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A Review on Image Denoising Techniques

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Abstract — *In the modern age, visual information transmitted in the form of digital images is becoming a major method of communication, but during transmission the images often gets corrupted with noise. The exploration for efficient image denoising methods still remains a valid challenge for researchers. Despite the complexity of the recently proposed methods, most of the algorithms have not yet attained a pleasing level of applicability; each algorithm has its assumptions, advantages, and limitations. This paper presents a review of some noteworthy work in the area of image denoising. Behind a brief introduction, some of the popular approaches are categorized into different sets and an overview of different algorithms and analysis is presented here. Potential future work in the area of image denoising is also discussed.*

Keywords: *Wavelet Transform Linear and Non-linear filtering, Spatial Domain, Transform Domain.*

I. Introduction

Digital images play a very important part both in applications such as television magnetic resonance imaging computer tomography as well as in field of science and technology such as geographical information system and astronomy. Sets of data collected by image sensors and other devices are generally contaminated by noise .Also noise can introduced due to transmission errors and compression. Hence denoising is often a necessary and first step to be performed before image data is analyzed and processed. An efficient denoising technique must be applied to compensate for such data corruption. Noise is generally modeled as Gaussian noise (Normal), Uniform noise and Impulse noise (salt and pepper noise) as in [4], [7]. The impulse noise is of two types, Fixed valued and random valued. The fixed valued impulse noise is also known as salt and pepper noise which can have value either 0 or 255. Here 0 represent complete black and 255 represent complete white on gray scale image. The random valued impulse noise can have any value between 0 and 255; hence its removal is very important and difficult. Image de-noising is an important pre-processing step for image analysis.It refers to the task of recovering a good estimate of the true image from a degraded observation without altering and changing useful structure in the image such as discontinuities and edges. Image denoising still remains an important challenge for researchers because denoising process removes noise but introduces artifacts and also causes blurring. In this paper different techniques for image noise reduction are discussed. This paper also gives insight about which algorithm should be used to obtain the most reliable estimate of original image from its degraded version as in [10]

This paper is organized as follows. In section II noise model for different types of noise is defined. Section III gives the brief idea about the evolution of image denoising techniques. Section IV gives the classification of various image denoising methods. Finally, section V gives the conclusions of the work.

II. Noise Models

Impulse noise 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. Hence unlike Gaussian noise, for an impulse noise corrupted image all the image pixels are not noisy, a number of image pixels will be noisy and the rest of pixels will be noise free. 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 (gray level - 0) and it appears as black and white spots on the images. If p is the total noise density then salt noise and pepper noise will have a noise density of p/2.This can be mathematically represented in eq. (1).

$$\mathrm{y_{ij}} = \begin{cases} 0 \text{ or } 255 & \text{with probability p} \\ \mathrm{x_{ij}} & \text{with probability } 1-\mathrm{p} \end{cases} \quad (1)$$

Where y_{ij} represents the noisy image pixel, p is the total noise density of impulse noise and x_{ij} is the uncorrupted image pixel. At times the salt noise and pepper noise may have different noise densities p_1 and p_2 thus the total noise density will be p=.$p_i + p_2$

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.

We can mathematically represent random valued impulse noise as in (2).

$$y_{ij} = \begin{cases} n_{ij} & \text{with probability } p \\ x_{ij} & \text{with probability } 1-p \end{cases} \quad (2)$$

Where n_{ij} is the gray level value of the noisy pixel.

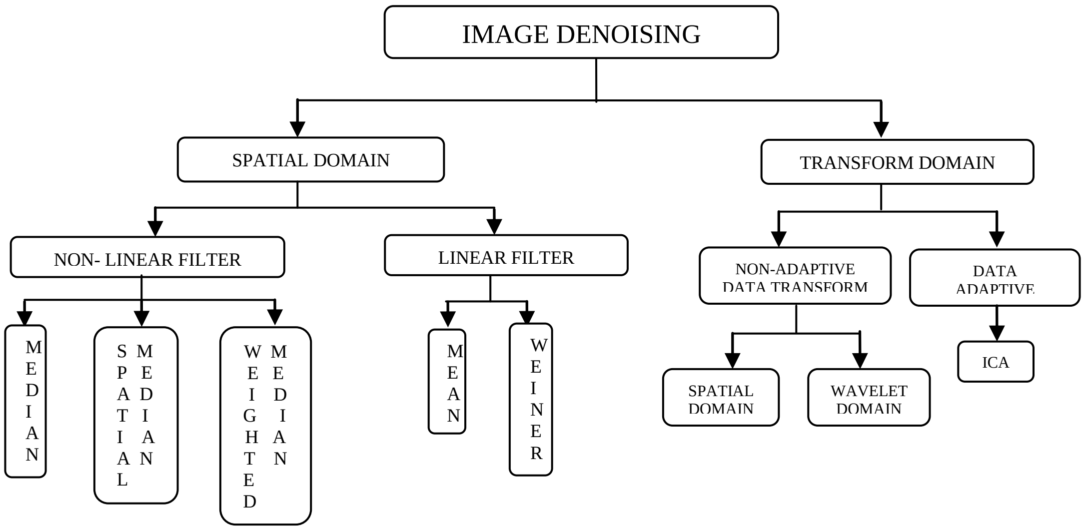
III. Evolution of image denoising techniques

Basic problem in image processing is to suppress the noise in corrupted image. Firstly a spatial domain approach has been adopted. One of the biggest advantage of this filter domain approach is a speed but a disadvantage is that this method was unable to preserve edges, which are identified as discontinuities in the image, On the other hand wavelet domain approach having a great advantage of preserving edges .Hence with wavelet domain gaining popularity various algorithm for denoising in wavelet domain were introduced Later on it was found that considerable improvements in perceptual quality could be attained by translation invariant algorithms based on thresholding of an Undecimated Wavelet Transform. Multiwavelets were also employed to acquire similar results. To reduce the artifacts these thresholding methods were applied to the non orthogonal wavelet coefficients as in [13].

IV. Classification of Image Denoising Methods

There are two fundamental approaches to image denoising, spatial filtering methods and transform domain filtering methods.

Figure: 1 Classification of Image Denoising Method



4.1 Spatial Filtering

It is a traditional method to remove noise from image where spatial filters are used. Spatial filters are further classified as non-linear and linear filters.

4.1.1 Non-Linear Filters

Spatial filters employ a low pass filtering on groups of pixels with an assumption that noise occupies the higher frequency region of the spectrum. Generally spatial filters eliminate noise to a considerable extent but at the cost of blurring images which in turn makes the edges in pictures invisible. In the recent year's variety of non linear filters have been developed. The simplest nonlinear filter is the median filter as in [11].

A) Median Filter

Median filter is one of the most important filters to remove random valued impulse noise. It comes under the category of non linear filters. In this filter the value of corrupted pixel in noisy image is replaced by median value of corresponding window. Median value is the value in the middle position of any sorted sequence as in [2]. Consider that the pixel values in neighbor-hood are taken into a sequence $x_1, x_2, x_3, \cdots, x_n$ and it becomes $x_{i1} \geq x_{i2} \geq x_{i3 \ldots\ldots\ldots} \geq x_{in}$ after sorting in descending order or $x_{i1} \leq x_{i2} \leq x_{i3 \ldots\ldots} \leq x_{in}$ in ascending order

(3)

$$x_{madian} = Med\{x_i\}$$

$$= \begin{cases} x_{i\frac{(n+1)}{2}} & .n \text{ is odd} \\ \frac{1}{2}\left[x_{i\left(\frac{n}{2}\right)} + x_{i\left(\frac{n}{2}\right)+1}\right] & ,n \text{ is even} \end{cases} \quad (4)$$

(B) Spatial Median Filter (SMF)

The spatial median filter is also noise removal filter where the spatial median is calculated by calculating the spatial depth between a point and a set of point. This spatial depth is defined by

$$S_{depth} = 1 - \frac{1}{N-1}\left\|\sum_{i=1}^{N} \frac{X - x_i}{\|X - x_i\|}\right\| \quad (5)$$

In this filter after finding out the spatial depth of each point lying within the filtering mask, this information is used to decide whether the central pixel of window is corrupted or not, If central pixel is uncorrupted then it will not be changed. We then find out the spatial depth of each pixel within the mask and then sort these spatial depths in descending order .The point with largest spatial depth represent the spatial median of the set. If central pixel is corrupted with noise then it is replaced by calculated spatial median as in [3].

(C) Weighted Median Filter (WMF)

The centre weighted median filter is an extension of the weighted median filter. The weighted median filter previously designed gives more weight to some values within the window whereas centre weighted median filter gives more weight to the central value of a window thus easier to design and implement than other weighted median filter.

4.1.2 Linear Filters

Linear filters also known as average filter are generally of two types: mean filter and wiener filter Linear filters too tend to blur sharp edges, destroy lines and other fine image information, and execute poorly in the presence of signal-dependent noise.

(A) Mean Filter

Mean filter is a simple sliding window spatial filter that replaces the centre value of the window with the average values of its all nearest pixels values together with itself. It is implemented with the convolution mask, which provides the outcome that is weighted sum of vales of a pixel and its neighbours. It is also called linear filter. The kernel is square. Often 3×3 mask is use.

(B) Weiner Filter

Weiner filtering process requires the information on the spectra of noise and original signal and it mechanism perform well only if the underlying signal is smooth. To overcome the weakness of spatial Domain filtering Donoho and Johnstone proposed wavelet based denoising schemes.

4.2 Transform Domain

Classification of Transform domain filtering approach depends upon choice of basis function. The basis functions can be further classified as Non-data adaptive and data adaptive. Primarily we will discuss Non-data adaptive transforms because they are more popular as in [6].

4.2.1 Non-Data Adaptive Transform

(A) 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. But these methods are time consuming and may produced artificial frequencies in processed image.

(B) Wavelet Domain

Wavelet Domain process is again subdivided into two distinct techniques i.e. linear and non-linear techniques:

(i)Linear Filters

Generally used linear filter in this category is Wiener filter. Wiener filter yield most advantageous outcomes in the wavelet domain. Wiener filtering is used where data corruption can be modeled as a Gaussian process and accuracy criterion is mean square error. But wiener filtering results in filtered image which is visually more displeasing than original noisy image

(ii) Non-Linear Threshold Filtering

Non-Linear threshold filtering is the most investigated domain in denoising using wavelet transform. It basically uses the property of wavelet transform and the fact that wavelet transform maps noise in signal domain to that of noise in transform domain. Thus while signal energy becomes more concentrated into fewer coefficients in transform domain noise energy does not. The method where small coefficients are removed leaving other coefficients untouched is known as Hard Thresholding. However this method produces spurious blips known as artifacts. To overcome these demerits soft thresholding was introduced where coefficients above the threshold are shrunk by the absolute value of threshold itself.

- **Non-Adaptive Thresholds**
  Non-Adaptive thresholds generally used are VISUShrink. When the number of pixels reaches infinity it shows best performance in terms of MSE. VISU Shrink generally yields smoothed images.
- **Adaptive Thresholds**
  Adaptive Threshold technique involves SURE Shrink, VisuShrink and Bayes Shrink methods. The Performance of SURE Shrink improved in comparison to the VISU Shrink because SURE Shrink uses a mixture of the universal threshold and the SURE [Stein's Unbiased Risk Estimator] threshold. When noise levels are higher than signal magnitudes the assumption that one candistinguish noise from the signal solely based on coefficient magnitudes is violated. Bayes-Shrink outperforms SURE-Shrink most of the times. Bayes-Shrink minimizes the Bayes' Risk Estimator purpose assuming Generalized Gaussian prior and thus yielding data adaptive threshold

(iii) Non-Orthogonal Wavelet Transform

Non-orthogonal Wavelet Transforms involves Shift Invariant Wavelet Packet Decomposition (SIWPD) where numbers of basic functions are obtained. Then by using Minimum Description length principle the best basis function is found out which yield smallest code length for given data .Then thresholding was applied to denoise the data. In addition to this Multiwavelets is explored which further increases the performance but also increases the computational complexity as in [7].

(iv) Wavelet Coefficient Model

This method utilizes the multi resolution properties of Wavelet Transform. The modeling of the wavelet coefficients can either be deterministic or statistical. This approach produces excellent output but computationally much more complex and costly as in [10].

- **Deterministic**
  The Deterministic method of modeling involves forming tree structure of wavelet coefficients. Here every level in the tree representing each scale of transformation and every nodes representing wavelet coefficients
- **Statistical Modeling of Wavelet Coefficients**
  This approach focuses on some more interesting and appealing properties of the Wavelet Transform such as multiscale correlation between the wavelet coefficients, local correlation between neighborhood coefficients etc. The following two methods explain the statistical properties of the wavelet coefficients based on a probabilistic model.
- **Marginal Probabilistic Model**
  The generally used Marginal probabilistic models under this category are Gaussian mixture model (GMM) and the Generalized Gaussian distribution (GGD).GMM is simple to use but GGD is more accurate.
- **Joint Probabilistic Model**
  Here Hidden Markov Models (HMM) and Random Markov Field Models are generally used. The disadvantage of HMM is the computational burden of the training stage hence a simplified HMM was proposed.

4.2.2 Data-Adaptive Transforms

Independent component analysis (ICA) transformation methods recently gain more importance include key component analysis, factor analysis, and projection detection. ICA most extensively used method for blind source partition problem. One advantage of using ICA is it's assumption ofsignal to be Non-Gaussian which helps denoising of images with Non-Gaussian as well as Gaussian distribution. Some applications of ICA method are machine fault detection, seismic monitoring, reflection cancelling, finding hidden factors in financial data text document analysis, radio communications, audio signal processing, image processing, data mining, time series forecasting, defect detection in patterned display surfaces, bio medical signal processing. Disadvantage of ICA based methods is the computational cost because it uses a sliding window and it involves sample of at least two image frames of the same scene as in [5].

III. Conclusion

Performance analysis of denoising algorithms is measured by peak signal-to-noise ratio (PSNR), mean square error (M.S.E) as well as in terms of visual quality of the images. Different densities of noise is added to test image for the evaluation of PSNR Many techniques assume the noise model to be Gaussian, but this assumption may not always remain true because of the different nature of various noises present in the image. Generally noise with different variance values is added in the natural images to test the performance of the algorithm.

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