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Comparative Study of Denoising Methods for Satellite Image Restoration Using Matlab

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Abstract: In image processing, noise can be defined as unwanted random variation of brightness in gray scale images or color information in color images. In most of the image processing applications, the noise pixels are incorporated with the image pixels and it becomes very difficult task to retrieve the useful image pixels or information from the noisy images. The quality of the image is certainly degraded and unable to further processing of the noisy images. Moreover the result obtained from the noisy images may be undesirable and unexpected one. So excellent image denoising method is necessary to remove the unwanted noisy pixels and retain and manipulate the image pixels. In this paper, we compared and simulate the various denoising methods based on filtering and wavelet transform approach for satellite images. All the denoising methods have been tested with different size and resolution the satellite images.

Keywords: satellite image; noise; denoising; filtering; wavelet transform

I. INTRODUCTION

In the satellite image processing, the image received from the satellite contains enormous amount of data for the further processing or analysis. The received satellite image always corrupted with noise. So the corrupted image should be processed with suitable denoising method before it is applied for various applications. Even though noise is always undesirable, but in some situation the amount of noise is useful added with the original image, for example to improve apparent sharpness and the prevent artifacts. However in many applications, noise is considered as unwanted, undesirable one and the reason for image degrading. The objective of the image denoising process is to recover the original image from the noisy image in order to perform the image processing tasks such as segmentation in efficient and accurate manner. The removal of noise pixels from image is an uphill task for researchers. Many denoising algorithms have been developed but all of them having its own advantages and disadvantages. The selection of algorithm is also application dependent. For example, the denoising algorithm developed for medical image is not suitable for satellite or any other images. Similarly it is not wise to apply the algorithm developed for the removal of salt and pepper noise to any other noise removal. Image restoration is the process of any form of image degradation reduction in the image. In satellite image processing, the image is degraded or corrupted by blurring and noise. The main source for blurring is atmospheric turbulence, relative motion between camera and ground. In the satellite image noise is introduced in many stages: transmission channel, quantization process and measurement process. Moreover lenses, digitizer and camera also contribute to the image degradation. In this paper, we performed the comparative study of the various denoising algorithms. The paper is organized as follows. The detailed study of various noises is presented in Section II. The complete survey of denoising methods based on filtering and wavelet transform is included in Section III. The wavelet transform based denoising approach is presented in IV. The information related to the wavelet threshold is presented in section V. The experimental simulation results are presented in Section VI. Finally, some conclusions of the experimental results were given in Section VII.

II. NOISE MODEL AND TYPE OF NOISE

Consider if f(x,y) is the original image and g(x,y) is the noise that is added to the original image, then the noisy or corrupted image can be represented as n(x,y) and (x,y) denotes the pixel location in the image. According to the behavior of the noise, that can be classified as either additive or multiplicative. The additive and multiplicative noise can be represented as (1) and (2) respectively

$$n(x,y) = f(x,y) + g(x,y) \quad (1)$$

$$n(x,y) = f(x,y) * g(x,y) \quad (2)$$

A. *Gaussian Noise*

One of the most important noise degrade the image quality is gaussian noise that is evenly distributed over the image. When this additive noise is added to the original image, in the output noisy image every pixel is the sum of a random gaussian distributed noise value and image pixel value. In color cameras most amplification is performed in the blue color channel than in the green or red channel. So there is more noise in the blue channel as compared to other two channels. The syntax for gaussian noise in MATLAB is given by J = imnoise(I,'gaussian',m,v) . This adds Gaussian white noise of mean m and variance v to the image I. The default value of mean is zero and variance is 0.01

B. *Salt and Pepper Noise*

This type of noise also referred to as impulsive or spike noise. The main source for the salt and pepper is errors occurred during the analog to digital conversion and transmission. The image containing the salt and pepper noise has only two possible values as dark pixels in the bright regions (low value- zero) and bright pixels in dark regions (high value- one). The probability of each is typically less than 0.1. The value of unaffected pixels remains unchanged. The syntax for salt and pepper noise in MATLAB is given by

J = imnoise(I,'salt & pepper',d)

This adds salt and pepper noise to the image I, where d is the noise density. The default value of d is 0.05.

C. Speckle Noise

This multiplicative noise signal which follows gamma distribution is multiplied with the original image pixels to generate the noisy image. Generally all coherent systems such as Synthetic Aperture Radar (SAR) images, Laser, Ultrasound images suffered by this speckle noise. The syntax for speckle noise in MATLAB is given by

J = imnoise(I,'speckle',v)

This adds multiplicative noise to the original image I, by using the equation J = I+n*I, where n is uniformly distributed random noise with mean 0 and variance v. The default for v is 0.04. [2]

D. Poisson Noise

Fully developed speckle noise follows a Poisson distribution. The syntax for Poisson noise in MATLAB is given by

J = imnoise(I,'poisson')

This generates the Poisson noise from the data instead of adding artificial noise to the data. According to poisson statistics, the unit8 and uint16 intensity of images must correspond to the number of photons. The double-precision images are used when the number of photons per pixel can be much larger than 65535.

II. SPATIAL FILTERING APPROACH FOR IMAGE DENOISING

The process denoising in image processing refers to the recovery of the original image from the noisy corrupted image. Number of denoising methods has been proposed till date and every method has its own advantages and disadvantages. In addition, their application depends upon noise present in the image and the type of image. The selection of an appropriate denoising method is the first successful step in the restoration process. Filters play a vital role in the image degradation removal process i.e., image restoration. Image denoising is classified into two main categories: spatial domain filtering approach and transform domain filtering approach.

Image filtering is the process of modifying or enhancing an image. By using image filtering, we can emphasize or enhance some features and remove other unwanted features. In this, the value of a pixel in the output image is calculated by applying an algorithm to the values of the pixels in the neighborhood of the corresponding input pixel. In the filtering approach, denoising is performed using convolution and moving window principle. If f(x) is the one dimensional input signal subjected to filtering, and z(x) is the filtered output, then the output filter can be expressed mathematically in as

$$z(x) = \int f(x)\, h(x-t) \qquad (1)$$

in the above equation $h(t)$ is impulse response that completely characterizes the filter. The integral in the above equation represents a convolution integral and can be expressed as $z = f * h$. In the case of two dimensional discrete images the equation (1) becomes

$$z(i,j) = \sum_{i}^{i+k} \sum_{j-l}^{j+l} w(t,u) h(i-t, j-u) \qquad (2)$$

where $h(t,u)$ is referred to as the filter weights or filter kernel. In practical systems, $h(t,u)$ is always be non-negative which results in some blurring of the image. If the coefficients are alternatively positive and negative, the kernel is a filter that gives the information only about the edges of the corresponding image. In digital image processing, the filter kernel $h(t,u)$ maybe defined arbitrarily and this gives rise to wide range of linear and non-linear filters.

A. Linear Filters

In this, the value of an output pixel is a linear combination of the values of the pixels in the input pixel's neighborhood. The main problem associated with linear filters is destroying lines and other fine details of image and blurring the sharp edges. This category includes average filter and wiener filter.

a. Average Filter

An average filter works on the principle of reducing the intensity variation between adjacent pixels. In this, the center value in the window replaces with the average of all the neighboring pixel values. By doing this, it replaces unrepresentative pixels their surroundings. This can be implemented with a convolution mask or kernel, usually 3× 3 square kernel, which provides a weighted sum of the values of a pixel and its neighbors. If the sum of the coefficients of the mask is one, then the average brightness of the image remains unchanged. If the sum of the coefficients of the mask is zero, the average brightness is lost, and the result is dark image.

b. Weiner Filter

Weiner filtering is based on a statistical approach. This filtering method requires the information about original image and the spectra of noise and also this method works well only if the image is smooth. If the variance is large, wiener filtering performs little smoothing and if the variance is small, it performs more smoothing. This approach often produces better results than average filtering but it requires more computation time. Moreover it is selective than a comparable linear filter, keeping the preserving edges and other high-frequency parts of an image.

B. Non Linear Filters

In the non linear filtering approach, the image noise is removed without any attempts to explicitly identify it. Non linear filtering method employ a low pass filtering on image with the assumption that the noise added with the image occupies the higher region of frequency spectrum. This filter removes noise to some extent but at the cost of blurring images results in the edges in pictures invisible. The example for non linear filter is median filter. The principle behind the median filtering is similar to using an average or mean filtering. In the case of average filtering, the value of an output pixel is determined by the mean of the neighborhood pixels. However, in the case of median filtering, each output pixel is an average of the pixel values in the neighborhood of the corresponding input pixel, rather than the mean. The median filter is less sensitive than the mean filter to the outliers (extreme values in the image). So median filtering is the best approach to remove the outliers without reducing the sharpness of the image. This filter follows the moving window principle and can be

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implemented with a convolution mask or kernel, usually 3× 3, 5×5 or 7×7 window or square kernel. The median of window is calculated and then this value replaced the center pixel value of the window.

IV. WAVELET TRANSFORM BASED APPROACH FOR IMAGE DENOISING

The wavelet is defined as a set of orthonormal basis functions generated by dilation and translation of scaling function φ and a mother wavelet ψ. The wavelet basis or function can be localized in both frequency and space. This means the wavelet transform analyses the image information on both frequency and time scale. But the fourier transform can be localized only in spatial domain. The wavelet basis is defined as,

$$\psi(j,k)^{(x)} = 2^{\frac{j}{2}}\psi(2^j x - k) \quad (3)$$

The scaling function is defined as,

$$\phi(j,k)^{(x)} = 2^{\frac{j}{2}}\phi(2^j x - k) \quad (4)$$

The denoising based on wavelets is performed by first decomposing the corrupt image into wavelet coefficients. Then, the wavelet coefficients are modified based on the soft or hard thresholding function. Finally, the inverse wavelet transform is performed on modified coefficients to obtain the reconstructed image. Basic procedure for wavelet based denoising is

1. Apply discrete wavelet transform to the noisy Image. The wavelet transform decompose the image information into the wavelet coefficients.
2. Perform thresholding function to the wavelet coefficients components. Thresholding may be either soft or hard thresholding according to the application. The coefficients are smaller than threshold is removed and the larger coefficients are retained
3. Apply the inverse discrete wavelet transform on the retained coefficients to obtain denoised estimate that is the reconstructed image.

Hard thresholding function is based on crisp logic which produces the result either 0 or 1. If the coefficients are larger than threshold, they are retained; otherwise, it is set to zero. The hard thresholding can be defined as

$$T_H = \begin{cases} x \; for \; |x| \geq t \\ 0 \quad otherwise \end{cases} \quad (5)$$

In soft thresholding function the argument shrinks toward zero by the threshold. The soft-thresholding method yields more visually pleasant images over hard thresholding. The soft thresholding can be defined as

$$T_s = \begin{cases} sgn(x)(|x| - t) \; for \; |x| \geq t \\ 0 \quad otherwise \end{cases} \quad (6)$$

Mallat [4] propose an algorithm for the efficient implementation of the wavelet transform. In this discrete wavelet coefficients calculated for a finite set of input data. This input data is applied to two convolution functions, each of which creates an output data that is half the length of the original input. First half of the output is produced by the low pass filter function and most of the information of the input signal (coarse coefficients) and the second half of the output is produced by the high pass filter function (detail coefficients). The low pass filter coefficients are used as the original signal for the next set of coefficients. This procedure is repeated recursively until a trivial number of low pass filter coefficients are left. The output of the process contains the remaining low pass filter outputs and the accumulated high pass filter outputs. This procedure is termed as decomposition. According to the inverse Mallat's algorithm, the quadrature mirror filters are applied with the coarse and detail coefficients. The outputs of the two filters are summed and are treated as the coarse coefficients for the next stage of reconstruction. This procedure is continued until the original data is obtained [9].

V. WAVELET THRESHOLDING

There are number of methods for wavelet thresholding. Most widely used methods for image denoising include VisuShrink, SureShrink and BayesShrink [1, 3].

The thresholding method VisuShrink was proposed by Donoho [6]. In this threshold value t is proportional to the standard deviation of the noise. This hard thresholding method also known as universal threshold is defined as

$$T = \sigma\sqrt{2 \log n} \quad (7)$$

where *n* represents the signal size or number of samples, σ is the noise level and σ2 is the noise variance present in the signal and in VisuShrink a single value of threshold applied globally to all the wavelet coefficients. The main drawbacks of this method is (i) This method cannot be applied for minimizing the mean squared error (ii) removes too many coefficients (iii) It can only deal with an additive noise and cannot remove speckle noise.

SureShrink is soft thresholding proposed by Donoho and Johnstone [6]. Since this method specifies a threshold value for each level of resolution (j) in the wavelet transform, also known as level dependent thresholding [1]. The objective of the SureShrink wavelet thresholding is to minimize the mean squared error, defined as

$$MSE = \frac{1}{n^2}\sum_{x,y=1}^{n}(n(x,y) - s(x,y))^2 \quad (8)$$

where *s*(*x*,*y*) is the original signal without noise, *n*(*x*,*y*) is the estimate of the signal and *n* is the size of the signal. SureShrink removes noise by thresholding the empirical wavelet coefficients. This SureShrink threshold is defined as

$$T = \min\,(t, \sigma\sqrt{2 \log n}) \quad (9)$$

where *t* is the value that minimizes Stein's Unbiased Risk Estimator, *n* is the size of the image and σ denotes the noise variance

The thresholding method BayesShrink was proposed by Chang, Yu and Vetterli [1]. The objective of this method is to minimize the bayesian risk. This approach soft thresholding rule and is sub band dependent. In this, thresholding is done at each band of resolution in the wavelet decomposition. The Bayes threshold is defined as

$$T_b = \frac{\sigma^2}{\sigma_s} \quad (10)$$

where σ_s is the signal variance without noise and σ^2 is the noise variance.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

For the simulation using Matlab a data base of 20 satellite images was created to test the filtering and wavelet based approaches of image denoising. All the algorithms and methods are coded in Matlab 7.10 (R2010a) and executed using Intel core i3 system with 2GB RAM. Fig 1 shows the comparative results of various method of image denoising. Fig 1(a) shows the test satellite images. For the faster and

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easier execution, the color image is converted into gray scale or intensity images as shown in Fig 1(b). The salt and pepper noise is added to the gray scale image as shown in Fig 1(c). The denoising result for the average filter, weiner filter, median filter and discrete wavelet transform using BayesShrink wavelet threshoding is shown in Fig 1(d), 1(e), 1(f), 1(g) respectively

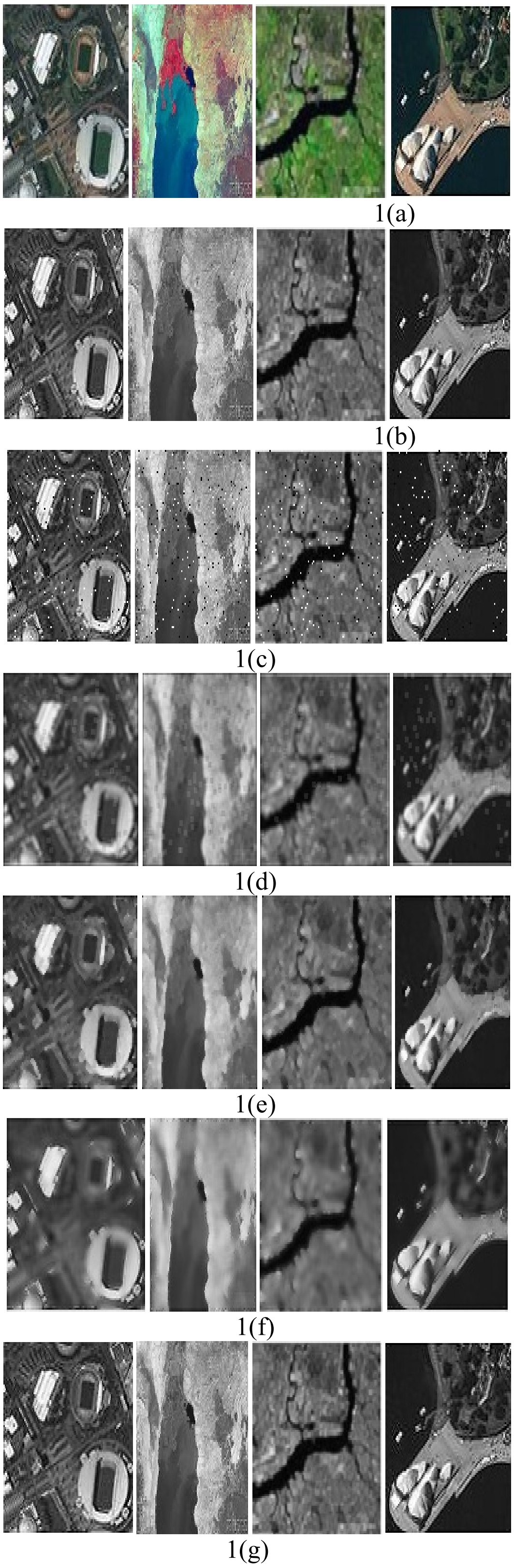

Figure 1. The Result of Denoising Methods (a) The original Image (b) the gray scale Image (c) The gray scale image with salt and pepper noise (d)The denoised image using average filtering method (e) the denoised image using median filtering method (f) The denoised image using weiner filtering method (g) The denoised image using DWT and Bayes Shrink wavelet thresholding.

VII. CONCLUSION

In this paper, the performance of various spatial domain linear and non linear filtering and wavelet transform based denoising method is analysed and simulated using MATLAB. This Comparative study and the simulation result for the test satellite images shows that wavelet transform outperforms the other standard spatial domain filters. Even though all the filtering approach performs well but they have some constraints regarding resolution degradation. The mean filter is performed well in applications when or where only a small portion of the image needs to be processed. The weiner filtering method requires the information about original image and the spectra of noise and also this method works well only if the image is smooth. This approach often produces better results than average filtering but it requires more computation time. The median filter produce output image that has no noise present in it and is close to the original input. Moreover, in the median filter, after denoising, the sharpness of the image is retained. The wavelet transform is best suited for the removal of the noise, especially gaussian noise because of its properties like multi resolution and multiscale nature.

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