FUSION USING MULTI-SCALE TRANSFORM BASED TECHNIQUES: AN APPLICATION TO MULTI-FOCUS CAMERA IMAGES

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Abstract

This paper aims in presenting the significance and usefulness of shift-invariant based Multi-scale Transform (MST) techniques in multi-focus image fusion. MST techniques overcome the shortcomings of the shift-variant based fusion techniques, as well as traditional Fourier-based methods. MST based fusion techniques provides characterization of local spectral and spatial properties of non stationary image at different scales, which is essential for multi-focus image fusion. MST based fusion techniques, namely, Stationary Wavelet Transform (SWT) and Non Sub-sampled Contourlet Transform (NSCT), have been selected for the fusion of multi- focus images. The accuracy of fusion techniques have been evaluated in terms of Root Mean Square Error (RMSE) and Peak Signal-to-Noise Ratio (PSNR). Analysis of result shows that shift-invariant NSCT technique not only extract visual information from source images, however, also effectively avoid the introduction of artifacts. It significantly outperforms SWT based fusion technique both quantitatively and quantitative measures.

Keywords: Image Fusion, Shift-invariant, Non Sub-sampled Contourlet Transform

1. Introduction

Due to the restricted depth-of-focus of lenses in charge coupled device (CCD) devices, it is frequently not possible to obtain an image that covers all the relevant objects 'in focus'. To overcome this problem is to exploit the concept of multi-focus image fusion, in which several images with different focus points are combined to form a single image with all objects fully focused, and, therefore, could be used for image processing based applications [2]. During the fusion process, all the important visual information found in the input images must be transferred into the fused image without introduction of artifacts. The fusion technique should be reliable and robust to imperfections [2-3]. Further, the concept of image fusion has been extended to many applications, such as, remote sensing, biomedical imaging, computer vision [1-3].

Over the years, a number of techniques for multi-focus image fusion have been proposed. One of the simplest approaches is to operate directly on input images, by pixel approach, using operators, such as, the weighted averaging [2]. However, this often leads to the insertion of undesired effects, such as, loss of contrast. Further, many researchers have recognized the effectiveness of MST based techniques for image fusion perspective [2-5]. The basic idea of such technique is to perform a MST on each source image first, and then employ some fusion rules to construct a composite multi-scale representation of the fused image, followed by an inverse MST. The commonly used MST techniques include the Discrete Wavelet Transform (DWT), Stationary Wavelet Transform (SWT) and Non Sub-sampled Contourlet Transform (NSCT) [4-8].

Due to the fact that the DWT has many advantages, such as localization and direction, over the pyramid transform, the DWT-based methods are generally superior to the pyramid-based methods [2-4]. However, it is found that DWT suffers with the problem of poor directionality and lack of shift invariance due to aliasing between sub-bands, whereas, SWT suffers from poor directionality. Therefore, to resolve the limitation of DWT and SWT, NSCT has been introduced. NSCT based fusion techniques possess the property of shift-invariance, multi-directionality and characterization of local spectral properties of non stationary image at different scales. Furthermore, these properties are desirable in image analysis applications, such as, edge detection, contour characterization, image fusion and image enhancement.

Thus, the main objective of this study is to evaluate the comparison of performance of SWT and NSCT based fusion techniques for the fusion of multi-focus images.

2. An overview of image fusion techniques

The MST base shift-invariant techniques which are selected for this study are SWT and NSCT.

2.1 Fusion method based on Stationary Wavelet Transform

The Discrete Wavelet Transform (DWT) is not a shift-invariant transform i.e., it suffers with the problem of linear continuity. This limitation can be overcome by using some of the DWT's extensions, such as, Stationary Wavelet Transform (SWT), also known as 'a` trous' algorithm [5-6]. In the "à trous" algorithm, the down-sampling step is suppressed and instead the filter is up-sampled by inserting zeros between the filter coefficients.

In the SWT technique, it uses a 2-D filter derived from the scaling function. This produces two images, of which one is an approximation image while other is a detailed image called the wavelet plane. A wavelet plane, represents the horizontal, vertical and diagonal detail between 2^j and 2^{j-1} resolution and is computed as the difference between two consecutive approximations I_{l-1} and I_l levels [4-8].

Further, all the approximation images obtained, by applying this decomposition, have the same number of columns and rows as the original image**,** since filters at each level are up-sampled by inserting zeros between the filter coefficients, make the size of the image same.

2.2 Fusion method based on Non Sub-sampled Contourlet Transform

In order to reduce the frequency aliasing of contourlets, enhance directional selectivity and shift-invariance, [9] proposed Non Sub-sampled Contourlet Transform. This is based on the Non Sub-sampled Pyramid Filter Banks (NSPFB) and the Non Sub-sampled Directional Filter Banks (NSDFB) structure. The former provides multi-scale decomposition using two channel non sub-sampled 2-D filter banks, while the later provides directional decomposition i.e. it is used to split band pass sub-bands in each scale into different directions [9].

As a result, NSCT is shift-invariant and leads to have better frequency selectivity and regularity than CT [8-9]. The scheme of NSCT structure is shown in Figure. 1 (a). The NSCT structure classify 2-Dimensional frequency domain into wedge-shaped directional sub-band as shown in Figure. 1(b).

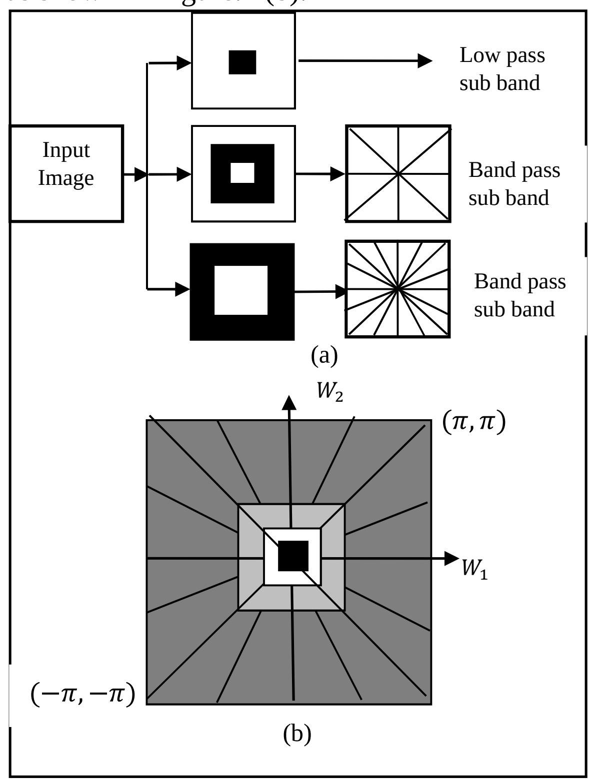


Figure 1: Two level NSCT decomposition (a) NSFB structure hat implements the NSCT (b) the corresponding frequency partition

The general fusion procedure adopted for the multi-focus images using SWT and NSCT [11-12] techniques can be summarized as follows (Fig. 1):

i) First, MST i.e. SWT or NSCT is applied to all input co-registered images, one by one, to get their coefficients according to the mathematical decomposition procedure related to each one of the technique, along with up-sampling and histogram matching.

ii) Perform a Multi-scale Transform (SWT/NSCT) on each source images, one by one, to get their corresponding coefficients.

iii) Obtain coefficients form the different source images are combined using defined fusion rule, to get the fused coefficients.

iv) Apply Inverse MST technique reconstruction with new fused coefficient to obtain the fused image.

v) The obtained coefficients generated in step (i)) from the different input images, are combined according to defined fusion rules to get the fused coefficients.

vi) The fused coefficients are subject to an inverse MST i.e. SWT or NSCT to construct the fused image.

As a result, a new MS image. It may be noted that DWT and NSCT techniques has its unique mathematical properties, which leads to different image decomposition procedure of an image.

Here, the fusion rules used in this study can be defined as follows

Average Fusion Rule

The Average Fusion Rule takes the average of the coefficients of the I_A and I_B images. This rule can be mathematically expressed as (Eq. 1).

$$I^F(n,m) = \left(I_A(n,m) + I_B(n,m)\right)/2 \qquad \dots (1)$$

3. Evaluation Criteria

It is obvious, that in most cases, there is slight variation among fusion results i.e. quantitative evaluation method sometimes produce results that cannot be supported by visual inspection. Therefore, in order to assess the quality of the fused image other than simple visual inspection of the images, some quantitative assessment criteria have been defined. The quantitative indicators which have been used for this purpose are Root Mean Square Error (RMSE), Peak Signal-to-Noise Ratio (PSNR) [10-11]. The mathematical formulation of these indicators are outlined below.

i) Root Mean Square Error (RMSE)

The root mean square error is a frequently-used measure of the differences between the fused image and the original image. RMSE is the most valuable performance evaluation criterion when original image is present. RMSE is a good measure of accuracy [10-11].

$$RMSE = \sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{\left(F(i,j) - R_o(i,j)\right)^2}{M \times N}} \qquad \dots (2)$$

where, M, N indicate the size of the image is M×N. F(i,j), 〖 R〗 _o (i,j) indicate the gray value row i and in the column j of the image. With smaller RMSE, there is less difference between them.

ii) Peak Signal-to-Noise Ratio (PSNR)

The PSNR index reveals the radiometric distortion of the final image compared with the original. PSNR can reflect the quality of reconstruction. The larger value of PSNR indicates less amount of image distortion [11].

$$PSNR = 10log\left(\frac{255}{RMSE}\right)^2 \qquad \dots (3)$$

It may be noted that the following conditions must be satisfied for a good fusion of images:

i) The smallest possible RMSE.

ii) The highest possible PSNR.

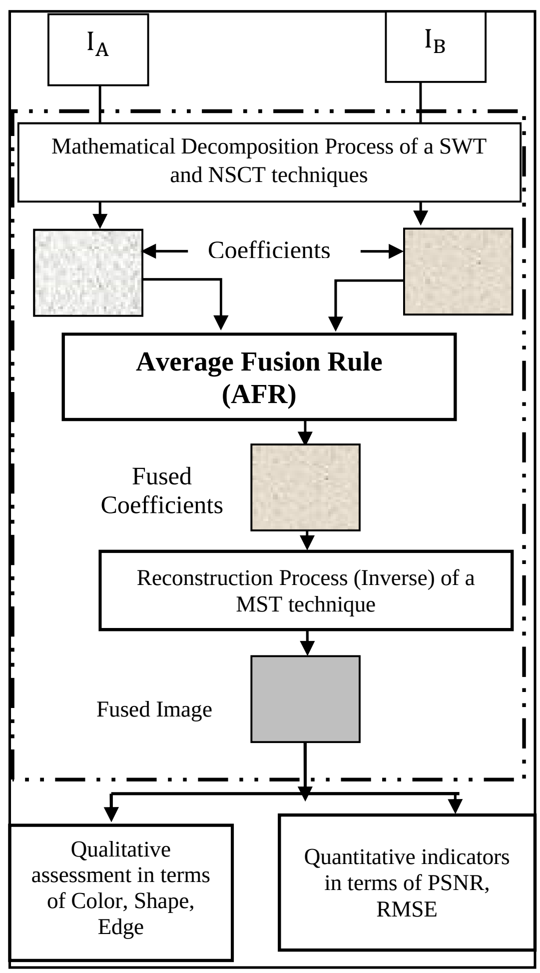


Figure 2: General methodology adopted for SWT and NSCT based image fusion

4. Evaluation of Results and Discussion

The image fusion techniques used in this study, have been evaluated using multi-focus datasets acquired from CCD cameras. Datasets corresponding to different focus angle, orientation and shape and size have been preferred, in order to examine the performance of fusion process.

Different datasets have been taken for the implementation of fusion techniques as shown in Table 1.

Table 1: Data used

DS-I


(a) Image A


(b) Image B

DS-II


(a) Image A


(b) Image B

DS-III


(a) Image A


(b) Image B

4.1 Qualitative analysis of the fused images

A visual comparison of the fused images is used for the qualitative assessment, since it is a simple, yet an effective method for showing the major advantages and disadvantages of a fusion technique. In this paper, two different pixel-based image fusion algorithms, SWT and NSCT, are compared for the fusion of multi-focus images, as shown in Figure (3, 4 & 5).

DS-I


(a) Image A


(b) Image B


(c) SWT

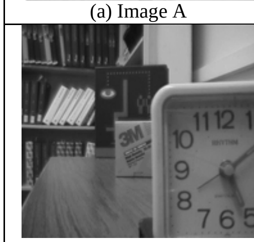

(d) NSCT

Figure 3: Fusion results generated by different fusion techniques for DS-I dataset.

DS-II


(a) Image A


(b) Image B


(c) SWT

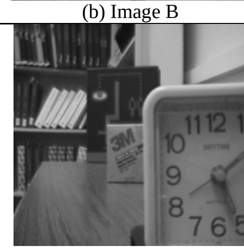
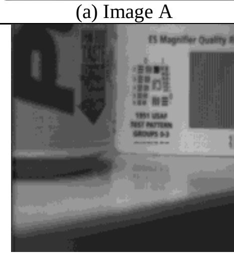

(d) NSCT

Figure 4: Fusion results generated by different fusion techniques for DS-II dataset.

DS-III


(a) Image A


(b) Image B


(c) SWT

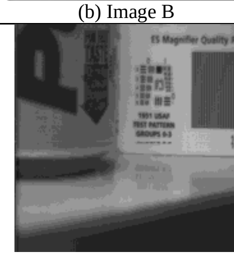

(d) NSCT

Figure 5: Fusion results generated by different fusion techniques for DS-III dataset.

With reference to Figure (3, 4 & 5), it is found that fused images generated using NSCT based fusion technique yields better result visually, when to compared to SWT based fusion technique.

4.2 Quantitative analysis

The results of the various parameters of accuracy assessment for the fused images generated using different image fusion techniques for different datasets has been discussed below.

4.2.1 Analysis based on RMSE and PSNR

Generally, smaller RMSE value, represents a greater accuracy measure, whereas higher values of PSNR reflect less amount of image distortion. The experimental results of RMSE and PSNR are given in Tables 2.

Table 2: PSNR and RMSE values for different fusion techniques

Dataset	Method	PSNR	RMSE
DS-I	SWT	30.7100	5.8573
	NSCT	31.9013	4.9471
DS-II	SWT	29.8070	8.2450
	NSCT	32.8952	6.3480
DS-III	SWT	31.6187	5.8818
	NSCT	32.0211	4.6733

With reference to Table. 2, A low value for RMSE and high value of PSNR are observed for NSCT based fusion technique for all the datasets, followed by SWT based technique. This is a indication of less image distortion.

Thus, statistically, it can be inferred that NSCT technique yields the better result in terms of quantitative indicators, followed by SWT based fusion technique.

5 Conclusion

In this study, a comparative assessment of different fusion techniques using different multi-focus images has been carried out both, quantitatively and qualitatively. The result shows that the NSCT based fusion technique provides the best result, both in terms of qualitatively and quantitatively parameters. NSCT based technique emerged as one of the most effective fusion technique for the fusion of multi-focus images by minimizing the artifacts. Eventually, it can be concluded from this study that analysis of non-stationary multi-focus images used for fusion can be analyzed and fused effectively by using NSCT based fusion technique. The outcome of this study could therefore be utilized for further image processing applications.

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