International Journal of Engineering
Journal Homepage: www.ije.ir

RESEARCH NOTE

Fusion of Panchromatic and Multispectral Images Using Non Subsampled Contourlet Transform and FFT Based Spectral Histogram

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PAPER INFO

Paper history:
Received 28 May 2014
Received in revised form 18 May 2015
Accepted 03 September 2015

Keywords:
Image Fusion
Non Subsampled Contourlet Transform
Multispectral Image
Panchromatic Image

ABSTRACT

Image fusion is a method for obtaining a highly informative image by merging the relative information of an object obtained from two or more image sources of the same scene. The satellite cameras give a single band panchromatic (PAN) image with high spatial information and multispectral (MS) image with more spectral information. The problem exists today is either PAN or MS image is available from satellite camera. In many remote sensing applications, there is a need for enhancement of the MS image with more spatial resolution for further analysis. In this work, a new fusion technique is proposed in order to get a combined image by integrating PAN image and MS image. PAN and MS images are decomposed using non subsampled contourlet transform (NSCT). Then, the fourth order correlation coefficient (FOCC) is found between the low frequency components of both images. If FOCC is greater than an optimum threshold value, then the corresponding higher frequency components of the PAN image are injected into the respective locations of the MS image. Otherwise MS image components are retained. For calculating the optimum threshold value, *n* number of test fused images are formed by using *n* arbitrary threshold values. FOCC between the PAN image and the test fused images are plotted for various threshold values. Similarly, hamming distance of FFT based spectral histogram curves between the MS image and the above test fused images are plotted. The point of intersection of these two curves gives the optimum threshold value. The fused image is obtained using inverse NSCT. The evaluation shows that the proposed work gives better improved results than the other existing methods.

***doi**: 10.5829/idosi.ije.2015.28.10a.08*

1. INTRODUCTION

Image fusion is often required to acquire a more reliable image from different source images of a same object. This process is most commonly used in studying the satellite images. Essentially to get the fine details of the Earth's surface and to study the topography of different land masses, high spatial resolution image is required. Most of the existing equipments cannot capture both spectral and spatial information efficiently. The sensor limitations in capturing the both have led to the necessity for the fusion of two source images. The panchromatic image is enriched with spatial information and low in spectral information. The multispectral image has rich spectral information but less spatial information. The panchromatic images capture all the radio metric photons in a very broad wavelength band. The panchromatic images usually contain ROYG spectrum because all the photons in panchromatic image are grouped in one bandwidth. Panchromatic images are presented as gray scale images. In gray scale image, the pixel digital levels are proportional to the intensity of the reflected solar radiation by the source objects on the detector. The multispectral image has discrete bands in the visual and infrared regions across the electromagnetic spectrum [1, 2]. The panchromatic and multispectral images can be captured either from the sensors of the same satellite or from the sensors of different satellites.

In the existing methods of image fusion, such as intensity hue saturation (IHS) [3, 4], principal

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Please cite this article as: S. M. Seraphin Sujitha and D. Selvathi, Fusion of Panchromatic and Multispectral Images Using Non Subsampled Contourlet Transform and FFT Based Spectral Histogram, International Journal of Engineering (IJE), TRANSACTIONS A: Basics Vol. 28, No. 10 (October 2015) 1455-1462

component analysis (PCA) method [5] and brovey method [6], the resultant output possesses high spatial resolution but suffers from spectral distortion. Besides, the combined algorithms of generalized IHS [7] and the optimization methods give a trade-off relationship between minimum spectral distortion and improvement of the spatial information. To overcome this limitation, in some works [8] adopted wavelet transform method such as high pass filter is used to transfer high frequency components of the panchromatic image into the low resolution MS image. This provides a far less spectral distortion than its previous methods. Using multiresolution analysis techniques, high resolution multispectral image is obtained. In these methods, the panchromatic and multispectral images are decomposed into low and high frequency components. During the fusion process, the low frequency components of multispectral image are not changed. Discrete wavelet transform (DWT) [9, 10], curvelet transform [11], support value transform [12] and contourlet transform [13] based methods lack directional selectivity and ignore geometric properties. Hence, these shift variants transform preserve better spectral information but may lack spatial information resulting in blurring and artifacts. To overcome these drawbacks, NSCT [14, 15] which is shift invariant and non-redundant transform is used.

In the new adaptive context based decision methods [16], correlation coefficients are found between the PAN and MS image coefficients. The MS image coefficients are replaced by the corresponding pixel coefficient of the PAN image coefficients, if this similarity index is greater than the given threshold value. Otherwise, the multispectral image details are retained. The resultant fused image retains both the spectral and spatial information, if the correlation between the source images is good. In poorly correlated source images, the fused image has high spatial information but reduced spectral information. So, in order to preserve both spatial and spectral information, an optimum threshold value has to be found to decide whether to inject the high frequency details of PAN into the high spectral content MS image or not .

In this proposed work, FOCC [17] is calculated between the low frequency NSCT components of the PAN and MS images. If the FOCC is greater than the chosen threshold, then the corresponding high frequency coefficients of the panchromatic image are transferred into the corresponding locations of the high frequency NSCT subbands of multispectral image. If the FOCC is lesser than the chosen threshold, no changes are made in the multispectral image subbands. For finding the optimum threshold value, *n* arbitrary threshold values are chosen and using each threshold value, fused images are obtained following the proposed fusion rule. In this work to find an optimum threshold, the hamming distance of the FFT [3] based spectral histogram is taken for the input multispectral image and then fused images obtained from different arbitrary threshold values are plotted against the respective arbitrary threshold values. Similarly, FOCC measurement between the input panchromatic image and the fused images is calculated and plotted against the arbitrary threshold values. The threshold value corresponds to that point of intersection of the two curves which gives the optimal threshold value. This optimum threshold value is used to get the final fused image.

2. PROPOSED IMAGE FUSION METHOD

The proposed work aims to get a high spatial resolution multispectral image. The multispectral images are richer in spectral information than spatial information. Panchromatic images are rich in spatial information. So nonredundant panchromatic image details are to be injected into the multispetral image without loss of colour informationn. So, for injecting the panchromatic image detail coefficients into the multispectral image, at first a measure of the degree of correlation between the pixels of low frequency components of the panchromatic image and the multispectral image is found to be important. Selecting the correlation coefficient of low frenquency components is a good parameter for deciding the level of pixel injection because it gives the relationship between the change in one variable corresponding to a change in the other variable in the data set. In this proposed work, FOCC is used because the correlation coefficient based methods increase the chance of finding the noise free spatial information. The fourth order correlation coefficient computed for two *M* x *N* input images is given by:

$$FOCC = \frac{1}{M\times N}\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(F(i,j)-\mu_F)^2(G(i,j)-\mu G)^2}{\sqrt{(\sum_{i=1}^{M}\sum_{j=1}^{N}(F(i,j)-\mu_F)^4)(\sum_{i=1}^{M}\sum_{j=1}^{N}(G(i,j)-\mu G)^4)}} \quad (1)$$

where *F(i,j)* and *G(i,j)* are the two input images and μ_F and μ_G are the mean of the input images. *M* and *N* denote the size of the input images.The steps involved in the proposed methodology are shown in Figure 1.

In this proposed fusion method, NSCT is used to decompose the input panchromatic image and the multispectral image into low and high frequency components. NSCT is used because it is shift invariant and non-redundant transform. The FOCC is found between the low frequency components of the multispectral image and the panchromatic image. It is calculated by taking 5x5 sliding window around each low frequency component of the pixel. At first suitable arbitrary threshold values in between the range of 0.1 and 1 with the step interval of 0.1 is taken to fuse the given input panchromatic and multispectral image. If the FOCC between them is greater than the selected arbitrary threshold value, then the corresponding $(i,j)^{th}$ coefficient of the high frequency component of the panchromatic image is injected into the $(i,j)^{th}$ position of all high frequency NSCT subband locations of the multispectral image.

If the FOCC between the low frequency components is lesser than the threshold value, then there is no change in the multispectral image subbands. Then inverse NSCT is applied to get the fused image. Good fusion result depends on choosing the correct optimum threshold value as it decides the level of pixel injection. The corresponding high frequency coefficients of the panchromatic image replace the respective pixel locations of high frequency component of multispectral image as per the chosen threshold value. Spectral distortion may occur if proper threshold value is not selected. The obtained fused results should possess high spatial resolution without losing the colour information.

So the calculation of a proper threshold value is important as it decides the inferring of the pixels. So the chosen threshold value is based upon the information of the input source images. To choose a proper threshold value for easy computation, at first, arbitrary threshold values from 0 to 1 in the step interval of 0.1 are taken and these threshold values are used to decide the level of injection of the high frequency PAN image coefficients into the MS image. So, for *n* arbitrary threshold values *n* numbers of fused images are obtained.

The FOCC between the input PAN image and the obtained fused images using the arbitrary threshold values ranging from 0 to 1 in steps interval of 0.1 are plotted on a graph as shown in Figure 2. For the MS image in order to filter the spectral components and to reduce the computation time, FFT is used. Normalized histogram gives the values of the probability of occurrence of each gray level. For each subband of the MS image, FFT is used as linear convolution operator to find the spectral histogram. So a statistical similarity measure between thespectral bands of MS image histograms is calculated. In image processing, the image is transformed in frequency domain, because convolution by multiplication in the frequency domain is computed faster than on convolution in the spatial domain when large size filter is used. So FFT based spectral histograms on the MS image and the test fused images which are obtained for each threshold value ranging from 0 to 1 in steps interval of 0.1 are found. The hamming distances between the spectral components of the multispectral image and test fused images are calculated and these give the measure of spectral similarity coefficients and are plotted on a graph as shown in Figure 2 using bicubic interpolation method. The graph has one FOCC curve and three FFT based spectral histogram curves corresponding to three subbands. Each subband intersects at a point where the spatial information and spectral information corresponding to that subband is high. The threshold value corresponding to that intersection point is the optimum threshold value (α_{best}) which is used for final fused output.

To find optimum threshold value (α_{best}) for the input images, the following steps are implemented:

1) The MS image and the PAN image are fused by using the above proposed fusion algorithm. For this, initial threshold value α = 0.1 is chosen. Then increment threshold value α by step intervals of 0.1 is defined and fuse the input images using the new threshold value. This process is repeated up to the threshold value α = 1. Hence *n* fused test images are obtained.

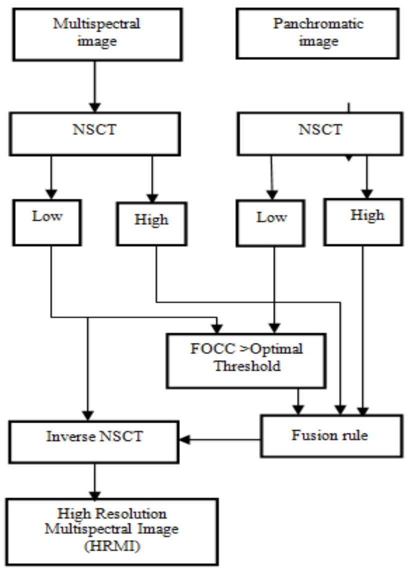


Figure 1. Block diagram of proposed work.

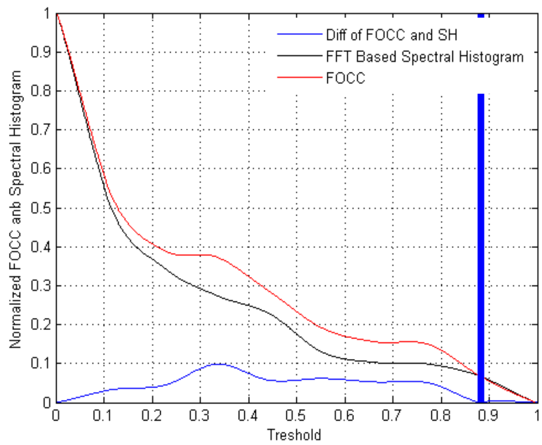


Figure 2. Similarity curves for optimum threshold calculation for band 1.

2) Calculate FOCC between the given PAN image and the obtained test set fused images corresponding to the arbitrary threshold value α = 0.1 to 1; it is plotted against the respective threshold values.
3) Apply FFT in the given MS image and the obtained test set fused images corresponding to the arbitrary threshold value α = 0.1 to 1. Then the hamming distance between the FFT coefficient of MS image and the test set fused images is found and plotted against the different threshold values α.
4) The FFT based hamming distance curve of the MS image and the FOCC curve of the PAN image intersect at a point. The threshold value corresponding to that point is the optimum threshold value.

3. RESULTS AND DISCUSSION

The panchromatic images obtained from satellites have high spatial content whereas multispectral images obtained from satellites have high spectral content. The spatial content in multispectral image is improved by applying the proposed NSCT and FFT based method. The sample input images [2] are shown in Figure 3(a) and 3(b). Figure 3(a) shows a multispectral image which is taken by a multispectral satellite channels at specific frequencies across the spectrum. It has high spectral content and low spatial content. Figure 3(b) shows the high resolution panchromatic image. It has high spatial content and low spectral content.

The input PAN and MS images are decomposed into low frequency and high frequency components using NSCT. The low frequency components contain the spectral information while the high frequency components contain the directional information.The inverse NSCT is taken for the low frequency components of multispectral image and the high frequency components of the multispectral image after injecting the detail coefficients from the PAN image using the proposed algorithm in order to produce an image enriched with both colour and spatial content.The fused image obtained using the proposed technique is analyzed with that of the existing image fusion techniques using IHS and DWT methods. Figure 3(c)-3(f) show the fused result of IHS, Wavelet, NSCT and the proposed fused image for the input PAN and MS images as shown Figure 3(a) and (b), respectively.

[2] http://www.satimagingcorp.com/satellite-sensors /geoeye-1.html.

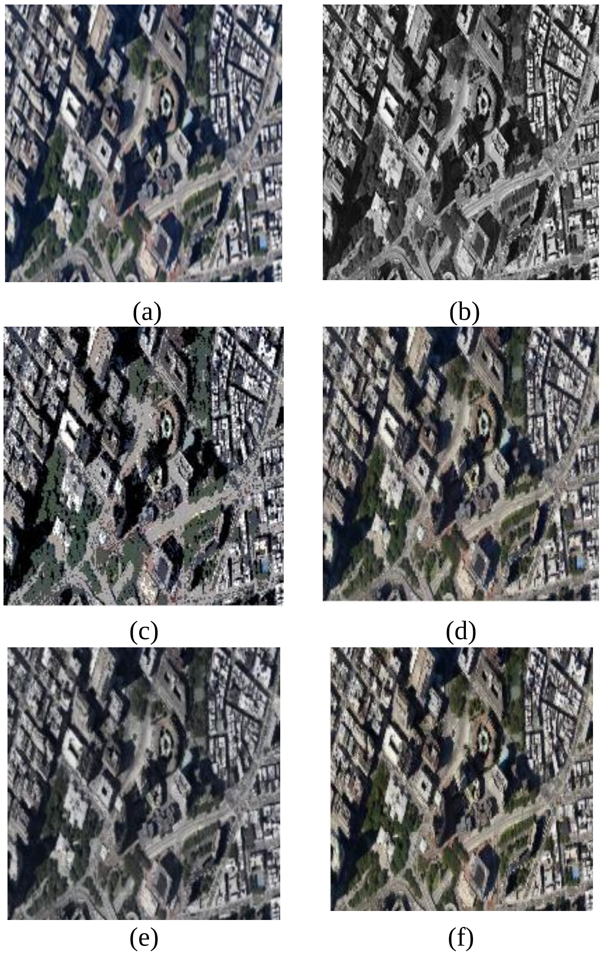


Figure 3. (a) Multispectral image, (b) panchromatic image, (c) IHS transform image, (d) wavelet transform image, (e) NSCT image and (f) proposed fused image.

3. 1. Performance Calculation The performance of proposed work is evaluated using the following measures [18-20]. Root mean square error (RMSE): It gives a measure of how well the resultant fused image pixels agree with the source image pixels. It is used to decide the degree of mismatch of the source image with the fused image. So smaller value of RMSE indicates the resultant fused image is good. RMSE is defined as:

$$\mathrm{RMSE} = \sqrt{1/\mathrm{M} \times \mathrm{N} \left(\sum_{i=1}^{M} \sum_{j=1}^{N} (\mathrm{Fij} - \mathrm{Gij})^2\right.} \quad (2)$$

where Fij and Gij are sets of $M \times N$ pixel data of source image and resultant fused image respectively. Relative average spectral error (RASE): To find the quality of the fused image, relative average RMSE is used to find out the local variation of errors. K is the mean pixel value for the L spectral bands of fused image.

$$\mathrm{RASE} = 100/\mathrm{K}\sqrt{1/\mathrm{L}\sum_{i=1}^{L}\mathrm{RMSE}^2(\mathrm{B_i})} \quad (3)$$

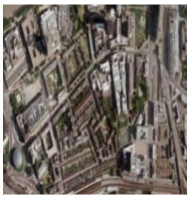
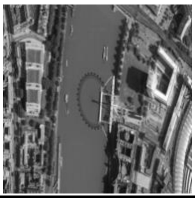
$$RMSE^2(B_i) = bias^2(B_i) + STD^2(B_i) \quad (4)$$

Erreur relative globale adimensionnelle de synthese (ERGAS): The ERGAS is used to calculate the spectral distortion in the fused image.

$$ERGAS = 100\ P/M \sqrt{1/L\,(\sum_{i=1}^{L} \frac{RMSE^2(Bi)}{K_i^{\,2}}} \quad (5)$$

P and *M* are resolution values of PAN and MS image, respectively. K_i is the mean of pixel value of each *L* spectral band of MS image. Small value of ERGAS indicates smaller spectral distortion.

TABLE 1. Evaluation of qualitative and quantitative measure of the proposed method comparing with existing method

Multispectral image	Panchromatic image	Proposed fusion image	Fusion methods	RMSE	RASE	ERGAS	CC	D	UIQI
			IHS	11.132	0.118	2.505	0.923	17.027	0.893
			Wavelet	21.587	0.224	3.719	0.949	18.299	0.928
			Proposed	**10.759**	**0.111**	**2.626**	**0.983**	**10.759**	**0.983**
			IHS	9.8514	0.096	2.365	0.855	12.01	0.844
			Wavelet	14.356	0.139	2.835	0.952	10.897	0.951
			Proposed	**9.0071**	**0.087**	**2.248**	**0.983**	**6.6871**	**0.982**
			IHS	12.117	0.105	2.339	0.859	22.52	0.828
			Wavelet	0.1783	0.178	3.156	0.951	15.069	0.930
			Proposed	**9.8932**	**0.094**	**2.320**	**0.982**	**7.4074**	**0.981**
			IHS	12.790	0.122	2.643	0.882	24.28	0.845
			Wavelet	15.600	0.154	2.975	0.957	12.093	0.950
			Proposed	**8.1775**	**0.080**	**2.165**	**0.985**	**6.0029**	**0.985**
			IHS	12.935	0.145	3.131	0.896	24.24	0.853
			Wavelet	14.099	0.159	3.281	0.963	11.086	0.954
			Proposed	**7.3837**	**0.083**	**2.366**	**0.988**	**5.1833**	**0.988**
			IHS	13.440	0.118	2.485	0.901	26.02	0.864
			Wavelet	15.038	0.141	2.7981	0.966	11.581	0.953
			Proposed	**7.257**	**0.068**	**1.9518**	**0.989**	**4.9479**	**0.988**

Universal image quality index (UIQI): The UIQI parameter helps to study the quality of fused image. It is defined as:

$$\mathrm{UIQI} = (\sigma_{fg}/\sigma_f\sigma_g)(2x_f x_g/(x_f^2 + x_g^2))(2\sigma_f\sigma_g/(\sigma_f^2 + \sigma_g^2)) \quad (6)$$

where x_f, σ_f and x_g, σ_g are the mean and standard deviations of the original and fused image, respectively. Correlation coefficient (CC): This measure is used to calculate the amount of spatial information transferred from the input image to fused image. It is given by:

$$\mathrm{CC} = \frac{1}{M\times N}\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(F(i,j)-\mu_F)(G(i,j)-\mu_G)}{\sqrt{(\sum_{i=1}^{M}\sum_{j=1}^{N}(F(i,j)-\mu_F)^2)(\sum_{i=1}^{M}\sum_{j=1}^{N}(G(i,j)-\mu_G)^2)}} \quad (7)$$

where $F(i,j)$ and $G(i,j)$ are the input and fused images respectively. μ_F and μ_G are the mean of the input image and fused image, respectively. Degree of distortion (D): It reflects the level of the fused image distortion. It is defined as:

$$D = 1/M \times N \sum_{i=1}^{M}\sum_{j=1}^{N} (|F_{ij} - G_{ij}|) \quad (8)$$

The smaller value of the *D* indicates that distortion is small.

The performance of the proposed method using NSCT as well as existing methods such as fusion using IHS and fusion using DWT are analyzed by computing various parameters to know the effectiveness of techniques used for fusion. The quality metrics and quantitative performance measures in terms of RMSE, RASE, ERGAS, CC, D and UIQI are computed for different PAN and MS image sets [3] and are given in Table 1.

Table 1 depicts the quantitative error measurement metrics for the wavelet, IHS and the proposed methods. Quantitative metrics show improved results obtained by choosing an optimum threshold value for deciding the level of pixel injection in image fusion. As can be seen from Table 1, the objective metrics obtained by the proposed method are all very good on comparing with image fusion using IHS and wavelet transform methods. The global quality indexes are calculated by comparing the pansharpened image with the original MS image. Relative average spectral error (RASE), ERGAS, relative mean square error (RMSE), degree of distortion (D) values of the proposed method are lower and universal image quality index and correction coefficient (CC) values of the proposed method are higher than those of other fusion methods. So the spectral and spatial quality of fused images is closer to the input source images. Higher CC and lower RASE, RMSE and ERGAS value imply that the fusion method used allows a high quality transformation of the MS content when the spatial resolution is increased. The UIQI and correlation coefficient for the proposed method are much improved when compared to those of the IHS method and better over wavelet method. This shows that large amounts of spatial information are transferred from the panchromatic image to fused resultant image.
Distortion is very less than the other fusion methods. The distortion D parameter for the fused results of the proposed NSCT and FFT based spectral histogram algorithm when compared with the existing wavelet and IHS method fused image results is found to be half of the value of the existing fused image results. Hence the colour information is preserved in the fused images. It is observed from the fused output images that the edges and spectral details are clearly visible. In order to find spectral similarity, FFT based spectral histogram can be used in the proposed work and the effectiveness of this algorithm has to be studied.

[3] http://www.satimagingcorp.com/satellite-sensors /geoeye-1.html.

4. CONCLUSION

The input images are decomposed by NSCT and these result in better output since it is a multiscale, multidirectional and shift invariant transform. In order to avoid insertion of noise during fusion and to preserve the spatial similarity between the images, the higher order correlation coefficient is used. The optimum threshold value is taken as the parameter to decide the level of pixel injection. The selected optimum threshold depends upon the characteristics of the input images. The fused resultant image preserves both the spectral and spatial information. So, the proposed method is an effective approach for obtaining an output with high spatial resolution image without loss of colour spectral information. The proposed fusion method is compared with existing methods such as IHS and DWT and its performance is found better.

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P A P E R I N F O

Paper history:
Received 28 May 2014
Received in revised form 18 May 2015
Accepted 03 September 2015

Keywords:
Image Fusion
Nonsubsampled Contourlet Transform
Multispectral Image
Panchromatic Image

چکیده

فیوژن تصویر روشی برای به دست آوردن یک تصویر بسیار پرمعنی با ادغام اطلاعات نسبی از یک شیء به دست آمده از دو یا چند منبع تصویر از همان صحنه است. دوربین های ماهواره ای یک تصویر پانکروماتیک تک باند (PAN) با اطلاعات مکانی بالا و تصویر چند طیفی (MS) با اطلاعات طیفی می دهند. مشکلی که امروز وجود دارد این است که تصویر MS یا PAN از دوربین ماهواره ای در دسترس است. در بسیاری از کاربردهای سنجش از دور، یک نیاز برای بهبود تصویر MS با رزولوشن فضایی بالاتر برای تجزیه و تحلیل بیشتر وجود دارد. در این کار، یک روش فیوژن جدید به منظور به دست آوردن یک تصویر ترکیبی با یکپارچه سازی تصویر PAN و تصویر MS ارائه شده است. تصاویر PAN و MS با استفاده از NSCT تجزیه می شود. پس از آن، ضریب همبستگی مرتبه چهارم (FOCC) بین اجزای فرکانس کم از هر دو تصویر پیدا می شود. اگر FOCC از یک مقدار آستانه مطلوب بیشتر باشد، اجزای فرکانس بالاتر تصویر PAN مربوطه به مکان های مربوطه از تصویر MS تزریق می شوند. در غیر این صورت اجزای تصویر MS حفظ می شوند. برای محاسبه مقدار آستانه مطلوب، n تعداد تصویر ترکیب شده تست با استفاده از n مقدار آستانه دلخواه تشکیل می شود. FOCC بین تصویر PAN و تصاویر فیوژن تست برای مقادیر مختلف آستانه رسم می شود. به طور مشابه، فاصله همینگ از منحنی هیستوگرام طیفی که بر اساس FFT است بین تصویر MS و تصاویر ترکیب شده تست بالا رسم می شود. نقطه تقاطع این دو منحنی مقدار آستانه مطلوب را می دهد. تصویر ترکیب شده است با استفاده از معکوس NSCTبه دست می آید. ارزیابی نشان می دهد که کار پیشنهادی نتایج بهبود یافته ای بهتر از سایر روش های موجود می دهد.

***doi**: 10.5829/idosi.ije.2015.28.10a.08*