Performance Evaluation of Fusion of Infrared and Visible Images

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Abstract—**In recent years, Fusion of Images is playing a vital role in the area of image processing. Fused images are helpful for many applications in image processing like segmentation, image enhancement and many other areas. In order to improve the effect of fusion of visible and infrared image images of the same scene, this paper presents an image fusion method based on lifting wavelet. Firstly, the source images are decomposed using lifting scheme associated with wavelet transform (LWT). Secondly, weighted averaging approach is used to fuse low frequency lifted wavelet coefficients of the visible and infrared images. Then to combine the high frequency coefficients fusion rule of local energy maximum is used. Post the fusion of low and high frequency coefficients of the source images, the final fused image is obtained using the inverse Lifting wavelet transform (LWT). The performance parameters such as Signal to Noise ratio(SNR), Peak Signal to Noise ratio(PSNR), Entropy, Mutual Information and Edge Information evaluated on the fused image reflect that improved subjective and objective results as well timeliness are obtained at higher levels of image decomposition.**

Keywords—**Lifting Scheme, Weighted Averaging, Local energy Maximum, Image Fusion, Signal to noise ratio, Entropy**
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1. INTRODUCTION

The images obtained in the visible spectrum are called Visible images. They vary according to the illumination conditions in the environment in which the image is captured. Visible image holds the details of the necessary features present in an object [1]. Because visible images change according to the illumination and conditions under which they are taken, they are viable to result in error or otherwise wrong recognition. The images that are captured using an infrared sensor camera in the far infrared region are called Infrared images. Infrared image gives the measure of energy radiations from the photographed object and it is less sensitive to the illumination changes and is even operable in darkness [2]. The surrounding environment and the physical excretions may influence the change in energy radiated from an object. In Infrared images it is difficult to distinguish the features of the object, which is the primary requisite for acquiring the correlation with the database images [3]. Also, infrared image as a standalone image does not provide high resolution data [4]. Hence, visible and infrared images fusion carried out to get an enhanced image provides a better solution to extract the best features of both the images useful in areas such as target recognition system [5].

2. LIFTING SCHEME

Lifting scheme is efficient and simplest algorithm to calculate discrete wavelet transforms. This scheme is used to generate second-generation wavelets, which are not necessarily translation and dilation of one particular function. Initially it was a method to improve a given discrete wavelet transforms to obtain specific properties [6]. Later to calculate any wavelet transform as a sequence of simple lifting steps, it is considered as an efficient algorithm. Digital signals are usually a sequence of integer numbers, while wavelet transforms result in floating point numbers. It is of great importance to have a transform algorithm that converts integers to integers to carry out an efficient reversible implementation. A lifting step can be modified to operate on integers, while preserving the reversibility. Hence, to implement reversible integer wavelet transforms the lifting scheme is used.

The block diagram showing forward lifting operation is as shown in Figure. 1.

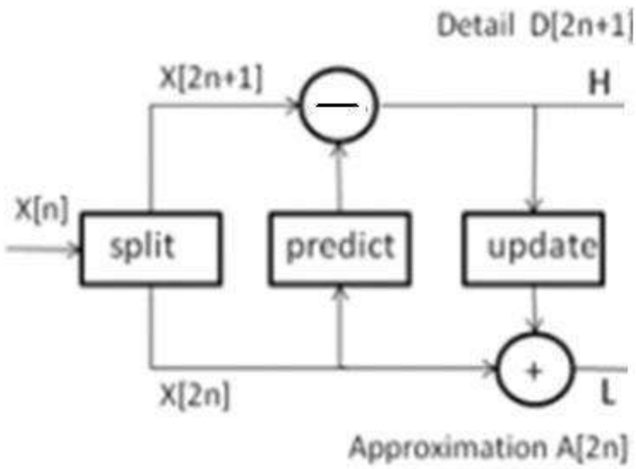

Figure. 1 Forward Lifting scheme for a signal

Constructing wavelets using lifting scheme consists of three steps:

- *Split phase:* This stage splits the entire set of signal into two sequences. One sequence consists of even indexed samples and the other sequence consists of odd indexed samples. Each sequence consists if one half of the samples of the original signal. This phase is also called lazy wavelet since no mathematical operation is performed [1].

- *Predict phase:* This phase is also known as primal Lifting and makes use of the property of correlation between the samples i.e., since the samples are highly correlated the intermediate odd indexed samples can be easily predicted from the two successive even indexed samples. The output from this phase constitute the high frequency component (detail) of the signal. The operation of predict phase is shown by equation (1).

$$D[2n+1] = X[2n+1] - 0.5(X[2n] + X[2n+2]) \ldots\ldots (1)$$

- *Update Phase:* This phase is also known as dual lifting.The update phase provides an approximate (scaled) version of the input signal (image) as shown by equation

  (2). The shifted and scaled version of the detail coefficients is added with the even indexed samples resulting in an approximation(low frequency) version of the input [4].

$$A[2n] = X[2n] + 0.25(D[2n-1] + D[2n+1]) \ldots\ldots\ldots\ldots (2)$$

The lifting procedure for an image involves performing the above mentioned operations successively on rows and columns resulting in the image being categorized into different sub-bands namely Approximate (LL), Horizontal (LH)), Vertical (HL) and Diagonal (HH). This process is called decomposition and a single level image decomposition is as shown in Figure 2.

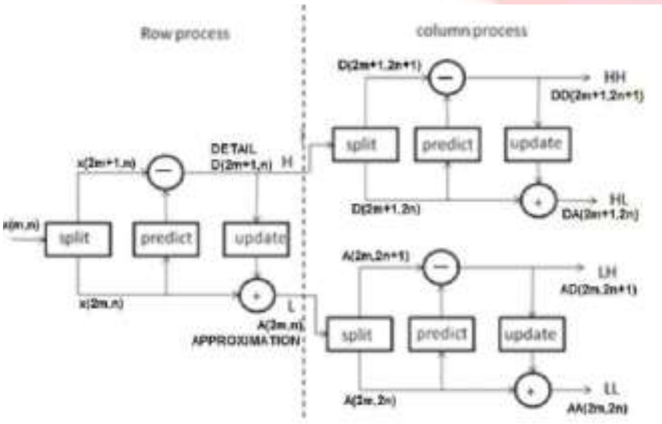

Figure. 2 Forward Lifting scheme for a image

3. FUSION TECHNIQUES

Image fusion is a method which can merge multiple features in images from different imaging devices or sensors to one image. This image or scene is complete and includes more details. Based on different stages of image fusion, it is usually disposed on three levels: The feature level, the pixel level and the decision level fusions. Different methods for fusion are employed depending on the application. In this paper, wavelet domain fusion method is employed.

3.1 Fusion rule for Low Frequency Coefficients:

In the process of the wavelet domain image fusion, the low frequency coefficients not only includes the contours and original information of image but also affects the edge details of image [3]. Based on the low frequency part of the coefficients weighted average fusion strategy is used. If the source images are A and B and fused image is F, then the low frequency wavelet coefficient matrix of fused image is given by

$$Cn(F)=\alpha Cn(A)+\beta Cn(B) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

There are three cases among them:

- If the purpose is to improvise the image fusion effect of A, choose $\alpha>\beta$;
- If the purpose is to improvise the image fusion effect of B, choose $\alpha<\beta$;
- If the two source images of the same scene is from the same imaging model and images collected at different time, we can choose $\alpha=\beta=0.5$.

Since the visible and infrared images used in this paper is of the same scene, from the same imaging model and images are collected at different times $\alpha=\beta=0.5$ is chosen.

3.2 Fusion rule for High Frequency Coefficients:

The high-frequency part of the image determines the image details and important information. The fusion of high frequency part of the wavelet coefficients is performed with larger absolute value coefficients being selected as the fusion strategy [2].

The basic idea is first in the high frequency sub image corresponding to the source images respectively, a region of a window is selected for the fusion coefficients as the center, the size of window can be optional and processed according to the rules:

- If absolute value of the high frequency coefficients within the window is greater in visible image than the infrared image, then the high frequency visible image coefficients is chosen as the high frequency coefficient of the fused image.
- If absolute value of the high frequency coefficients within the window is lesser in visible image than the infrared image, then the high frequency infrared image coefficients is chosen as the high frequency coefficient of the fused image.

Finally on the fused low frequency and high frequency coefficients, the inverse lifting operation is applied to get the fused image.

4. INVERSE LIFTING SCHEME

Inverse lifting scheme is exactly reverse process of forward wavelet transform. In lifting scheme, it is very easy to find out inverse wavelet transform because it can be obtained by just changing sign [4]. The block diagram of inverse lifting scheme for a signal is as shown in figure. 4:

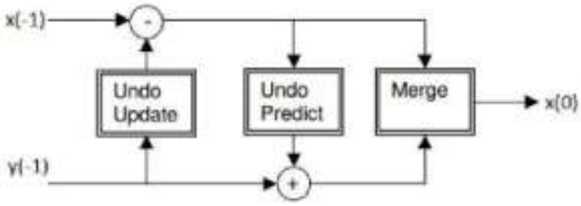

Figure. 4 Inverse Lifting scheme for a signal

Inverse lifting wavelet transform consists of following steps:

- *Undo Update phase:* This phase is also known as inverse dual lifting phase. Original even samples are recovered by simply removing (subtracting) the update Information from the detail coefficient. The equation (4) represents undo update, which is given as

$$\hat{X}(2n) = A(2n) - 0.25[\ D(2n+1) + D(2n-1)\ ] \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

- *Undo predict phase:* This phase is also known as inverse primal lifting. Odd samples can be recovered by adding prediction information to detail coefficients. The equation (5) represents undo predict, which is given as

$$\hat{X}(2n+1) = D(2n+1) + 0.5[\hat{X}(2n) + \hat{X}(2n+2)] \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

- *Merge Phase:* This phase is also known as undo split phase. Even samples are interpolated by inserting zeros in between the samples and then odd samples are placed in place of zeros in order to get the estimate of the original signal.

The inverse lifting procedure for an image involves performing the above mentioned operations successively on rows and columns of different sub-bands namely Approximate (LL), Horizontal (LH)), Vertical (HL) and Diagonal (HH). This process is called reconstruction and a single level image reconstruction is as shown in Figure. 5

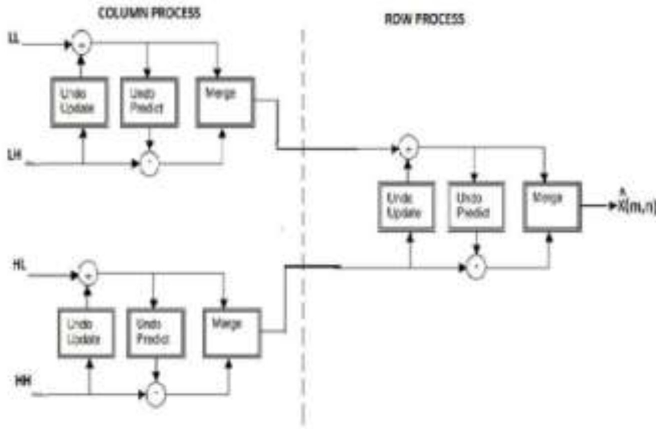

Figure. 5 Inverse Lifting scheme for an image

5. INVERSE LIFTING SCHEME

The sequence flow can be explained with the help of algorithm which includes the following steps [7].

Step 1: The registered visible and infrared images are first decomposed into the approximation and detail coefficients using the lifting scheme.

Step 2: The approximate coefficient of both images are fused using weighted averaging approach to get the approximation coefficients of the fused image.

Step 3: The detail coefficients of both images are fused using maximum energy rule.

Step 4: The inverse lifting operation is performed on the fused coefficients to get the fused image.

The pictorial representation as a sequence of steps can be used for the representation of the flowchart for the working of our paper.

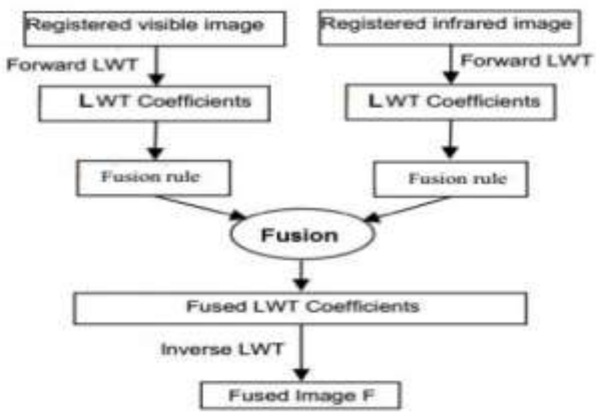

Figure 6. Flow Chart

6. RESULTS AND DISCUSSION

The visible and infrared image set considered for the purpose of implementation of the above mentioned fusion algorithm employing the lifting scheme are as shown below. The fused image obtained from the first, second and third level fused coefficients form the results [5].

In the fused image obtained by the proposed fusion algorithm, it can be observed that along with the major information contents in the visible image, the finer information in the infrared image such as the watermark and other features are transferred to the fused image [7].

Figure. 7 Visible image

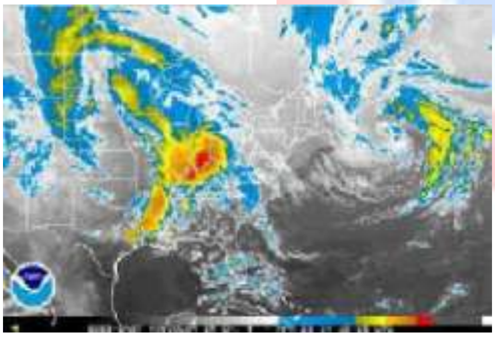

Figure. 8 Infrared image

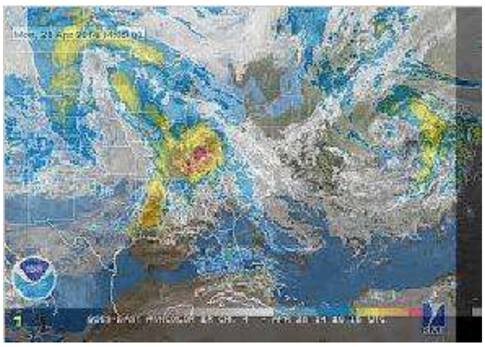

Figure. 9 Fused image at first level

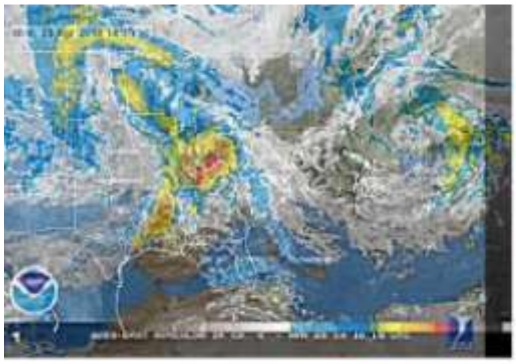

Figure.10 Fused image at second level

Figure. 11 Fused image at third level

The outcome of image fusion can be evaluated on the basis of amount of redundant energy removed finer (edge) details that are transferred to the fused image, the amount of information that is conveyed as well as the improvement in the image as compared to the input data set.

Table 1. Performance Parameters

	Decomposition level 3	**Decomposition level 2**	**Decomposition level 1**
SNR	38.5005	38.2987	38.2569
PSNR	27.7901	28.5526	28.6125
ENTROPY	2.0644	1.7063	1.1349
MUTUAL INFORMATION	1.3068	1.2867	1.2676
EDGE INFORMATION	0.4392	0.4304	0.4229

The various performance parameters that are evaluated as a part of this paper to examine the quality of the fused image are as listed below.

A. *SNR*: The SNR values for the different fused images of the above image set from different levels of fusion are tabulated as shown above . We observe that, the value of the SNR is maximum for the fused image obtained from third level coefficients and this value decreases as the fused image is obtained from second and first level respectively [2]. This can be explained on the basis of decrease in redundant energy at higher decomposition levels.

B. *PSNR:* The PSNR values for the different fused images of the above image set from different levels of fusion are tabulated as shown above. We observe that, the value of the PSNR is maximum for the fused image obtained from first level and this value decreases as the fused image is obtained from second and third level coefficients respectively [1]. This can be explained on the basis of increase in the mean square error (MSE) at higher decomposition levels.

C. *ENTROPY:* The ENTROPY values for the different fused images of the above image set from different levels of fusion are tabulated as shown above. We observe that for each image set, the value of the ENTROPY is maximum for the fused image obtained from third level coefficients and this value decreases as the fused image is obtained from second and first level coefficients respectively. This can be explained on the basis of amount of information conveyed by each of the fused image. The amount of redundant information is less in the case of fused image obtained from third level coefficients [7].

D. *MUTUAL INFROMATION:* The MI values for the different fused images of the above image set from different levels of fusion are tabulated as shown above. We observe that for each image set, the value of the MI is maximum for the fused image obtained from third level coefficients and this value decreases as the fused image is obtained from second and first level respectively. This can be explained on the basis of decrease in joint entropy at higher decomposition levels [5].

E. *EDGE INFORMATION:* The EDGE INFORMATION values for the different fused images of each image set from different levels of fusion are tabulated as shown above. We observe that for each image set, the value of the EDGE INFORMATION is maximum for the fused image obtained from third level coefficients and this value decreases as the fused image is obtained from second and first level coefficients respectively. This can be explained on the basis of increase in the amount of finer information transfer at higher levels of image decomposition.

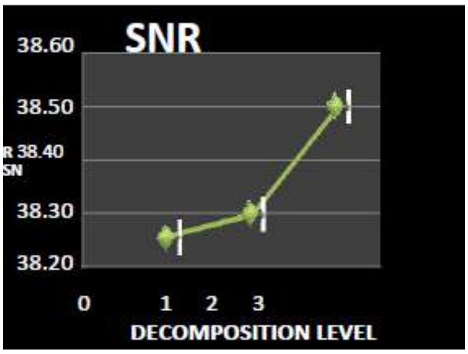

Figure. 12 SNR at different decomposition levels

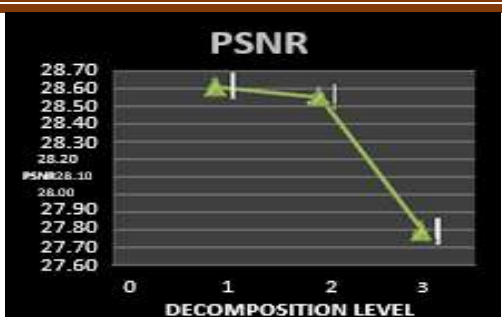

Figure. 12 PSNR at different decomposition levels

7. CONCLUSIONS

Wavelet analysis is very powerful and is extremely useful for image enhancement because of its property of multi-resolution. Also the wavelet analysis is done on the entire image coefficients rather than sections at a time. As seen by the proposed method where we have used lifting scheme for image fusion, we can infer about the image quality through the observation of the performance parameters.

SNR is highest for the fused image obtained from the third level coefficients. Due to less redundant information present in the image at higher decomposition levels. The PSNR is low for the fused image obtained from the third level coefficient due to less redundant information. The Entropy will be high for the fused image obtained from third level coefficient due to its information concentration. The mutual information is lowest for the fused image obtained from the third level coefficient due to high information concentration. The edge information is highest for the fused image obtained from the third level coefficient due to its higher information translation capability.

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