Multi-Focus Image Fusion by Using a Pixel-Based SML Comparison Map

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Abstract. The fusion of images which have different focal lengths can play important role for visual enhancement. It can also be used as a pre-processing step for various processing modules such as edge detection and feature extraction in order to improve the performances. In this paper, we propose a pixel-based algorithm which uses SML(Sum of Modified-Laplacian) as a focus measure for multi-focus image fusion. After the centers of focused areas in images are calculated, the 2-level SML comparison map is made by measuring the distance from the centers. And we adopt the median filter on the comparison map to reduce the effect of noise. Simulation results showed the proposed algorithm can successfully improve the visual quality of combined image subjectively as well as objectively.

Keywords: Multi-Focus Image Fusion, SML(Sum of Modified-Laplacian), Median Filter, Comparison Map.

1 Introduction

Multi-focus image fusion is main interest of this paper, and it is the technology of making composite image which is focused in all areas from more than two images of which focal points are different from each other. The purpose of it is to provide a wide depth of fields and enhance the whole sharpness of composite image. Thus, we can get visually clear image after the image fusion and use it as a pre-processing to improve performance of image processing or computer vision programming such as feature extraction, edge detection and so on.

There are several techniques which are closely related to the multi-focus image fusion. One is focal stacking technique that accumulates the multiple images by calculating the degree of focus according to the depth [1]. On the other hands, some techniques have used the focus measure through the transform or filtering technique and taken the best part of image by comparing its value. IHS(Intensity-Hue-Saturation) transform, multi scale transform, high-pass filtering and wavelet transform are typical examples [2]. In general, most fusion algorithm adopts block-based approach. The images are partitioned into square blocks and the better substitutes are selected by comparing the amounts of focus within a block. Also, the quad-tree

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structure has been used for adaptive multi scale fusion to deal with a small-sized object [3].

In this paper, we propose a pixel-based fusion algorithm which use SML(Sum of Modified-Laplacian) as a focus measure. Firstly, the 3-level SML comparison map is generated and the pixels in medium level are reallocated to low or high level by comparing the distances from the centers of mass of each level. And the median filter is adopted to remove the noise in the 2-level comparison map. The final composite image can be composed by selecting better candidates according to the 2-level SML comparison map.

2 Multi-Focus Image Fusion and SML

Figure 1 shows general conceptual diagram of block-based image fusion method. It divides the source images to several blocks and calculates focus measure of each block. The composite image takes one block which has higher value of focus measure between source A and B.

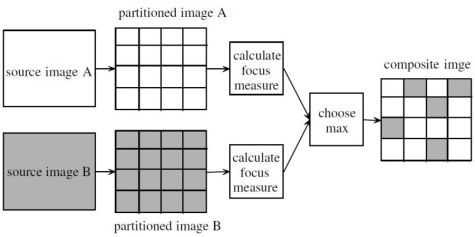


Fig. 1. General conceptual diagram of block based image fusion method [3].

Many kinds of focus measure have been introduced to calculate the degree of focus within a block [4]. The simplest focus measure is to use the variance of image pixel's gray values. And some measures, such as EOG(Energy Of Gradient) or Tenenbaum's method, use the first derivative of pixel value. SF(Spatial Frequency) method can be considered as a modified version of EOG. Meanwhile EOL(Energy Of Laplacian) or SML use the second derivative. In this paper, we adopt SML as a focus measure because it showed better performance in many cases [5].

The SML value of a pixel can be calculated as follows. Firstly, every ML(Modified-Laplacian), which is defined by equation (1), is calculated at each position in source images. In equation (1), *f(x,y)* denotes the intensity value of gray scale image and the step size always equals to 1 in this paper.

$$\begin{aligned}\nabla^2_{ML} f(x,y) \; = \; & |2f(x,y) - f(x-step,y) - f(x+step,y)| \\ & + |2f(x,y) - f(x,y-step) - f(x,y+step)|. \end{aligned} \quad (1)$$

And the SML corresponds to the sum of ML within a window only when the value of ML is between T_1 and T_2 as shown in equation (2). The lower threshold T_1 is selected as the average of all ML value. The upper threshold T_2 is selected as smaller value between source A's and B's maximum value of ML. The parameter N determines the window size of $(2N+1) \times (2N+1)$. The size of SML window affects the performance, but there is a trade-off between accuracy and computing time.

$$SML = \sum_{i=x-N}^{x+N} \sum_{j=y-N}^{y+N} \nabla_{ML}^2 f(i,j) \quad for \quad T_1 \leq \nabla_{ML}^2 f(i,j) \leq T_2 . \tag{2}$$

3 The Proposed Algorithm

3.1 Generation and Filtering of SML Comparison Map

Figure 2 shows the general block diagram of proposed algorithm. When two source images with different focal lengths are given, the output of this process is the 2-level SML comparison map to be used for selecting better candidate to produce final composite image. The whole process consists of 4 steps.

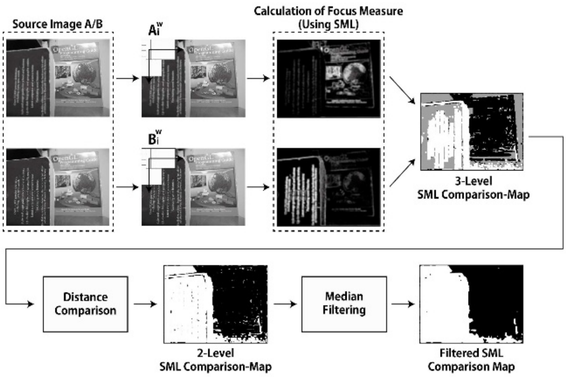


Fig. 2. The generation and filtering the SML comparison map

Step 1. Calculation of pixel-based SML: As explained in previous section, SML is calculated at every pixel of each source image by window A_i^w, B_i^w. The results are M_i^A and M_i^B respectively. ($i = 0, 1, 2, \cdots, (number\ of\ pixels)$)

Step 2. Generation of 3-level SML comparison map: After the SML values are obtained at step 1, the 3-level comparison map can be produced as equation (3). When there are significant gap between two SML values at position of given pixel, we think that pixel belongs to a low (0) or high (255) level with high probability. But it is considered as an ambiguous (128) level when the gap is not greater than a threshold.

$$P = \begin{cases} 0 & (I > Th)\ and\ (M_i^A > M_i^B) \\ 128 & (I \leq Th) \\ 255 & (I > Th)\ and\ (M_i^A < M_i^B) \end{cases} , \quad I = |M_i^A - M_i^B| . \tag{3}$$

Step 3. Generation of 2-level SML comparison map: In this step, we reallocate the ambiguous medium level into low or high level. Because the focal length cannot vary abruptly, the comparison map is likely to have large correlation in spatial domain. Thus we calculate each image's center of mass(CoM) of the focus area and compare the distance from the ambiguous position to the centers of mass and assign the level of closer one.

Step 4. Median filtering: Even though the 2-level comparison map can be obtained at step 3, there are many small-sized noises and these may deteriorate the performance. Therefore it is desirable to filtering the comparison map. In this paper, we use median filter because it can suppress the isolated noise and preserve the edge of level boundary.

3.2 Making a Composite Image

To make composite image, we use the 2-level SML comparison map which is obtained at step 4. Equation (4) gives the composition rule. When P=0, we take the pixel from source image A *and vice versa*.

$$C_i = \begin{cases} A_i^w \ (P = 0) \\ B_i^w \ (P = 255)\,. \end{cases} \tag{4}$$

The performance of multi-focus fusion scheme is evaluated in two ways. One is the subjective way, the resulting composite image is directly evaluated via human eye. Another is to use the numerical objective measure of *RMSE* [6] to calculate the amount of difference between the composite image and the original image of entirely focused.

4 Experimental Results

4.1 Experimental Setup

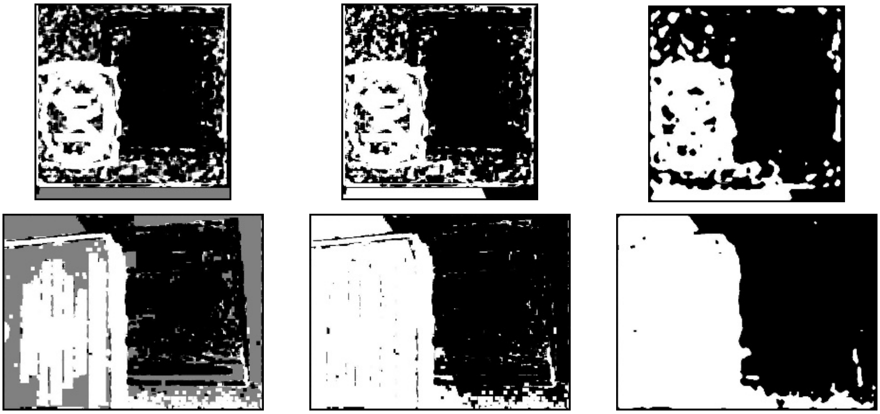
Figure 3 shows test images for making composite image. There are two kinds of test data set, one is 'Clocks' and the other is 'Books' [7, 8]. The test images are gray scale and there sizes are 512X512 and 758X569 respectively. This experiment worked on Windows 8 64-bits OS and MATLAB R2014a.

(a) (b)

Fig. 3. Test images. (a) Clocks; (b) Books.

4.2 Improving Performance Using Proposed Algorithm

Figure 4 shows the process of the SML map generation to improve performance. Figure 4-(a) is the 3-level SML comparison map where we can find the ambiguous errors of the gray(128) pixels which are mainly located on plain texture region. And we confirm that these ambiguous pixels are suitably classified and the 2-level SML comparison map is obtained as Figure 4-(b). Even though there exists some classification error in upper left side of ‘Books’ map, generally it makes reasonable results. Finally, Figure4-(c) is median filtered map where the isolated noise are clearly erased.

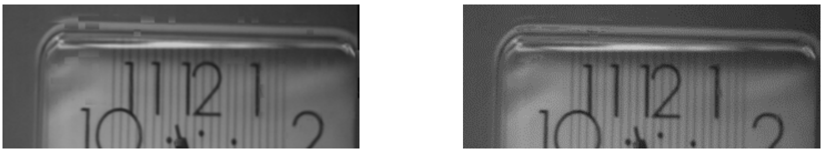


(a) (b) (c)

Fig. 4. Comparison of 3-steps of SML comparison map. (a) 3-level map; (b) 2-level map; (c) Median Filtered 2-level map.

4.3 Result Images and Evaluation

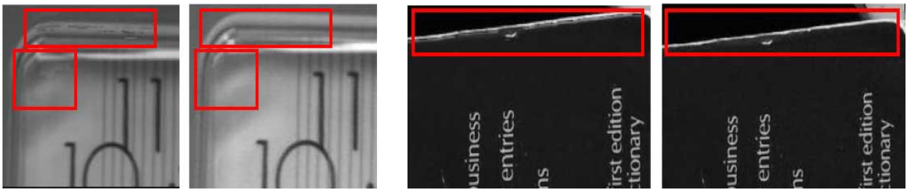
Conventional block-based SML processing may cause blocky error. In contrasts, our proposed pixel-based SML method can tone down these errors. Figure 5-(a) shows blocky error in top of clock. But in Figure 5-(b), remarkably reduce blocky error and it feels smooth.



(a) (b)

Fig. 5. Comparison of block based SML result and pixel based SML result. (a) Block based SML; (b) Pixel based SML.

As shown in Figure 6, we can observe the visually enhancement of multi-focus image fusion performance in boxed area. Figure 6-(a) has more clear result at plain texture area and Figure 6-(b) has more vivid line at the boundary of book. Finally, we compute *RMSE* to check the numerical and objective improvement. As shown in Table 1, we can draw a conclusion that suggested pixel-based image fusion method improve performance both ‘Clocks’ and ‘Books’ image.



(a) (b)

Fig. 6. Comparison of non-filtered and filtered composite image. (a) Part of ‘Clocks’ composite image; (b) Part of ‘Books’ composite image.

Table 1. Comparison of RMSE between SML comparison map non-filtered and filtered

	Median Filter	
Test Image	Non-Filtered	Filtered
Clocks	3.13	2.84
Books	14.01	13.91

5 Conclusion

In this paper, we suggested a multi-focus image fusion scheme using SML as a focus measure. Most conventional fusion schemes were based on block processing. In contrary, the proposed method calculated SMLs at each pixel and the resulting image was composed by pixel-based approach to reduce the blocky artifacts. To generate more reliable comparison map, we labeled ambiguous pixels which have similar SML values as ambiguous level and reallocated them to low or high level according to the distance from the centers of focus. Also the median filtering was applied to eliminate the isolated error while preserving the edges of comparison map. Simulation results said that the visual quality of composite image was greatly enhanced by using the proposed algorithm. Also we could find *RMSE* values were decreased after median filtering.

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