International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 08 | Aug 2019 www.irjet.net p-ISSN: 2395-0072

Lunar Image Fusion Based on DT-CWT, Curvelet Transform and NSCT

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Abstract - *The process of combining information from high spectral resolution lunar image and high spatial resolution lunar image is known as multi sensor lunar image fusion. The multi spectral lunar image usually consists of images in different bands. The features and missing locations of various moon surface images from various instruments can be extracted and viewed accurately using image fusion. Previously various methods have been used for multi sensor image fusion. To extract features of the moon surface, this paper involves image fusion methods based on Dual Tree-Complex Wavelet Transform (DT-CWT), Curvelet transform and Nonsubsampled Contourlet transform (NSCT). The spectral resolution of the fused image is preserved after image data fusion. The fused lunar image also shows good spatial information. From the results of statistical evaluation parameters demonstrated for the study site, the results of the used techniques are found and are compared.*

Key Words: *Curvelet Transform, DTCWT, Image Fusion, Lunar Image, Multi Sensor, NSCT.*

1. INTRODUCTION

The process of combining two or more images to form a new image by using a certain fusion rule is known as image fusion [1][2]. The use of image fusion in current image processing systems is increasing, mainly because of the sophisticated image acquisition techniques. There are many conventional image fusion algorithms. These can be classified as (a) projection and substitution methods, as Intensity- Hue-Saturation (IHS) color fusion, and Principal Component Analysis (PCA) fusion; (b) band ratio and arithmetic combination, such as Brovey, multiplicative and Synthetic Variable Ratio (SVR), and (c) the wavelet fusion techniques in which spatial features from high resolution image is fused into low resolution image [7][9].

Image fusion methods can be classified into two – Transform domain and spatial domain. The fusion methods such as averaging, Brovey method, PCA and IHS based methods come under spatial domain fusion. In case of spatial domain methods, there is a drawback. There will be spectral distortion in the fused image. Spectral distortion can be reduced by using transform domain image fusion. The multi resolution analysis has become a very useful tool for analyzing remote sensed images [4].The wavelet transform concentrate more on vertical and horizontal features. In order to retain features from different angles, the curvelet transform is useful [3][5]. But NSCT is multi scale in nature. With its flexibility, multi direction quality, and shift invariant image decomposition, it can be efficiently implemented in image fusion [8]. This method shows a better performance in spatial and spectral quality of the fused image compared to other methods of fusion.

In this paper, NSCT fusion method is proposed to obtain appreciable spatial and spectral resolution and the results are compared with DTCWT and Curvelet transform methods. This paper is organized as follows. In Section II describes the study area and dataset used, Section III describes the methodology for DTCWT, curvelet transform and NSCT, Section VI discusses the results and analysis of the fused image and Section V concludes the paper with future work.

2. IMAGE DATASET

Lunar image data set is acquired from the Indian satellite Chandrayaan-1, HySI and TMC. Hyperspectral Imager (HySI) of Chandrayaan-1 has spatial resolution of 80 m and performed mapping in the 400-900 nm band with spectral resolution of 15nm with swath coverage of 20 km. Terrain Mapping Camera (TMC) of Chandrayan-1 has spatial resolution of 5 m with 20 km swath. The input study area is shown in Fig -4. (a) and (b).

3. METHODOLOGY

3.1DT-CWT Fusion

The DT-CWT has its real and imaginary parts of transform split into two trees. The real part of this complex wavelet is obtained as the difference of two separable wavelets and is oriented in -450. Real 2D wavelet oriented at +450. Four more oriented real wavelets in the direction of +750, -750, +150 and -150 can be obtained. The real part of the complex Dual Tree wavelet Transform alone constitutes the Real Oriented 2D Dual Tree Transform. This transform has six distinct directions and there will be two wavelets in each direction. It gives a perfect reconstruction as the filters are chosen from a perfect reconstruction bi-orthogonal set. It is applied to lunar images using complex filtering which is separable, in two dimensions. It can be chosen over DWT as it gives good results. The methodology of DTCWT based image fusion is shown in Fig -1.

The low spatial resolution multispectral image is a histogram matched with the high resolution image. The complex wavelet transform is applied to high spatial resolution image and low spatial resolution image. In complex wavelet transform two DWT with different filters are used, this decomposes the image into two approximations subbands and six detailed subbands.

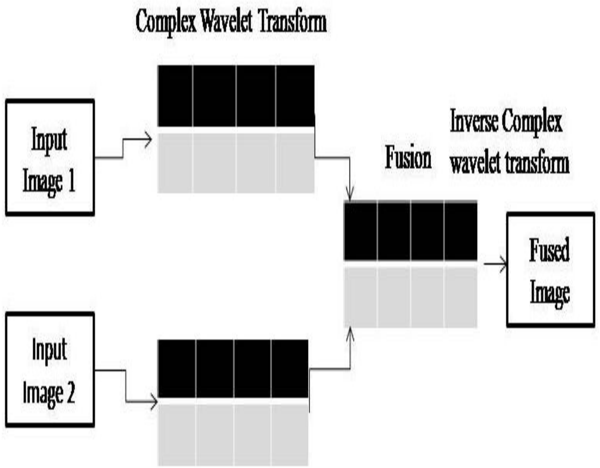


Fig -1: Architecture for Dual Tree Complex Wavelet Transform (DTCWT) Image fusion

The two approximation subbands has the low frequency components which are filtered using two different opposite direction filter. The six detailed subbands have high frequency components, which are symmetrically opposite in direction. The approximation subbands are fused using averaging fusion rule and the detailed coefficients are also fused using the averaging method. Then the inverse complex wavelet transform is applied to get the fused image.

3.2 Curvelet Fusion

Curvelet is used to represent an image at different scales and different angles. It is like an extension of the wavelet transforms [6][11]. The curvelet transform is the multi scale transform which consists of directional elements. The methodology of curvelet image fusion is shown in Fig - 2.

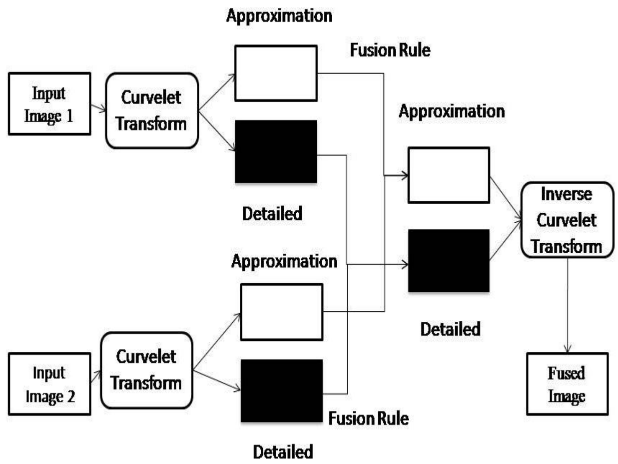


Fig -2: Architecture for Curvelet Image Fusion

The low spatial resolution multispectral image is resampled to the size, high spatial resolution image using a bilinear interpolation technique. Curvelet transform is performed to both high spatial resolution image and the low spatial resolution image; both the images are decomposed into the approximation and detailed coefficients. The low frequency components of the decomposed image are fused using the averaging method. The high frequency components are fused using different fusion rules like maximum method. Inverse curvelet transform to obtain the fused image.

3.3 NSCT Fusion

NSCT is a flexible and shift invariant computational framework suitable for lunar images. There will be two stages, Non-Subsampled Directional filter bank and Non-Subsampled Pyramid [10]. In the non-subsampled directional filter bank, the direction decomposition occurs in x stages in high frequency from non-subsampled pyramid at each scale and gives $2x$ directional subimages as input image. With the help of two channel filter banks, one image of high frequency and one image of low frequency can be produced at each level of non-subsampled pyramid decomposition. The subsequent decomposition is performed to decompose the low-frequency components of the image. Non-Subsampled Pyramid results in y+1 subimages. It consists of one low-frequency image and y high-frequency images with same size as that of the input image, where y is number of levels of decomposition.

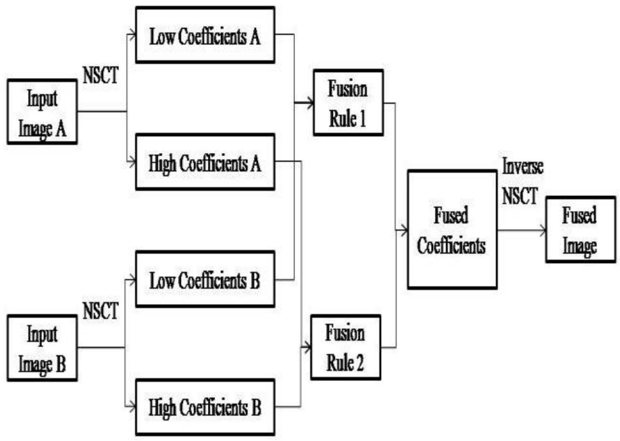


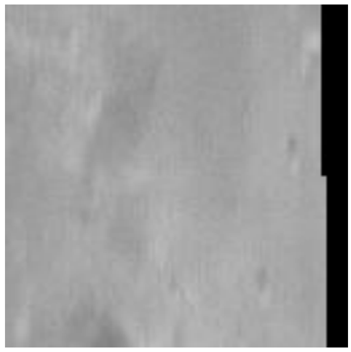
Fig -3: Architecture of NSCT Image Fusion

Firstly, we take the image and apply NSCT to get low-frequency and high-frequency subimages. Then fusion of low-frequency subimages is done using Pulse coupled neural network (PCNN) method. Later the fusion of high-frequency sub-image is also done using PCNN method. After this, *l*-level Inverse NSCT is performed on the fused low-frequency and high-frequency sub-images is done to get the fused image. The process of NSCT image fusion is shown in Fig -3.

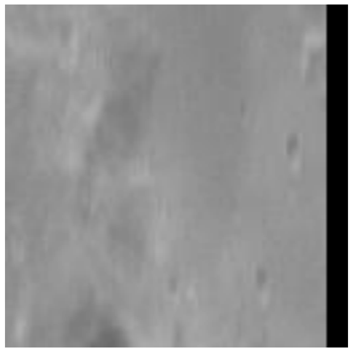
4. RESULTS AND DISCUSSIONS

Fusion of the high spatial resolution image of TMC and high spectral resolution image of HySI is performed using the three methodologies stated in Section III and the output of study area is shown in Figure 5.

Using visual and statistical parameters, the fused images are compared. It is observed that most of the fused images shows good enhancement in spatial details of the moon surface due to different illumination angle of the input images. Visual comparison indicates that NSCT fusion shows better visual interpretability of craters compared to the other fusion techniques. The contrast features present in high resolution image and low resolution image are highly visible in the fused image. But the spectral characteristics of the multispectral image were well preserved in NSCT fusion since the fusion takes in the spectral domain, which is evident from Correlation coefficient, Entropy and Average gradient in Table 1.

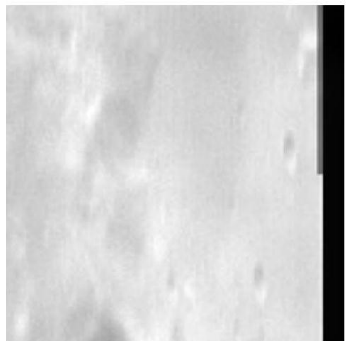


(a)

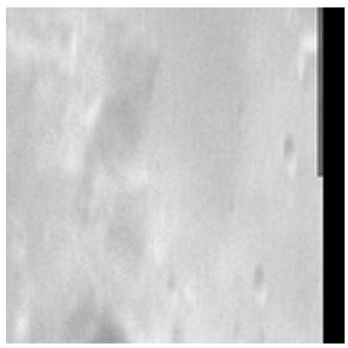


(b)

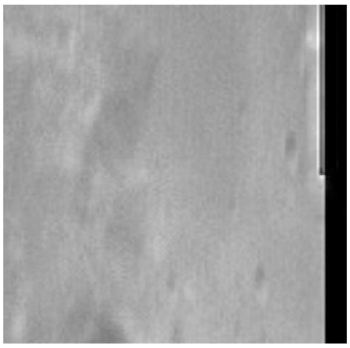
Fig -4: (a) High spectral resolution image (Chandrayaan HySI 80m), **(b)** High spatial resolution image (Chandrayaan TMC 5m)



(a)



(b)



(c)

Fig -5: (a) DTCWT Fusion, **(b)** Curvelet Fusion and **(c)** NSCT Fusion

Table -1: Statistical Evaluation of Image Fusion for the input Study Area

Statistical Parameter	Band	Fusion Techniques		
		DTCWT	Curvelet	NSCT
Correlation Coefficient	Band 1	0.9920	0.9928	**0.9987**
	Band 2	0.9975	0.9982	**0.9994**
	Band 3	0.9863	0.9868	**0.9976**
	Band 4	0.9819	0.9825	**0.9967**
	Band 5	0.9983	0.9995	**0.9996**
Standard Deviation	Band 1	41.3228	41.3370	**47.1759**
	Band 2	38.9459	38.9778	**41.7462**
	Band 3	38.7510	38.7860	**41.8890**
	Band 4	38.1223	38.1933	**41.0190**
	Band 5	36.5783	36.5970	**36.9006**
Entropy	Band 1	0.3960	0.3279	**0.4604**
	Band 2	0.3889	0.3218	**0.5512**
	Band 3	**0.3883**	0.3218	0.3466
	Band 4	**0.3835**	0.3218	0.2867
	Band 5	0.3873	0.3218	**0.5360**
RMS Error	Band 1	21.8023	20.8726	**2.3813**
	Band 2	12.6555	11.6747	**1.4963**
	Band 3	11.1648	10.4636	**2.9502**
	Band 4	9.2809	8.8848	**3.3769**
	Band 5	3.0423	1.7691	**1.0671**
Average Gradient	Band 1	18.0173	19.8021	**28.3858**
	Band 2	15.8016	16.7597	**21.9935**
	Band 3	14.9826	16.0375	**21.3210**
	Band 4	14.2921	15.4590	**20.0218**
	Band 5	14.3247	14.7708	**17.0609**
	Band 5	14.3247	14.7708	**17.0609**

The correlation coefficient gives the relation between the original image and the fused image. Its range is from 0 to 1. If the correlation coefficient is 0, this means that there is no relation between the fused image and the original image. If the value is 1, it means that the fused image is highly related to the original image. Standard deviation means the deviation of the fused image from the original image. Entropy is used to calculate the amount of information in an image. High entropy means high amount of information is being retained. RMS Error represents the amount of error between the fused image and the original image. The low value of RMSE represents better performance. Average Gradient describes the amount of visual information present in an image.

From the results of correlation coefficient, the method of NSCT fusion retains 99.84 % of spectral information. The method of DTCWT retains 99.12 % and the curvelet method retains 99.19 %. This implies that the NSCT image fusion retains more spectral information than that of the DTCWT and curvelet image fusion. The standard deviation of the NSCT fusion is 41.74614 whereas DTCWT and curvelet fusion have the values of 38.74 and 38.77 respectively. The entropy of the NSCT fused image is 0.4362 which is more when compared to DTCWT and curvelet fused image entropy values of 0.3888 and 0.3230 respectively. From RMS error, it is revealed that the NSCT fused image has less error compared to the DTCWT and curvelet fused images. The average gradient value of the NSCT fusion method is 21.76, which is more than the value of DTCWT and curvelet methods having 15.48 and 16.57 respectively. Overall, the NSCT fused lunar image has good clarity and better performance when compared to fused lunar images of the other techniques used.

5. CONCLUSION

The average values of statistical parameters considered are calculated for the fusion methods to obtain the statistics. The obtained statistics are compared with the dual tree complex wavelet transform and curvelet transform. The higher value in the average gradient and entropy indicates that the spatial information is much retained in the NSCT method. Higher values in correlation coefficient indicate that the spectral information is well preserved in the NSCT fusion. The lower value of root mean square error of NSCT method shows that there is less amount of error between the fused and the original image. Good spatial fidelity is shown by NSCT image fusion. The spectral features are also retained in a good manner in case of NSCT fusion method. So, it can be concluded that nonsubsampled contourlet transform (NSCT) produced better results for the lunar image data fusion compared to the other methods used.

ACKNOWLEDGMENT

We acknowledge the use of data from the Chandrayaan-1, first lunar mission of the Indian Space Research Organization (ISRO), archived at the Indian Space Science Data Center (ISSDC).

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