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Review of Different Techniques for Image Denoising

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ABSTRACT: In this paper, different techniques of image denoising that deal with removing or reducing different types of noise from a distorted image, are reviewed. Nowadays, the tendency is to speeding-up the applied algorithms to overcome the processing delay of the classical iterative methods (having 50 to 100 iterations or even more). This is apparent when dealing with high levels of noise. Since it is necessary to have idea about the noise present in the image to select the appropriate denoising algorithm, this paper state first a brief description of noise and its different types including Gaussian, salt and pepper and speckle noise. Image denoising techniques are then presented, namely; classical techniques (such as mean, order and adaptive filters) and transform-based techniques (such as wavelet and contourlet transforms).

KEYWORDS: image restoration; classical filters; Gaussian noise; impulse noise, salt and pepper noise, speckle noise, mean filters, order filters, adaptive filters, wavelet transform, contourlet transforms.

I. INTRODUCTION

The large proliferation of digital cameras and the widespread use of the Internet have produced a huge number of digital images that were generally taken by different unknown imaging devices under undefined lighting conditions, which made balancing and restoring the properties of the real scene necessary. The quality of these images is often improved by the digital processing of the image. The most important treatment methods are image denoising of noisy images. Denoising is more significant than any other tasks in image processing [1]. Reserving the details of an image and removing the random noise as far as possible is the goal of image denoising approaches. Noise removal is essential in digital imaging applications in order to enhance and recover fine details that are hidden in the data. In many occasions, noise in digital images is found to be additive in nature with uniform power in the whole bandwidth and with Gaussian probability distribution. Such a noise is referred to as Additive White Gaussian Noise (AWGN). It is difficult to Suppress AWGN since it corrupts almost all pixels in an image. In denoising there is always a trade off between noise suppression and preserving actual image discontinuities. To remove noise without excessive smoothing of important details, a denoising technique needs to be spatially adaptive [2].And there is another type of noise called Speckle noise which is considered multiplicative noise and it is one of the most complex abnormalities that appear in the Synthetic Aperture Radar Sensors (SAR), Ultrasonic systems and laser systems. There is many techniques are used to restore or denoise image like classical filters, discrete wavelet transform and contourlet transform. Hence, it is necessary to have knowledge about the noise present in the image so as to select the appropriate denoising algorithm.

The paper is organized as follows: Section II contains RELATED WORK. Section III includes the Types of Noise and review of the different image denoising techniques. Finally, section IV concludes this paper.

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II. RELATED WORK

There has been a significant amount of work done on the field of image denoising techniques. Some techniques are able to produce good results in many practical scenarios. A traditional way to remove noise from image data is to employ spatial filters. A spatial filter is used to clean up the output of lasers, removing aberrations in the beam due to imperfect, dirty or damaged optics. Spatial filters can be further classified into non-linear and linear filters. Linear filters process time-varying input signals to produce output signals, subject to constraint of linearity. A mean filter is the optimal linear filter for Gaussian noise. In spite of their filtering responses, linear filters tend to blur sharp edges, destroy lines and other fine image details, and perform poorly in the presence of signal-dependent noise [3].The wiener filter requires the information about the spectra of the noise with the original signal and it works well only if the underlying signal is smooth [4]. Non-linear filters have many applications, especially in removing certain types of noise that are not additive, but at the cost of blurring of images and producing images with bad edges. There is a variety of nonlinear median type of filters are developed to overcome these defects [5]. In addition, to overcome the weakness of filters, Donoho and Johnstone proposed the wavelet based denoising techniques. Wavelets are mathematical functions that analyze data according to scale or resolution and they aims in studying a signal in different windows or at different resolutions. In that sense, if the signal is viewed in a large window, gross features can be noticed. but if it is viewed in a small window, only small features can be noticed. It should be noted that Wavelets can provide some advantages over Fourier transforms. For example, they do a good job in approximating signals with sharp spikes or signals having discontinuities. The wavelet equation produces different wavelet families like Daubechies, Haar, Coiflets, etc [6]. The wavelet-based techniques are fast, but they cannot recognize the curvature edges well, so another transform which can deal with complex image edges is recently presented. That is the contourlet transform which was proposed by Do and Vetterli in 2002, as a two-dimensional transform method for image representations. The contourlet transform has properties of multiresolution, localization, directionality, critical sampling and anisotropy. Therefore the contourlet transform is capable of capturing contours and finding details in images with few coefficients [7].

III. TYPES OF NOISE AND IMAGE DENOISING TECHNIQUES

The different types of Noise and denoising techniques are as follows:

Types Of Noise

Noise is any unwanted information produced in the image during image acquisition or transmission therefore they are two types of noise additive noise and multiplicative noise. We will talk about them in details and generally our focus is to remove certain type of noise (Additive Noise) [8].So we will apply different algorithms to remove this kind of noise.

a) Gaussian Noise

Gaussian noise is evenly distributed over the signal. This means that each pixel in the noisy image is the sum of the true pixel value and a random Gaussian distributed noise value. As the name indicates, this type of noise has a Gaussian distribution [8], which has a bell shaped probability distribution function given by eq. (1).

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

Graphically, it is represented as shown in Fig.1.

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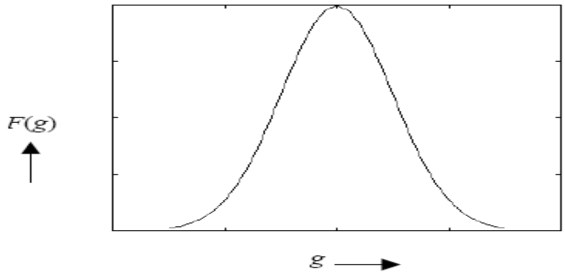

Fig.1 Gaussian noise

Where g represents the gray level, m is the mean or average of the function; σ is the standard deviation of the noise and σ^2 is the variance of noise.

b) Salt and pepper noise

Salt and pepper noise is an impulse type of noise, which is also referred to as intensity spikes. This is caused generally due to errors in data transmission. It has only two possible values, a and b. The probability of each is typically less than 0.1. The corrupted pixels are set alternatively to the minimum or to the maximum value, giving the image a "salt and pepper" like appearance .Unaffected pixels remain unchanged. For an 8-bit image, the typical value for pepper noise is 0 and for salt Noise 255. The salt and pepper noise is generally caused by malfunctioning of pixel elements in the camera sensors, faulty memory locations, or timing errors in the digitization process [9]. The probability density function for this type of noise is shown in Fig.2.

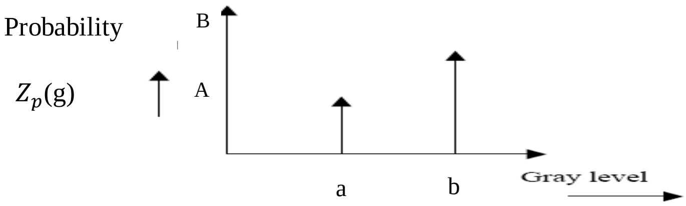

Fig. 2 Salt and Pepper noise

Where the probability density function Z_p (g) represent by two values

$$Z_p(g) = \begin{cases} A & \text{for } g = a \text{ ("pepper")} \\ B & \text{for } g = b \text{ ("salt")} \end{cases}$$

c) Speckle Noise

Speckle noise is a multiplicative noise. This type of noise occurs in almost all coherent imaging systems such as laser, acoustics and SAR (Synthetic Aperture Radar) imagery .The source of this noise is attributed to random interference between the coherent returns. Fully developed speckle noise has the characteristic of multiplicative noise [10]. Speckle noise follows a gamma distribution as shown in Fig.3 and is given in eq. (2).

$$F(g) = \frac{g^{\alpha-1}}{(\alpha-1)!\,a^{\alpha} e^{-g/a}} \qquad \text{eq. (2)}$$

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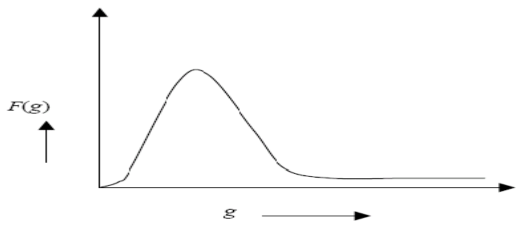

Fig.3 Speckle Noise distribution

Where g represents the gray level and a^{α} represents the standard deviation of speckle noise.

Image Denoising Techniques

There are different techniques to denoise or restore the noisy image, the best method which remove or reduce the noise from the image with preserving the details of image as possible. In this paper we will speak and compare between classical method and modern method like Wavelet transform and contourlet transform.

A) Denoising the image by filters

Noise is present in an image either in an additive or multiplicative form [10].

An additive noise follows the rule in eq. (3)

$w(x, y)=s(x, y)+n(x, y)$ eq.(3)

While the multiplicative noise satisfies as shown in eq. (4)

$w(x, y)=s(x, y)\times n(x, y)$ eq.(4)

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

- ***Mean filters***

Mean filters (or averaging filters) function by finding some form of an average within the NXN window , using the sliding window concept to process the entire image . Mean filters are linear filters because that the convolution mask operation provides a result that is a weighted sum for the pixel and its neighbourhoods .Mean filter work best with Gaussian noise, but there are side effect, these filter are blurring the image edges. The mean filters have the disadvantage of blurring the image edges or details [10].

1. Arithmetic Mean Filter

The most basic mean filter are the arithmetic mean filter. Which find the arithmetic average of the pixels values in the window depending on the convolution concept, where we use weighted convolution mask with different sizes like 3*3 using the sliding window over the matrix that represent the image and replace the centred value with the correct value according to the result of arithmetic mean filter equation [11].

2 .Geometric Mean Filter

The Geometric Mean Filter works best with Gaussian noise and retains detail information better than an arithmetic mean filter. But this filter is ineffective in the presence of pepper noise [11].

- ***Order Filters***

There are three types of this filter that arrange the data then do arithmetic operation on it.

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1. Median Filter

Median Filter uses windows of size 3*3, 5*5, 7*7 to select middle pixel value from the ordered set. it is done by , first sorting all the pixel values from the lowest to largest pixel value , then replace the pixel being considered with the middle pixel value, note that the median value must be written to separate array or buffer so that the result are not corrupted as the process is found by weighted sum of the pixels and its neighbourhoods, this filter can be used for removing or elimination of salt and pepper noise, that mean this filter work very good with this type of noise[12].

2. maximum and minimum filter

The maximum and minimum filter are two filters that can be used for elimination of salt and pepper noise, where the maximum filter selects the biggest value within an ordered window of pixel values, whereas the minimum filter selects the smallest value. The minimum filter used for remove salt type noise, whereas the maximum filter works best for pepper type noise [13].

3. Midpoint filter

The midpoint filter is the average of the maximum and minimum within the window and works best with Gaussian noise [13].

- ***Adaptive filter***

Adaptive filters are capable of denoising non-stationary images, that is, images that have abrupt changes in intensity. Such filters are known for their ability for alters its basic behaviour as the image is processed, it may act like a mean filter on some parts of the image and a median filter on other parts of the image. Such filter is known for its ability in automatically tracking an unknown circumstance or when a signal is variable with little a priori knowledge about the signal to be processed [14]. An adaptive filter iteratively adjusts its parameters during the scanning of the image to match the image generating mechanism. This mechanism is more significant in practical images, which tend to be non –stationary. One of the important adaptive filters is Wiener filter ,this filter works better with Gaussian noise only, and its linear filter [15]. It estimates the local mean and variance around each pixel as shown in the following eq. (5).

$$\text{Wiener Filter} = m + \frac{\sigma_l^2 - \sigma_n^2}{\sigma_l^2} \left(f(r,c) - m\right) \qquad \text{eq.(5)}$$

Where σ_n^2 is the noise variance, m and σ_l^2 is the local mean and variance around each pixel and they are defined as follows eq. (6) and eq.(7)

$$m = \frac{1}{N^2} \sum_{(r,c)\in w} f(r,c) \qquad \text{eq. (6)}$$

$$\sigma_l^2 = \frac{1}{N^2} \sum_{(r,c)\in w} f^2 - m^2 \qquad \text{eq. (7)}$$

B) Denoising The Image By Transforms

1. Wavelet Transform

Last years, many constructions of wavelets have been introduced in both the mathematical analysis and in signal processing literature. In mathematical analysis, wavelets were originally constructed to analyze and represent geophysical signals using translates and dilates of one fixed function. In signal processing, wavelets originated in the context of sub band coding, or more precisely, quadrature mirror filters. The connection between the two approaches was made by the introduction of multiresolution analysis and the fast wavelet transform by Mallat and Meyer. A major breakthrough was the construction by Daubechies of orthogonal [16].The procedure for noise reduction is applied on the wavelet coefficients achieved using the wavelet decomposition and representing the image at different scales. After noise reduction, the image is reconstructed using the inverse wavelet transform. Decomposition and reconstruction are accomplished using two banks of filters constrained by a perfect reconstruction condition. The threshold selection for this denoising technique is application dependent. The transformed signal is a function of two variable the translation

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and scale parameter. It is convenient to view the decomposition as passing a signal Cj,k through a pair of filters Hand G with impulse response h(n) and g(n) and down sampling the filtered signals by two [17].Where h(n) and g(n) are defined as shown in eq.(8).

$$h(n) = h(-n)\ ,\ g(n) = g(-n) \qquad \text{eq.(8)}$$

The pair of filters H and G corresponds to the half band low pass and high pass filters, respectively, and is called the quadrature mirror filters in the signal processing it is shown in Fig.(4).

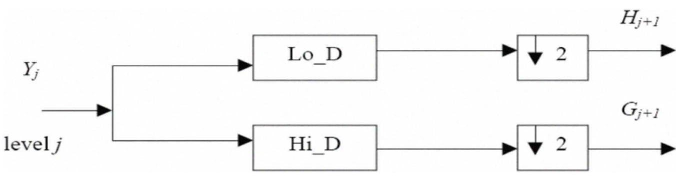
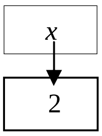


Fig.4 Quadrature mirror filters in the signal processing

Where 

convolve with filter *x and*

And down sampling

Fig.4 represents one-dimensional wavelet transforms and its basis functions.

The selection of a threshold is an important point of interest. It plays a major role in the removal of noise in images because denoising most frequently produces smoothed images, reducing the sharpness of the image. Care should be taken so as to preserve the edges of the denoised image. There are three types of threshold: Sure shrink,visu shrink and bayes shrink.

2. Contourlet Transform

Recently, there has been a growing awareness to the observation that wavelets may not be the best choice for representing natural images. This observation is due to the fact that wavelets are blind to the smoothness along the edges commonly found in images. Hence, recently, some new transforms have been introduced to take advantage of this property [18]. The contourlet transform is example of new transform, which is developed to sparsely represent natural image. The contourlet transform which was proposed by Do and Vetterli in 2002, is a new two-dimensional transform method for image representations. The contourlet transform has properties of multiresolution, localization, directionality, critical sampling and anisotropy. Its basic functions are multiscale and multidimensional. The contours of original images, which are the dominant features in natural images, can be captured effectively with a few coefficients by using contourlet transform. To see how one can improve the 2-D separable wavelet transform for representing images with smooth contours, consider the following scenario. Imagine that there are two painters, one with a "wavelet" -style and the other with a contourlet style, both wishing to paint a natural scene as shown in Fig.5.

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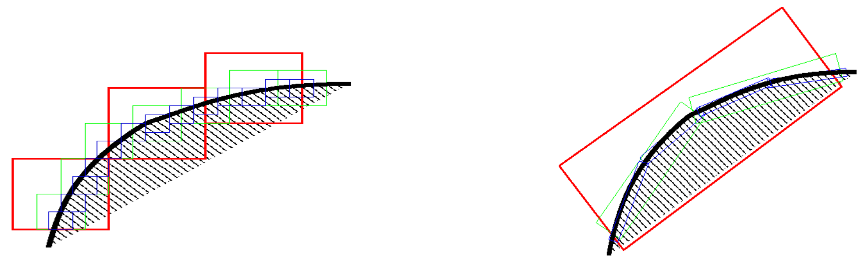

Fig.5 Two painters, one with a "wavelet" -style and the other with a contourlet style

The contourlet transform consists of two major stages: the sub band decomposition and the directional transform as shown in Fig.6. Where at the first stage, we used Laplacian pyramid (LP), and for the second one we used directional filter banks (DFB).

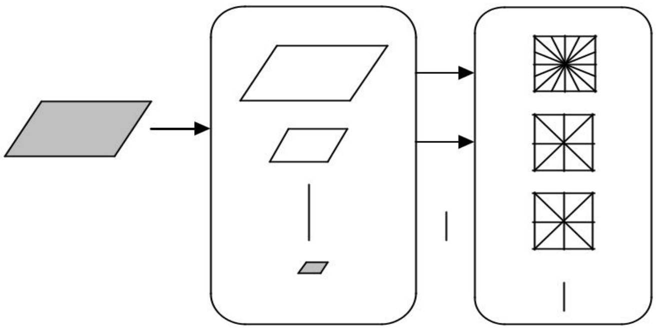

Fig.6 A flow graph of the contourlet transforms. The image is first decomposed into Sub bands by the Laplacian Pyramid and then each detail image is analysed by the directional filter bank.

The Laplacian pyramid (LP) decomposition only produce one band pass image in a multidimensional signal processing, that can avoid frequency scrambling. And directional filter bank (DFB) is only fit for high frequency since it will leak the low frequency of signals in its directional sub bands. This is the reason to combine DFB with LP, which is multi-scale decomposition and remove the low frequency. Therefore, image signals pass through LP sub bands to get band pass signals and pass those signals through DFB to capture the directional information of image. This double filter bank structure of combination of LP and DFB is also called as pyramid directional filter bank (PDFB), and this transform is approximate the original image by using basic contour, so it is also called discrete contourlet transform [19].

IV. CONCLUSION

In this paper different classical denoising techniques have been discussed. In order to get rid of the slow speed of such techniques, modern techniques such as wavelet-based and contourlet-based have been also reviewed. Modern techniques can outperform classical methods by their speed. The wavelet-based techniques are fast, but they cannot recognize the curvature edges well, so another transform which can deal with complex image edges have been discussed. It has been notice that the appropriate technology for denoising purpose is the contourlet-base technique

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which is fast as well as it is able to recognize edges well, since the contourlet transform is a directional transform, which is capable of capturing contours and fined details in images.

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