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Multi-focused Image fusion in HDWT Domain

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ABSTRACT

Multi-focused image fusion becomes crucial one to extend depth of field of machine vision cameras. It combines two or more images focusing different objects of the same scene to form multi-focused fused image. This paper proposes simple and effective method of multi-focused image fusion using local gradient energy in higher density discrete wavelet transform domain, which is shift invariant and over complete by a factor of 5. This wavelet transform transfers all spectral and spatial information of all source images into multi-focused fused image without any distortions. The qualitative and quantitative analyses using metrics without reference prove the proposed method is considerably superior than other fusion methods using Discrete wavelet transform, Stationary wavelet transform, and double density discrete wavelet transform.

Keywords **- Multi-focused image fusion, Depth of field, Higher Density DWT, Multi-focused Image Fusion**

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I. INTRODUCTION

Now a day, the driving force in manufacturing industries is increased volume of production with lower cost, enhanced quality and shorter cycle time. It is necessary to inspect each and every part to produce good quality products. Human vision is eye-straining, inaccurate, qualitative, time consuming, subjective and costly. To inspect at high speed for real time applications, manufacturers look for accurate, reliable, consistent and fast automated visual inspection using machine vision system [3]. The shorter depth of field (DOF) is main problem in imaging system of machine vision. DOF is the distance between the innermost and outermost objects in the scene that appear focused in the image. In some cases, it is necessary to have larger depth of field imaging system to capture the entire scene with clear focus [20]. One way of extending DOF is multi focus image fusion (MFIF). MFIF combines two or more images of the same scene with different focus to form all-in-one focus image. Spatial and Multiscale Transform (MST) domain fusion are two approaches to MFIF. Fused image in spatial domain is obtained by combining the pixel value of source images using activity measurement and fusion rules. Spatial domain methods are simple but fail to transfer the unique features like contrast & sharpness of source images into fused image. Laplacian pyramid (LP) [2], gradient pyramid (GP) [11], ratio of low-pass pyramid (RP) [16], and contrast pyramids [17] were used in MST based fusion methods. As these pyramids introduced the blocking artifacts in the fused image, the critically sampled Discrete Wavelet Transform (DWT) was used for representing the source image at multi scale [1, 7]. But DWT suffers from shift variance and poor in directionality. One way to remove poor in directionality is to generalize DWT to generate the Discrete Wavelet Packet Transform (DWPT). DWT and DWPT are shift varying. Dual Tree Complex Wavelet Transforms (CWT) overcomes shift varying limitation by using complex valued filtering [5, 6]. It decomposes the real/complex signals into real and imaginary parts in transform domain. For perfect reconstruction, DWT and CWT use Finite Impulse Response filter for analysis and synthesis [8]. These filters can be either symmetric or orthogonal. To design filters to have both symmetric and orthogonal properties, the number of filters in filter bank is increased. This result M-band or M-Channel wavelet transform which consists of one scaling filters and M-1 wavelet filters. M-band wavelet transforms have more flexible tiling of the time frequency plane. They provide more detailed information of narrow band high frequency components in frequency responses [15]. Double density Discrete Wavelet Transform (DDWT) is an example of M-band DWT. But, DDWT does not increase the sampling with respect to frequency or scale of decomposition [12]. Higher-Density Discrete Wavelet Transform (HDWT) is another expansive dyadic wavelet transform which has intermediate scale between each pair of scales of DWT [13]. In this paper, MFIF based on HDWT is proposed. At each level, the source images are decomposed into one structural (LL) and eight detail sub-bands (LB, LH, BL, BB, BH, HL, HB and HH). To preserve the spectral and structural information in the fused image, a window-based activity measure with maximum absolute value fusion rule is used to form the fused wavelet coefficient map of the low frequency approximation sub bands and high frequency fused wavelet coefficients. The paper briefly reviews HDWT in section 2. The detailed procedure of the proposed methodology is presented in section 3. Performance metrics and experimental results are given in section 4 & 5. The last section concludes the paper.

II. HIGHER DENSITY DWT

The commonly used wavelet transform for MFIF is critically sampled DWT. DWT can be implemented using perfectly reconstructed Finite Impulse Response (FIR) filter banks [8]. But critically sampled DWT suffers from four shortcomings namely oscillations, shift variance, poor directionality and aliasing [14]. Among the four shortcomings, shift variance affects the performance of critically sampled discrete wavelet transform in image processing applications. Shift variance is due to down sampling and up sampling process during analysis and synthesis respectively. Improved performance can be obtained by using an over complete, redundant or expansive transform which expands an N point signal to M transform coefficients with M > N. Higher Density DWT is one of the expansive dyadic wavelet transform. Higher Density DWT uses three filters, one scaling filter 'Φ(t)' and two wavelet filters '$\Psi_1(t)$' and '$\Psi_2(t)$'where wavelet filter 'Ψ_1 (t)' is band pass and $\Psi_2(t)$' is high pass filter. The high pass filter is not down sampled and up sampled during analysis and synthesis respectively. The analysis and synthesis filter bank structure are shown in following Fig.1.

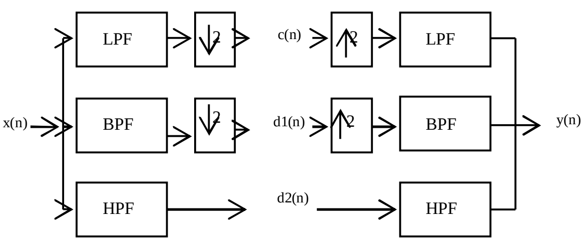

Fig. 1. Analysis and Synthesis filter of HDWT

In order to use HDWT for image fusion applications, it is necessary to implement a two-dimensional HDWT. This can be done by applying the transform first to the rows, then to the columns of an image. This is shown in Fig. 2, in which 1D over sampled filter bank is applied on the rows and then on the columns. This gives nine 2D sub bands namely LL, LB, LH, BL, BB, BH, HL, HB and HH where L stands for low pass filter, B stands for band pass filter and H stands for high pass filters. The relative sizes of the sub bands for an input 2D signal of size N X N is tabulated in Table 1. In comparison, the critically sampled two-dimensional DWT has four sub bands namely LL, LH, HL and HH. The size of each sub bands is N/2 X N/2. Therefore, the two-dimensional extension of HDWT is only 5-times expansive.

Table 1. Relative Size of Sub bands of HDWT

Sub Bands	Size
LL	N/2 X N/2
LB	N/2 X N/2
LH	N/2 X N
BL	N/2 X N/2
BB	N/2 X N/2
BH	N/2 X N
HL	N X N/2
HB	N X N/2
HH	N X N
Total	6N X 6N

III. PROPOSED METHODOLOGY

The proposed method to form the all-in-one focus image using HDWT involves the following three steps as shown in the Figure 3. In first step, the source images are decomposed into eight detail and one approximation sub bands by convolving with analysis filters of HDWT. In the next step, detail and approximation sub bands are fused by employing appropriate fusion rules. Final fused image is obtained by convolving with synthesis filters of HDWT.

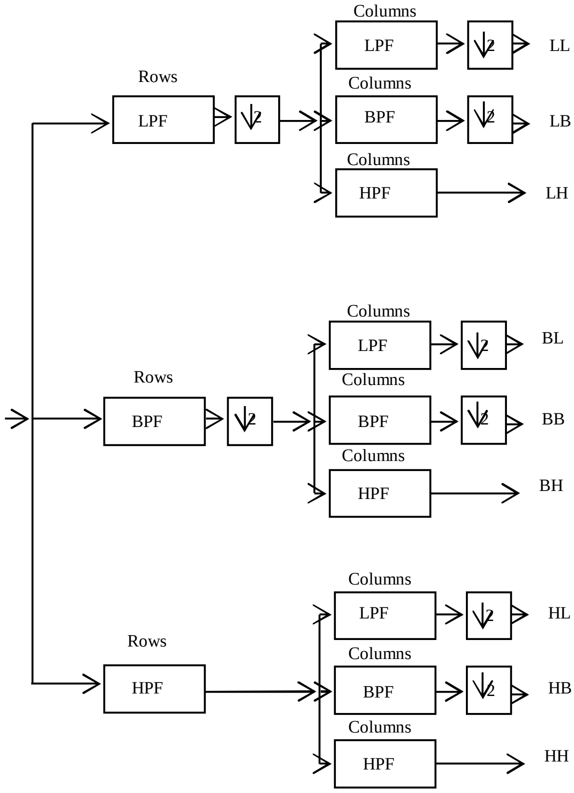

Fig. 2. 2D Filter bank structure of HDWT

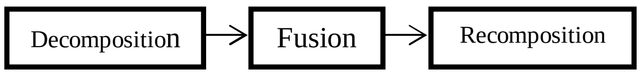

Fig. 3. Steps in MFIF using HDWT

At first, HDWT is applied to source images I_A and I_B to decomposed the source images into structural sub bands (LL_A & LL_B) and detail sub bands (LB_A, LH_A, BL_A, BB_A, BH_A, HL_A, HB_A & HH_A, LB_B, LH_B, BL_B, BB_B, BH_B, HL_B, HB_B & HH_B). Since, structural sub band contains the low frequency information and detail sub bands contain directional & edge information, separate fusion rules are used to fuse structural sub bands and detail sub bands. Since important features are larger than a pixel [7], it is better to consider the neighborhood of the pixel to form fused image. This paper employs feature extraction over window of size 3 x 3 and then selects the pixel based on the extracted features. To preserve the spectral and structural information in the all-in-one focus image, a window-based activity measure with maximum absolute value fusion rule is used to form the fused wavelet coefficient map of the low frequency approximation sub bands (L_F). To preserve the spectral and structural information in the fused image, a window-based activity measure with maximum absolute value fusion rule is used to form the fused wavelet coefficient map of low and high frequency fused wavelet coefficients. Finally, the fused image I_F is obtained by taking the inverse HDWT of fused structural sub band and detail sub bands.

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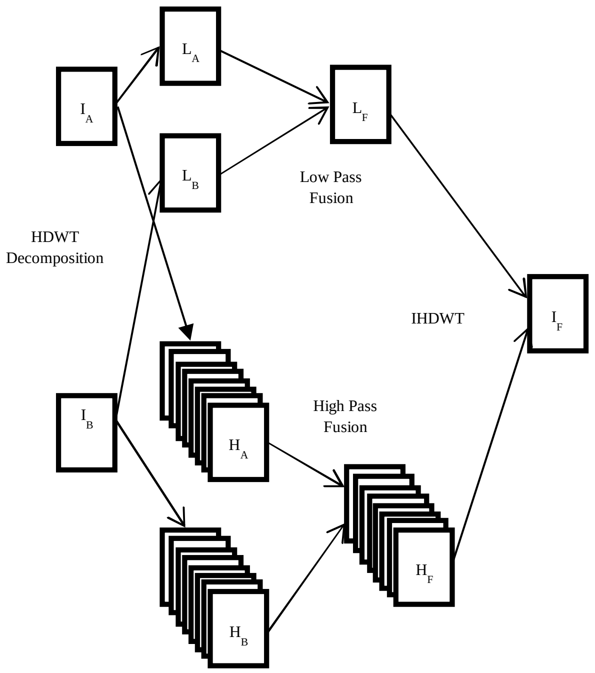

Fig. 4. Proposed Methodology

IV. PERFORMANCE METRICS

In general, numerous numbers of evaluation metrics are proposed in the literature to evaluate the performance of an image fusion algorithm. The main categories of these evaluation metrics are based on information theory, image feature, image structural similarity and human perception. Also, the performance of an image fusion algorithm can be evaluated in two different ways. The first way uses a known reference image to compare the fusion result whereas second way is a blind or non-referenced assessment for the practical applications for which reference images are not available. This paper uses only the blind assessment namely Normalized Mutual information (NMI), Nonlinear correlation information entropy (NCIE), Gradient fusion metric (GFM), Phase congruency fusion metric (PCFM), Structural similarity index measure (SSIM), and Human perception inspired quality metric (HPQM).

V. EXPERIMENTAL RESULTS

In this section, the results of proposed MFIF using HDWT are provided. To implement the proposed MFIF using HDWT, MATLAB simulation package of version R2017b is used. This method is tested with 20 set of images downloaded from www.image-net.org which are shown in figure 5. Each set of image consists of one left focused and one right focused image. The results of our method are compared with other fusion methods using DWT [7], SWT [10], and DDWT [4]. The results of MFIF are shown in Fig. 6. For all the fusion methods, only one level of decomposition (LOD) is set. For the proposed method, the activity level is measured using 3X3 window. Table 2 presents the quantitative results which are average of 20 set of pairs of images. From the results, it is inferred that the proposed MFIF using HDWT outperforms other MST domain image fusion using DWT, SWT and DDWT in terms of NMI, NCIE, GFM, PCFM, SSIM and HPQM.

Left Focused Image

Right Focused Image

Fig. 5. Test Images

Fig. 6. Results of Image Fusion using
(a) DWT, (b)SWT, (c)DDWT and (d) HDWT

Table 2. Results of Image Fusion (Average)

MST	DWT	SWT	DDWT	HDWT
NMI	1.15722	1.15155	1.15677	1.17323
NCIE	0.84122	0.84158	0.84166	0.84295
GFM	0.79502	0.79589	0.79907	0.79984
PCFM	0.91355	0.92111	0.92474	0.92543
SSIM	0.93491	0.93386	0.93586	0.93649
HPQM	0.79656	0.86036	0.83262	0.85760

VI. CONCLUSION

In this paper, a simple and effective method of multi-focused image fusion using Higher Density DWT is presented. The window based activity measure with maximum absolute value is used to form structural and detail sub band of multi-focused image in HDWT domain. To validate the proposed method, experiments were conducted on 20 sets of images and the results were compared with DWT, SWT and DDWT fusion methods. From the results, it is inferred that the proposed method preserves spatial and spectral information of sources images in fused image. Also, it produces superior results than other methods in terms of non-reference objective evaluation measures. The application of HDWT for other domains of image processing may be explored as future work. Also, the performance of proposed method may be explored using other types of activity measurement and fusion rule. Further, the number of source images at the input side may also be increased.

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