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Image Fusion using Laplacian Pyramid and Wavelet Transform

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Abstract— **Image fusion is one of important image processing technologies. It has recently become important in various application areas. Image fusion is a process in which two or more images from same or different image sensors are combined and fused together in order to obtain a new image that contains more information and has more positive image description to the same scene. In this paper, two different image fusion techniques (laplacian pyramid image fusion and wavelet transform image fusion) are implemented and performance of the fused images are evaluated and compared. We define a set of measures of effectiveness for comparative performance analysis and then used on proposed algorithms that has been applied on different sets of images.**

Index Terms— **Image fusion, Pixel based fusion, laplacian pyramid and wavelet fusion**

I. INTRODUCTION

Image fusion is a process in which two or more images are combined and fused to form a new image by using different techniques [4]. A complete image fusion process is carried out in specific steps. First pieces of the source images from different sensors are pre-processed, including filtering and processing of registration. Then it is followed by the application of image fusion algorithm. Finally, there is image fusion performance evaluation to determine whether it is the fusion algorithm or fusion. Fused image should have all the necessary information transferred from the source images.

The overall fusion process consists of different fusion levels. The different image fusion levels are: pixel-level image fusion, feature-level image fusion and decision-level image fusion. Pixel level image fusion is the lowest level of image fusion. It provides the detail information of image that cannot be brought by other level. It requires largest amount of information. Feature level image fusion is the middle level. It not only retains the sufficient important information, but also compresses the information. So it is beneficial to real time processing. Decision level is the highest level image fusion and the most complex. There is lower requirement of image registration in decision level fusion. In this paper, we have focused pixel-level fusion process, where a fused image is obtained from two input source images. [11]

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In pixel-level image fusion, some general requirements of pixel level fusion result are as:

(1) Fusion process should preserve all relevant information of the input imagery in the composite image (pattern conservation).

2) The fusion scheme should not introduce any artifacts or inconsistencies which would distract the human observer or subsequent processing stages.

(3) The fusion process should be shift and rotation invariant (i.e. the fusion result should not depend on the location or orientation of an object in the input imagery, which is crucial to pattern recognition or object detection).

II. PROPOSED METHODOLOGY

1. Laplacian Pyramid Based Image Fusion Method:

Due to the similarity to a Laplacian operator, a set of band-pass copies of an image is referred to as the Laplacian pyramid. At each level of laplacian pyramid fusion, the pyramid would be half the size of the pyramid in the preceding level and the higher levels will concentrate upon the lower spatial frequencies. The basic idea is to construct the pyramid transform of the fused image from the pyramid transforms of the source images and then the fused image is obtained by taking inverse pyramid transform [7,20]. Generally, each pyramid transform consists of three major phases: decomposition, formation of the initial image for recomposition and recomposition. The overall operation and proposed algorithm is as shown below.

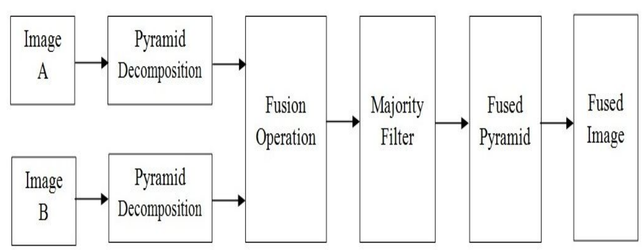

Figure 1: Laplacian Pyramid Based Image Fusion Method

Proposed Algorithm:

Step 1: Read two source images A and B of same size
Step 2: Reduce source images A and B
Step 3: Integrate reduced images
Step 4: Calculate pyramid coefficients of actual level for both images
Step 5: Chose maximum coefficients
Step 6: Apply high level analysis
Step 7: Reconstruct the fused image.

2. Wavelet Transform Based Image Fusion Method:

In this technique, each she source image is decomposed in rows and columns by low-pass (L) and high-pass (H) filtering and subsequent down sampling at each level to get approximation (LL) and detail (LH, HL and HH) coefficients. Scaling function is associated with smooth filters or low pass filters and wavelet function with high-pass filtering. Wavelet transforms provide a framework in which an image is decomposed, with each level corresponding to a coarser resolution band [1].

Wavelet transform is applied widely in signal analysis due to its excellent local time-frequency characteristics. It offers localized information from horizontal, vertical, and diagonal directions of any input image. The image is decomposed into multiple sub-bands by the wavelet transform. Each sub-band includes different information. The 2-level wavelet decomposition of image is shown in Figure 2. LL is the low frequency coefficient, which denotes the coarse features of the image. LH, HL, and HH are high frequency coefficients of vertical, horizontal, and diagonal directions respectively, which denote the detailed features of the image.

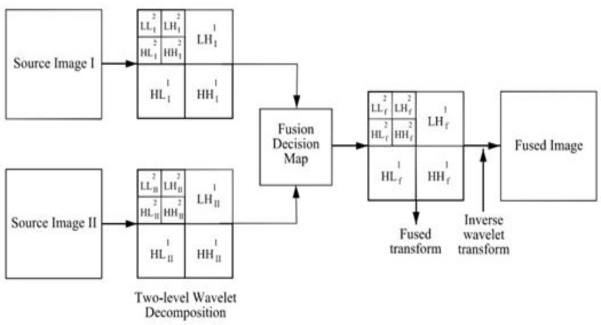

Figure 2: Wavelet based Image Fusion

Algorithm:

Step 1: Read two source images A and B of same size.

Step 2: Perform independent wavelet decomposition of the two images until level L to get approximation coefficients LL, LH, HL and HH.

Step 3: Apply pixel based algorithm for approximations which involves fusion based on taking the maximum valued pixels from approximations of source images.

LL^L_f = maximum (LL^L_I(i,j), LL^L_{II} (i,j))

Step 4: Apply binary decision fusion rule D_f for fusion approximation coefficients in two source images.

D_f(i,j) = 1, d_I(i,j) > d_{II}(i,j)

= 0, otherwise

Step 5: Then the final fused transform corresponding to approximations through maximum selection pixel rule is obtained.

Step 6: Apply inverse wavelet transform toreconstruct the resultant fused image and display the result.

III. Fused Image Quality Assessment

In order to verify the efficiency of image fusion, it needs a method of evaluation. The evaluation methods commonly can be divided into two broad categories: the subjective evaluation method and the objective evaluation method.

1. Subjective Evaluation:

Subjective assessment method is a man-made visual analysis for fused image, it is simple and intuitive. In addition to this, it has many advantages, such as it can be used to determine whether the image has shadow, whether the fusion image texture or color information is consistent and whether the clarify has been reduced. Therefore, the subjective assessment method is often used to compare the edges of fused images. It can get the differences of images in space decomposed force and clarity intuitively [14].

2. Objective Evaluation:

As the subjective assessment methods are not comprehensive and with certain one-sidedness. When the observation conditions change, the assessment results may be different. So, researchers made a number of methods named objective evaluation, those are quantitative analysis [14].

Following parameters are used for objective evaluation of the fused image.

1. Entropy (H):

The image entropy is an important indicator for measuring the image information richness.

$$H = -\sum_{i=0}^{L-1} p_i \log p_i \quad (1)$$

where, H = Pixel entropy

L = Image total grayscale

Pi = i pixel rate to image total N that is Pi = Ni/N

2. Spatial Frequency (SF):

Spatial Frequency Measurement (SFM) is used to measure the overall activity level of an image [1]. The SFM can be used to represent the clarity of an image, defined as follows,

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

where, RF and CF represented frequency in row and column spatial frequency of an image, respectively.

$$RF = \sqrt{\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=2}^{N}(F(m,n) - F(m,n-1))^2} \quad (3)$$

$$CF = \sqrt{\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=2}^{N}(F(m,n) - F(m-1,n))^2} \quad (4)$$

3. Standard Deviation (STD):

Standard deviation is used to reflect discrete case of the image gray intensity relative to the average. To some extent, the standard deviation can also be used to evaluate the image contrast size.

$$STD = \sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(f(i,j) - \hat{\mu})^2 / MN} \quad (5)$$

where, μ is the mean value of gray-scale image fusion in the above formula.

4. Total Fusion Performance Parameter ($Q^{AB/F}$) :

Total fusion performance $Q^{AB/F}$ is evaluated as a weighted sum of edge information preservation values for both input images Q^{AF} and Q^{BF} where the weights factors w^A and w^B represent perceptual importance of each input image pixel. The range is 0 = $Q^{AB/F}$= 1, where 0 means complete loss of input information has occurred and 1 indicates "ideal fusion" with no loss of input information.

$$Q^{AB/F} = \frac{\sum_{\forall n,m} Q^{AF}_{n,m} w^{A}_{n,m} + Q^{AF}_{n,m} w^{B}_{n,m}}{\sum_{\forall n,m} w^{A}_{n,m} + w^{B}_{n,m}} \quad (6)$$

5. Fusion Artifact ($N^{AB/F}$) :

Fusion artifacts represent visual information introduced into the fused image by the fusion process that has no corresponding features in any of the inputs. Fusion artifacts are essentially false information that directly detracts from the usefulness of the fused image and can have serious consequences in certain fusion applications. Total fusion artifacts for the fusion process A,B => F are evaluated as a perceptually weighted integration of the fusion noise estimates over the entire fused image.

$$N_{n,m} = \begin{cases} 2 - Q^{AF}_{n,m} - Q^{BF}_{n,m}, & if\ g^{F}_{n,m} > (g^{A}_{n,m}\ \&\ g^{F}_{n,m}) \\ 0 & , otherwise \end{cases} \quad (7)$$

$$N^{AB/F} = \frac{\sum_{\forall n,m} N_{n,m} (w^{A}_{n,m} + w^{B}_{n,m})}{\sum_{\forall n,m} (w^{A}_{n,m} + w^{B}_{n,m})} \quad (8)$$

6. Total Fusion Gain ($Q_{\Delta}^{AB/F}$) :

The total fusion gain of a fusion process is the sum of the individual gains with respect to each input:

$$Q_{\Delta}^{AB/F} = Q^{\Delta A/F} + Q^{\Delta B/F} \quad (9)$$

7. Fusion Loss ($L^{AB/F}$) :

Fusion loss $L^{AB/F}$ is a measure of the information lost during the fusion process.

$$L^{AB/F} = \frac{\sum_{\forall n,m} r_{n,m}[(1 - Q^{AF}_{n,m}) w^{A}_{n,m} + (1 - Q^{BF}_{n,m}) w^{B}_{n,m}]}{\sum_{\forall n,m} w^{A}_{n,m} + w^{B}_{n,m}}$$

(10)

Wher

$$r_{n,m} = \begin{cases} 1 \ , & if\ g^{F}_{n,m} < g^{A}_{n,m}\ or\ g^{F}_{n,m} < g^{B}_{n,m} \\ 0 \ , & otherwise \end{cases} \quad (11$$

)

8. Root Mean Square Error (RMSE):

The root mean square error is defined by the differences between a reference image pixel value and the fused image pixel value. The RMSE between the standard reference image R and fused image F can be defined as:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (R(i,j) - F(i,j))^2}{M \times N}} \quad (12)$$

where, M = Number of rows in the image and
N = Number of columns in the image

If RMSE is zero, the fusion is perfect. Therefore the lower the value of RMSE, the better is the fusion.

9. Peak Signal to Noise Ratio (PSNR):

Peak signal to noise ratio is an engineering term for the ratio between the maximum power of a signal and the power of corrupting noise that affects the fidelity of its representation. PSNR can be defined as:

$$\mathrm{PSNR} = 10 \lg \frac{255 \times 255}{\mathrm{RMSE}^2} \quad (13)$$

PSNR basically projects the ratio of the highest possible value of the data to the error obtained in the data.

IV. Experimental Results

To validate the effective of the algorithm, the two images of the same scene taken at different times are tested and the proposed techniques are compared with the general clarity. The proposed techniques are tested over different database images. The performance parameter such as entropy, spatial frequency, standard deviation, total information transferred, total fusion gain, total loss of information, fusion artifact, root mean square error and peak signal to noise ratio are calculated. The results of few different database images (Boat.jpg, Roar.jpg and Chetan.jpg) are shown below.

Experimental results obtained in table 1 (for Boat.jpg), table 2 (for Roar.jpg) and table 3 (for Chetan.jpg) reflect that all the parameters show good results for wavelet transform based fused image. Entropy, standard deviation, spatial frequency, total information transferred, fusion artifacts, fusion gain and peak signal to noise ratio of wavelet fused image are greater than pyramid fused image. Also loss of information and root mean square error are less in wavelet fused image. Also entropy, standard deviation and spatial frequency of wavelet fused image are greater than both the source images.

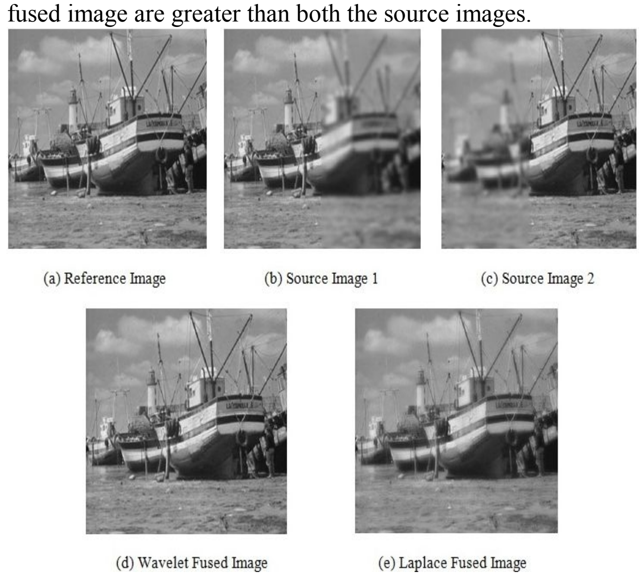

Figure 3: Test image : Boat.jpg

Figure 4: Test image : Roar.jpg

(a) Reference Image (b) Source Image 1 (c) Source Image 2

(d) Wavelet Fused Image (e) Laplace Fused Image

Figure 5: Test image : Chetan.jpg

Table 1: Performance Characterization Results for Image "Boat.jpg"

Parameters	Reference Image	Source Image 1	Source Image 2
Entropy	7.1649	7.0779	7.0667
Standard Deviation	0.1753	0.1617	0.1667
Spatial Frequency	0.0726	0.0487	0.0590

Parameters	Wavelet Fused Image	Laplacian Fused Image
Entropy	7.1668	7.0709
Standard Deviation	0.1749	0.1629
Spatial Frequency	0.0737	0.0577
Total Fusion Performance	0.6229	0.6032
Fusion Artifacts	0.3199	0.1056
Total Fusion Gain	0.3513	0.3024
Total Fusion Loss	0.2171	0.3440
RMSE	0.0108	0.0289
PSNR	67.8469	63.5545

Table 2: Performance Characterization Results for Image "Roar.jpg"

Parameters	Reference Image	Source Image 1	Source Image 2
Entropy	7.0332	7.0191	6.6994
Standard Deviation	0.2577	0.2490	0.2512
Spatial Frequency	0.0589	0.0407	0.0404

Parameters	Wavelet Fused Image	Laplacian Fused Image
Entropy	7.0197	7.0171
Standard Deviation	0.2541	0.2497
Spatial Frequency	0.0550	0.0490
Total Fusion Performance	0.5916	0.5889
Fusion Artifacts	0.3762	0.1264
Total Fusion Gain	0.3724	0.3376
Total Fusion Loss	0.2203	0.3479
RMSE	0.0155	0.0237
PSNR	66.2479	64.4182

Table 3: Performance Characterization Results for Image "Chetan.jpg"

Parameters	Reference Image	Source Image 1	Source Image 2
Entropy	7.8660	7.8379	7.8528
Standard Deviation	0.2549	0.2474	0.2527
Spatial Frequency	0.0959	0.0743	0.0883

Parameters	Wavelet Fused Image	Laplacian Fused Image
Entropy	7.8666	7.8501
Standard Deviation	0.2543	0.2501
Spatial Frequency	0.0915	0.0849
Total Fusion Performance	0.8229	0.8169
Fusion Artifacts	0.1562	0.0738
Total Fusion Gain	0.1428	0.1197
Total Fusion Loss	0.0990	0.1462
RMSE	0.0088	0.0199
PSNR	68.7239	65.1862

In order to test the performance of the proposed image fusion techniques, the experiments are conducted on set of two source images. Each image has different focuses and size of each image is 512×512 pixels. Fusion process is carried on these images and performance parameters are evaluated. All the performance parameters show better results in wavelet transform than laplacian pyramid transform method.

CONCLUSION

In this paper, we have presented two image fusion techniques viz. laplacian pyramid based image fusion and wavelet transform based image fusion. Experimental studies were conducted by applying these two image fusion techniques. Experimental results conclude that wavelet based image fusion provides better result both visually (subjectively) and quantitatively (objectively). All the parameters show better results for wavelet fused image than that of pyramid fused image for all the test images. Entropy, standard deviation, spatial frequency, total information transferred, fusion artifact, fusion gain and peak signal to noise ratio of wavelet fused image are greater than pyramid fused image. Also loss of information and root mean square error is less in wavelet fused image than that of laplacian pyramid fused image. Also entropy, standard deviation and spatial frequency of wavelet fused image are greater than both the source images. However, to the algorithm in terms of complexity and real-time, there are still enough to be further improved.

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