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Image Fusion Method Based On Combined Filtering Techniques

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Abstract: The term image fusion refers to integration of information from different images of same object. The resulting fused output will be more clear and informative than the inputs. This paper proposes an efficient image fusion method based on different filtering techniques. The method is using two scale decomposition and weighted average based reconstruction schemes. Two different edge preserving filters called guided filter and local edge preserving filter are used for improving the efficiency of fused outputs. Two parallel fused results are produced for each input pair based on guided filter based fusion and LEP filter based fusion. These fused results are compared to find the best fused result.

Keywords: image fusion; two scale decomposition; guided filter; LEP filter; weighted average; mutual information.

I. INTRODUCTION

Basically image fusion is the process of combining information from different images and produces a single fused output[1]. The final fused output will contain more details than any of the inputs. Basic steps in image fusion procedure can be listed as follows:

1. Image Decomposition: All the inputs are decomposed into different layers or levels. [2][3] shows a wavelet based decomposition using discrete wavelet transform and [5] shows a pyramid based decomposition scheme. [7] shows a novel image segmentation scheme that divide input image into different patches.

2. Image Fusion: Here apply the fusion operator on inputs. There may be single fusion operator or may employ different fusion operator for different decomposition levels.

3. Image Reconstruction: Reconstruction is the final step in fusion process. Generally reconstruction is the inverse procedure of decomposition step done initially, i.e. for wavelet based approach reconstruction is the application of inverse wavelet transform [3] and for pyramid based approach it is the application of inverse pyramid transform [5].

The most common and effective conventional image fusion approaches are image fusion method using Discrete Wavelet Transforms (DWT)[2][3], Principal Component Analysis (PCA)[4], Laplacian Pyramid[5], Support Vector Machine (SVM)[6], Higher Order Singular Value Decomposition (HOSVD)[7], complex extensions of EMD[8], Support Value Transform (SVT)[9] etc. But the common drawback is that all these methods require multi-scale decomposition. Image fusion with Guided Filtering [10] is another method which requires only two-scale decomposition. Guided filter [11] employed in this method is a good edge preserving image filter which is producing better output than all conventional methods. In this work another edge preserving filter called Local Edge Preserving (LEP) filter [12] is used along with the guided filter. In many cases LEP is capable to provide better results than guided filter based approach. The remainder of this paper is organized as follows. In section II, the edge preserving image filters are briefly reviewed. Section III describes the proposed image fusion algorithm. The experimental results and discussions are presented in Section IV. Finally, Section V concludes the paper.

II. EDGE PRESERVING IMAGE FILTERING

Edge Preserving Image Filters are different from conventional type of image filters since it preserves edge information. Guided and Local Edge Preserving (LEP) image filters are two efficient edge preserving smoothing filters.

A. Guided Image Filter

The guided image filter [11] is an edge preserving smoothing filter that filters binary, gray scale, or RGB input image P, where the filtering process is guided by image I. The guidance image I can be a binary, gray scale or RGB image and must have the same number of rows and columns as P. The output image will be a linear transform of this guidance image.

B. LEP Image Filter

LEP [12] is an efficient edge preserving filter and is different from previous filtering techniques in its local adaptive property. LEP is taking average of gradient of image instead of taking simple image for calculating pixel values.

TABLE I
Guided and LEP Filter Parameters

Filters	**Linear Parameters (for each window w)**		**Output (Q_i)**
	a_w	**b_w**	
Guided	cov(IP) / [var(I) + ϵ]	mean(P) – a*w* * mean(I)	mean(a*w*) * I_i + mean(b*w*)
LEP	var(P) / [var(P) + ά * (∑∇ I2-β) / N]	mean(P) – a*w* * mean(P)	mean(a*w*) * P_i + mean(b*w*)

Where I : Guidance image, P : Input image, cov(IP) : covariance of IP, mean(I) : mean of image I in given window, var(I) : variance of I in given window, ϵ : regularization parameter, ά and β : parameters of LEP and I : gradient of I.

III. IMAGE FUSION PROCEDURE

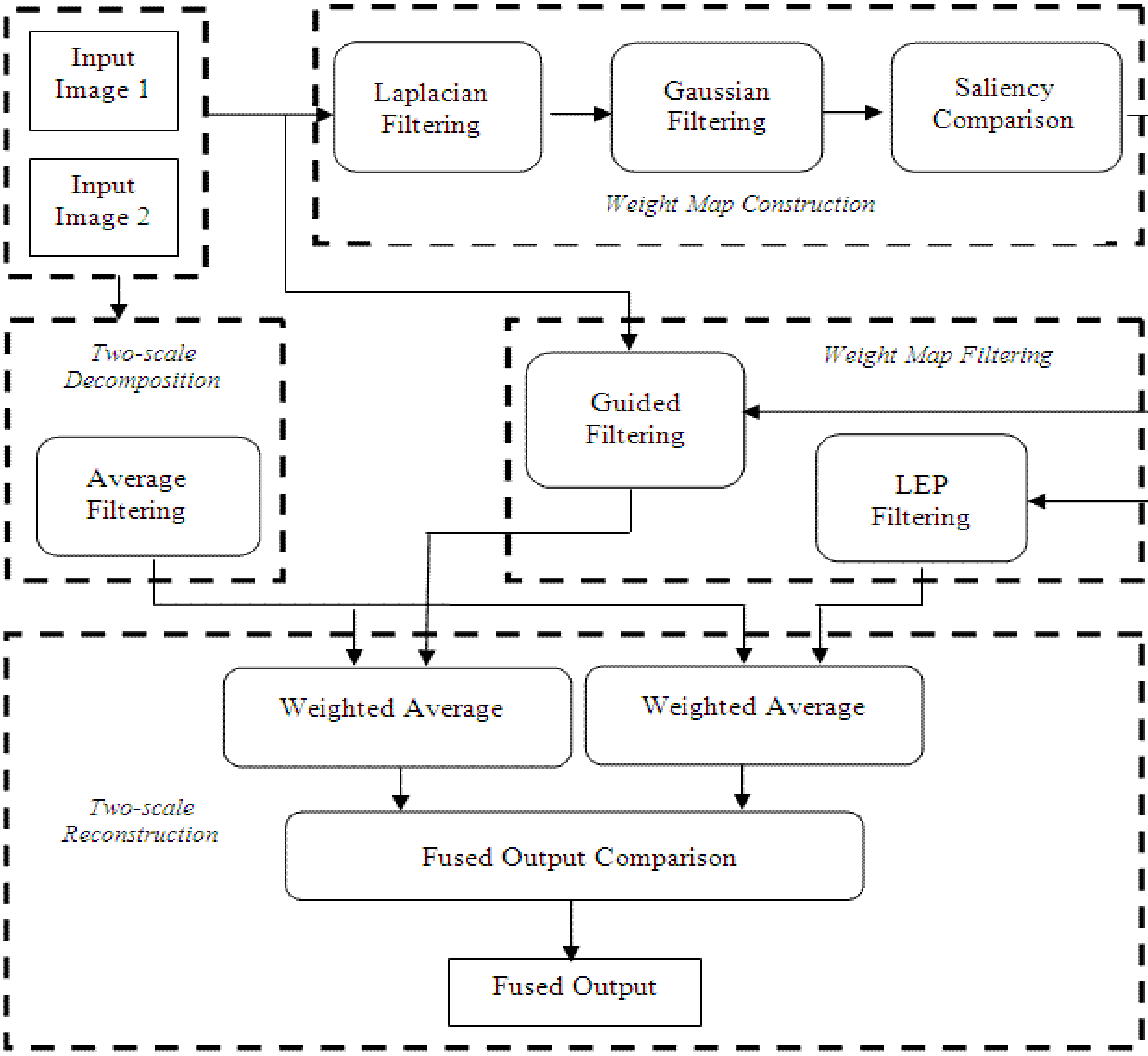

Fig. 1 Architecture of proposed method.

The main steps in this method are two-scale decomposition of input images, weight map construction, weight map filtering and two-scale reconstruction of fused outputs.

A. Two-scale Input Image Decomposition

The initial step in this method is to decompose both input images into two layers. An average (mean) filter M is used to do the two-scale decomposition. M decomposes the input image into base and detail layers. The size of M is set to 31×31. Here I_1 represents the first input image and I_2 represents the second input image. The average filtering operation can be represented as

$$I_1 * M = B_1. \quad (1)$$

$$I_2 * M = B_2. \quad (2)$$

B_1 and B_2 in equation (1) and equation (2) represent the base layers of I_1 and I_2. These base layers include the large scale information. The detailed layers can be obtained by simple subtraction of base layers from corresponding input images. The detailed layers can be represented as

$$I_1 - B_1 = D_1. \quad (3)$$

$$I_2 - B_2 = D_2. \quad (4)$$

D_1 and D_2 represent the detail layer corresponding to I_1 and I_2 respectively. Detailed layers contain small scale information.

B. Weight Map Construction

Weight map corresponding to each input image is constructed in this step. A Laplacian filter followed by a Gaussian filter is used here. Initially Laplacian filter L is applied on I_1 and I_2, which will give high pass images corresponding to I_1 and I_2. The Laplacian filtering operation is given in equation (5) and equation (6)

$$I_1 * L = H_1. \quad (5)$$

$$I_2 * L = H_2. \quad (6)$$

Here H_1 and H_2 represent the high pass images of I_1 and I_2. Size of Laplacian filter L is set to 3×3. These high pass images are then filtered using a low pass Gaussian filter G of size 11×11. The Gaussian filtering operation can be represented as follows

$$H_1 * G = S_1. \quad (7)$$

$$H_2 * G = S_2. \quad (8)$$

The output of Gaussian filter is saliency maps S_1 and S_2. This saliency maps are compared to generate the weight maps. The weight maps P_1 and P_2 can be generated as follows

$$P_1(m,n) = 1 \text{ If } S_1(m,n) \geq S_2(m,n), \text{ else } P_1(m,n) = 0 \quad (9)$$

Here (m.n) represent the pixel positions. P_1 is the weight map corresponding to first input image I_1. Similarly we can find the weight map P_2 for input I_2.

$$P_2(m,n) = 1 \text{ If } S_2(m,n) \geq S_1(m,n), \text{ else } P_2(m,n) = 0 \quad (10)$$

Weight maps are black and white images and these weight maps are again filtered for improving the quality of final output.

C. Weight Map Filtering

The initial weight map is filtered to improve the quality of final fused output. Here we are using two different filters in parallel and generates two fused outputs based on these two filters. Guided[11] and LEP (Local Edge Preserving)[12] are the two filters used for this purpose. These are edge preserving smoothing filters that preserves the edge information very well. The Guided filtering operation for getting base layer can be represented as follows

$$(I_1, P_1) * G_1 = G\_B_1. \quad (11)$$

$$(I_2, P_2) * G_1 = G\_B_2. \quad (12)$$

Here G_1 is the guided filter; This guided filter takes two inputs, guidance image and image to be filtered. G_B_1 and G_B_2 represent the base layers of guided filter output. I_1 and I_2 acts as guidance image and P_1 and P_2 are images to be filtered. The radius of guided filter r_1 is set to 45 in this case. The Guided filtering operation for getting detail layer can be represented as follows

$$(I_1, P_1) * G_2 = G\_D_1. \quad (11)$$

$$(I_2, P_2) * G_2 = G\_D_2. \quad (12)$$

G_2 is the guided filter; G_D_1 and G_D_2 represent the detail layers of guided filter output. The radius r_2 of filter G_2 is set to 7. i.e. the filter size 7 will produce base layer and 45 will give detail layer. The LEP filtering operation for getting base layer can be represented in equation (13) and equation (14). The main difference between guided and LEP filter is that LEP requires only one input while guided filter requires two.

$$P_1 * L_1 = L\_B_1. \quad (13)$$

$$P_2 * L_1 = L\_B_2. \quad (14)$$

Here L_1 is the LEP filter; L_B_1 and L_B_2 represent the base layers of LEP filter output. P_1 and P_2 are images to be filtered and radius r_1 of filter L_1 is set to 20. The detail layer of filtered outputs can be obtained by filtering P_1 and P_2 using LEP filter L_2 with radius r_2=2. The filter sizes 2 and 20 will give best results for LEP filter.

$$P_1 * L_2 = L\_D_1. \quad (15)$$

$$P_2 * L_2 = L\_D_2. \quad (16)$$

D. Two-scale Input Image Reconstruction

This step reconstructs the original final fused output images. The image reconstruction is based on a technique called weighted averaging. The weighted average operation for guided filter based fusion operation can be represented as

$$(G\_B_1 * B_1) + (G\_B_2 * B_2) = G\_B. \quad (17)$$

$$(G\_D_1 * D_1) + (G\_D_2 * D_2) = G\_D. \quad (18)$$

Here G_B and G_D represent the fused base layer and fused detail layer based on guided filter based weighted average operation. The fused output image corresponding to guided filter based fusion G_F is given by

$$G\_B + G\_D = G\_F. \quad (19)$$

The weighted average operation for LEP filter based fusion operation can be represented as

$$(L\_B_1 * B_1) + (L\_B_2 * B_2) = L\_B. \quad (20)$$

$$(L\_D_1 * D_1) + (L\_D_2 * D_2) = L\_D. \quad (21)$$

Here L_B and L_D represent the fused base layer and fused detail layer based on LEP filter based weighted average operation. The fused output image corresponding to LEP filter based fusion L_F is given by

$$L\_B + L\_D = L\_F. \quad (22)$$

The results G_F and L_F are the two fused outputs from Guided and LEP filter based methods. Now compare these fused results to find the best quality output. In this paper the fused output image quality is measured by an information theory based fusion quality matric called mutual information (MI).

E. Calculation of Mutual Information (MI) and Comparisonof Fused Results

This module calculates the MI values and compares the fused outputs to identify the best output. The term mutual information [13][14] gives the amount of source image information preserved in the fused output. The mutual information is measured on the basis of marginal entropies and joint entropies. Mutual information of fused output with source images are calculated as follows

$$M(I_1) + M(G\_F) - J(I_1, G\_F) = M\_I(I_1, G\_F). \quad (23)$$

$$M(I_2) + M(G\_F) - J(I_2, G\_F) = M\_I(I_2, G\_F). \quad (24)$$

$$M(I_1) + M(L\_F) - J(I_1, L\_F) = M\_I(I_1, L\_F). \quad (25)$$

$$M(I_2) + M(L\_F) - J(I_2, L\_F) = M\_I(I_2, L\_F). \quad (26)$$

Here the function M_I(X,Y) represents the mutual information, I_1 and I_2 represents the first and second source images, G_F and L_F represents the fused outputs of Guided and LEP filter and the functions M(X) and J(X,Y) indicates the marginal and joint entropies respectively. The final MI value for an output is the normalized mutual information value of that output with I_1 and I_2. The MI fusion quality matrices of filtered outputs can be calculated as follows

$$2\{ [M\_I(I_1,G\_F) / (M(I_1) + M(G\_F))] + [M\_I(I_2,G\_F) / (M(I_2) + M(G\_F))] \} = MI_1. \quad (27)$$

$$2\{ [M\_I(I_1,L\_F) / (M(I_1) + M(L\_F))] + [M\_I(I_2,L\_F) / (M(I_2) + M(L\_F))] \} = MI_2. \quad (28)$$

Here MI_1 represents the MI quality matric value for Guided filter fusion output and MI_2 represents the quality matric value for LEP filter fusion output. Compare these values and select the best fused result.

IV. Experimental Results and Discussion

A. Results

Different categories of inputs considered here are case 1: Images taken under different light settings i.e. multi-exposure images, case 2: Multi-focus images. Samples inputs from multi-exposure and multi-focus images classes are shown in Fig. 2 and Fig. 3. The examples for fused image results using two filters are shown in Fig. 4 to Fig. 9.

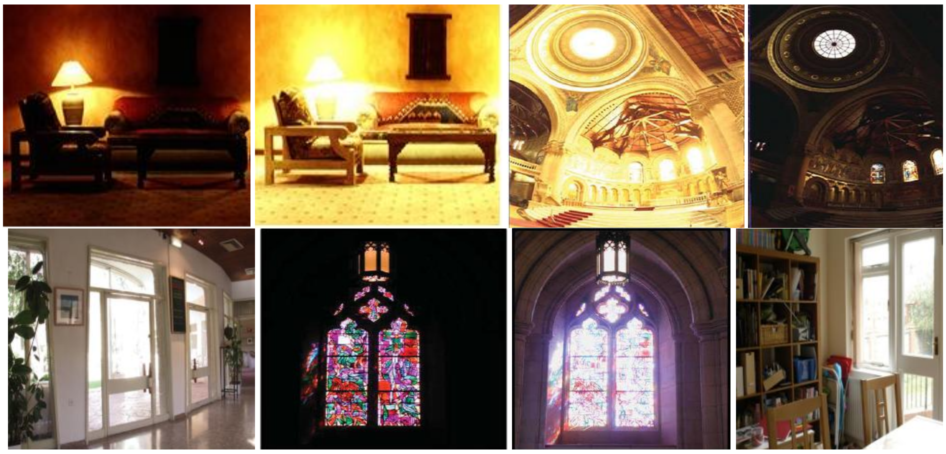

Fig. 2 Sample inputs of multi-exposure image set

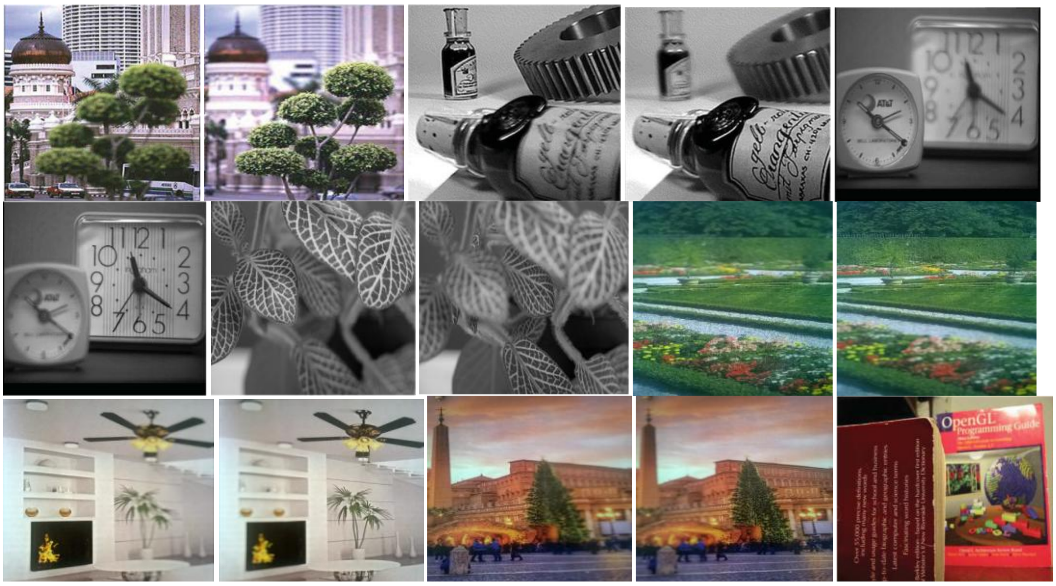

Fig. 3 Sample inputs of multi-focus image set

Fig. 4 Case 1-Example1: (a) Input 1, (b) Input 2, (c) Best fused output (LEP filter based output) and (d) Guided filter based output

Fig. 5 Case 1-Example2: (a) Input 1, (b) Input 2, (c) Best fused output (LEP filter based output) and (d) Guided filter based output

Fig. 6 Case 1-Example3: (a) Input 1, (b) Input 2, (c) Best fused output (LEP filter based output) and (d) Guided filter based output

Fig. 7 Case 2-Example1: (a) Input 1, (b) Input 2, (c) Best fused output (Guided filter based output) and (d) LEP filter based output

Fig. 8 Case 2-Example2: (a) Input 1, (b) Input 2, (c) Best fused output (Guided filter based output) and (d) LEP filter based output

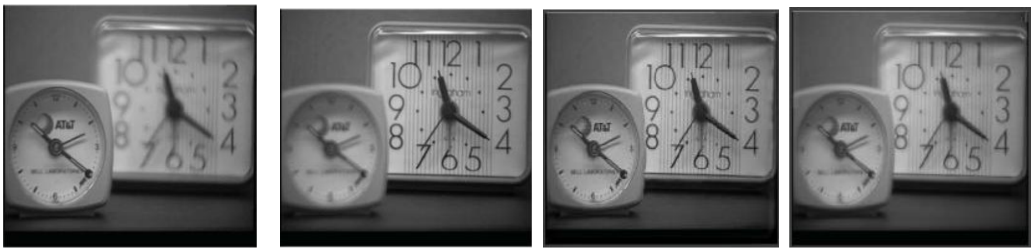

Fig. 9 Case 2-Example3: (a) Input 1, (b) Input 2, (c) Best fused output (Guided filter based output) and (d) LEP filter based output

B. Analysis of filter parameters

The parameters of guided filter [10] are set as r_1=45, r2=7, ε_1=0.3 and ε_2= 10^{-6} for analysis. The parameters of LEP [12]; r_1, r_2, ά and β are set as r_1=20, r_2=2, ά=0.1 and β=1. Where r1 represents the radius of filter for getting first decomposition layer i.e. base layer and r2 is the radius for second decomposition layer i.e. detailed layer. ε_1 and ε_2 are regularization parameters of guided filter. ά and β and horizontally and vertically varying parameters that is sensitive to gradient of image.

C. Observations from the experiment

The results of analysis of guided filter based and LEP filter based fusion methods are shown in TABLE II. Best values are indicated as bold. Experimental results of 6 different inputs sets, 3 sets from each input class are given in the table. The inputs given in TABLE II are same that are shown in Fig. 2 and Fig. 3. Higher value of MI indicates higher quality output.

TABLE III

Comparison of MI values of Guided & LEP filter based methods

Inputs (Results shown in Fig. 4 to Fig. 9)		**Guided Filter Based Fusion**	**LEP Filter Based Fusion**
Multi-exposure	Fig. 4 a & Fig. 4 b	0.341	**0.482**
	Fig. 5 a & Fig. 5 b	0.176	**0.367**
	Fig. 6 a & Fig. 6 b	0.133	**0.411**
Multi-focus	Fig. 7 a & Fig. 7 b	**0.275**	0.185
	Fig. 8 a & Fig. 8 b	**0.341**	0.248
	Fig. 9 a & Fig. 9 b	**0.402**	0.330

V. Conclusion

In this paper we have presented a new image fusion method based on different filters. Initially an average filter is used for decomposition purpose. Then a Laplacian and a Gaussian filter followed by two parallel edge preserving filters are used for creating the weighted maps. These edge preserving filters used in this work are Guided and LEP filters which will preserve edge information very well and provides better quality outputs than ordinary image fusion methods. From the study we have identified that both Guided and LEP filters provide different output qualities for different categories of inputs. The quality of final fused output is compared on the basis of a fusion quality measure called mutual information (MI). The value of MI is directly proportional to image quality. We have considered two categories of inputs such as multi-exposure inputs and multi-focus inputs. Experimental results show that for multi-exposure inputs, the LEP filter output is the best and for multi-focus inputs guided filter gives better output than LEP filter.

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