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Multi Focus fusion based on Complex Wavelet for Surveillance application

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Abstract: Image fusion deals with the integration of multi modal images from various sensors, with visual and infrared, to MMW images, aiming at achieving improved image quality to better support improved image classification, monitoring, surveillance and etc. The main goal of this paper is to introduce a new approach to fuse visual image and infrared images by complex wavelet taking depth of focus into consideration. First, the theoretical basis of complex wavelet is described together with its key properties (e.g. approximate shift invariance, good directional selectivity, perfect reconstruction (PR), limited redundancy and efficient order- N computation). Secondly, the new method for fusing multi modal images of different focal length based on complex wavelet is proposed. Finally, experiment results show that the fusion method based on complex wavelet transform is remarkably better than the fusion method based on classical discrete wavelet transform.

Keywords: Image fusion; CWT; image entropy; multi focus; visual image; IR image.

I. Introduction

Multifocus image fusion has been used widely in the field of image analysis task such as target recognition, remote sensing and medical image processing. The aim of image fusion is to combine relevant information from two or more source images into one single image such that the single image contains most of the information from all the source images. In the application of digital camera, optical lenses suffer from a limited depth of focus. Because of this limitation, it is often not possible to get an image that contains all relevant objects in focus. Part of the image which is out of focus has less depth of field. One possible solution to overcome this problem is to take several pictures with different focus settings and combine them together into a single frame to get all the information from the less focus area using image fusion method. The goal is to enhance the image quality and information so that it provides more detail information than the information available in single image.

Computer systems have been developed those are capable of extracting meaningful information from the recorded data coming from the different sources. The integration of data, recorded from a multi sensor system, together with knowledge, is known as data fusion [1], [2]. The fused image should have more useful information content compared to the individual image. The different image fusion methods can be evaluated using different fusion parameters and each parameter varies due to different fusion rule effect.

In recent years image fusion algorithms are used as effective tools in medical, remote sensing, industrial automation, surveillance, and defense applications. Many of these applications require dealing with multiple images having different focusing depth or multiple images of the same scene captured using different sources in one algorithm. None of the image fusion method has been reported which deals with multi focus and multi modal images simultaneously [3].

So, we propose a novel region based complex wavelet image fusion for surveillance application taking focal length into consideration, which also overcomes the limitations of various approaches as mentioned in [3].

The paper is organized as follows. A detailed explanation of the methodology that will be used is described in Section II. The proposed algorithm is discussed in Section III. Experimental results of the partial work are presented in Section IV. Finally, in Section V the concluding remarks are given.

II. Basic Theory

The proposed method utilizes region based approach as mentioned in [4], complex wavelet transform, normalized cut segmentation algorithm and high boost filtering which is described briefly in this section.

A. Complex Wavelet Transform

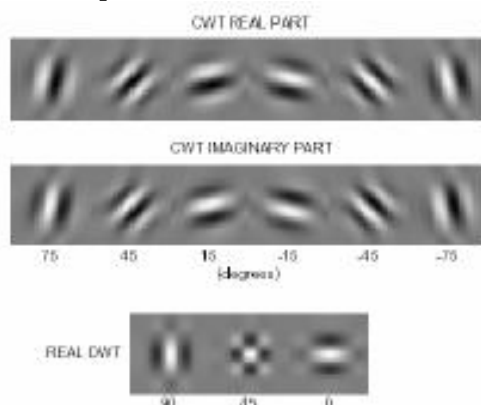
There have been a lot of research efforts on image fusion, and many fusion methods have been proposed. However, these image fusion methods are not enough and cause some difficulties for image analysis and

application. The advantage of wavelet transform is that it can analyze signal in time domain and frequency domain respectively and the multi-resolution analysis is similar with Human Vision System. The Discrete Wavelet Transform (DWT) in its maximally decimated form established by Mallat as in [6] is widely used in image processing now. Standard DWT (Discrete Wavelet Transform), being non-redundant, is a very powerful tool for many non-stationary Signal Processing applications, but it suffers from three major limitations. First, it is shift sensitive due to which small changes in input signal makes unpredictable changes in DWT coefficients. Second, it suffers from poor directionality because DWT coefficients reveal only three spatial orientations. Third, DWT analysis of real signals lacks the phase information that accurately describes non-stationary signal behavior. To reduce these limitations, many researchers developed real-valued extensions to the standard DWT such as WP (Wavelet Packet Transform), and SWT (Stationary Wavelet Transform). These extensions are highly redundant and computationally intensive. Complex Wavelet Transform (CWT) is also an alternate, complex-valued extension to the standard DWT. The initial motivation behind the development of CWT was to avail explicitly both magnitude and phase information. The Dual-Tree Complex Wavelet Transform (DT CWT) has the following properties [8]:

- Approximate shift invariance;
- Good directional selectivity in 2-dimensions (2-D) with Gabor-like filters also true for higher dimensionality: m-D);
- Perfect reconstruction (PR) using short linear-phase filters;
- Limited redundancy: independent of the number of scales: 2:1 for 1-D (2^m :1 for m-D);
- Efficient order-N computation - only twice the simple DWT for 1-D (2^m times for m-D);

In this paper, we propose an image fusion method based on CWT multi-resolution analysis. The most important property of CWT is that it can separate more directions than the real wavelet transform [5, 8]. 2-D DWT produces three band pass sub images at each level, which are corresponding to LH, HH, HL, and oriented at angles of 0° , $\pm 45^\circ$, 90° . 2-D CWT can provide six sub images in two adjacent spectral quadrants at each level, which are oriented at angles of $\pm 15^\circ$, $\pm 45^\circ$, $\pm 75^\circ$. This is shown in Fig 1.

Figure 1 2-D impulse responses of the complex wavelets at level 4 (6 bands at angles from -75° to $+75^\circ$) and equivalent responses for a real wavelet transform (3 bands)



The strong orientation occurs because the complex filters are asymmetry responses. They can separate positive frequencies from negative ones vertically and horizontally. So, positive and negative frequencies won't be aliasing. The orientations of details are shown in Fig 2.

Figure 3 shows the transform of an isotropic synthetic image at level 3, which also contains details at different scales. The orientation selectivity is clearer under each scale in comparison with the classical wavelet transform. Since CWT has so many advantages, we consider use CWT to carry out image fusion instead of DWT.

Figure 2 Directional selectivity of the frequency space corresponding to the complex wavelet transform

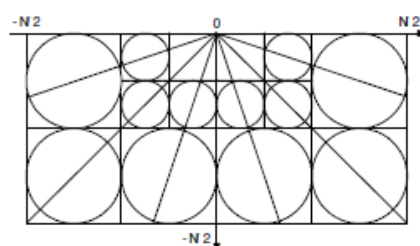


Figure 3 Left: isotropic test image containing various scale information, right: magnitude of its complex wavelet transform at level 3 showing both directional and scaling properties



B. Normalized cut segmentation

In normalized cut segmentation method, the set of points are labeled as a weighted undirected graph $G = (V, E)$ where the nodes of the graph are the points in the image. Every pair of nodes are connected by an edge and the weight on each edge $W(i, j)$ is a function of similarity between nodes i and j . The degree of similarity and dissimilarity between two nodes depends on the normalized cut weight value $N\text{-cut}(A, B)$ between the nodes A and B [9]. To improve $N\text{-cut}$ weight criteria, it is desirable to emphasize high frequency components which represent the image details without eliminating low frequency components to get an accurate segmentation.

C. High Boost filtering

As mentioned earlier, the accuracy of region based image fusion method depends on how well the regions are extracted from the source images for fusion. The inaccurate segmentation directly affects on final fused image because undesired region segmentation leads to the bad quality fused image. In this method image segmentation process is treated as graph partition criterion. The normalized cut segmentation can measure both total similarity within group and total dissimilarity between groups. The high boost filter is the only filter which provides a suitable solution which not only preserves the low frequency information but also enhances the high frequency detail information [7]. The high boost filter is chosen among the other edge detector operators like Laplacian, Sobel, and Canny due to its simplicity and implementation cost.

III. Proposed Fusion Scheme

We design an approach based on the complex wavelet transform for fusing a multi focus visual images. First the registered multi focus images are decomposed by complex wavelet respectively, then the approximate and detail parts of two images are fused according to some rule at each level, finally the fused image is reconstructed. This is illustrated by Fig. 4. The steps for fusion are:

1. Take two multi focus images (IA and IB) as input and compute their average (Iavg).
2. CWT is applied on image IA, IB and Iavg which gives first level decomposed image of one approximate image and 6 high pass sub band images for each image.
3. Fuse IA and Iavg of visual image by adopting the following proposed approaches:
 - average of the low level image and maximum of the high pass sub bands(avg,max)
 - maximum of low level image and maximum of high pass sub bands(max,max)
 - No average only maximum of high pass sub bands.(no avg,max).

Similarly, the fusion rule is applied on IB and Iavg.

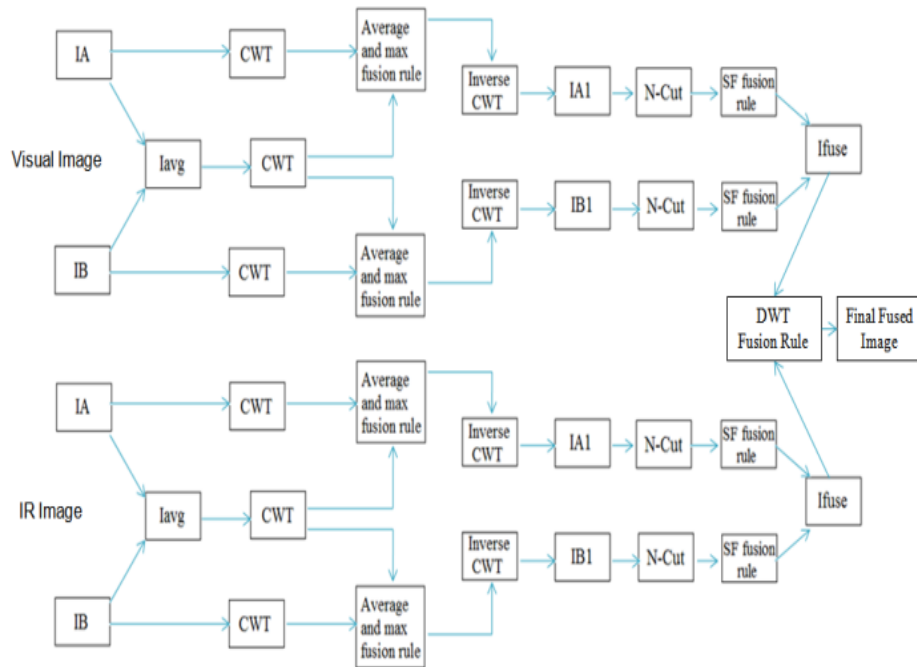
4. Next, apply Inverse CWT to get the output IA1 and IB1.
5. The normalized cut segmentation algorithm is applied on image IA1 and IB1 and 'n' numbers of regions are segmented.
6. We have used a fusion rule to compare extracted regions from different kind of source images as mentioned in [7]. The fusion rule is based on spatial frequency (SF) which is used to identify good region extracted from multi focus source images. The SF is used to measure the overall clarity of an image or region. The higher the spatial frequency, the more the image details are. If nth region of an IA1 image is defined by F then, the spatial frequency of a region is calculated using Row frequency (RF) and Column frequency (CF) as described in (1) and (2) respectively. The SF is calculated using:

$$RF = \sqrt{\frac{\sum ([F(i,j) - F(i,j-1)])^2}{MN}} \quad (1)$$

$$CF = \sqrt{\frac{\sum ([F(i,j) - F(i-1,j)])^2}{MN}} \quad (2)$$

$$SF = \sqrt{RF^2 + CF^2} \quad (3)$$

7. The resultant output is best focused visual image.
8. Apply the same procedure with the multi focus IR images and finally the best focused Visual and best focused IR images are fused taking the average of the low components and maximum of high pass sub bands.

Figure 4 Block diagram of the proposed system

IV. Experimental Results

The proposed method was applied to a number of registered set of multi focus visual images and multi focus IR images as shown in fig. 5 and fig. 7 respectively. The results for multi focus fusion of visual images using various proposed combinations of CWT are as shown in fig. 6. Fig. 8 illustrates the results for multi focus IR images. Lastly, the final fusion result of best focused visual and best focused IR image is shown in Fig. 9.

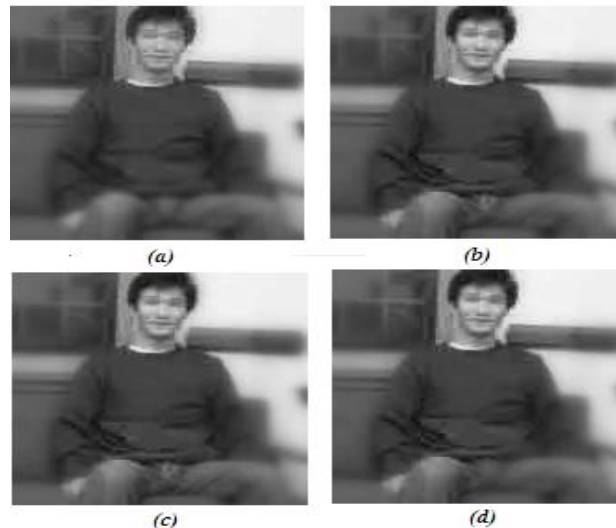
Figure 5 Multi focus visual images: (a) Input image IA (b) Input image IB**Figure 6 Output fused visual image using various methods (a) CWTMAX (b) Proposed algo (avg,max) (c) Proposed algo (max,max) (d) Proposed algo (no avg,max)**

Figure 7 Multi focus IR images: (a) Input image IA (b) Input image IB



Figure 8 Output fused IR image using various methods (a) CWTMAX (b) Proposed algo (avg,max) (c) Proposed algo (max,max) (d) Proposed algo (no avg,max)

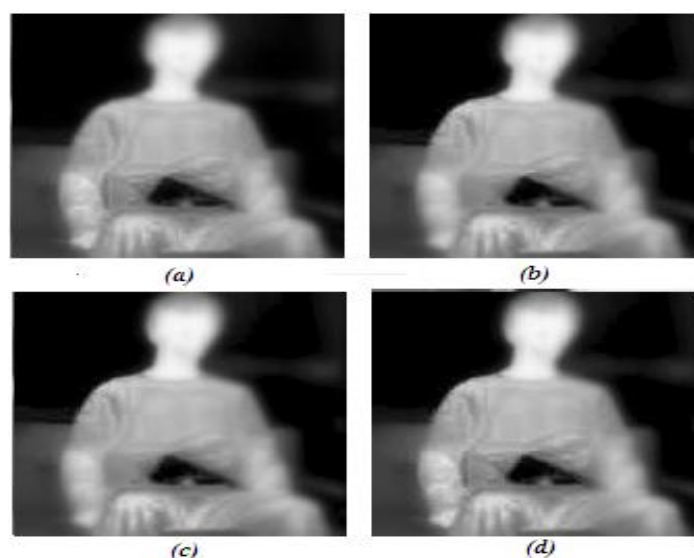
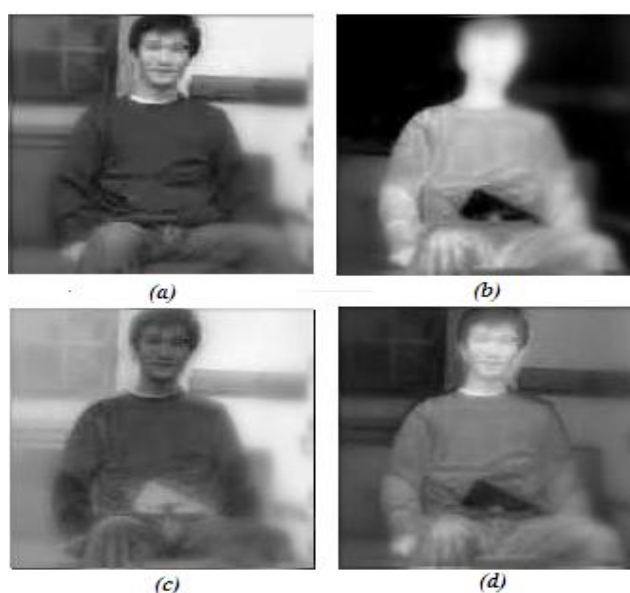


Figure 9 (a) Best focused Visual image (b) Best focused IR image (c) Fused output-Inverting IR (d) Fused output



Fusion performance can be measured correctly by estimating how much information is preserved in the fused image compared to source images. Most widely used reference based image fusion performance parameters are Entropy, Root mean square error (RMSE), Structural similarity index (SSIN), Peak signal to noise ratio (PSNR) as in [10]. Table I depicts the sample reading produced by the 4 image quality metric for each of the 3 proposed algorithms.

Table I Image Metric Reading

FUSION METHOD	Entropy	RMSE	PSNR	SSIM
CWTMAX	7.1615	6.8953	31.3597	0.1458
Proposed Agorithm (avg,max)	7.2087	6.0981	32.4269	0.1399
Proposed Agorithm (max,max)	7.2117	6.2489	32.2148	0.1400
Proposed Agorithm(no avg,max)	7.2038	6.1667	32.3297	0.1406

V. Conclusion

The proposed algorithm provides novel framework for region based image fusion methods which uses the CWT approach. This novel approach is applied on large number of dataset of each category and simulation results are found with superior visual quality compared to other earlier reported pixel and region based image fusion method. Here fusion rules are applied on broad range of images. The novel SF based rule is used for single sensor based multi focus images. Proposed algorithm is compared with standard reference based and non reference based image fusion parameters and from simulation results, it is evident that our proposed algorithm preserves more details in fused image. There are number of other advantages of proposed algorithm. We have used complex wavelet transform with approximate shift invariance, good directional selectivity, PR, limited redundancy and efficient computation. Then, we carry out image fusion using CWT instead of classical DWT, design an image fusion approach based on CWT. We have compared the results for variation in CWT and from the results its evident that CWT (avg, max) provides better result. Region based algorithms are less sensitive to noise, misregistration, and contrast change so proposed algorithm has this advantage. The proposed algorithm can be extended further by applying it for different categories of images like medical images and remote sensing images. Currently, it is evaluated for multi focus images. In future, complex fusion rules and their combinations can be explored to improve robustness of proposed region based image fusion approach.

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