Multi-Focus Image Fusion based on Stationary Wavelet Transform and extended Spatial Frequency Measurement

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Abstract

In this paper, we propose a multi-focus image fusion approach based on Stationary Wavelet Transform (SWT) and extended the Spatial Frequency Measurements (SFM). Our proposed approach, two fused images are firstly decomposed into four subbands, which are one approximation subband (LL) and three details subbands (HL, LH and HH). Next, each subband is partitioned into blocks and each block is identified the clearer regions by computing the focus measure using the extended Spatial Frequency Measurement (SFM). Finally, the recovered fused image is reconstructed by performing the Inverse Stationary Wavelet Transform. From the experimental results, we found that the proposed method outperforms the traditional Wavelet Transform and SFM based methods in terms of objective and subjective assessments.

1. Introduction

Nowadays, the image fusion has become an essential sub-topic in digital image processing research area. The main objective of image fusion is to combine information from two or more source images of the same scene to obtain an image with completely information. One example application of the image fusion, the main general problem of inexpensive cameras, we can not take every object on different distances to obtain an image with focus on all objects in the same scene so that a multi-focus image fusion method is needed in order to get the in focus or sharply images.

The simplest image fusion technique is to compute the average pixel-by-pixel gray level value of the source images [1]. However, this technique leads to undesirable side effects such as contrast reduction. In the past two decades, a variety of image fusion methods were introduced such as Laplacian pyramid [2], Contrast pyramid [3], Ratio pyramid [4], and Discrete Wavelet Transform (DWT) [5-6]. In DWT based method, the basic idea of this method is to perform decompositions on each source image then combine all these decompositions to obtain composite representation, from which the fused image can be recovered by finding inverse transform. This method had been proved to be an effective method [7]. However this method is not translation–invariant because of down-sampling process. If there is a movement of the object in the source images, the performance of this method will deteriorate.

In this paper, a multi-focus image fusion approach based on Stationary Wavelet Transform (SWT) [8] and extended Spatial Frequency Measurement is proposed. One advantage of SWT is translation–invariant, without down-sampling process. Therefore, all approximation and detail coefficient subbands have the size same as the images source. In our proposed method, two fused images are firstly decomposed into four subbands, which are one approximation subband (LL) and three details subbands (HL, LH and HH). In fusion process, the extended Spatial Frequency Measurement [9] is adopted. The recovered fused image is reconstructed by performing the Inverse Stationary Wavelet Transform.

The rest of this paper is organized as follow. Section 2 and 3, the concepts of Stationary Wavelet Transform and the extended Spatial Frequency Measurement are described. Finally, the proposed image fusion method, experimental results and conclusion are presented in section 4, 5 and 6, respectively.

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2. Stationary Wavelet Transform

Stationary Wavelet Transform (SWT) is similar to Discrete Wavelet Transform (DWT) [4-5] but the only process of down-sampling is suppressed that means the SWT is translation-invariant. The 2-D SWT decomposition scheme is illustrated in Figure 1.

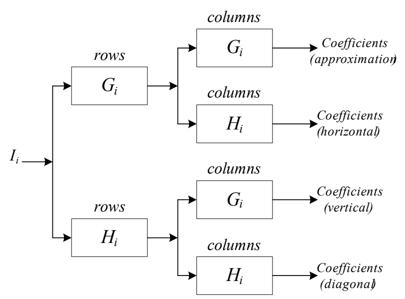
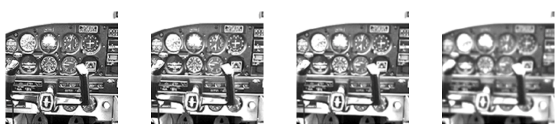


Figure 1. SWT decomposition scheme

where I_i, G_i, H_i are a source image, low-pass filter and high-pass filter, respectively.



(a) LL band (b) r = 0.5 (c) r = 1.0 (d) r = 2.0

Figure 2. An approximation subband image (LL) and its Gaussian blurred images at various radius (r)

3. Spatial Frequency Measurement (SFM)

SFM is used to measure the overall activity level of an image [10]. The extended SFM can be used to represent the clarity of an image, defined as follows,

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

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

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

$$SDF = \sqrt{\frac{1}{M \times N} \sum_{j=1}^{N-1} \sum_{i=2}^{M} \left[I(i,j) - I(i-1,j+1) \right]^2} \tag{4}$$

$$SF = \sqrt{(RF)^2 + (CF)^2 + (MDF)^2 + (SDF)^2} \tag{5}$$

where *RF,CF,MDF,SDF and SF* represented frequency in row, column, main diagonal, secondary and all spatial frequency of an image, respectively.

Table 1. SFM values of Fig. 2

Fig.2	(a)	(b)	(c)	(d)
SFM	82.514	57.307	41.655	29.672

Fig. 2(a) shows an approximation subband of Tiger image. Fig. 2(b)-(c) show the various blurred images of Fig. 2(a) after blurring with a Guassian of radius 0.5, 1 and 2. As can be seen from Table 1, when the image gets more blurred, the spatial frequency decreases consequently. For detail subbands, it also produced the same results. These lead to reflect the clarity or in focus regions.

4. Proposed approach

4.1 Multi-focus Image fusion scheme

Fig. 3 shows our proposed approach of the multi-focus image fusion scheme.

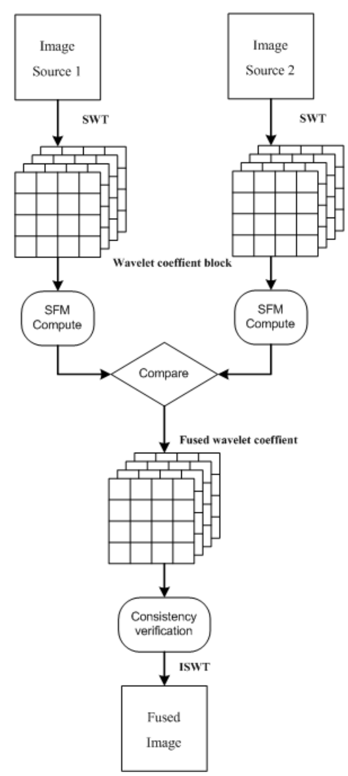


Figure 3. Proposed image fusion scheme

The proposed fusion procedure consists of the following steps.

A) Decompose the two source images using SWT at one level resulting in three details subbands and one approximation subband (HL, LH, HH and LL bands)

B) Partition the coefficients from each subbands into blocks of size $M \times N$. Denote the ith coefficients blocks from each subbands of image1 and image2 by ωA_i^s and ωB_i^s, respectively.

where $s = \{LL, HL, LH, HH\}$ subbands

C) Compute the spatial frequency values of each blocks ωA_i^s and ωB_i^s using Eqa.(1-5), Eqa.(1) for HL subband, Eqa.(2) for LH subband, Eqa.(3)+Eqa.(4) for HH subband , and LL subband using Eqa.(5).

D) Compare the spatial frequency values of two corresponding blocks ωA_i^s and ωB_i^s, the simple rule for construct the ith fused coefficient block ωF_i^s is given by

$$\omega F_i^s = \begin{cases} \omega A_i^s, & SF\omega A_i^s > SF\omega B_i^s \\ \omega B_i^s, & SF\omega A_i^s < SF\omega B_i^s \\ \dfrac{\omega A_i^s + \omega B_i^s}{2}, & otherwise \end{cases} \quad (6)$$

where ωF_i^s is fused coefficient blocks and $SF\omega A_i^s, SF\omega B_i^s$ is spatial frequency value of ωA_i^s and ωB_i^s block , respectively.

E) Verify and correct on the fusion result obtained in step D using a majority filter with a 3×3 window, if center block comes from image1 but the neighbor of its surrounding block are from image2, then this center block will be changed to be from image2, and vice versa.

F) Finally, the fused image is reconstructed by performing the inverse SWT on the results, obtained from step E.

4.2 Image quality assessments

To evaluate the performance of fused image, the RMSE and edge measurements [11] are used. The RMSE and Edge measurements for the reference image R and awfused image F (both of size $M \times N$) are defined as follows.

$$RMSE = \sqrt{\frac{1}{M \times N}\sum_{m=1}^{M}\sum_{n=1}^{N}[R(m,n) - F(m,n)]^2} \quad (7)$$

where $R(m,n)$ and $F(m,n)$ are the pixel value at position (m,n) of R and F, respectively. Smaller the values mean the better image quality.

$$Edge = \frac{1}{M \times N}\sum_{m=1}^{M}\sum_{n=1}^{N}\left(Q_R(m,n) - Q_F(m,n)\right)^2 \quad (8)$$

where $Q_R(m,n)$ and $Q_F(m,n)$ are the edge gradients of the R and F using Sobel operator. Smaller the values of Edge measurement mean the better image quality.

5. Experimental results

The experimental results are performed on eight sets of 256-gray scale level images that have different SFM values and various sizes shown in Fig 5. The sizes of images are 640x480, 256x256 and 512x512 pixels. Because of the lack of space, only two tested fusion images are shown. Fig. 6 illustrates the example of out-of-focus tested images.

5.1 Comparison of image fusion results

Table 2 shows the results obtained from our proposed method compared to other methods. As can be seen, the results show that for all tested images sets our proposed method (SWTSFM) outperform DWT[7] and SFM[1] based methods in term of objective assessment.

Table 2. Fused image quality results

Figure	Methods	RMSE	Edge
Fig (4c)	SFMSWT	4.4820	0.7171
	SFM	4.5067	0.7848
	DWT	6.2157	1.9035
Fig (4d)	SFMSWT	4.4901	1.4991
	SFM	4.9018	1.8201
	DWT	8.1012	1.7680

For subjective assessment, Fig. 7 and 8 show the magnified detail of image fusion results. We can see that our proposed method yields the best result. The DWT [7] and SFM [1] based methods, the fused images are contained blocking and ringing artifacts. In addition, they are suffered from uneven gray level compared to the original images.

5.2 Comparison of Wavelet Filter

In this section, the different kinds of Mother wavelet filters are used [10]. From the experimental results, we found that Biorthogonal wavelet filter (bior3.5) is the best and suitable for using in decomposition process over Orthogonal wavelet filters (Daubechies) illustrated in Table 3 (showing only bior3.5and db4).

5.3 Effect of block sizes

Fig. 4 shows the RMSE's obtained from our proposed approach using different block sizes (4x4, 8x8 and 16x16). We demonstrate that the suitable block sizes are depended on the overall activity level of the source images (SFM value). The optimal block size is image-dependent. When SFM value of the source image is low, the larger block size is needed. Therefore, the small block size is suitable for the source images that have high SFM values.

Table 3. Results of fused images

Figure 5 /Block size	Wavelet Filters	RMSE	Edge
a	db4	3.6960	1.1646
(16x16)	bior3.5	**3.5172**	**1.0386**
b	db4	**4.4805**	**0.7105**
(16x16)	bior3.5	4.4820	0.7171
c	db4	4.5769	0.9137
(8x8)	bior3.5	**3.4648**	**0.7995**
d	db4	5.0546	1.8136
(8x8)	bior3.5	**4.4901**	**1.4991**
e	db4	2.4076	0.3976
(16x16)	bior3.5	**2.2314**	**0.3711**
f	db4	5.9337	3.2998
(4x4)	bior3.5	**5.6965**	**3.1215**
g	db4	8.0876	4.7325
(4x4)	bior3.5	**7.5044**	**4.0367**
h	db4	5.8773	3.8705
(4x4)	bior3.5	**5.5506**	**3.6669**

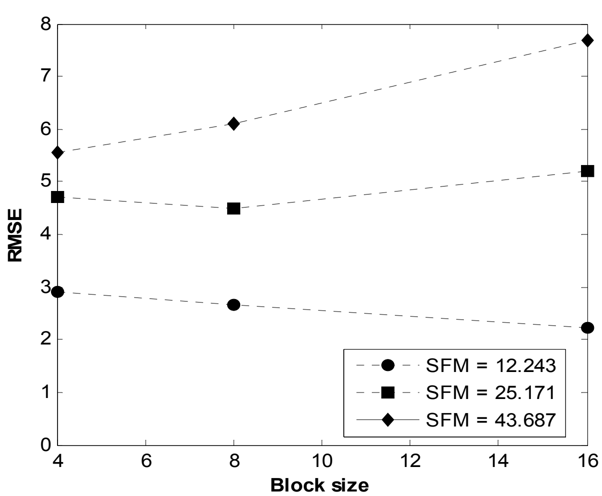


Figure 4. Variations of RMSE at different block sizes: 4x4, 8x8 and 16x16 of three tested images

6. Conclusion

In this paper, a method of multi-focus image fusion is proposed. It is based on the use of Stationary Wavelet Transform and extended Spatial Frequency Measurement. The proposed method has an advantage over both DWT and SFM based methods. Therefore, our proposed approach leads to an effective method for multi-focus image fusion.

References

[1] Li S., Kwok J.T., Wang Y., "Combination of images with diverse focuses using the spatial frequency", Information Fusion, 2001, pp.169-176.

[2] P.T. Burt, and E.H. Andelson, "The Laplacian pyramid as a compact image code", IEEE Transactions on Communication,April 1983, pp.532-540.

[3] A, Toet,L.J. van Ruyven, and J.M. Valeton, "Merging thermal and visual images by a contrast pyramid", Optical Engineering, 28 July 1989, pp.789-792.

[4] Toet A., "Multiscale contrast enhancement with application to image fusion", Optical Engineering, May 1992, pp. 1026-1031.

[5] Gonzalo Pajares, and Jesus Manuel la Cruz, "A wavelet-based image fusion tutorial", Pattern Recognition, 2004, pp.1855-1872.

[6] G.Piella, "A general framework for multiresolution image fusion:from pixel to regions", Information Fusion, 2003, pp.259-280.

[7] Wang W., Shui P., and Song G., "Multifocus image fusion in wavelet domain", International Conference on Machine Learning and Cybernetics, November 2003, pp.2887-2890.

[8] Nason, G.P., and B.W. Silverman, "The stationary wavelet transform and some statistical applications", Lecture Notes in Statistics, 1995, pp.281-299.

[9] Y. Zheng, E. A. Essock, B. C. Hansen and A. M. Huan "A new metric based on extened spatial frequency and its application to DWT based fusion algorithms", Information Fusion, 2007, pp. 177-192.

[10] Tay, D.B.H., "Rationalizing the coefficients of popular biorthogonal wavelet filters", IEEE Transactions on Circuits and Systems for Video Technology, September 2000, pp.998 – 1005.

[11] Yamsang N., and Udomhunsakul S., "Influence of SFM to objective assessment of compressed image", International Conference on Multimedia and Ubiquitous Engineering, April 2007, pp.704-709.

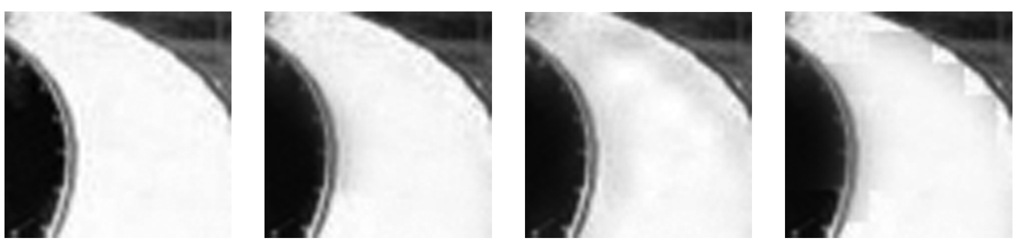
(a) SFM = 14.5396 (b) SFM = 21.5656 (c) SFM = 25.0089 (d) SFM = 25.1708

(e) SFM = 12.2432 (f) SFM = 29.6254 (g) SFM = 32.8797 (h) SFM = 43.6877

Figure 5. The reference images with SFM values

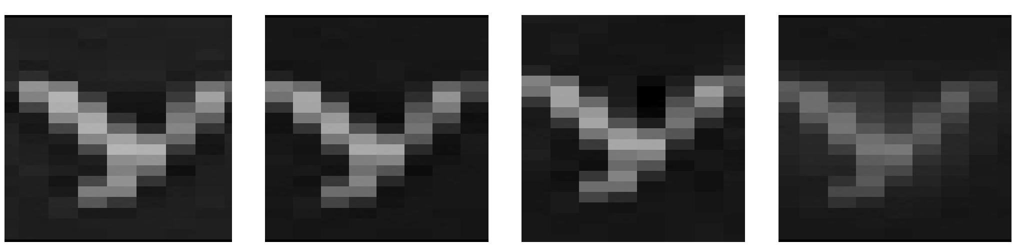
(a) (b) (c) (d)

Figure 6. Tested Images (a) source image (focus on the left)
(b) source image (focus on the rigt) (c-d) artificially produce blurred images



(a) reference image (b) proposed method (c) DWT based method (d) SFM based method

Figure 7. Local magnifications (white border area) of Fig. 5 (d) and fusion results



(a) reference image (b) proposed method (c) DWT based method (d) SFM based method

Figure 8. Local magnifications of Fig. 5 (c) and fusion results