Performance Evaluation of Image Fusion for Impulse Noise Reduction in Digital Images Using an Image Quality Assessment

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Abstract

Image fusion is the process of combining two or more images into a single image while retaining the important features of each image. Multiple image fusion is an important technique used in military, remote sensing and medical applications. In this paper, Image Fusion based on local area variance is used to combine the de-noised images from two different filtering algorithms, Vector Median Filter (VMF) and Spatial Median Filter (SMF). The performance of the Image Fusion is evaluated by using a new non-reference image quality assessment; Gradient based Image Quality Index (GIQI), to estimate how well the important information in the source images is represented by the fused image. Experimental results show that GIQI is better in non-reference image fusion performance assessment than universal image quality index (UIQI).

***Keywords**: Image Restoration, Image Fusion, Image Quality Assessment, Impulse Noise, Image Processing.*

1. Introduction

Order statistics filters exhibit better performance as compared to linear filters when restoring images corrupted by impulse noise [1][2]. Impulse noises are short duration noises which degrade an image. They may occur during image acquisition, due to switching, sensor temperature. They may also occur due to interference in the channel and due to atmospheric disturbances during image transmission. The goal of the filtering action is to cancel noise while preserving the integrity of edge and detail information. In this paper, vector median filter (VMF) [6] and spatial median filter (SMF) [6] are used to filter the impulse noise image. The two filtered images are fused into a single image using an image fusion algorithm, producing better quality image compared to individually de-noised images. The purpose of image fusion is to get most information from source images.

Several image fusion methods on multi-scale transformations have been proposed. Well known examples of these are based on Laplacian Pyramid Transform (LPT) [3] and Discrete Wavelet Transform (DWT) [4]. However, multi-resolution approaches, are generally shift-variant and sensitive to noise [5]. In our paper, an image fusion algorithm based on local area variance is proposed. The algorithm divides the two source images into non-overlapping rectangular blocks. Variance of each corresponding block in two source images is calculated to determining the sharpness values between two blocks. The fundamental idea behind our method is to construct a fused image by choosing the sharper image blocks within the source images.

The image fusion analysis can be carried on from the perspective of subjective quality analysis and objective quality analysis [7]. The former is a comparison analysis in visual sense, based on the knowledge of visual clarity and spectral characteristics; the latter mainly uses some commonly-used quality analysis formulas to work out the corresponding fusion image and source image's index data and make comparison analysis. One such evaluation is Universal Image Quality Index (UIQI), where local image statistics are used to define a similarity between input and fused images. In our paper, a new quality metric GIQI is proposed, by adding the local gradient information to the UIQI metric.

The rest of the paper is organized as follows: Section 2 gives the introduction to impulse noise in images, Section 3 presents two different filtering algorithms for removal of impulse noise, Section 4 presents an image fusion algorithm, Section 5 presents image fusion quality index, Section 6 presents Experimental results and finally Section 7 reports conclusion.

2. Impulse Noise in Images

Impulse noise [8] corruption is very common in digital images. Impulse noise is always independent and uncorrelated to the image pixels and is randomly distributed over the image. There are different types of impulse noise namely salt and pepper type of noise and random valued impulse noise. In salt and pepper type of noise the noisy pixels takes either salt value (gray level -225) or pepper value (grey level -0) and it appears as black and white spots on the images. In case of random valued impulse noise, noise can take any gray level value from zero to 225. In this case also noise is randomly distributed over the entire image and probability of occurrence of any gray level value as noise will be same.

3. Filtering Algorithms

The Vector Median Filter (VMF): In VMF, the vector pixels in a particular kernel or window are ordered based on a suitable distance measure. The sum of the distances between each vector pixel and the other vector pixels in the window is calculated. The distances are arranged in the ascending order and then the same ordering is associated with the vector pixels. The vector pixel with the smallest sum of distances is the vector median pixel. The vector median filter is represented as

$$X_{VMF} = vectormedian\ (window) \tag{1}$$

If d_i is the sum of the distances of the i^{th} vector pixel with all the other vectors in the kernel, then

$$d_i = \sum_{j=1}^{N} \Delta(X_i, X_j) \tag{2}$$

Where $(1 \le i \le N)$ and X_i and X_j are the vectors, $N=9$. $\Delta(X_i,X_j)$ is the distance measure given by the L_1 norm or the city block distance which is more suited to non correlated noise. The ordering may be illustrated as

$$d_1 \le d_2 \le d_3 \le \ldots, \le d_9 \tag{3}$$

and this implies the same ordering to the corresponding vector pixels i.e.

$$X_{(1)} \le X_{(2)} \le \ldots, \le X_{(9)} \tag{4}$$

where the subscripts are the ranks. The vector pixel with the smallest sum of distances is the vector median pixel, it will correspond to rank 1 of the ordered pixels, i.e.

$$X_{VMF} = X_{(1)} \tag{5}$$

The Spatial Median Filter (SMF): The SMF is based on the spatial median quantile function which is a L_1 norm metric that measures the difference between two vectors. The spatial depth between a point and a set of points is defined by

$$S_{depth}(X,x_1,x_2,\ldots\ldots x_N)=1 - \frac{1}{N-1}\left\| \sum_{i=1}^{N} \frac{X - xi}{\|X - xi\|} \right\| \tag{6}$$

Let $r_1,r_2,\ldots.r_N$ represent $x_1,x_2,\ldots..x_N$ in rank order such that

$$\begin{aligned} &S_{depth}(r_1,x_1,x_2,\ldots\ldots x_N) \\ \ge\ &S_{depth}(r_2,x_1,x_2,\ldots\ldots x_N) \\ \ge\ & \\ \ge\ &S_{depth}(r_N,x_1,x_2,\ldots\ldots x_N) \end{aligned} \tag{7}$$

And let r_c represent the center pixel under the mask. Then

$$SMF(x_1,x_2,\ldots\ldots x_N) = r_1 \tag{8}$$

4. Image Fusion

Given two images, it is required to combine the images into a single one that has all objects without producing details that are non-existent in the given images. Although the fusion algorithm can be extended straightforwardly to handle more than two source images, we only consider the fusing of two source images. The algorithm consists of the following steps:

a. Input images A and B are divided into non-overlapping rectangular blocks with size of mxn (10x10 blocks). The j^{th} image blocks of A and B are referred by A_j and B_j respectively.

b. Variance (VAR) of A_j and B_j are calculated for determining the sharpness values of the corresponding blocks and the results of A_j and B_j are denoted by VAR_j^A and VAR_j^B, respectively. VAR is defined as:

$$\mathrm{VAR} = \frac{1}{\mathrm{m}\times\mathrm{n}} \sum_x \sum_y (f(x,y) - \overline{f}) \qquad (9)$$

Where $\overline{f}$ is the average grey level over the image.

$$\overline{f} = \frac{1}{m\times n} \sum_x \sum_y f(x,y) \qquad (10)$$

c. Sharpness values of two corresponding blocks A_j and B_j are compared to determine the sharper image block, and j^{th} block of the fused image (F) is constructed as:

$$F_j = \begin{cases} A_j & VAR_j^A > VAR_j^B \\ B_j & VAR_j^B > VAR_j^A \\ (A_j+B_j)/2 & Otherwise \end{cases} \qquad (11)$$

5. Image Fusion Quality Index

Wang and Bovik [9] proposed a universal objective image quality assessment metric which is easy to calculate and applicable to various image processing applications. That metric is a Universal Image Quality Index (UIQI). The metric is a combination of three factors: loss of correlation, luminance distortion and contrast distortion. Besides these three factors, many studies show that in human visual system gradient (edge) information plays a very important role when human subject judges the quality of an image. In this paper, a new metric GIQI is presented based on UIQI by adding the local gradient information. Before performing quality analysis, we use an edge detector (such as sobel operator) to quickly process the image and get the gradient information for each image pixel, which is denoted as g. The new metric is presented as follows.

Given two real valued sequences $x=\{x_1,\ldots,x_n\}$ and $y=\{y_1,\ldots,y_n\}$, $\overline{x}$ is the mean of x, $\sigma_x^{\,2}$ is variance of x, $\sigma_y^{\,2}$ is variance of y and σ_{xy} is the covariance of x,y.

$$\sigma_x^2 = \frac{1}{n-1} \sum (x_i - \overline{x})^2 \qquad (12)$$

$$\sigma_y^2 = \frac{1}{n-1} \sum (y_i - \overline{y})^2 \qquad (13)$$

$$\sigma_{xy} = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \overline{x})(y_i - \overline{y}) \qquad (14)$$

Then, we can compute GIQI as

$$Q = \frac{\sigma_{xy}}{\sigma_x\sigma_y} \cdot \frac{2\,\overline{xy}}{\overline{x}^{\,2} + \overline{y}^{\,2}} \cdot \frac{2\sigma_x\sigma_y}{\sigma_x^2+\sigma_y^2} \cdot \frac{2g_x g_y}{g_x^2+g_y^2} \qquad (15)$$

The Q can be decomposed into four components as

Q_{GIQI}=(correletation)x (luminance) x (Contrast) x (gradient)

The value of the four components is in the range of [0, 1]. Therefore, the final value of the quality metric is normalized between [0, 1].

Fusion Performance Evaluation:

For the fusion of input image A and image B resulting in a fused image F, the performance evaluation is done as follows.

Image A and the fused image F are divided into blocks with 10x10 pixels. Calculate the GIQI for each block and using mean to evaluate overall image quality.

$$Q_{A/F} = \frac{1}{K}\sum_{j=1}^{K} Q(x_j, y_j) \qquad (16)$$

Where K is the number of blocks.
Similarly for image B and fused image F,

$$Q_{B/F} = \frac{1}{K}\sum_{j=1}^{K} Q(x_j, y_j) \qquad (17)$$

Then the fusion quality index (GIQI) can be given as

$$Q_{AB/F} = \frac{W_a * Q_{A/F} + W_b * Q_{B/F}}{W_a + W_b} \qquad (18)$$

Where w_a and w_b are local weights between 0 and 1 indicating some distinguished features of the source images A and B, such as variance, marginal information and so on.

6. Experimental results

The proposed Image Quality Analysis method (GIQI) for image fusion performance evaluation was tested on the true color parrot image with 290x290 pixels. The impulse noise is added into the image with noise density 0.4. The noisy image is processed using VMF and SMF algorithms. The filtered images are fused into a single image using the Image fusion method in section IV. The experimental results are shown in Figure 1. Table (1) shows the results of UIQI and GIQI of fused image with different noise densities.

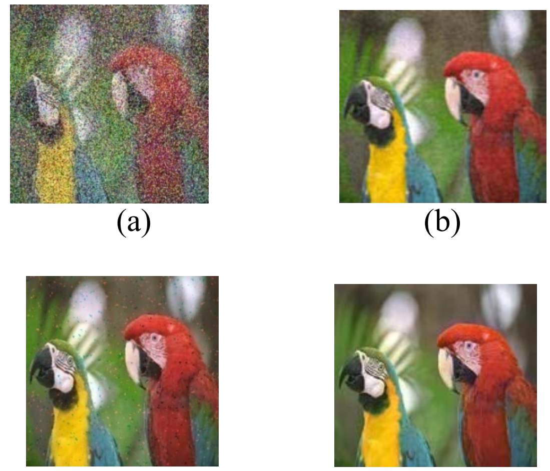
(a) (b) (c) (d)

Figure 1 a) impulse noise image with noise density 0.4, b) Vector Median Filter c) Spatial Median Filter d) Fused Image

Table 1: Performance Evaluation of Fusion Method

	ND 0.2	ND 0.4	ND 0.6	ND 0.8
UIQI	0.821	0.714	0.586	0.368
GIQI	0.886	0.764	0.602	0.394

ND-Noise Density

7. Conclusion

This paper presents three concepts. First, two different filtering algorithms, VMF and SMF for removal of impulse noise in images are presented. Then, an Image Fusion algorithm is presented, for fusing the two de-noised images into a single image by choosing the sharper image blocks between the two source images. In the last, an objective non-reference image fusion performance assessment is presented, by using a Gradient based Image Quality Index (GIQI). By using GIQI, one can evaluate the performance of different image fusion algorithms.

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