Image Fusion using Image Blocks and Modified Discrete Wavelet Transform

Wisarut Chantara and Yo-Sung Ho
School of Electrical Engineering and Computer Science
Gwangju Institute of Science and Technology
123 Cheomdangwagi-ro, Buk-gu, Gwangju 61005, Republic of Korea
{wisarut, hoyo}@gist.ac.kr

***Abstract*— In digital photography, all the structures of normal digital cameras have the finite depth of field problem. Photographers could only focus with one point. This means the objects apart from the focus range appear with blurring effect. In order to solve this problem, this paper presents an image fusion technique to extend the depth of field. Image blocks and modified discrete wavelet transform is applied to source images. The method is operated with DWT coefficients. The approximation coefficients are applied with spatial frequency and selected based on a maximum sharpness focus measurement, while the detail coefficients are applied with sum-modified-Laplacian and chosen based on a maximum information based fusion scheme is proposed. The performance of the proposed method was conducted and compared with conventional methods. Experiment results show that the proposed method can extend the depth of field considerably.**

Keywords-Depth of field; image blocks; discrete wavelet transform; spatial frequency; sum-modified-Laplacian

I. INTRODUCTION

Image fusion is the process producing a single image from a set of source images, such as multi-focus, multi-sensor and multi-frame images. The fused image has more complete information which is more useful for human or machine perception. Image fusion includes important application in many different fields such as medical imaging, satellite imaging, microscopic imaging, computer vision and robotics. The advantages of image fusion improve reliability and capability by redundant information and complementary information respectively. Then, image fusion algorithm provides an all-focused image (also referred to as an extended depth-of-field image).

In the past, many fusion techniques and algorithms for in-focused detection and fusion have been proposed to obtain all-focused images. Zang et al. [1], proposed a way of medical image fusion technique according to wavelet transform. The method used different characters of wavelet theory, enactment threshold to wipe off the noise and the convolution process. Liu et al. [2], presented multi-focus image fusion strategy based on the lifting scheme of wavelets gives substantial information in the fused image. Desale et al. [3], proposed a study and analysis of image fusion technique by way of PCA, DCT and DWT. Li et al. [4], introduced a method based on the selection of image blocks from source images to construct the fused image using spatial frequency, while Huang et al. [5], evaluated focus measurement in multi-focus image fusion.

This paper proposes an image fusion algorithm by measuring focal regions and combining in-focused parts to the complete image. The final image displays sharply all-focused image and shows the depth of field can be extended exceedingly.

II. PROPOSED METHOD

In this paper, the proposed method is used to measure in-focused regions and combine these regions to all-focused image as shown in Fig. 1. The following techniques are involved in the proposed method's implementation.

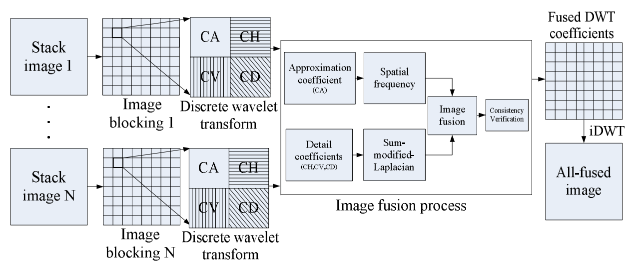

Figure 1. Proceduce of the proposed method

A. Block partition stack images

We capture stack source images using the Lytro camera [6]. A set of images is same viewpoint with different focus [7]. After that we partition the stack source images into blocks (8×8 blocks). It is clear that this method can avoid the problem of shift-variant [5].

B. Discrete wavelet transform

Discrete wavelet transform (DWT) converts the stack source images from the spatial domain to frequency domain. According to Fig. 2, the image is divided by vertical and horizontal lines. The first-order DWT output contains the approximation coefficient (CA) or low-frequency coefficient and the detail coefficients (CH, CV and CD) or high-frequency coefficients. CA is sensitively with human eyes [8] while CH, CV and CD have more detail information about the image. The DWT can minimize color distortion.

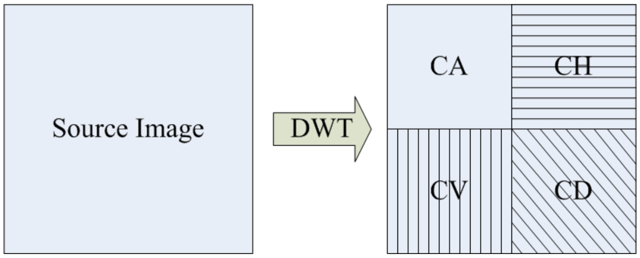

Figure 2. DWT Decomposition

1) Approximation coefficient

Approximation coefficient is the source image at the coarser resolution level, which can be considered as a smoothed and subsampling version of the source image. Most information of the source image is kept in the approximation coefficient. Then, we utilize the spatial frequency (SF), which indicates the overall active level in an image and originated from the human visual system, on the approximation coefficient. The SF is expressed as:

$$SF = \sqrt{(CF)^2 + (RF)^2} \tag{1}$$

Where RF and CF are the row frequency and column frequency respectively:

$$RF = \sqrt{\frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=2}^{N} [f(i,j) - f(i,j-1)]^2} \tag{2}$$

$$CF = \sqrt{\frac{1}{M \times N} \sum_{j=1}^{N} \sum_{i=2}^{M} [f(i,j) - f(i-1,j)]^2} \tag{3}$$

For $M \times N$ image with the approximation coefficient $f(i, j)$ at position (i, j).

2) Detail coefficients

The detail coefficients contain the detailed information of an image, which usually have large values correspond to sharp intensity changes and preserve salient information in the image. Moreover, The energy of the detail coefficients of an in-focused image is much larger than that of a blurred image. Then, we apply sum-modified-Laplacian (SML) to the detail coefficients. It can effectively represent the salient features and sharp edge of the image. The SML is expressed as:

$$\begin{aligned} &F(x,y) = \sum_{i=x-N}^{i=x+N} \sum_{j=y-N}^{j=y+N} \nabla^2_{ML} I(i,j) \\ &for\ \nabla^2_{ML} I(i,j) \geq T_{SML} \\ &where\ \nabla^2_{ML} I(i,j) = \left|\frac{\partial^2 I}{\partial x^2}\right| + \left|\frac{\partial^2 I}{\partial y^2}\right| \end{aligned} \tag{4}$$

Where T_{SML} is a threshold value of SML and $I(i, j)$ is the detail coefficients at position (i, j).

C. Image fusion process

The approximation and detail coefficients of DWT structures are combined as:

$$\begin{aligned} &F_{i,j} = D^m_{i,j} \\ &\text{where} \\ &m = \underset{t}{\operatorname{argmax}}\{C^t_{i,j}\}, t = 1,2,\dots,N \end{aligned} \tag{5}$$

Where $F_{i,j}$ is a fused coefficient in a final image at position (i, j). While $D^m_{i,j}$ is a maximum coefficient information at position (i, j). $C^t_{i,j}$ is DWT coefficient information at t stack source image at position (i, j). N is a set of stack source images.

D. Consistency verification

After combining the fused DWT coefficient, we verify the result by a consistency verification process (CV). If the considering pixel is to come from source image A, but with the majority of its surrounding pixels from B, this pixel will be changed to come from B. A majority filter is implemented with 3 × 3 window size.

E. All-focused Imaging

Finally, we perform the inverse DWT on the combined wavelet coefficients, which are obtained by the CV process from the previous step. Then, an all-focused image is reconstructed into a final image.

III. EXPERIMENT RESULTS

In this section, we present the outcomes of the proposed method with different sample images. We conducted experiments on sample images of size 512 × 512 pixels. The experiment parameters are assigned as: image blocks = 8 × 8 blocks, SML window size = 3 × 3 pixels, T_{SML} = 10 and CV window size = 3 × 3 pixels.

Figure 3. Experimental sample images

To prove our proposed method performance, the comparative methods (such as pixel averaging, DWT and SF) are compared with the proposed method. Fig. 4 and Fig. 5 illustrate the image fusion result using different methods.

Figure 4. (Top-left) Pixel averaging, (Top-right) DWT, (Bottom-left) SF, (Bottom-right) Proposed method

Figure 5. (Top-left) Pixel averaging, (Top-right) DWT, (Bottom-left) SF, (Bottom-right) Proposed method

From the criterion evaluation, the mutual information (MI) and the peak signal-to-noise ratio (PSNR) are considered with respect to the reference images. The proposed method provides effective results when compared with other conventional methods as shown in Table I. The quality of fused image would be better with higher MI and PSNR values.

TABLE I. PERFORMANCE OF DIFFERENT FUSION METHOD

Images	Criteria	Pixel Avg.	DWT	SF	Proposed Method
Figure 4.	MI	4.147	3.943	4.453	**4.608**
	PSNR(dB)	26.994	24.357	28.232	**28.310**
Figure 5.	MI	7.155	7.598	7.113	**7.818**
	PSNR(dB)	24.542	21.324	24.517	**24.831**

IV. CONCLUSIONS

In this paper, we propose an image fusion method using image blocks and modified discrete wavelet transform. To improve the DWT algorithm, we present the adapted DWT method using spatial frequency and sum-modified-Laplacian. As a result of that we can correctly find out and merge the focal regions to all-focused image. From the experiment results, we can confirm that our proposed method properly working well and show that the depth of field can be extended greatly.

ACKNOWLEDGMENT

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