. According to Shannon's assumption, one element of a large number of messages from an information source is just as likely as another, so the digital number of one pixel in an image is just a likely as another pixel. In any one image the number of pixels can be very large. In such cases, to quantify the information content of an image Shannon's assumption can be satisfied. Hence, it is reasonable to use the Shannon's entropy in image analysis. By applying Shannon's entropy in evaluating the information content of an image, the formula is modified as:

$$H = -\sum_{i=1}^{G} d(i)\ ln_2\ d(i)$$

Where G is the number of gray level of the image's histogram ranging for a typical 8-bit image ranges between 0 to 255 and $d(i)$ is the normalized frequency of occurrence of each gray level. To sum up the self-information of each gray level from the image, the average information content is estimated in the units of bit per pixel.

To evaluate the use of entropy in image analysis, simple binary image was tested. Two gray levels 0 and 255 were equally distributed in the image of size 16*16 pixels. Entropy *(H)* was computed as one bit/pixel. The value implied that 1 bit information content was contained in each pixel of this image. If any one of the pixel in this image was extracted, only 1 bit information in either gray level 0 or 255 could be interpreted. Hence, the value indicated the average information content in the image. Moreover, even in a larger sized binary image (such as 32*32), the entropy was also 1 bit/pixel. Although the image sizes are different, any one pixel in these two images could only present 1 bit information. Other than the image size, distribution of gray levels has no effect on the entropy value of an image. For instance to compute the entropy of binary image where the gray levels are of random distribution, the value still yielded 1 bit/pixel. Although the distribution of gray levels could be in various forms, the equal frequency of gray levels still generated the same amount of information content in the image. As frequency of gray level of 255 was decreased, a pixel in this image had a higher probability to present gray level 0 than 255. Any one pixel in an image was more likely to be gray level 0. Less amount of information content was presented, and a decrease in entropy implied a decrease in information content. As a consequence, entropy or average information content of the image is not affected by image size or pattern of gray levels but by the frequency of each gray level.

The 8-bit image illustrate that entropy was governed with number of gray levels and their frequencies. Entropy can directly reflect the average information content of an image. The maximum value of entropy was produced when each gray level of the whole range had the same frequency.

The entropy has been applied in image processing methods as a measure of information but has not been used to assess the affect of information change in pan-sharpened images. The reason is that entropy sees information as frequency of change in the digital numbers in images. It cannot distinguish information belonging to the scene and noise, i.e. from a child image of multi-sensor fusion, if its entropy is higher than the parent images it may be deduced that the child image contains more information than either of the parent images. But it is not clear if that 'more information' is in the form of noise or useful information. The amount of useful information in the pan-sharpened image is given by peak signal to noise ratio parameter and is evaluated in the study.

2.2 Correlation Coefficient (C_C)

The correlation coefficient [29] is one of the parameter used in analysis of image pan-sharpening methods. It is used to determine the amount of preservation of spectral content in two images. The higher correlation coefficient indicates more preservation of spectral content. Given two images the correlation coefficient C_C is given as:

$$C_c = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Where xi, yi are the gray values of homologous pixel synthesized image and real high-resolution image.

2.3 Peak Signal to Noise Ratio (PSNR)

It is the ratio between the maximum possible power of signal and the power of corrupting noise that affects the fidelity of its representation. PSNR is usually expressed in logarithmic decibel. PSNR computes the peak signal to noise ratio value between multispectral and pan-sharpened images. Higher the value of PSNR indicates image is more reconstructed. Its value will be high when the pan-sharpened image and reference multispectral images are similar. Higher the value implies better fusion. This can be given by following equation.

$$PSNR = 20\log_{10}\left(\frac{L^2}{\frac{1}{MN}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(I_M(i,j) - I_s(i,j)\right)^2}\right)$$

Where
L is the number of gray levels in the image.

2.4 Normalized Root Mean (RMSE)

The normalization root mean square error used in order to access the effects of information changing for the fused image. When level of information loss can be expressed as a function of the original multispectral image pixel M_k and fused image pixel F_k, by using normalized root mean square error between M_k and F_k image in band k. The normalized root mean square error $NRMSE_K$ between F_k and M_k is a point analysis in multispectral space representing the amount of change in the original multispectral pixel and the corresponding output pixel using the following equation.

$$NRMSE_K = \sqrt{\frac{1}{nm * 255^2}\sum_{i}^{n}\sum_{j}^{m}\left(F_k(i,j) - M_k(i,j)\right)^2}$$

2.5Relative Average Spectral Error (RASE)

It is the Relative average Spectral Error and characterizes the average performance of a method in the considered spectral bands, RASE is independent of units, the number of spectral bands and accordingly of calibration coefficient and instrument gains. The value is expressed in percentage and has a tendency to decrease as the quality increases. The RASE indexed is expressed as follows.

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

Where M is the mean radiance of the N spectral bands of the original MS bands

2.6 Mean Gradient (MG)

Mean gradient has been used as a measure of image sharpness. The gradient at any pixel is the derivative of the DN values of neighboring pixels. Generally sharper image have higher gradient values. Thus any image pan-sharpening method should result in increased gradient values because this process makes the images sharper compare to the low-resolution image. The gradient defines the contrast between details variation of pattern on the image and the clarity of the image. MG is the index to reflect the expression ability of the little detail contrast and texture of the image. It can be given by

$$\bar{G} = \frac{1}{(m-1)(n-1)}\sum_{i=1}^{m-1}\sum_{j=1}^{n-1}\sqrt{\frac{\Delta I_x^2 \;\; + \Delta I_y^2}{2}}$$

$$\Delta I_x \; = f(i+1,j) - f(i,j)$$

$$\Delta I_y \; = f(i,j+1) - f(i,j)$$

2.7 Standard Deviation (SD)

The standard deviation (σ) which is the square root of variance reflects the distribution or spread in the data. Thus a high contrast image will have large variance and low contrast image will have a low variance. It indicates the closeness of the pan-sharpened image to the original multispectral image at pixel level. The ideal value is zero.

$$\sigma = \sqrt{\frac{1}{N}\;\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

Where x_i is the data vector and $\bar{x}$ is the mean value

$$\bar{x} = \frac{1}{N}\sum_{1}^{N} x_i$$

III. RESULTS AND DISCUSSIONS

The image pan-sharpening or fusion of low-resolution multispectral data (IRS 1D LISS III; 23.5m resolution) was carried out by integrating with high resolution panchromatic data (IRS PAN; 5.8m resolution). Pan-sharpening was attempted using the Brovey transform based pan-sharpening, PCA based pan-sharpening, Adaptive Intensity Hue Saturation (AIHS) based pan-sharpening, Intensity Hue Saturation Wavelet Transform based pan-sharpening (IHSWT) and gamma corrected Intensity Hue Saturation Non Sub-sampled Contourlet Transform (IHSNSCT) based pan-sharpening. This study was carried out over four data sets as mentioned in figure of Hyderabad city, AP**,** India and their vicinity with both urban and rural features. The images used were corrected for system errors and processed in order to reduce speckle and atmospheric influences. The images then are co-registered to make pixels coincide. An improper co-registration of images causes the formation of artifacts in sharpened image and a higher rms error will lead to a higher degree of mis-registration of images. Hence the images considered for image pan-sharpening in this study are co-registered to an rms error of 0.2.

Figure 2 shows different pan-sharpened images. Different qualitative and quantitative measures as stated above are applied on these pan-sharpened images and experimental results are shown in table 1. These pan-sharpened images are compared and evaluated quantitatively and qualitatively using entropy, mean, standard deviation, correlation coefficient between a input raw multispectral image and pan-sharpened image, correlation coefficient between a panchromatic image and pan-sharpened image, peak signal to noise ratio, normalized root mean square error, mean gradient, relative average spectral error. After computation of quality parameters of conventional and non conventional pan-sharpening methods, from the results it is observed that entropy value is more in gamma corrected IHSNSCT sharpening method followed by AIHS and PCA. This is because in gamma corrected IHSNSCT transformation method the gray level value of each pixel is modified by panchromatic image and gamma error correction of intensity component. But the correlation coefficient between input raw multispectral and PCA sharpening method is more compare to IHS methods [11], which is an indication of more spectral content. It is evident from the comparative study that PCA imparts better improvement among Brovey and IHS based pan-sharpening methods. Among, all the methods of image pan-sharpening, it is observed that gamma corrected IHSNSCT based image sharpening method provide the highest entropy of 7.6216, correlation of 0.89 between the pan-sharpened image and multispectral image. However the correlation coefficient of other methods depends on the characteristics of area. Hence, gamma corrected IHSNSCT method improves and preserves spectral characteristics in the pan-sharpened image to the some extent. Mean gradient value is high in gamma corrected IHSNSCT method it indicates that this method preserves more spatial information.

It has been observed that Intensity Hue Saturation Wavelet Transform based sharpened image (IHSWT) and IHSNSCT based sharpened image has a "better look" compared to the original raw multispectral image. Almost all the features like urban, vegetation and water are well presented and the color scheme is virtually good as the original input raw MS image. Thus with a visual estimate, result of the Intensity Hue Saturation Wavelet Transform (IHSWT) and IHSNSCT are considered to be the best among all the pan-sharpening methods. The spatial parameters evaluated are found to be high for gamma corrected IHSNSCT method than other methods. Entropy is high in IHSNSCT method sharpened image indicates that the information content is more in this image. NRMSE (0.081) and RASE (12.09) values are less in PCA based pan-sharpening than Brovey and IHS methods. It indicates PCA method preserves more spectral information.

In gamma corrected Intensity Hue Saturation Non Sub-sampled Contourlet Transform (IHSNSCT) method of pan-sharpening the mean gradient (11.98) value is more compared to other methods of pan-sharpening. Correlation coefficient between input raw multispectral image and pan-sharpened image is always high in IHSNSCT method, it is an indication of high colour integrity in IHSNSCT method and enhancement of spectral quality information also more. Hence, it is substantiated quantitatively that gamma corrected Intensity Hue Saturation Non Sub-sampled Contourlet Transform (IHSNSCT) is a powerful method for image pan-sharpening. It is observed that the IHSNSCT method has high Peak signal to noise ratio compared to other methods. This is an indication of information improvement rather than noise.

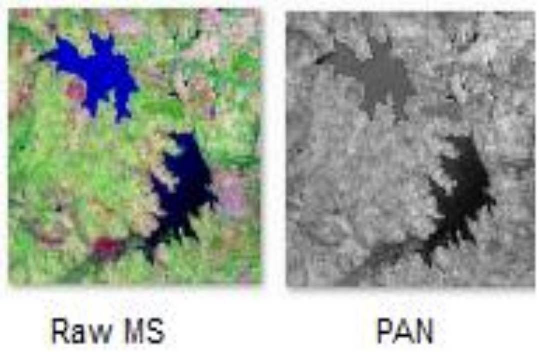

Fig1: **Input raw multispectral and pan images**

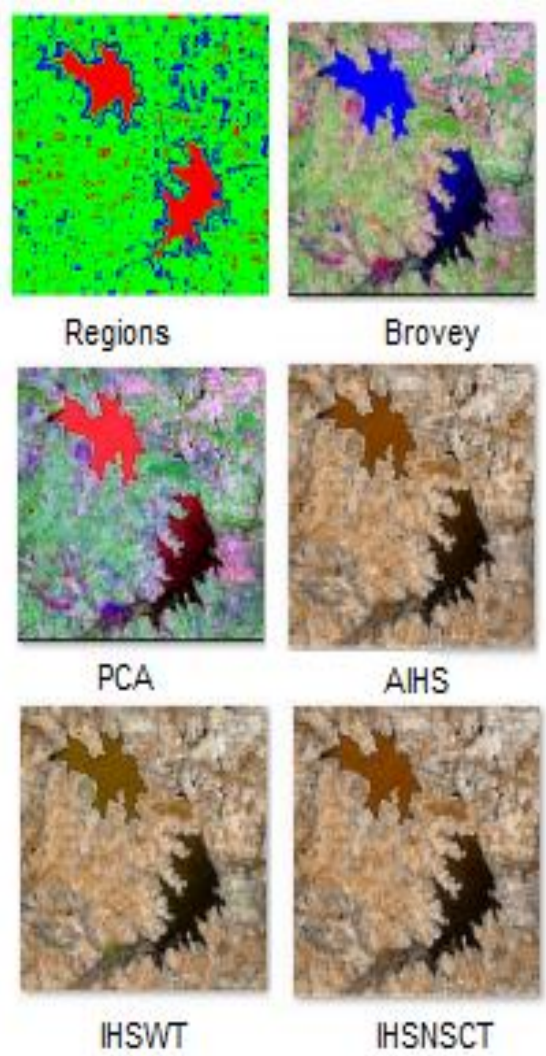

Fig 2: **Regions and Different pan-sharpened images**

Table 1. **Comparison results of qualitative and quantitative information of pan-sharpened images.**

Quality Matrix / Pan-sharpened Methods	Entropy	Mean	SD	CC with Raw MS Image	CC with Pan Image	PSNR	NRMSE	RASE	MG
Brovey	7.5930	131.6384	51.663	0.8912	0.6254	28.23	0.0912	14.78	10.91
PCA	7.7080	132.4248	46.572	0.8983	0.5217	26.12	0.0811	12.09	8.82
AIHS	7.6200	135.7635	46.074	0.8256	0.6177	27.67	0.0900	14.98	10.90
IHSWT	7.6042	136.9904	45.664	0.8866	0.5912	27.16	0.0878	14.32	11.12
IHSNSCT	7.6216	137.5430	45.273	0.8952	0.6698	29.01	0.0831	13.98	11.98

IV. CONCLUSIONS

This study has demonstrated the potentials of image pan-sharpening methods as a tool for improving the performance of low-resolution images. Among the image pan-sharpening methods analyzed, PCA is found to be the best method followed by AIHS and Brovey transform. This is in terms of preserving the spectral characteristics for visualization. IHSWT and IHSNSCT methods both clearly sharpen the original image and greatly improve the spatial quality. This is also ascertained by the highest correlation coefficient between panchromatic image and gamma corrected IHSNSCT method. This is an indication of more spatial content is preserved in IHSNSCT sharpened image. Mean gradient and peak signal to noise ratio values demonstrate that the IHSNSCT is the best pan-sharpening method. Spectral content preservation is more in PCA method this can be viewed from error relative global synthesis and relative average spectral error values (RASE). A peak signal to noise ratio in gamma corrected IHSNSCT method when compared to the various image pan-sharpening methods also ascertains that improvement of multispectral information content is more for IHSNSCT transform method compared to AIHS, IHSWT and Brovey methods. It is concluded that gamma corrected IHSNSCT method preserves original spectral content and enhances and improves the spatial information of input images.

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