Multi-focus Color Image Fusion using NSCT and PCNN

Gayathri N.
Dept. of Electronics & Communication
Mar Baselios College of Engineering
Trivandrum, India

Deepa P. L.
Dept. of Electronics & Communication
Mar Baselios College of Engineering
Trivandrum, India

***Abstract*— Image fusion combines different images of same scene from different sensors or from the same sensor at different times to create a new image. Due to limited depth of focus of optical lens, it is often impossible to acquire an image that contain all relevant focused objects, some objects will be in focus some others will be out of focus. Using multi focus image fusion one can get one image with all of objects in focus. Image fusion methods are usually divided into spatial domain and transform domain techniques. One of the simplest spatial domain methods is block method but it causes block effect. Another important spatial based method is focused region based method which is able to detect the clear regions of source images and then directly copy the pixels from clear region to fused image. However, these methods generate artificial information and discontinuous phenomenon at border of focused region. This will affect visual fidelity of fused image. Compared with spatial based methods, methods using multi scale transform successfully overcome the above mentioned disadvantages. Image fusion methods based on Non-Subsampled Contourlet Transform (NSCT) and perform very well for gray scale images. In this paper, a new method multi-focus image fusion is proposed that is suitable for color images using NSCT and Pulse Coupled Neural Network (PCNN).**

***Index Terms*— NSCT, PCNN, multi-focus, Sum Modified Laplacian**

INTRODUCTION

Currently, varieties of image acquisition techniques are available. But these techniques cannot give all-in-focus images due to the limit of depth of focus of optical lens of camera. Therefore the image thus acquired may not contain details of all objects in the scene from which the image is captured. Such type of images are called multi-focus images, in which some area of the image will be in focus and some other area will not be in focus. In order to overcome this problem, multi focus image fusion techniques can be used. Multi focus image fusion technique is an image processing technique which gives an image which contains all objects in focus, from multiple images of the same scene taken at different focus. This fusion finds application in digital cameras, visual sensor networks, remote sensing applications and auto-focus cameras etc due to limit of depth of focus of optical lens.

In general image fusion methods can be either spatial domain or transform domain. In spatial domain methods is applied directly on pixel level of source images. But in transform domain method, the source images are decomposed into transform domain coefficients and fusion rule is applied to transform domain coefficients. After applying fusion rule, the coefficients obtained are taken inverse transform to obtain the fused image.

The spatial domain methods include pixel based fusion, by taking the average of pixel values of input images, but this may reduce the contrast of the fused image and may cause undesirable effects in the fused image. Block based method are another type of spatial domain based method in which pixels are replaced by blocks, where the input source images are divided into uniform blocks. But this may cause block effect, which may degrade the quality of fused image [3]. Block effect mainly occur due to the fact that, same block of the image may contain both focused areas and unfocused areas [4]. Focused region based method is another type of spatial domain method, here the pixel values of regions under focus is directly copied to the fused image. This method may result in discontinuities and artificial information at the boundaries of focused regions [5]-[7].

Many multi scale transform domains (MST) are available for image fusion, which give fused image of better quality than other spatial domain methods. The main advantage of MST methods is that, the transform coefficients obtained from transform contains detailed information of the source images and chooses the better details for image fusion [2]. Wavelet transform [8] and wavelet packet transform [9] are the two main approaches in MST domain. Wavelet techniques cannot effectively give the direction of edges of the images [10].

Contourlet transform proposed by M. N. Do and M. Vetterli [11], gives multi scale and multidirectional information and overcomes the disadvantages of wavelet based methods. Contourlet transform has up samplers and down samplers, due to lack of shift invariance, it causes pseudo Gibbs phenomena. Another MST proposed by A. L. Cunha *et al* is Non sub sampled Contourlet Transform (NSCT), gives multi scale and multidirectional transform and due to the absence of up samplers and down samplers, NSCT do not have pseudo gibbs phenomenon.

Most of the multi focus image fusion methods work on grayscale images only. Mostly used color space is RGB space, but cannot be used for color image fusion since correlation of image channel is not clearly emphasized [14], YCbCr outperforms the other color space in objective quality assessment [13].

In this paper, source images are converted to YCbCr space, NSCT is used to decompose the source images, SML based local visual contrast is used to fuse the low pass coefficients and Pulse Coupled Neural Network (PCNN) is used to fuse band pass directional coefficient.

The rest of the paper is organized as follows. In section II, color space is described. In section III, NSCT is described. In section IV, fusion rules are discussed. In section V and VI proposed work, comparison of fusion rules, experiment results and conclusion is presented.

II. COLOR MODELS TRANSFORMATION

A color model is used to specify, create and visualize, YIQ, HSV, HIS, YCbCr are different color models. Comparing the other color spaces YCbCr model gives high PSNR for multi-focus image fusion and better objective assessment qualities [13]. Y represents intensity component of the image, Cb gives blue chroma difference and Cr gives red chroma difference both giving color information. YCbCr model can be derived from RGB model by the following equations,

$$Y = 65.481\ R + 128.553\ G + 24.996\ B + 16 \quad (1)$$

$$Cb = -37.797\ R - 74.203\ G + 112.00\ B + 128 \quad (2)$$

$$Cr = 112.00\ R - 93.786 G - 18.214\ B + 128 \quad (3)$$

As only the Y component gives the intensity information, for fusion process only the Y component is needed and color information can be added later to the fused image.

III. NON SUB SAMPLED CONTOURLET TRANSFORM

NSCT decomposes the input image into low pass sub band coefficients and band pass directional coefficients. NSCT comprises of non sub sampled pyramid filter bank (NSPFB) and non sub sampled directional filter bank (NSDFB), which gives multi directional and multi scale, anisotropic and frequency localized information of the input image also effectively overcomes pseudo gibbs phenomenon. Figure 1 show the schematic diagram of NSCT decomposition [15]

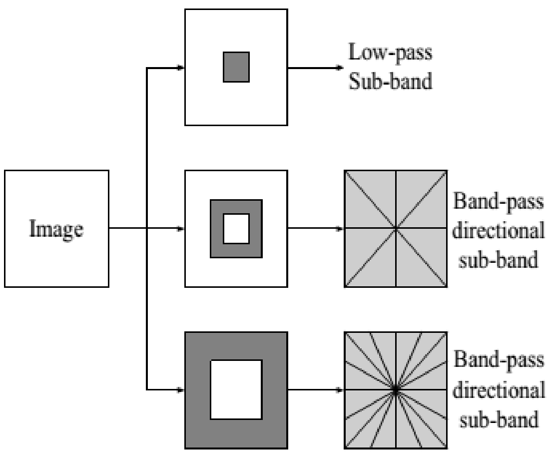

Figure 1. Schematic diagram of NSCT decomposition

NSPFB gives multi scale information by using a two-channel non-sub sampled filter bank. At each decomposition level, NSPFB gives one low frequency sub image and one high frequency sub image. For *k*-level decomposition, NSPFB gives $k+1$ sub images i.e., one low frequency sub image and k high frequency sub images of same size as that of the input source image[2].

NSDFB give precise directional detail information combining directional fan filters. NSDFB performs *l*-level decomposition of the high frequency sub image obtained from NSPFB and produces 2^l band pass directional sub images with same size of the input source image [2].

A. NSCT based image fusion

The two multi focus source images A and B are NSCT decomposed to low pass sub band images and band pass directional sub images. Separate fusion rules are used to select the coefficients from the low pass sub band images and high frequency sub band images. After applying fusion rules, inverse NSCT is performed to obtain the fused image. Figure 2 shows schematic diagram of NSCT based image fusion [15].

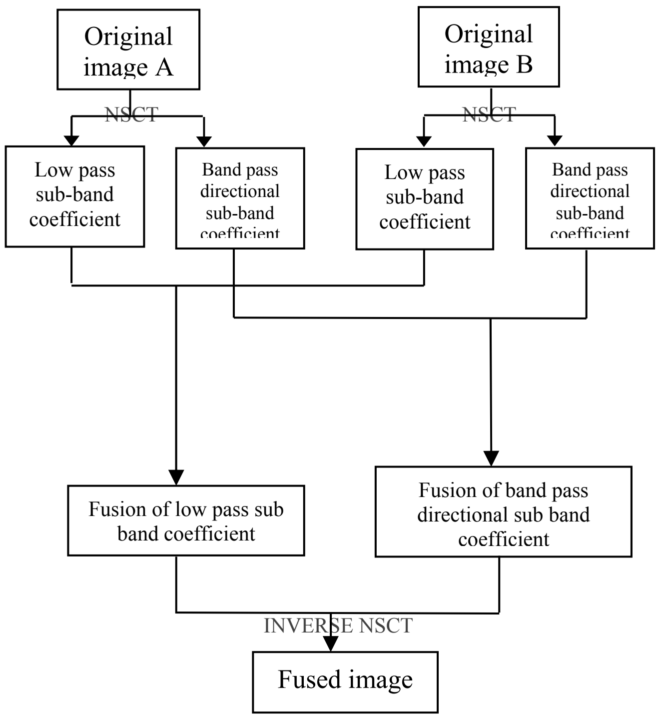

Figure 2. Schematic diagram of NSCT based image fusion

IV FUSION RULES

In NSCT based image fusion methods, the fusion rules affect the quality of the fused image. In different image fusion methods, different fusion rules are used to improve the performance of image fusion. In this paper, the proposed system uses SML based local visual contrast and PCNN based fusion rules for low pass sub band and band pass directional sub band images respectively for improving quality of fused image.

A. Fusion rule for low frequency sub bands

For spatial domain methods many methods such as laplacian energy, energy of image gradient, spatial frequency, tenengrad, Sum-Modified-Laplacian (SML) are the different focus measuring criteria. According to Huang, Wei, and Zhongliang Jing experiments done on several images show that SML show better performance than other focus measures in spatial domain [24]. SML gives better focus measure in transform domain also [25]. SML based local visual contrast considers nonlinear relationship between contrast sensitivity threshold of HVS and the background luminance [17]. SML is given by,

$$SML(i,j) = \sum_{m=-M}^{M} \sum_{n=-N}^{N} ML(i+m, j+n) \tag{4}$$

for a window with size (2M+1)(2N+1), where $ML(i,j)$ is the Modified Laplacian, which is defined as:

$$L(i,j) = \left|2L(i,j) - L(i-step,j) - L(i+step,j)\right| + \left|2L(i,j) - L(i,j-step) - L(i,j+step)\right| \tag{5}$$

where step is a variable spacing between coefficients and always is equal to 1. *L (i, j)* denotes the coefficient located at *(i, j)* in low frequency sub bands. SML based local visual contrast is given by

$$LV(i,j) = \begin{cases} \frac{SML(i,j)}{L(i,j)^{1+\alpha}}, if L(i,j) \neq 0 \\ SML(i,j), otherwise \end{cases} \tag{6}$$

where $\alpha \in (0.6, 0.7)$ is a visual constant. The low pass sub band coefficients are fused as follows:

$$L^F(i,j) = \begin{cases} L^A, if\ LV^A(i,j) \geq LV^B(i,j) \\ L^B, otherwise \end{cases} \tag{7}$$

where $LF(i,j)$ represents the coefficient located at (i,j) in low frequency sub bands of the initial fused image [2].

B. Fusion rule for high frequency sub bands

High frequency components of an image usually give information about edges, textures, boundaries etc. Selecting the best method for fusion of high pass sub band coefficients yields better quality fused image. In different multi scale transform image fusion methods, different rules have been used, in this paper a comparative study of three methods (1) Region based energy [18] (2) Log gabor energy [2] (3) PCNN [1] is done and it is found that PCNN based image fusion method perform better than the other two in terms of objective and subjective quality assessment.

PCNN is feedback network which is a model of visual cortex of mammalians. PCNN is a self organizing network, so no learning required. PCNN consists of three parts: receptive field, modulation field and pulse generator. Through the receptive field , neuron receives input signals from feeding and linking inputs through. The following are the iteration equations of PCNN:

$$F_{ij}(t) = exp(-\alpha_F)F_{ij}(n-1) + V_F \sum_{ab} M_{ij,ab}\, Y_{ab}(t-1) + S_{ij}$$

$$L_{ij}(t) = exp(-\alpha_L)L_{ij}(t-1) + V_L \sum_{ab} M_{ij,ab}\, Y_{ab}(t-1)$$

$$U_{ij}(n) = F_{ij}\left(1 + \beta_{ij} L_{ij}(n)\right) \tag{8}$$

$$Y_{ij}(n) = \begin{cases} 1 & U_{ij}(n) > \theta_{ij}(n) \\ 0 & otherwise \end{cases}$$

$$\theta_{ij}(n) = exp(-\alpha_\theta)\theta_{ij}(t-1) + V_\theta Y_{ij}(t)$$

where *i, j* refers to pixel location, F_{ij} is feeding input, L_{ij} is linking input. S_{ij} is input stimulus i.e., gray level of image pixel, U_{ij} is internal activity of neuron, θ_{ij} is dynamic threshold. Y_{ij} stands for the pulse output of neuron and is either 0 or 1. Attenuation time constants of F_{ij}, L_{ij} and θ_{ij} is given by α_L, α_F, α_θ, and inherent voltage potentials given by V_F, V_L, V_θ. β_{ij} is the linking strength. *t* varies from 1 to T_{max}, and n denotes current iteration [19].

Firing times is given by:

$$T_{i,j}^{l,k}(n) = T_{i,j}^{l,k}(n-1) + Y_{i,j}^{l,k}(n) \tag{9}$$

The iterations stops at t = T_{max}. The high frequency sub band coefficients of each source image are given as feeding input of PCNN. The decision is given by

$$D_{F,ij}^{l,k} = \begin{cases} 1, & if\ T_{A,ij}^{l,k}(n) \geq T_{B,ij}^{l,k}(n) \\ 0, & if T_{A,ij}^{l,k}(n) \geq T_{B,ij}^{l,k}(n) \end{cases} \tag{10}$$

V. Proposed Work

The following steps are done for multi focus color image fusion using NSCT and PCNN

(1) Convert the registered source images A and B from RGB space to YCbCr space.

(2) Perform NSCT decomposition on the Y component of image A.

(3) The low pass sub band coefficients are fused based on SML based local visual contrast.

(4) The high pass sub band coefficients are fused using PCNN.

(5) Inverse NSCT is performed on the fused low pass and high pass coefficients to obtain fused Y component.

(6) Color information is added to fused Y component to obtain fused color image

VI. Comparison Of Fusion Rules

In this paper comparison of two fusion methods with the proposed work are done. In the first method fusion is done using region energy [18], in the second method NSCT based fusion is done where the low pass sub band coefficients are fused using SML based local visual contrast and high pass sub band fusion is done using log gabor energy [2]. And in the proposed method also NSCT based fusion rule is done, SML based local visual contrast is used for low pass sub band coefficient fusion and PCNN based fusion is done for high pass sub band coefficient.

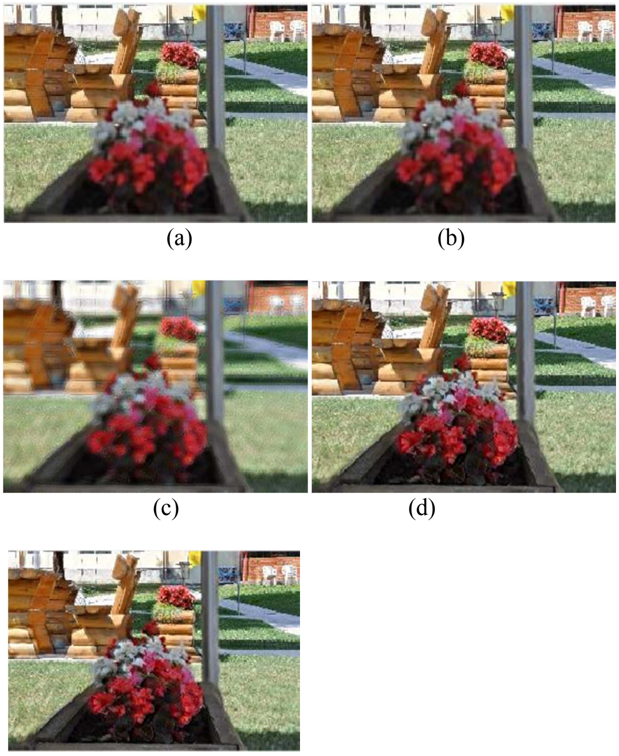
(a) (b) (c) (d) (e)

Figure 3: (a) Source Image A (b) Source Image B (c) Fused image method 1 (d) Fused image method 2 (e) Fused image proposed method

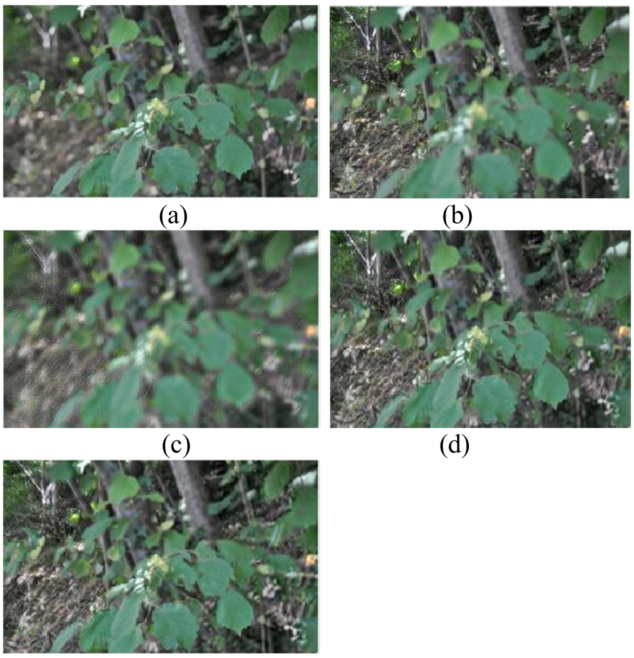
(a) (b) (c) (d) (e)

Figure 4: (a) Source Image A (b) Source Image B (c) Fused image method 1 (d) Fused image method 2 (e) Fused image proposed method

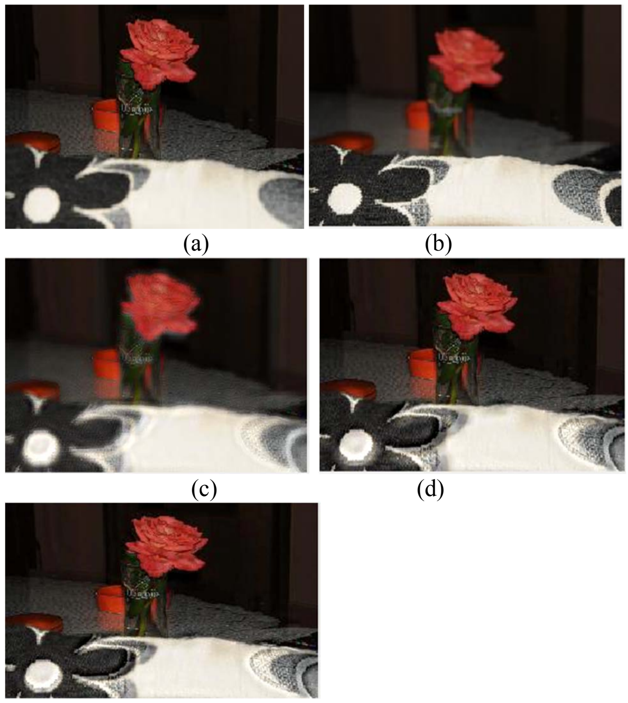
(a) (b) (c) (d) (e)

Figure 5: (a) Source Image A (b) Source Image B (c) Fused image method 1 (d) Fused image method 2 (e) Fused image proposed method

. And the quality of fused images thus obtained are assessed based on some objective criteria such as energy of gradient, threshold gradient [20], Energy of laplacian [20], modified laplacian [21], spatial frequency [22], Tenengrad [23], average of SSIM [2] of source image A and fused image and SSIM of source image B and fused image, similarly average of correlation coefficient and SML [2].

Table I,II and III gives comparison of objective criteria of different methods of multi-focus color image fusion of different source image pairs.

Table I. Evaluation of focus measure for image pair 1

Focus Measure	**Method 1**	**Method 2**	**Proposed method**
SML	41.7927	55.4500	56.8513
Energy of gradient	66.7586	90.6317	94.7282
Threshold gradient	11.6675	18.7841	19.4039
Energy of Laplacian	71.1786	88.8435	91.0572
Modified Laplacian	12.1058	21.7120	22.6617
Spatial frequency	5.5954	6.8261	7.0619
Tenengrad	7.2454e03	2.2155e04	2.3248e04
SSIM	0.7070	0.7083	0.7375
Correlation Coefficient	0.9499	0.9371	0.9442

Table II. Evaluation of focus measure for image set 2

Focus Measure	Method 1	Method 2	Proposed Method
SML	45.5696	58.0354	61.5274
Energy of gradient	70.3066	102.4495	109.9299
Threshold gradient	11.7885	19.0730	20.8191
Energy of Laplacian	79.8491	96.988	100.4333
Modified Laplacian	14.1485	23.0772	25.5209
Spatial frequency	5.8049	7.5029	7.8806
Tenengrad	3.5230e03	1.4654e04	1.6488e04
SSIM	0.6278	0.6398	0.6761
Correlation Coefficient	0.8633	0.8494	0.8577

Table III. Evaluation of focus measure for image set 3

Focus Measure	Method 1	Method 2	Proposed Method
SML	23.5062	30.1440	31.0734
Energy of gradient	32.1954	45.2165	47.0489
Threshold gradient	8.1871	11.5709	12.0365
Energy of Laplacian	30.2621	42.8910	43.9617
Modified Laplacian	5.1243	8.6701	9.2231
Spatial frequency	3.0660	3.8487	3.9504
Tenengrad	3.321e03	8.2977e03	9.0151e03
SSIM	0.8166	0.8063	0.8210
Correlation Coefficient	0.9636	0.9608	0.9615

Based on above three tables it is clear that most of the focus measures considered for study has more value for proposed based method. Since more the value for these focus measures means that more the quality of fused image. So it is clear that PCNN based method is better fusion rule for band pass directional sub band coefficients.

CONCLUSION

In this study, multi focus color image fusion is done in NSCT transform domain, where SML based rule is used to fuse low pass sub band coefficients and PCNN is used to fuse high pass sub band coefficients. Some experiments has been done in order to compare the quality of fused image based on different objective assessment evaluation criteria, based on these objective evaluation criteria it is clear that the proposed method based on NSCT and PCNN outperforms the other methods. The execution time of PCNN is more or less same as the existing methods.

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