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Stationary Wavelet Transform based Image Fusion using fusion rules

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Abstract: ***Multifocus image fusion is a current research topic in the area of image processing for visual sensor networks. Discrete wavelet transform based fusion algorithms suffer from unintended effects like smoothing of edges, loss of contrast and artifacts. To overcome these problems, Stationary Wavelet Transform based algorithm using fusion-rules is proposed and applied to multifocus images. Stationary Wavelet Transform well preserves the edges and avoid artifacts with its shift-invariance property. Entropy and spatial frequency based fusion rules in this work can effectively characterize the intensity variations in an image there by loss of contrast is minimized. Simulation results show that the proposed method can amply preserve the edges and also avoid artifacts with no loss of contrast.***

Keywords: Stationary Wavelet Transform, Entropy, Image Fusion, Spatial Frequency, Fusion rules.

I. INTRODUCTION

In visual sensor networks (VSN), the sensors are cameras which can capture, process and transmit a large number of images in surveillance, traffic and industrial applications [1]. However, an entire focused image is not captured by the cameras in visual sensor networks (VSN). This makes it difficult for VSN to analyze and understand the images. To address these issues, fusion techniques are desirable for fusing two or more images with divergent focus levels into a focused fused image.

II. LITERATURE REVIEW

The fusion techniques using Laplacian pyramids [2], Discrete Wavelet Transform (DWT) [3], discrete cosine transform [4], Walsh Hadamard Transform [5], multiresolution singular value decomposition (MSVD) [6], Wavelet based methods [7-12] are existing in the literature. The discrete wavelet transform (DWT) based method had been verified to be an effective image fusion technique. However, shift-variance property of DWT introduces unintended effects. The shift-invariant stationary wavelet transform (SWT) eliminates the unintended effects of DWT. Fusion rules are also essential to get a sharper fused image from source images considered for fusion. Hence, in this paper stationary wavelet transform and fusion rules based algorithm proposed for fusion.

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III. PROPOSED METHODOLOGY

(a) Multi-focused source images are considered for fusion.
(b) Perform RGB to YCbCr color Transform on source images.
(c) Apply 1-level SWT on source images to get low and high-frequency sub- bands using Eq. (1).

$$\begin{aligned} cA_{j+1,k_1,k_2} &= \sum_{n1}\sum_{n2} F_0^{\uparrow 2^j}(n_1-2k_1)F_0^{\uparrow 2^j}(n_2-2k_2)cA_{j,n_1,n_2} \\ cD^h_{j+1,k_1,k_2} &= \sum_{n1}\sum_{n2} F_0^{\uparrow 2^j}(n_1-2k_1)G_0^{\uparrow 2^j}(n_2-2k_2)cA_{j,n_1,n_2} \\ cD^v_{j+1,k_1,k_2} &= \sum_{n1}\sum_{n2} G_0^{\uparrow 2^j}(n_1-2k_1)F_0^{\uparrow 2^j}(n_2-2k_2)cA_{j,n_1,n_2} \\ cD^d_{j+1,k_1,k_2} &= \sum_{n1}\sum_{n2} G_0^{\uparrow 2^j}(n_1-2k_1)G_0^{\uparrow 2^j}(n_2-2k_2)cA_{j,n_1,n_2} \end{aligned} \quad (1)$$

(d) Spatial frequency based fusion rule is used to fuse low frequency coefficients in low- frequency sub- bands using Eqs. (2)-(4).

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

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

$$SF = \sqrt{(RF)^2 + (CF)^2} \quad (4)$$

(e) Entropy based fusion rule is used to fuse high frequency coefficients in high - frequency sub- bands using Eq. (5).

$$E = \sum_{j=0}^{G} p(i)\log_2 p(i) \quad (5)$$

(f) Get composite fused image by applying l-level inverse SWT on low- and high-frequency sub-bands using Eq. (6).

$$\begin{aligned} cA_{j,n_1,n_2} = \frac{1}{4}\sum_{i=0}^{3}\Bigg\{ & \sum_{k_1}\sum_{k_2} F_1(n_1-2k_1-i)F_1(n_2-2k_2-i)cA_{j+1,k_1,k_2} \\ & + \sum_{k_1}\sum_{k_2} F_1(n_1-2k_1-i)G_1(n_2-2k_2-i)cD^h_{j+1,k_1,k_2} \\ & + \sum_{k_1}\sum_{k_2} G_1(n_1-2k_1-i)F_1(n_2-2k_2-i)cD^v_{j+1,k_1,k_2} \\ & + \sum_{k_1}\sum_{k_2} G_1(n_1-2k_1-i)G_1(n_2-2k_2-i)cD^d_{j+1,k_1,k_2} \end{aligned} \quad (6)$$

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(g) Transform fused image in YCbCr to RGB color space.
(h) Evaluate fused image quality using reference and non-reference performance measures.

IV. RESULTS AND DISCUSSION

The proposed method is tested on artificial, natural and misregistered multi-focus images. The proposed method performance is compared with existing DWT [3], MSVD [6], SWT [8], DWT + Variance [9], and DTCWT [10] fusion methods in terms of performance measures.

The first experiment is performed on artificially created images. In this experiment two images Lena and Airplane [13] are used as reference. Artificial images were formed by convolution of referenced image with a Gaussian filter. Both reference and artificial images are shown in Fig. 1.

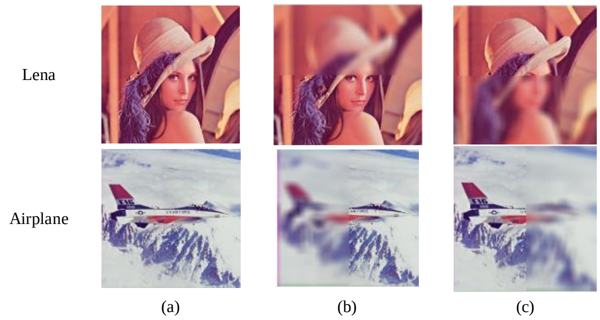


Fig. 1 (a) Reference images and (b)-(c) artificial images

The fused images are reflected in Fig. 2 and 3. The fused image quality is calculated, using reference measures PSNR and FSIM. In Table I, PSNR and FSIM values of all test images are high for fused image of proposed method.

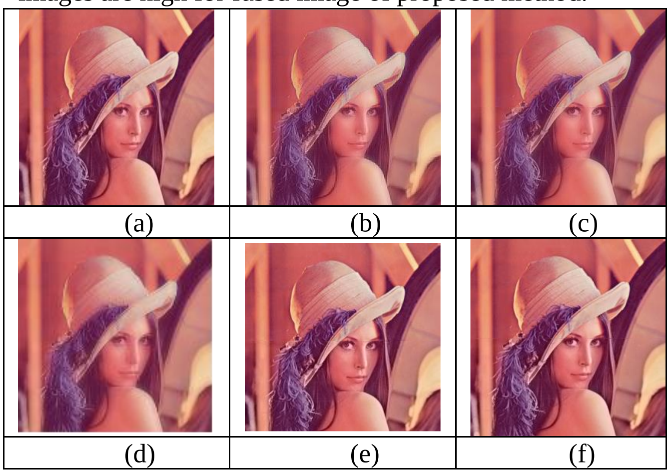
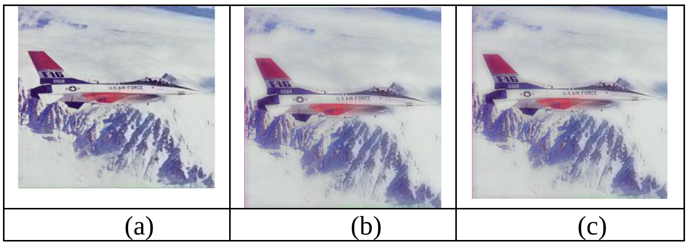


Fig. 2 Fused images (Lena) (a) DWT [3], (b) MSVD [6], (c) SWT [8], (d) DWT + Variance [9], (e) DTCWT [10] and (f) proposed method.



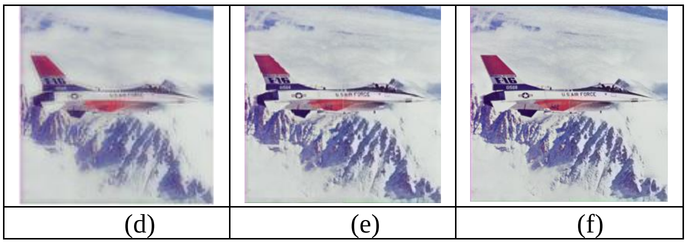


Fig. 3 Fused images (Airplane) (a) DWT [3], (b) MSVD [6], (c) SWT [8], (d) DWT + Variance [9], (e) DTCWT [10] and (f) proposed method.

Table- I: Comparison of PSNR and FSIM of different fusion methods

Artificial Multi-Focus Images	Fusion Method	PSNR	FSIM
	DWT [3]	27.1013	0.9105
	MSVD [6]	27.7903	0.9335
	SWT [8]	28.2727	0.9374
	DWT + Variance [9]	27.9178	0.9362
	DTCWT [10]	32.9903	0.988
Lena	Proposed method	**33.2801**	**0.9917**
	DWT [3]	25.3572	0.8859
	MSVD [6]	26.3356	0.9173
	SWT [8]	27.2888	0.9253
	DWT + Variance [9]	26.3935	0.9182
	DTCWT [10]	32.5604	0.9875
Airplane	Proposed method	**32.8355**	**0.9902**

The second experiment is run on natural multi-focus Map and Children images [14] with different focus levels are shown in Fig. 4 and 5.

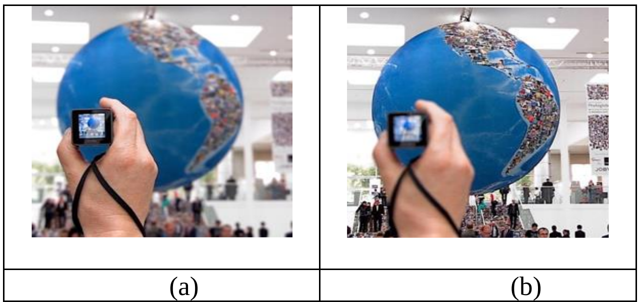


Fig. 4 Non-referenced Map image (a) foreground focused image (b) background focused image

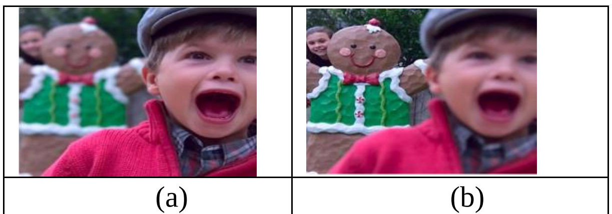


Fig. 5 Non-referenced Children image (a) reground focused image (b) background focused image

The experimental results of Map and Children image are shown in Fig. 6 and 7. One could notice that the fused images of proposed method give good quality than other methods. Natural and misregistered image fusion performance is calculated using non-reference measures Q_{BC} [15] and Q_Y [16].

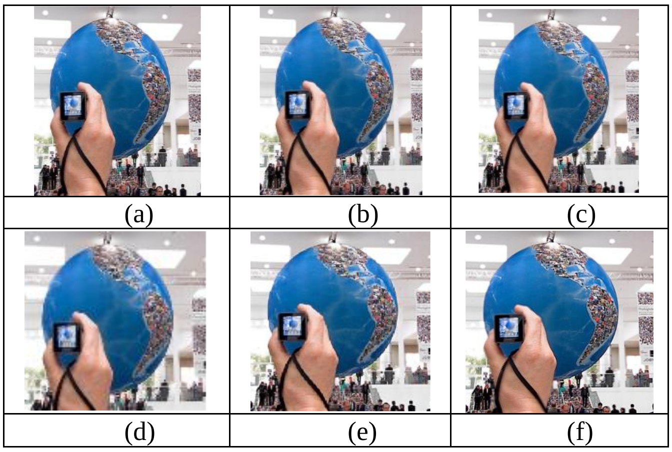


Fig. 6 Fused images (Map) (a) DWT [3], (b) MSVD [6], (c) SWT [8], (d) DWT + Variance [9], (e) DTCWT [10] and (f) proposed method.

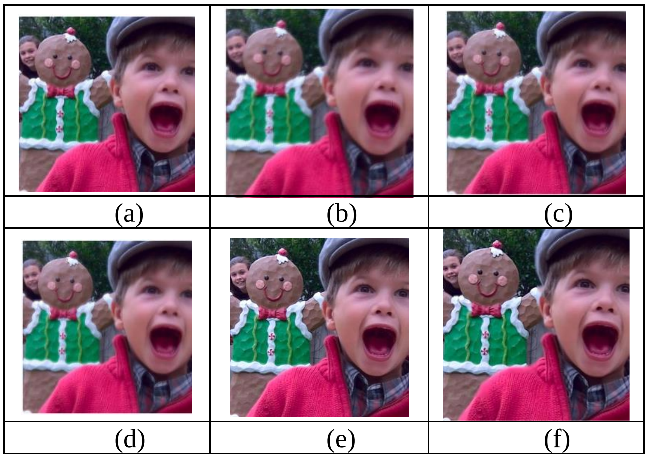


Fig. 7 Fused images (Children) (a) DWT [3], (b) MSVD [6], (c) SWT [8], (d) DWT + Variance [9], (e) DTCWT [10] and (f) proposed method.

Table II gives the comparison of various fusion methods. A high Q_{BC} and Q_Y value of proposed method shows that high contrast and sharpness are preserved in fused image.

Table- II: Comparison of QBC and QY of different fusion methods

Natural Multi-Focus Images	Fusion Method	Q_{CB}	Q_Y
Map	DWT [3]	0.7656	0.8645
	MSVD [6]	0.7711	0.9203
	SWT [8]	0.7733	0.9344
	DWT + Variance [9]	0.7589	0.9187
	DTCWT [10]	0.7778	0.927
	Proposed method	**0.8079**	**0.9373**
Children	DWT [3]	0.709	0.8736
	MSVD [6]	0.7056	0.8304
	SWT [8]	0.7137	0.923
	DWT + Variance [9]	0.7028	0.9021
	DTCWT [10]	0.7248	0.9345
	Proposed method	**0.7513**	**0.9495**

The third experiment is performed on misregistered multi-focus color images to assess the robustness of the proposed method.

Fig. 8 The Temple Misregistered source images (a) Foreground Focused image (b) Background Focused image

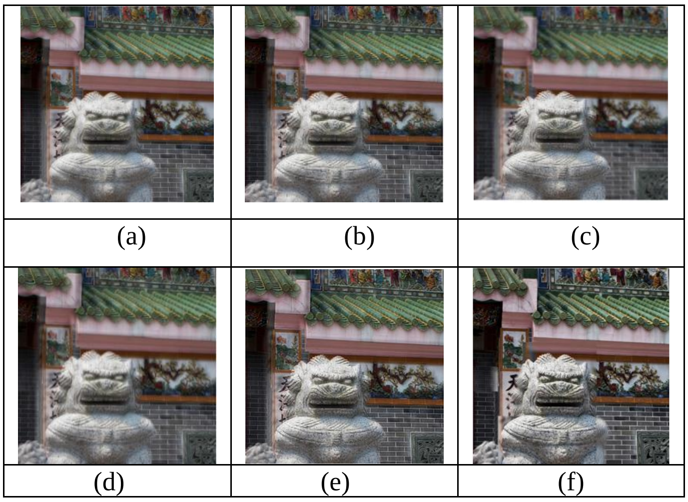


Fig. 9 Fused images (Temple) (a) DWT [3], (b) MSVD [6], (c) SWT [8], (d) DWT + Variance [9], (e) DTCWT [10] and (f) proposed method.

One pair of color images of the temple is considered for fusion. The source and fused images are shown in Fig. 8 and 9. We also compared the fusion results of temple in Table III. Fig. 10 describes that larger Q_{CB} and Q_Y of proposed method specify better fused image quality.

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Table- III: Comparison of QBC and QY of different fusion methods

Misregistered Multi-Focus Images	Fusion Method	Q_{CB}	Q_Y
	DWT [3]	0.5482	0.7215
	MSVD [6]	0.5618	0.8439
	SWT [8]	0.5634	0.8701
	DWT + Variance [9]	0.5526	0.8174
	DTCWT [10]	0.6298	0.9102
Temple	Proposed method	**0.7288**	**0.954**

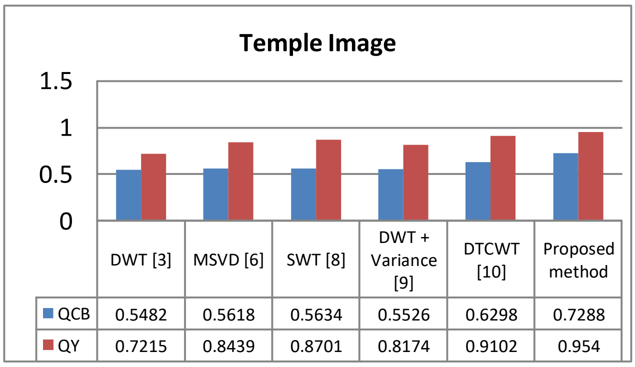

Fig. 10 Comparison for Q_{CB} and Q_Y

V. CONCLUSION

This paper proposes a stationary wavelet transform based image fusion using fusion rules for visual sensor networks. Due to its shift-invariance, SWT avoids unintended effects introduced by DWT. Fusion rules are effectively selected focused regions without loss of contrast. Experimental results prove that the proposed method produces a good quality fused image compared to other methods.

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