International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Comparative Analysis of Various Image Denoising Techniques: A Review Paper

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Abstract: ***Removal of noise from the original signal is still a challenging issue for researchers. Image denoising is a applicable issue found in diverse image processing and computer vision problems. The important property of a good image denoising model is that it should completely remove noise as far as possible as well as preserve edges. There are various existing methods to denoise image. Each method has its own advantages, disadvantages and assumptions. This paper presents a review of some significant work in the field of Image Denoising. The brief introduction of some popular approaches is provided and discussed. Insights and potential future trends are also discussed.***

Keywords: Image Denoising, Wavelet transforms, Gaussian noise, Speckle noise, linear filters, Thresholdin

1. Introduction

In today's growing digital world, Digital Images play an important role in daily routine applications such as Magnetic Resonance Imaging, Satellite Television as well as in areas of research and technology including Geographical Information System. Noise is unwanted signal that interferes with the original image and degrades the visual quality of original image. The main sources of noise in digital images are imperfect instruments, problem with data acquisition process, interference natural phenomena, transmission and compression [1]. Image denoising is a procedure in digital image processing for the removal of noise, which may corrupt an image during its acquisition or transmission, while retaining its visual quality. Thus; image denoising is the necessary and foremost step for image analysis. So, it is necessary to depute some effective image denoising techniques to prevent this type of corruption from digital images.

Image Denoising has a fundamental problem in the field of image processing. This paper provides various techniques for noise removal and gives us also the insights into the methods to determine which method will provide the reliable and approximate estimate of original image given its degraded version [17].

One of the methods used to remove noise is the wavelet transform in digital image. A wavelet is a mathematical function useful in digital signal processing and image compression. The use of wavelets for these purposes is a recent development, although the theory is not new. The principles are similar to those of Fourier analysis. In signal processing; wavelets make it possible to recover weak signals from noise. This has proven useful especially in the processing of X-ray and magnetic-resonance images in medical applications. Images processed in this way can be "cleaned up" without blurring or muddling the details. Techniques based on thresholding of wavelet coefficients are gaining popularity for denoising data. The idea is to transform the data into the wavelet basis, where the large coefficients are mainly the signal and the smaller ones represent the noise.

Modelling of noise is dependent on several factors such as data capturing instruments, transmission media, and quantisation of image and discrete sources of radiation. Depending on the noise model, different algorithms can be used. In ultrasound images, speckle noise [2] is observed whereas in MRI images rician noise [3] is observed.

2. Introduction to Image Denoising Techniques

Image denoising is the fundamental problem in Image processing. Wavelet gives the excellent performance in field of image denoising because of its characteristics like sparsity and multiresolution structure. With the popularity of Wavelet Transform for the last two decades, several algorithms have been developed in wavelet domain. The focus was shifted to Wavelet domain from spatial and Fourier domain. Ever since the Donoho‟s wavelet based thresholding approach was published in 2003, there was surge in the image denoising papers being published.

Although his approach was not revolutionary, it did not require tracking and correlation of the wavelet maxima and minima across the different scales as proposed by Mallat [4].Thus there was renewed interest in wavelet approach since Donoho's [5] demonstrated a simple solution to difficult problem domain. Researchers published different approaches to compute the simulation parameters for wavelet coefficients. To achieve optimum threshold, data adaptive threshold [6] were introduced. Substantial improvements in perceptual quality could be obtained by translation invariant method based on thresholding of an Undecimated Wavelet transform [7].Much effort has been devoted to Bayesian denoising in wavelet domain. Gaussian scale mixtures and hidden markov models have also become popular and more research is continued to be published

3. Various Noise Models

Noise is present in image either in additive or multiplicative form [8].

1. Additive Noise Model
Noise signal that is additive in nature gets added to the original signal to produce a corrupted noisy signal and follows the following model:

w(x, y) = s(x,y) + n(x,y) ……….(1)

2. Multiplicative Noise Model
In this model, noise signal gets multiplied to the original signal. The multiplicative noise model follows the following rule:

w(x, y) = s(x,y) × n(x,y) ……………………….(2)

Where, s(x,y) is the original image intensity and n(x,y) denotes the noise introduced to produce the corrupted signal w(x,y) at (x,y) pixel location.

4. Types of Noise

Various types of noise have their own characteristics and are inherent in images in different ways.

1. Gaussian Noise
Gaussian noise [9] is evenly distributed over the signal. Each pixel in noisy image is the sum of true pixel value and a random gaussian distributed noise value. This noise has a probability density function [pdf] of the normal distribution. It is also known as Gaussian distribution. It is a major part of the read noise of an image sensor that is of the constant level of noise in the dark areas of the image [24].

2. Salt and Pepper Noise
The salt-and-pepper noise are also called shot noise, impulse noise or spike noise that is usually caused by faulty memory locations ,malfunctioning pixel elements in the camera sensors, or there can be timing errors in the process of digitization .In the salt and pepper noise there are only two possible values exists that is a and b and the probability of each is less than 0.2.If the numbers greater than this numbers the noise will swamp out image. For 8-bit image the typical value for 255 for salt-noise and pepper noise is 0 [29].

Reasons for Salt and Pepper Noise:
a. By memory cell failure.
b. By malfunctioning of camera's sensor cells.
c. By synchronization errors in image digitizing or transmission.

3. Speckle Noise
Speckle noise [10] [11] is multiplicative noise. This type of noise occurs in almost all coherent systems such as SAR images, Ultrasound images etc. The source of this noise is random interference between the coherent returns.

4. Amplifier Noise
The typical model of amplifier noise is additive, Gaussian, independent at each pixel and independent of the signal intensity. In color cameras, blue color channels are more amplified than red or green channel, therefore, more noise can be present in the blue channel. Amplifier noise is a major part of the "read noise" of an image sensor, that is, of the consistent noise level in dark areas of the image [12]. This type of noise has a Gaussian distribution, which has a bell shaped probability distribution function given by,

$$F(g)= \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(g-m)^2/2\sigma^2} \quad ..(3)$$

5. Various Denoising and Filtering Techniques

Various denoising techniques have been proposed so far and their application depends upon the type of image and noise present in the image. Image denoising is classified in three categories: Spatial Filtering, Transform Domain Filtering and Wavelet Thresholding Method. Objectives of any filtering approach are:

- To suppress the noise effectively in uniform regions.
- To preserve edges and other similar image characteristics.
- To provide a visually natural appearance [13].

5.1 Spatial domain filtering

This is the traditional way to remove the noise from the digital images to employ the spatial filters. Spatial domain filtering is further classified into linear filters and non-linear filters [14].

5.1.1 Linear Filters
A mean filter is the optimal linear for Gaussian noise in the sense of mean square error. Linear filters tend to blur sharp edges, destroy lines and other fine details of image. It includes Mean filter and Wiener filter [14].

a) Mean Filter
This filter acts on an image by smoothing it. It reduces the intensity variations between the adjacent pixels [15]. Mean filter is an averaging linear filter. Here the filter calculates the average value of the image with noise in a predefined area and the centre pixel intensity value is then changed by average value of pixels in the neighborhood. This process is repeated for all pixel values in the entire image.

b) Weiner Filter
Weiner filtering [16] method requires the information about the spectra of noise and original signal and it works well only if the underlying signal is smooth. Weiner method implements the spatial smoothing and its model complexity control corresponds to the choosing the window size. H(u, v) is the degradation function and H(u, v)* is its conjugate complex. G(u, v) is the degraded image. Functions Sf(u, v) and Sn(u, v) are power spectra of original image and the noise. Wiener Filter assumes noise and power spectra of object a priori.

$$f(u,v) = \left[\frac{H(u,v)^*}{H(u,v)^2 + \left[{Sn(u,v)}/{Sf(u,v)}\right]}\right] G(u,v) \quad \text{.....(4)}$$

5.1.2 Non- Linear

In recent years, a variety of non-linear median type filters such as rank conditioned, weighted median, relaxed median, rank selection have been developed to overcome the shortcoming of linear filter. With the non-linear filter, noise is removed without any attempts to explicitly identify it. Spatial filters employ a low pass filtering on the group of pixels with the assumption that noise occupies the higher region of frequency spectrum. Generally spatial filters remove the noise to reasonable extent but at the cost of blurring the images which in turn makes the edges in the picture invisible.

a) Median Filter

Median Filter Median filter is a best order static, non- linear filter, whose response is based on the positioning of pixel values on basis of rank contained under the filter region. Median filter yield good result for salt and pepper noise. These filters are basically smoothers for image processing, as well as in signal processing. The benefit of the median filter over linear filters is that the median filter can remove the effect of input noise values with huge magnitudes [30].

5.2 Transform domain filtering

The transform domain filtering can be divided according to choice of basic functions.

5.2.1 Spatial Frequency Filtering

Spatial frequency domain denoising method is a kind of Transform Domain, filtering where low pass filters (LPF.) is used by using Fast Fourier Transform (FFT).Here denoising is done by designing a cut-off frequency. The main disadvantage of Fast Fourier Transform (FFT) is the fact that the edge information is spread across frequencies because of FFT basis function and it is not being localized in time or space which means that time information is lost and hence low pass filtering results in smearing of the edges.But these methods are time consuming and may produced artificial frequencies in processed image[18].

5.2.2 Wavelet Domain Filtering

Working in Wavelet domain is preferred because the Discrete Wavelet Transform (DWT) make the signal energy concentrate in a small number of coefficients, hence, the DWT of the noisy image consists of a small number of coefficients having high Signal to Noise Ratio (SNR) while relatively large number of coefficients is having low SNR. After removing the coefficients with low SNR (i.e., noisy coefficients) the image is reconstructed by using inverse DWT. As a result, noise is removed or filtered from the observations [18]. A major advantage of Wavelet methods is that it provides time and frequency localization simultaneously. Moreover, wavelet methods characterize such signals much more efficiently than either the original domain or transforms with global basis elements such as the Fourier transform [19]

5.3 Wavelet Based Thresholding

Wavelet thresholding is a signal estimation technique that exploits the capabilities of Wavelet transform for signal denoising. It removes noise by killing coefficients that are irrelevant relative to some threshold that turns out to be simple and effective, depends heavily on the choice of a thresholding parameter and the choice of this threshold determines, to a great extent the efficiency of denoising. There are several studies on thresholding the Wavelet coefficients [20]. The process, commonly called Wavelet Shrinkage, consists of following main stages [21]:

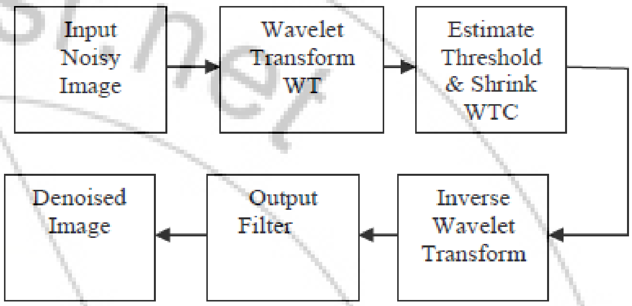

Figure 1: Block diagram of Image Denoising using Wavelet Transform

5.3.1 Thresholding Method

There are various thresholding techniques which are used for purpose of image denoising such as hard and soft thresholding. Hard thresholding which is based on keep and kill rule is more instinctively appealing and also it introduces artifacts in the recovered images [22] whereas soft thresholding is based on shrink and kill rule, as it shrinks the coefficients above the threshold in absolute value [23]. In practice, soft thresholding has been used over hard thresholding because it gives more visually pleasant image as compared to hard thresholding and reduces the abrupt sharp changes that occur in hard thresholding [24]. In MATLAB, by default, hard thresholding is used for compression and soft thresholding for denoising [25].

5.3.2 Threshold Selection Rules

In image denoising applications, the selection of threshold value should be such that Peak Signal to Noise Ratio (PSNR) is maximize [20]. Finding an optimal value for thresholding is not an easy task. A small threshold will pass all the noisy coefficients and hence the resultant images may still be noisy whereas a large threshold makes more number of coefficients to zero, which leads to smooth image and image processing may cause blur and artifacts, and hence the resultant images may lose some signal values [26]. Threshold selection is based on non adaptive threshold and adaptive threshold.

a) Non Adaptive Threshold

Visu Shrink is non adaptive universal threshold, which depends only on a number of data points. It is found to yield an overly smoothed estimate. It suggests a best performance in terms of mean square error (MSE), when number of pixels reaches infinity. Its threshold value is quite large due to its dependency on number of pixels in image [27]. The drawback is that it cannot remove the

Speckle noise. It can only deal with additive noise. Threshold T can be calculated using the formulae,

$$T = \sigma\sqrt{2logn^2} \quad \text{.......(5)}$$

where σ is the noise level and n is the length of the noisy signal [19].

b) Adaptive Threshold

There are two types of adaptive threshold i.e. Sure Shrink and Bayes Shrink. Sure Shrink derived from minimizing Stein's Unbiased Risk Estimator, an estimate of MSE risk. It is a combination of universal threshold and SURE threshold. It is used for suppression of noise by thresholding the empirical wavelet coefficient.. The goal of Sure Shrink is to minimize the mean square error. Sure shrink suppresses the noise by thresholding the empirical wavelet coefficient [21]. The Bayes Shrink method has been attracting attention recently as an algorithm for setting different thresholds for every subband. Here subbands are frequency bands that differ from each other in level and direction [28]. The purpose of this method is to estimate a threshold value that minimizes the Bayesian risk assuming Generalized Gaussian Distribution (GGD) prior.

6. Conclusion and Future Scope

In this paper, numerous amounts of Image Denoising Techniques are discussed. The selection of Denoising technique depends on what kind of denoising is required. Further, it depends on what kind of information is required.

The purpose of this paper is to present a survey of digital image denoising approaches. As images are very important in each and every field so, Image Denoising is an important pre-processing task before further processing of image like segmentation, feature extraction, texture analysis etc. The above survey shows the different type of noises that can corrupt the image and different type of filters which are used to improve the noisy image. The study of various denoising techniques for digital images shows that wavelet filters outperforms the other standard spatial domain filters. Spatial filters operate by smoothing over a fixed window and it produces artifacts around the object and sometimes causes over smoothing thus causing blurring of image. Therefore, Wavelet transform is best suited for performance because of its properties like sparsity, multiresolution and multiscale nature.

As the future perspective can be seen, the mentioned methods can be implemented that to look how it can be used on different images. With different spatial resolution, different behaviours of same image would be quite interesting.

Since selection of the right denoising procedure plays a major role, it is important to experiment and compare the methods. As future research, we would like to work further on the comparison of the denoising techniques. If the features of the denoised signal are fed into a neural network pattern recognizer, then the rate of successful classification should determine the ultimate measure by which to compare various denoising procedures.

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