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Image Fusion using Wavelet Transform

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Abstract— Image fusion is the process of extracting meaningful visual information from two or more images and combining them to form one fused image. Image fusion is important within many different image processing fields from remote sensing to medical applications. Previously, real valued wavelet transforms have been used for image fusion. Although this technique has provided improvements over more naive methods, this transform suffers from the shift variance and lack of directionality associated with its wavelet bases. These problems have been overcome by the use of a reversible and discrete complex wavelet transform (the Dual Tree Complex Wavelet Transform DT-CWT). However, the existing structure of this complex wavelet decomposition enforces a very strict choice of filters in order to achieve a necessary quarter shift in coefficient output. The proposed work introduces an alternative structure to the DTCWT that is more flexible in its potential choice of filters and can be implemented by the combination of four normally structured wavelet transforms. The use of these more common wavelet transforms enables this method to make use of existing optimized wavelet decomposition and recomposition methods, code and filter choice.

Keywords— Image fusion, wavelet transform, fused mages, wavelet based fusion, multi-resolution.

I. INTRODUCTION

Image fusion is the process by which two or more images are combined into a single image retaining the important features from each of the original images. The fusion of images is often required for images acquired from different instrument modalities or capture techniques of the same scene or objects (like multi-sensor, multi-focus and multi-modal images). For example, in multi-focus imaging one or more objects may be in-focus in a particular image, while other objects in the scene may be in focus in other images. For remotely sensed images, some have good spectral information whereas others have high geometric resolution. In the arena of biomedical imaging, two widely used modalities, namely the magnetic resonance imaging (MRI) and the computed tomography (CT) scan do not reveal identically every detail of brain structure. While CT scan is especially suitable for imaging bone structure and hard tissues, the MR images are much superior in depicting the soft tissues in the brain that play very important roles in detecting diseases affecting the skull base. These images are thus complementary in many ways and no single image is totally sufficient in terms of their respective information content. The advantages these images may be fully exploited by integrating the complementary features seen in different images through the process of image fusion that generates an image composed of features that are best detected or represented in the individual images. Important applications of the fusion of images include medical imaging, microscopic imaging,

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Remote sensing, computer vision, and robotics. The first step toward fusion, which may be interpreted as a preprocessing step is the registration which brings down the constituting images to a common coordinate system as fusion of images is meaningful only when common objects in images have identical geometric configuration with respect to size, location and orientation in all the images. In the next step, the images are combined to form a single fused image through a judicious selection of proportions of different features from different images. Fusion techniques include the simplest method of pixel averaging to more complicated methods such as principal component analysis and wavelet transform fusion. Several approaches to image fusion can be distinguished, depending on whether the images are fused in the spatial domain or they are transformed into another domain, and their transforms fused. Li et al. [1] have suggested a multisensory image fusion using wavelet transform in which a cascaded sequence of forward and reverse wavelet transform on multimodal images produce a fused image. Other common wavelet transform based fusion schemes include maximum selection (MS) just picks the wavelet transform coefficient in each sub-band with the largest magnitude. Burt and Kaczynski [2] used a normalized correlation between the two images' sub-bands over a small local-area and the resultant coefficient for reconstruction is calculated from this measure via a weighted average of the two images' coefficients. Zu Shu-long [3] proposed wavelet based fusion approach using 'gradient' criteria, while Hill et al. [4] achieved fusion through the application of the shift invariant and directionally selective Dual Tree Complex Wavelet Transform (DT-CWT). In this proposed work, an image fusion algorithm based on wavelet transform is proposed. In the proposed scheme, the images to be processed are decomposed into sub-images with the same resolution at same levels and different resolution at different levels and then the information fusion is performed using high-frequency sub-images under the comb ined 'gradient' and ' relative smoothness' criterion and finally these sub-images are reconstructed into a resultant image having plentiful information. The developed scheme is applied to fuse multi-focus, multi-modal and remotely sensed multi-sensor images.

II. RELATEDWORKS

In this paper, the emphasis is on the images fusion, hence pre-registered images were used. In case of images not being registered, we have adopted a point-based method for registering the multimodal images. Wavelet transform is a powerful mathematical tool used in the fields of signal processing. It is used to divide the given function or signal into different scale components such that each scale component can be studied with a resolution that it matches. Mallat [10]

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used the wavelets to be the foundation of new powerful approach to signal processing and analysis called the Multi-resolution Theory. The same approach has been extended to multi-dimensional signal decomposition. The most common form of transform image fusion is wavelet transform fusion [1], [2], [3], [4]. In common with all transform domain fusion techniques the transformed images are combined in the transform domain using a defined fusion rule then transformed back to the spatial domain to give the resulting fused image. Wavelet transform fusion is more formally defined by considering the wavelet transforms '*w*' of the 'n' registered input images *Ij(x,y), j=1,2…n* together with the fusion rule '*f*'. Then, the inverse wavelet transform *w-1* is computed, and the fused resulting image *I(x, y)* is reconstructed as depicted in figure 1.

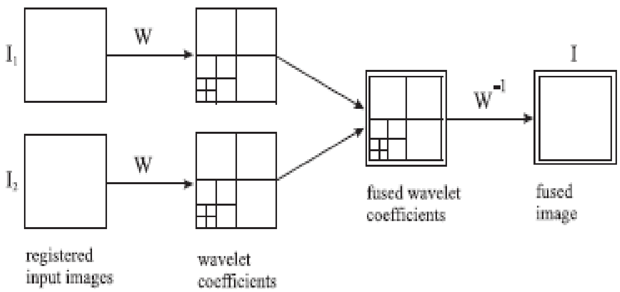

Figure 1: Fusion of wavelet transforms of Images

III. WORKING PRINCIPLE OF SYSTEM

We use a scheme for fusion of different registered set of images of same scene obtained through different modalities. The basic idea is to decompose each registered image into sub-images using forward wavelet transform which have same resolution at same level and different resolution at different levels. Information fusion is performed based on the high frequency (detailed coefficients) sub-images and resulting image is obtained using inverse wavelet transform. The proposed scheme uses two criterions namely the 'gradient' and 'smoothness' measure which we discuss first.

A. The Gradient Criterion

Given a gray image *I(x, y)*, the gradient at any pixel location (x, y) is obtained by applying two dimensional direction derivative

$$\nabla I(x,y) = \begin{bmatrix} Gx \\ Gy \end{bmatrix} = \begin{bmatrix} \dfrac{\partial I(x,y)}{\partial x} \\ \dfrac{\partial I(x,y)}{\partial y} \end{bmatrix}$$

The gradient magnitude and two fast decreasing approximations can be obtained by using equation,

$$G = |\nabla I(x,y)| = \sqrt{Gx^2 + Gy^2} \approx |Gx| + |Gy|$$

B. The Relative Smoothness Criterion

The second criterion of relative smoothness uses the statistical moments of gray-level histogram of the region in the neighborhood of the pixel (x, y). Let z be the random variable denoting gray levels and p (zi), i=1, 2…L-1, be the corresponding histogram of the region in the neighborhood of pixel (x, y), where L is the number of distinct gray levels. The second moment or variance of z about mean is given by, where m is the mean gray level of z given by below term,

$$\sigma^2(z) = \sum_{i=0}^{L-1} (z_i - m)^2 \, p(Z_i)$$

$$m = \sum_{i=0}^{L-1} Z_i \, p(Z_i)$$

The measure for relative smoothness in the neighborhood of pixel (x, y) [11] can be thus established as,

$$R(x,y) = 1 - \frac{1}{1 + \sigma^2(z)}$$

The measure R(x, y) nears zero in neighborhoods of constant intensity and approaches one for large variances.

C. Image Fusion

Let I1(x, y), I2(x, y), in(x, y) be the n registered images to be fused. The decomposed low frequency also referred to as the approximation coefficient sub-images be lI1j(x,y), lI2j(x,y), … lInj(x,y) and decomposed high frequency also called as the detailed coefficients be hI1j k(x,y,), hI2j k(x,y), … hInj k(x,y) respectively, where 'j' is the parameter of resolution, j=1,2…J and for every 'j', 'k' = 1,2,3 which represent directional sensitive wavelet decomposition namely along horizontal, vertical and diagonal directions. For every even parameter of resolution i.e. j=2, 4…J, the magnitude of the gradient of the image generated from the high frequency components be GIij k(x, y), i=1, 2…n. For every odd parameter of resolution i.e. j=1, 3, J, the relative smoothness of the image generated from the high frequency components be RIij k(x, y), i=1, 2…n.

D. Image Reconstruction

Using the inverse wavelet transform, and fused high and low frequency components evaluated above we reconstruct the image. This reconstructed image has information integrated from all the different images sources. This scheme shows the high frequency image fusion between *n* images under the combined gradient and relative smoothness criterion.

E. Extension to Colored Images

The same method can be used for fusing colored images. We can covert the colored images from RGB (Red, Green, Blue) to HIS (Hue, Saturation, Intensity) space and process only the Intensity component of the HIS space to acquire the fused image. Performance evaluation is an essential part of Image fusion processing so one can further adjust the algorithm parameter through analyzing, testing and evaluating the effects of the fusion algorithm and performance so that the whole fusion process can be optimized. Performance parameters are of two types: with reference image and without reference image.

Without Reference Image When the reference image is not available then the performance of the image fusion algorithms cab be evaluated using following metrics.

1. Information Entropy: Entropy is used to evaluate the information quantity contained in an image. If entropy of fused image is high, it indicates that the fused image contains more information.

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2. Standard Deviation: Degree of dispersion between the value Of each Pixel and the average value of image.

With Reference Image When the reference image is not available then the performance of the image fusion algorithms cab be evaluated using following metrics.

1. Mean Square Error: The MSE represent the cumulative squared error between the original image and reconstructed image. The lower the value of MSE, the error may be lower.
2. Peak Signal To Noise Ratio: PSNR used for quality measurement ratio between original image and reconstructed image. The higher the PSNR, the better the quality of the reconstructed image.

IV. EXPERIMENTAL RESULTS

The proposed algorithm is independent of imaging technology and can be used for fusing images obtained through any multi-sensor image acquisition system. Also no information is required about the method of acquisition of image. For the purpose of experiments three different pairs of images were considered. These image pairs were preregistered and no information no information was available about the acquisition method of these images. The proposed algorithm was implemented in MATLAB version R2015b. The Haar Wavelet was used as the mother wave and the resolution parameter *'j'* was taken up to 6. The use of Haar wavelet was for the ease of implementation. Equal contribution of each low frequency subimage was considered in the experiments. In the first experiment a pair of multi-focus image was taken. In figure 2(a) the clock in front is in focus while in figure 2(b) the clock at the back is focused. Figure 2(c) shows the image obtained after fusion. In the second experiment, multi-sensor images were considered. Figure 3(a) is an infra red or IR image while 3(b) is panchromatic image of the same scene. The fused image is shown in Figure 3(c). CT-MR image pair was taken up for third experiment. Figure 4(a) is the CT image of the human brain showing bones and hard tissue. Figure 4(b) is the MR image showing soft tissues. The fused CT-MR image is shown in figure4(c).

Fig. 2(a) Fig. 2(b) Fig. 2(c)

Figure2: (a), (b) original multi-focus image pair (c) Fused image obtained on application of proposed algorithm

Fig. 3(a) Fig. 3(b) Fig. 3(c)

Figure3 :(a) original IR image (b) original Panchromatic image (c) Fused image obtained on application of proposed algorithm

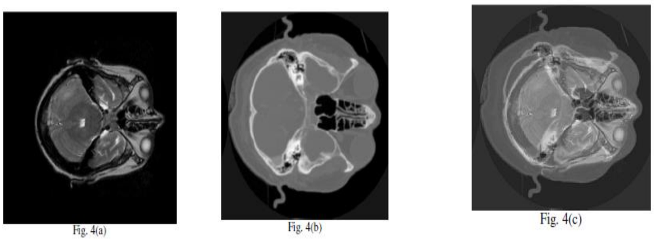

Fig. 4(a) Fig. 4(b) Fig. 4(c)

Figure4: (a) original CT image (b) original MR image (c) Fused image obtained on application of proposed algorithm

V. CONCLUSION

The results of the proposed method have been compared with that of some widely used wavelet transform based image fusion methods both qualitatively and quantitatively. Experimental results reveal that the proposed method produces better fused image than that by the latter. The use of both gradient and relative smoothness criterion ensures two fold effects. While the gradient criterion ensure that edges in the images are included in the fused algorithm, the relative smoothness criterion ensures that the areas of uniform intensity are also incorporated in the fused image thus the effect of noise is minimized. It should be noted that the proposed algorithm is Domain-independent. That means it uses knowledge of neither the imaging device nor the objects being imaged. Therefore, it can be applied to fusion of different kinds of multi-modal images. Second, as the actual fusion is done during the construction of modified coefficients, the scheme has been extended to fusion of 'n' images as already proposed in the algorithm.

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