A Pan-Sharpening Based on the Non-Subsampled Contourlet Transform and Discrete Wavelet Transform

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Abstract-Pan-sharpening methods based on the non-subsampled contourlet transform (NSCT) and discrete wavelet transform (DWT) are proposed. NSCT is shift invariant version of contourlet transform and it is a very effective method in capturing intrinsic geometrical structures of the objects and describing the directional information of the image. NSCT has characteristics of high resolution, shift-invariance, and high directionality and DWT is widely used in pan-sharpening due to its properties such as multiresolution, localization, critical sampling, and limited directionality (horizontal, vertical, and diagonal directions). So the technique can be enhanced by combining NSCT with DWT. Since lower number of decomposition levels maintains better spectral quality, whereas higher number of decomposition levels maintains the spatial quality, therefore in proposed system a lower number of decomposition levels are used for multispectral (MS) images whereas a higher number of decomposition levels are used for pan chromatic images (PAN). This retains both spectral qualities and spatial qualities of an image, and due to lower number of decomposition levels for MS image the computation time can be decreased. Additionally NSCT is performed before up sampling the MS image and not after, this would more likely to retain the detailed information and structures of the MS image. Using NSCT- algorithm in pan sharpening the technique can be enhanced so that more efficient and more informative pan sharpened image can be obtained for scientists and astronomers applications. Combining DWT with NSCT algorithm the scheme can be enhanced so that efficient pan sharpened image can be obtained.

Key words— Discrete Wavelet Transform (DWT), Non-subsampled contourlet transform (NSCT), Shift invariant, Upsampling.

I. INTRODUCTION

Remotely sensing applications are increasing now a days such as satellites, medical harnesses etc. The satellites observe the earth from very far distance and because of technological and physical restrictions the satellite sensors cannot produce more informative images that is they cannot produce images having both high spectral resolution and high spatial resolution. Either they provide an image with high spectral resolution or an image with high spatial resolution. Basically satellite sensors produce two types of images, one the pan-chromatic (PAN) images and other is the multispectral images (MS). Pan-chromatic images will be having high spatial resolution and low spectral resolution whereas multispectral images will be having high spectral resolution and low spatial resolution. In some areas like medical diagnosis, wildlife habitat, map construction, and in scientists and astronomers work there is a need of an image which has both high spectral resolution and high spatial resolution, for this reason pan sharpening came into existence in image processing. The word Pan-sharpening is produced by 'Pan-chromatic-sharpening', it means considering a pan-chromatic images to 'sharpen' a multispectral image.Here sharpen means increasing the spatial resolution of the multispectral image. The combination of spatial information extracted from pan-chromatic images into the multispectral image results an image with both high spatial resolution and spectral resolution, this technique is known as pan-sharpening. In other words pan sharpening is the process of integrating high resolution panchromatic and lower resolution multispectral image to obtain a one high resolution color image.

In this paper, pan sharpening performed is based on the advanced NSCT transform it is different from the standard NSCT based pan sharpening. The proposed NSCT based pan sharpening uses the different number of decomposition levels for both MS and PAN image, which it uses lower number of decomposition levels for MS image and higher number of decomposition levels for PAN image, because Lower number of decomposition levels preserves better spectral quality, whereas higher number of decomposition levels maintains the spatial quality. And it improves the method by using relevant up sampling algorithm. Applying up sampling after applying the NSCT transform is more likely to preserve the structural and detail information (edges) of MS image. Interpolation algorithm is used for up sampling. NSCT is a shift-invariant version of contourlet transform (CT) and has some excellent properties including multilevel and multidirectional properties. NSCT provides a better representation of the contours and NSCT eliminates the down samplers and the up samplers during the decomposition and the reconstruction of the image, therefore using NSCT technique for pan-sharpening improves the both spectral and spatial qualities of multispectral image. DWT is most widely used transformation for pan-sharpening because it has excellent properties and also some drawbacks so combining NSCT and DWT the quality of images can be enhanced.

Advantages of Proposed Method

- The drawback of Wavelet can be overcome by contourlet transforms.
- Using NSCT based pan-sharpening computation time can be decreased.
- Combining DWT with NSCT algorithm the scheme can be enhanced so that efficient pan sharpened image can be obtained.
- Improves the spatial and spectral quality by combining DWT-NSCT.
- Moreover up sampling of MS images is performed after NSCT and not before. By applying up sampling after NSCT, structures and detailed information of the MS images are more likely to be preserved.

II. NON-SUB SAMPLED ONTOURLET TRANSFORM

Pan-sharpening is generally performed using a multilevel decomposition to get high and low frequencies separately. Multilevel decomposition methods used by Pan-sharpening decompose MS and Pan images, and then introduce spatial details extracted from Pan into MS image that are missing in MS images. Many number of pan-sharpening methods have been invented based on the wavelet transform [10]. They provide satisfactory results but, it is shown that CT is a better method than the wavelet transform. CT is able to find and join the points of breaks in continuity to form a linear edge (contours). It is done by a multilevel transform followed by a local directional transform. Wavelet-like coefficients are grouped by using the local directional filter bank (DFB) to obtain a smooth contour [11]. A shift-invariant version of CT is a NSCT and it has some very good properties including multilevel and multidirectional properties. NSCT gives a better description of the edges (contours) of an image. CT employs the Laplacian pyramid for multiscale decomposition and the DFB for directional decomposition. To reduce the frequency aliasing of CT and to accomplish the shift invariance, NSCT eliminates the down samplers and the up samplers during the decomposition and the reconstruction of an image.

NSCT is built upon 1) The non-subsampled pyramid filter banks (NSPFBs) and 2) The non-subsampled directional filter banks (NSDFBs), as shown in Fig. 1 [12].

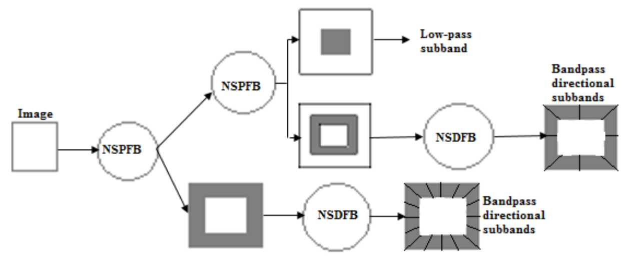

Fig 1. Non-subsampled contourlet transform

III. DISCRETE WAVELET TRANSFORM

For repeated decomposing an image discrete wavelet transform DWT is used as a mathematical tool. DWT decomposes an image into frequency sub band at different scale from which it can be correctly reconstructed. DWT divides the image signal into high frequency and low frequency components. The low frequency component incorporates coarse information of an image signal and high frequency component incorporates information of edge components of an image. It is a multi-scale analysis technique. Two dimensional discrete wavelet transform (2D DWT) implements image fusion. The quality of an image is to evaluate amount of detail information in the image, it's increased by filtering method of wavelet transform and the scale is changed by sampling method.

Discrete wavelet transform is applied to both type of PAN and MS satellite images to produce the coefficients for these images. The coefficients of these images are fused and inverse DWT is applied to produce pan-sharpened image. The image is converted from the spatial domain to frequency domain using DWT. The image is divided by vertical and horizontal lines and represents the first order of DWT, and the image can be represented by four parts LL1, LH1, HL1 and HH1 respectively. At every level there are two sets of coefficients

1) Approximation (LL)
2) Detail (HL, LH and HH).

During first level decomposition first DWT is performed in the vertical direction, followed by horizontal direction. The first level of decomposition produces four sub bands namely LL1, LH1, HL1, and HH1. For the next level of decomposition, the previous level is used as the input because the edges details of an image is present in the detailed coefficients mainly in HH and not in the approximation coefficients. This process will be continued till the decomposition levels reach to the specified level.

IV. RELATED WORK

Till now there are many pan sharpening techniques have been invented those increase the spatial resolution of the color multispectral image by extracting the spatial information from the pan chromatic images but those have some drawbacks.

1**.** V. P. Shah, N. H. Younan, and R. L. King,“An efficient pan-sharpening method via a combined adaptive PCA approach and contourlets,”(2008) [1]has studiedStandard PCA fusion in which in adjacent band of the spectrum, land cover types likely to behave similar, introducing a significant amount of redundancy in information gathered by the sensor. Here this redundant information will be arranging in such a way that each output band is uncorrelated with the others by using the principle component analysis (PCA). There is greater correlation between the neighboring pixels of a multispectral image both spectrally and spatially, this makes the use of efficient data transformation approach mandatory before performing pan-sharpening. Principal component analysis (PCA) and Wavelets methods are the popular choice for spectral and spatial data transformations respectively. Recently used PCA-based pan-sharpening technique will make an assumption that the very first principal component (PC) of greater variance is a perfect choice for substituting or replacing it with high spatial resolution details from the histogram matched greater resolution panchromatic (PAN) image. In this paper they proposed a combined PCA and contourlet approach for pan-sharpening, here the PCA is used to minimize the spectral distortion and the use of non-subsampled contourlets for spatial data transformation in pan-sharpening. The PCA fusion technique is similar to the IHS fusion technique, here PC1 being replaced by the PAN image. And pre-processing steps will be applied before the image fusion, and histogram matching will be performed between the PAN image and PC1. The PCA fusion technique is having an advantage compared to the IHS technique in that it can simultaneously apply the PCA to all bands in the MS image.

2. M. Chikr El-Mezouar, N. Taleb, K. Kpalma, and J. Ronsin, “A new intensity-hue-saturation fusion technique imagery with color distortion reduction for IKONOS,” [3].To correct pan-sharpened images these authors proposed the “Normalized Difference Vegetation Index (NDVI)”. It is one of the new intensity-hue-saturation (IHS) technique for image fusion with reduction in the color distortion. Among many of the existing image fusion algorithms, Intensity used one. For IKONOS imagery when the IHS method is used, there we can observe the color distortion, this is mainly due to the range of wavelengths in an IKONOS Pan image. This is based on fact that the gray values of Pan Image are far larger in the green vegetated regions than the intensity (I) grey values and there is an appearance of high reflectance in Near Infrared (NIR) and Pan Bands in vegetation area. Here the authors proposed a new intensity-hue-saturation fusion technique imagery with color distortion reduction to solve this problem. This technique consider the use of “Normalized Difference Vegetation Index (NDVI)” to recognize the vegetation area and then amplify it in the green (G) band by using the red (R) and the NIR bands. We obtain an intensity image with grey values comparable to the Pan Image grey values. Hence there is reduction in the color distortion in the fused image. It efficiently improves the fusion quality compared to co IHS techniques.

3.M. Chikr El-Mezouar, N. Taleb, K. Kpalma, and J. Ronsin, “An IHS-based fusion for color distortion reduction and vegetation enhancement in IKONOSimagery,” [4]this paper discusses the color distortion reduction in the vegetation areas. Both multispectral (MS) and panchromatic image data are provided in IKONOS imagery, both will be having different spatial resolutions. For larger area scale application IKONOS images are pan-sharpened for the visual explanation. Many intensity-hue-saturation (IHS) based methods are used in pan-sharpening process. However, most of these processes produce color distortion because of the unnatural spectral response of sensors, especially in vegetation areas. This vegetation enhancement is achieved using vegetation indexes (VI). Here they proposed a new fusion approach that produces images with natural colors. Further a high-resolution normalized difference VI is proposed in this process and used in describing the vegetation area. The process is performed in 2 steps. MS fusion using the IHS technique and vegetation enhancement. Vegetation enhancement is a correction step here, and it depends on the application. The new approach provides very good results in terms of objective quality measures.

4. Arthur L. da Cunha, Jianping Zhou, 1“The NonsubsampledContourlet Transform: Theory, Design, and Applications”. [11]In this paper the authors discussed non-subsampled contourlet transform (NSCT) and its applications. The non-subsampled pyramid filter banks and non-subsampled directional filter banks are used in NSCT construction. The resultant image decomposition is

multidirection, multiscale, and shift invariant and that is efficiently implemented. The vital part of the proposed technique is the non-separable two-channel non-subsampled filter bank (NSFB). We use the less stringent design condition of the NSFB to design filters that result to a NSCT with better frequency selectivity and regularity when compared to the contourlet transform. We propose a design structure based on the mapping approach that allows for a fast implementation based on a ladder structure and only uses 1D filtering in some cases. In addition, it ensures that the corresponding frame elements are symmetric and regular. In image denoising and enhancement applications this technique can be more useful

6. M. N. Do and M. Vetterli, "The contourlet transform: An efficient directional multiresolution image representation,"[7].In this paper the authors were discussed the contouelet transform. The disadvantages of commonly used one-dimensional transforms, such as the Fourier transform and wavelet transforms is in capturing the geometry that is geometrical structure of an image such as edges. In this paper authors proposed a true two-dimensional transform that can capture the natural geometrical structure of an image that is key in visual data. The main problem in investigating geometrical structure in an image comes from the discrete nature of the image data. Unlike other techniques, such as curvelets that will first develop a data transform in the continuous domain and then it will discretize for sampled data, but this technique starts with a discrete domain development and then studies its convergence to an expansion in the continuous domain. Here they used non-separable filter banks in the development of a discrete domain multiresolution and multidirection. This development results in a flexible multiresolution, local, and multidirectional image and so it is named the contourlettransform. The contourlet transform will be having fast iterated filter bank algorithm that requires an order operations for pixel images. Moreover they established a link between the developed filter bank and the associated continuous domain contourlet expansion via a directional multiresolution analysis framework. And they showed contourlets achieve the optimal approximation rate for piecewise smooth functions with discontinuities along twice continuously differentiable curves.

7. Standard NSCT based pan-sharpening method steps:

In standard NSCT based pan-sharpening is illustrated in the Fig. 2 Here PAN and MS are obtained from satellite sensors these are having high spatial and spectral resolution respectively. There is same levels of decomposition used for both the images to produce high frequency and low frequency components. Up-sampling is done for MS images before applying the transformation.

The algorithm for standard NSCT based pan-sharpening steps are as follows.

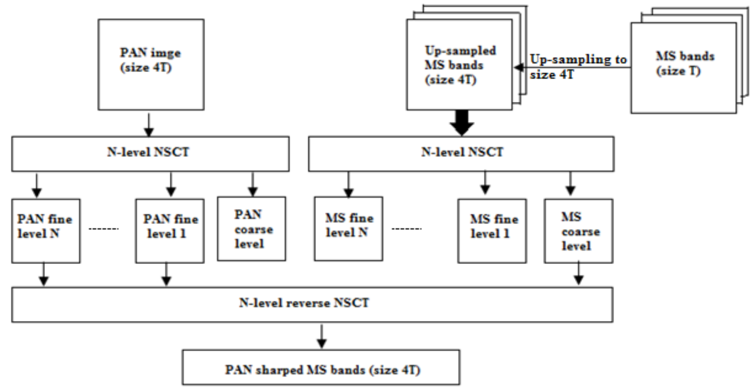

Fig. 2 Standard NSCT-based pan-sharpening method

1) Size of MS image is increased to the size equal to PAN image by up-sampling. That is resize of MS image is done using bi-linear interpolation algorithm.
2) Next decomposition is performed on both images that is transform Pan and up-sampled MS images by applying same level of a subband and a directional decomposition such as the subsampled or non-subsampled wavelet or contourlettransform. This results into separation of low frequency (called as coarse level) and high frequency (fine level) components.
3) Apply a fusion rule onto the NSCT transform coefficients.
4) Generate the pan-sharpened image by performing the NSCT inverse transform.

   This procedure is shown in the Fig. 2

The standard pan-sharpening methods using the non-subsampled contourlet transform shown in the Fig 2. Here MS and Pan Images are transferred by decomposition using the same number of decomposition levels for both the PAN and MS image, then fusion rules are performed on these obtained coefficients. The dataset resolution ratio decides the number of decomposition levels used. A two scale decomposition level is sufficient for QuickBird, IKONOS, and Worldview-2 imagery to provide satisfactory results, whereas a one scale decomposition level required for the Landsat-7 imagery. For each MS band, the pan-sharpened NSCT coefficients are obtained from a combination of the coarse level coefficients of the corresponding MS band and the fine levels coefficients of the Pan image. Then the NSCT inverse transform is used to generate the corresponding pan-sharpened MS band.

Disadvantages of Standard NSCT based pan-sharpening method

- Lower number of decomposition levels preserves better spectral quality, whereas higher number of decomposition levels maintains the spatial quality. But standard NSCT pan sharpening uses same number of decomposition levels for both PAN and MS images.
- Applying up sampling before NSCT does not preserve the structural and detail information of MS image.
- Does not preserve good spectral and spatial qualities and increases the computation time.

V. METHODOLOGY AND ALGORITHMS

A. NSCT-Based Pan-Sharpening

The proposed NSCT based pan-sharpening consists of two new ideas, those are

1) Using different number of decomposition levels for both MS and PAN image.
2) Applying up-sampling of MS image after performing the NSCT

Different Numbers of Decomposition Levels:The decomposition level estimation in [12] shows that the number of decomposition levels for a wavelet based multi-resolution multisensory image fusion. In that paper the authors showed that the lower number of decomposition levels retains good spectral quality, whereas a higher number of decomposition levels is maintain the good spatial quality. So the pan-sharpening is improved by adequate number of decomposition levels for image decomposition. In the proposed system, we have showed the NSCT based pan-sharpening with a different number of decomposition levels, where the number of decomposition levels for MS bands is lower than the number of decomposition levels for Pan Images.

Up-sampling of MS image after performing the NSCT: Typically, MS images are resampled to the same pixel size as the Pan image before the pan-sharpening process. It was shown that a good up-sampling method can improve considerably the results [8] and [9].Up-sampling is an important and necessary step in a pan-sharpening process. The interpolation performed during up-sampling can improve the quality of the pan sharpened images [8]. The authors in [9] proposed a technique, based on NSCT, to up-sample images for remote sensing applications. At first, an MS image is decomposed using NSCT, then the interpolation is conducted on the resulting NSCT coefficients. Finally, the up-sampled image is generated through inverse NSCT, applied to the interpolated coefficients. This technique relies on an important property stating that there is some similarity between high-frequency coefficients of the same direction regardless of the level. In our experiments, the bi-linear interpolation algorithm is used. The efficiency of this method was proven quantitatively and qualitatively through a comparison with existing methods.

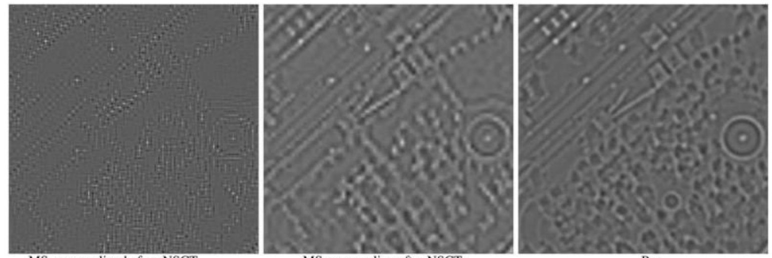

Fig. 3 Fine level 1 NSCT coefficients

Fig. 3 shows fine level 1 of the MS images and the Pan image. The left image corresponds to the up sampled MS band to which NSCT was applied, whereas the middle image is the result of the NSCT decomposition followed by up sampling. The last image represents fine level 1 obtained by applying NSCT on the Pan image. As it can be observed, the middle image is more similar to the right image than the left one.

A Pan-Sharpening Based on the NSCT method steps:

The block diagram of NSCT is shown in the fig.4

1. Rad PAN and MS images into MATLAB and extract the R, G, B bands.
2. Apply NSCT on each bands of MS image and PAN image.
3. The obtained MS coefficients are then up-sampled using the bi-linear interpolation algorithm.
4. The coarse level of the pan-sharpened MS band is the up-sampled coarse level of the MS band.
5. Fine levels 2 and 3 of the pan-sharpened MS band are set to fine levels 2 and 3 of the Pan image.
6. Fine level 1 of the pan-sharpened MS band is obtained by fusing the coefficients of the same level obtained from both the MS band and the Pan image.
7. The fusion rule uses the local energy (LE) of each coefficient calculated within a (2M+1)*(2N+1) window to generate a decision map.
   For the (x, y) position, the LE is given by

$$\mathrm{LE}(x, y) = \sum_{i=-M}^{M} \sum_{j=-N}^{N} (\mathrm{Fine\_level\_coeff}(x+i, y+j))^2$$

This map is used in order to decide whether the Pan coefficient or the MS coefficient will be used, according to the following formula

Fused_fine_level_coeff(x,y)=

$$\begin{cases} \text{MS\_fine\_level\_coeff}(x,y), & \text{if LE of MS}(x,y) \geq \text{LE of PAN}(x,y) \\ \text{Pan\_fine\_level\_coeff}(x,y), & \text{otherwise.} \end{cases}$$

8. Finally apply inverse NSCT and concatenate every bands to form a spatially and spectral improved MS image.

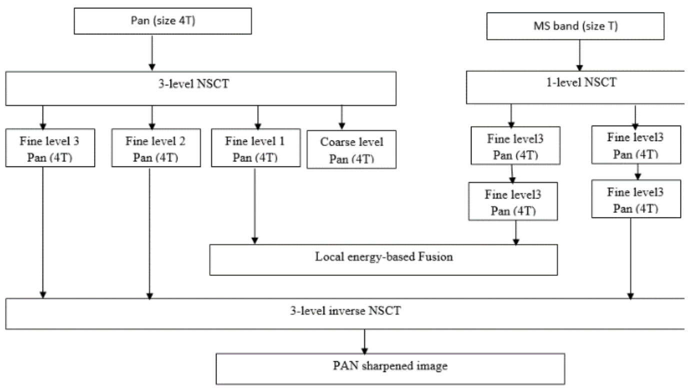

Fig 4. Proposed NSCT based pan-sharpening

B. DWT based pan-sharpening

The wavelet transform is widely used in pan-sharpening due to its properties such as multiresolution, localization, critical sampling, and limited directionality (horizontal, vertical, and diagonal directions).

A Pan-Sharpening Based on the DWT method steps:

The block diagram of DWT is shown in the fig. 5.

1) Read the MS image and PAN image into mat lab.
2) Extracts the bands of MS image separately to produce Red, Green, Blue bands.
3) Apply DWT2 to each bands of an MS image and PAN image separately, which produces the low, mid and high frequencies.
4) Replace the mid frequency and high frequency of all R, G, and B bands by PAN image mid frequency and high frequency.
5) Apply inverse DWT2 on RGB frames.
6) Concatenate all the RGB frames to produce the pan-sharpened image.

Enhanced NSCT and DWT based image fusion steps are shown below and block diagram is shown in the fig 6.

1) Perform the NSCT based pan-sharpening.
2) Perform the DWT based pan-sharpening.
3) Fuse the images obtained from both methods by image averaging.

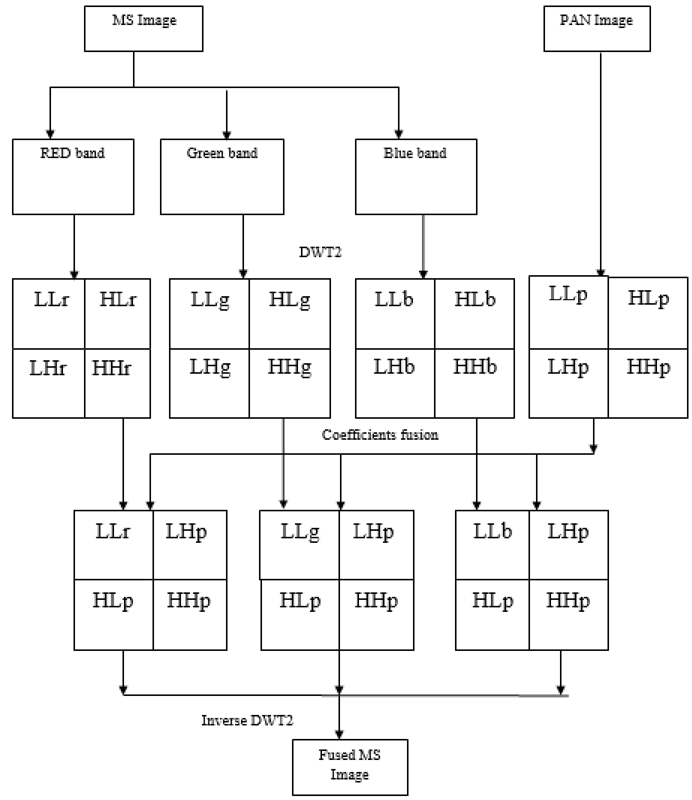

Fig 5. DWT based pan-sharpening

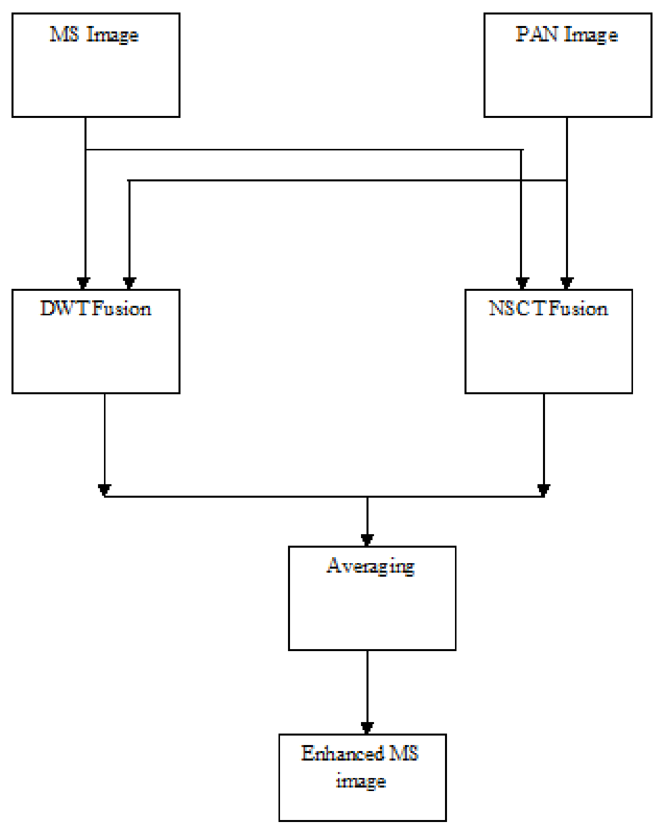

Fig 6. Combined NSCT-DWT based pan-sharpening

VI. CONCLUSION

The NSCT-based pan-sharpening method of existing form is considered. Moreover, the up sampling process is considered to resize the MSi image equal to PAN image. The improvement of the NSCT based image pan-sharpening is assured by using a low number of decomposition levels for MS images.Moreover, the upsampling process is considered. We propose to use upsampling after applying NSCT in order to preserve the detail information existing in the MS images. Thus, a method is proposed, where in addition to different numbers of decomposition levels, the interpolation is conducted after NSCT. The obtained fine levels from MS and Pan Images are fused using the LE as the fusion rule. The proposed method provides pan-sharpened images with a good spectral quality, which is improvement of quality, compared to the standard NSCT-based method, and is assured. By combination of NSCT and DWT image quality can be enhanced more.

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