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Image Denoising Techniques-An Overview

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ABSTRACT
Image denoising is a applicable issue found in diverse image processing and computer vision problems. There are various existing methods to denoise image. 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. This paper presents a review of some major work in area of image denoising. There have been numerous published algorithms and each approach has its assumptions, advantages and limitations. After brief introduction various methods have been explained for removing noise.

General Terms
Image Noise

Keywords
Denoising, Filters, Transform Domain, Wavelet Thresholding

1. INTRODUCTION
In an increasingly digital world, Digital Images play an important role in day to day applications such as Digital Cameras, Magnetic Resonance Imaging, Satellite Television as well as in areas of research and technology including Geographical Information System. Generally, data sets collected by image sensors are contaminated by noise. Imperfect instruments, problems with data acquisition process, and interfering natural phenomena can all corrupt the data of interest. Thus noise reduction is an important technology in Image Analysis and the first step to be taken before images are analyzed. . Therefore, Image Denoising techniques are necessary to prevent this type of corruption from digital images [1]. Noise can also be introduced by transmission errors and compression. Different noise sources like dark current noise introduced different types of noises.. Dark current noise usually present due to the thermally generated electrons at sensor sites. It is proportional to the exposure time and highly dependent on the sensor temperature. Shot noise which follows a Poisson distribution, is due to the quantum uncertainty in photoelectron generation. Amplifier noise and quantization noise arises when number of electrons converts into pixel intensities [2].This paper provides different methodologies for noise reduction. It also gives us the insights into the methods to conclude which method will provide the consistent and approximate estimate of original image from given its degraded version.

2. DEVELOPMENT OF RESEARCH IN IMAGE DENOISING
Image Denoising has remained a fundamental problem in the field of image processing. Due to properties like sparsity and multiresolution structure, Wavelet transform have become an attractive and efficient tool in image denoising. With Wavelet Transform gaining popularity in the last two decades various algorithms for denoising in Wavelet Domain were introduced. The focus was shifted from the Spatial and Fourier domain to the Wavelet Transform domain. Although Donoho's theory was not revolutionary, his methods did not need tracking or correlation of the wavelet maxima and minima across the different scales as proposed by Mallat [3]. Thus, there was a rehabilitated interest in Wavelet based denoising techniques since Donoho [4] demonstrated a simple approach to a difficult problem. Researchers published different ways to compute the parameters for the Wavelet thresholding. Data adaptive thresholds were introduced to attain optimum value of threshold [5]. Later efforts found that considerable improvements in perceptual quality could be obtained by changing invariant methods based on thresholding of an Undecimated Wavelet Transform [6]. These thresholding techniques were applied to the non orthogonal Wavelet coefficients to reduce artifacts. Multiwavelets were also used to get similar results. Probabilistic models using the statistical properties of the wavelet coefficient seemed to outperform the thresholding techniques and gained ground. Recently, much effort has been devoted to Bayesian denoising in Wavelet domain, Hidden Markov Models and Gaussian Scale. Data adaptive transforms such as Independent Component Analysis (ICA) have been explored for sparse reduction. The development continues to focus on using different statistical models to model the statistical properties of the wavelet coefficients and its neighbours [7].

3. NOISE MODELS
Noise is present in image either in additive or multiplicative form.

3.1 Additive Noise Model
Noise signal that is additive in nature gets added to the original signal to generate a corrupted noisy signal and follows the following rule:

$$w(x, y) = s(x,y) + n(x,y) \qquad \text{...........(1)}$$

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 .

3.2 Multiplicative Noise Model
In this model, noise signal gets multiplied to the original signal. The multiplicative noise model follows [8] the following rule:

$$w(x, y) = s(x, y) \times n(x,y) \qquad \text{..........(2)}$$

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

4.1 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 [9]. This type of noise has a Gaussian distribution, which has a bell shaped probability distribution function given by,

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

where g represents the gray level, m is the mean or average of the function and σ is the standard deviation of the noise. Graphically it is [10] represented as,

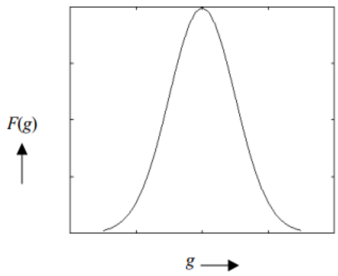

Figure1. Gaussian Distribution

4.2 Impulsive Noise

Impulsive noise is sometimes called as salt-and- pepper noise or spike noise. This kind of noise is usually seen on images. It represents itself as arbitrarily occurring white and black pixels. An image that contains impulsive noise will have dark pixels in bright regions and bright pixels in dark regions. It can be caused by dead pixels, analog-to-digital converter errors and transmitted bit errors.

4.2.1 Detection of Impulsive Noise

The noise affecting the image is stated to be an impulsive noise, if the ratio of the mean of the dynamics of the grey levels of the homogeneous regions to the maximum value of the dynamics of the grey levels of the homogeneous regions is greater than a threshold value then [11].

$$(\text{mean}(D(n))/\max(D(n)))>\lambda \quad \text{……….. (4)}$$

4.3 Speckle Noise

Speckle noise is considered as multiplicative noise. It is a granular noise that degrades the quality of images obtained by active image devices such as active radar and synthetic aperture radar (SAR) images. Due to random fluctuations in the return signal from an object in conventional radar that is not big as single image-processing element, speckle noise occurs. It increases the mean grey level of a local area. Speckle noise makes image interpretation difficult in SAR images caused mainly due to coherent processing of backscattered signals from multiple distributed targets [9]. Speckle noise follows a gamma distribution and is given [10] as:

$$F(g)=\frac{g^{\alpha-1}}{(\alpha-1)!\alpha^{\alpha}}e^{\frac{-g}{\alpha}} \quad \text{……… (5)}$$

Where variance is σ^2 and g is the gray level. The gamma distribution is given below:

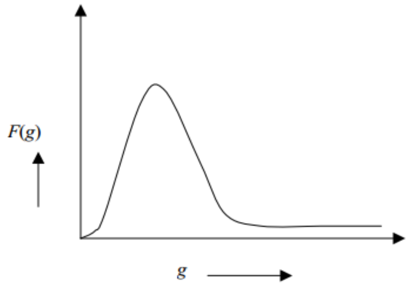

Figure2. Gamma Distribution

5. CLASSIFICATION OF DENOISING ALGORITHM

There are three basic approaches to image denoising – 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 [12].

5.1 Spatial Filtering

Spatial filtering is the method of choice in situations when only additive noise is present. It can be further classified into 2 categories: Linear filters and Non Linear Filters

5.1.1 Linear Filters

It is the method of choice in situations when only additive noise is present [13]. A mean filter is the optimal linear for Gaussian noise in the sense of mean square error. It blurs sharp edges, destroy lines and other fine details of image. It includes Mean filter and Wiener filter**.**

5.1.1.1 Mean filter

This filter provides smoothness in an image by reducing the intensity variations between the adjacent pixels. [8]. Mean filter is essentially an averaging filter. It applies mask over each pixel in the signal. Therefore, to make a single pixel, each of components of pixel which falls under mask are average filter. The main disadvantage is that edge preserving criteria is poor in Mean filter [9].

5.1.1.2 Wiener Filter

It is a filter that takes statistically approach to filter out noise that has corrupted a signal. Desired frequency response can be acquired using this filter. The Wiener filter approaches filtering from a different angle. For performing filtering operation it is essential to have knowledge of the spectral properties of the original signal and the noise, in achieving the criteria one can get the LTI filter whose output will be as close as original signal as possibl**e** [14].

5.1.2 Non Linear Filters

It is the method of choice in situations when multiplicative and function based noise is present [13].With non-linear filters, the noise can be removed without identifying it exclusively. In this case, the median of the neighborhood pixels determine the value of an output pixel [15]. Spatial filters make use of a low pass filtering on groups of pixels with the statement that the noise occupies the higher region of frequency spectrum. Normally, spatial filters eliminate noise to a reasonable extent but at the cost of blurring images which in turn makes the edges in pictures invisible.

5.1.2.1 Median Filter

Median filter belongs to the class of non linear filter. Median filtering is done by, firstly finding the median value by across the window, and then replacing each entry in the window with the pixel's median value [14]. If the window has an odd number of entries, then the median is simple to define: it is just the middle value after all the entries in the window are sorted numerically. But, for an even number of entries, there is more than one possible median. It is a robust filter. Median filters used for providing smoothness in image processing and time series processing [9]. The advantage of using median filtering is that it is much less sensitive than the mean to extreme values (called outliers). Therefore, it is able to remove these outliers without reducing the sharpness of image.

5.2 Transform Domain Filtering

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

5.2.1 Spatial Frequency Filtering

It refers the use of low pass filters using fast Fourier Transform. The noise is removed by deciding a cut-off frequency and adapting a frequency domain filter when the components of noise are decorrelated from useful signal [1]. 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 the localized nature of Wavelet Transform both in time and space provides a particularly useful method for image denoising when the preservation of edges in the scene is of importance [16].

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 [16]. 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 [17].

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 [18]. The process, commonly called Wavelet Shrinkage, consists of following main stages [19]:

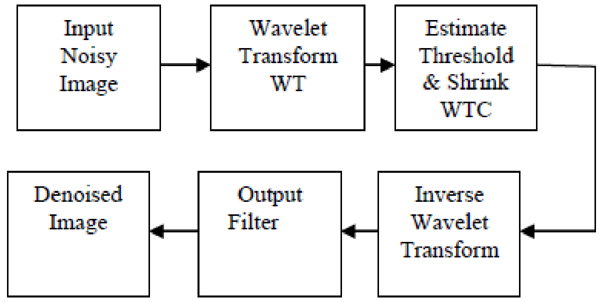

Figure3. Block diagram of Image denoising using Wavelet Transform

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 [20] whereas soft thresholding is based on shrink and kill rule, as it shrinks the coefficients above the threshold in absolute value [21]. 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 [22]. In MATLAB, by default, hard thresholding is used for compression and soft thresholding for denoising [23].

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 [18]. 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 [24]. Threshold selection is based on non adaptive threshold and adaptive threshold.

5.3.2.1 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 [25]. 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,

$$T = \sigma\sqrt{2logn^2} \quad \text{……… (6)}$$

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

5.3.2.2 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 [19]. 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 [26]. The purpose of this method is to estimate a threshold value that minimizes the Bayesian risk assuming Generalized Gaussian Distribution (GGD) prior.

6. CONCLUSION

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.

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