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Various Denoising Methods in Digital Image Processing: A literature Survey

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Abstract: Digital images provide sufficient information in various real world applications. But it is quite impossible to avoid quality degradation during image transmission process due to interruption of noise . Since the type and behaviour of the noise changes for different fields, thus plenty of denoising approaches are applied by the researchers to retrieve the quality of the image. This paper provides a thorough survey of various well known denoising methods used in spatial and frequency domain.

Keywords: Denoising, Image Processing, Noise, Filter, Spatial Domain, Transform Domain.

1. INTRODUCTION

Visual information conveyed in the form of digital image performs a vital role in modern technology, research areas and fields of medical science such as ultrasound, x-ray imaging, computer tomography, satellite communication etc. but the images obtained after transmission are often corrupted by noise. The main origins of noise in digital images are faulty capturing instruments (cameras, misaligned lenses), problems with data acquisition, natural phenomena, transmission and compression[1]. These noisy images need to be reconstructed to produce a visually high quality image so that it can be further used in the above mentioned application areas. So image denoising is the method of estimating original digital image from a noisy one but it is still a challenging problem for researchers as noise removal causes blurring and introduces artifacts in image.[2-4]

Different types of images are affected by different types of noise and thus unique noise model is used to describe each. Denoising method is a problem specific method and depends on the types of digital image and noise models. Different algorithms are used for the noise removal depending upon its nature. For example natural images are mostly affected by additive random noise which has gaussian probability distribution [5], ultrasound images are affected by speckle noise where asrician noise affects MRI images. But several denoising approach has its own assumptions, advantages and limitations.[6]

Now, careful and in-depth study of noise models is an essential ingredient for image denoising methods. To reduce the undesirable effects of noise, prior learning of noise models is essential for further processing which is characterized by Probability Density Function (PDF).

The flow of the paper is arranged as follows: In section 2 details of noise models are explained, in section 3 different denoising approaches are well described. Conclusions are written in section 4 and finally, references are written in section 5.

2. NOISE MODEL

Noise is an undesired signal that interferes with the original signal and degrades visual quality of digital image. Noise can hamper the original signal in two ways, either in additive or multiplicative manner and they are represented by the expressions

$$w(x,y) = s(x,y) + n(x,y) \quad (1)$$

$$w(x,y) = s(x,y).n(x,y) \quad (2)$$

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

Different noise models with its PDF are represented by:

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2.1 Gaussian Noise Model: Gaussian noise affects the image in the form of addition and is evenly distributed over the image. This means each pixel in the noisy image is the sum of the true pixel and random Gaussian distributed noise value. Gaussian noise generally corrupts gray values in digital image[7]. That is why Gaussian noise model essentially designed and characterizes by its bell shaped PDF given by-

$$P(g) = \sqrt{\frac{1}{2\pi\sigma^2}} e^{\frac{-(g-\mu)^2}{2\sigma^2}} \quad (3)$$

Where, g=gray value, σ=standard deviation, μ= mean.

2.2 White Noise: In white noise, the range of total noise power spreads from -∞ to ∞ in the frequency domain. Thus ideally the power content in white noise is infinite.

In case of this type of noise, the correlation operation is not possible because every pixel values are different from their neighboring pixel values.

2.3 Impulse Noise: The impulse noise can be categorized by two types: Fixed valued and random valued[7].

i)Fixed valued impulse noise (Salt and pepper noise): Salt and pepper noise occurs during transmission and in this not all the image pixels are affected instead of some pixel values are replaced by corrupted values either the maximum pixel value '255' or a minimum pixel value '0' for an 8 bit image.

ii) Random valued Impulse noise: In this case the corrupted image pixel can be changed to random value from 0 to 255 for an 8 bit image and hence the removal of this noise becomes very difficult.

2.4 Uniform Noise: Uniform noise is also known as quantization noise generated while quantizing the pixels of images to a number of distinct levels. In this type of noise model, the SNR is limited by min pixel value p_{min} and maximum pixel value p_{max}.The SNR is expressed as-

$$SNR_{dB} = 20\log_{10} \frac{(p_{min} p_{max})}{\sigma_n} \quad (4)$$

Where, σ_n =standard deviation of noise.

Uniform noise can be described by its PDF

$$P(g) = \begin{cases} \frac{1}{b-a} & \text{if } a<=g<=b \\ 0 & \end{cases} \quad (5)$$

Their mean $\mu = \frac{a+b}{2}$ and variance $\sigma^2 = \frac{(b-a)^2}{2}$.

2.5 Periodic Noise: This type of noise originates from electronics interference during image acquisition. This noise has the feature that it is spatially dependent, sinusoidal in nature at multiples of specific frequencies. It appears in the form of conjugate spots in the frequency domain thus it is easy to observe in frequency domain. The effects of periodic noise can be removed by using a notch filter.

2.6 Speckle Noise: Speckle noise which is also called drop out noise caused due to data transmission error. Speckle noise pattern is given by:

$$g(x,y) = f(x,y).n(x,y) + n_1(x,y) \quad (6)$$

Where $g(x,y)$ is observed image. $n(x,y)$ and $n_1(x,y)$ is the multiplicative and additive component of speckle noise. x, y indicates axial and lateral indices of image sample [8].

2.7 Short noise: The dominant noise in the lighter parts of an image sensor is typically created by statistical quantum fluctuations that is by variation in the number of photons sensed at any given exposure level. Short noise usually follows poisson's distribution.

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3. IMAGE DENOISING APPROACH

Image denoising approaches broadly classified into two categories depending upon the application areas and type of noise introduced in image [9]:

- Spatial Domain Approach
- Transform Domain Approach

3.1 Spatial domain [10-12]: A traditional way to remove noise from an image is spatial filtering because it directly deals with the image matrix. In this domain the image changes with respect to the scene.

3.1.1 Linear Filter: Linear filter is the traditional way of doing denoising but it tends to blur sharp edges, destroy lines and other fine details of the picture.

3.1.1.1 Mean Filter: The Mean Filter works on the basis of a sliding window by replacing the center value in the window with the mean value of all neighboring pixel values including it. With this principle, pixels are replaced that are unrepresentative of their surroundings. Sometimes this filter is implemented with a convolution mask which produces a result that is a weighted sum of values of a pixel and its neighbors. The mask is a square often a 3x3 karnel is used.

If the coefficients of the mask sum up to one, then the average brightness of the image remains unchanged and if the coefficients sum up to zero, the average brightness is lost, returns to a dark image.

The mean filtering works like LPF and does not allow high frequency components to pass through it and a tradeoff needs to be made between karnel size and amount of denoising because high karnel size is efficient in denoising but introduces more blurring effect in picture. This filter is used in those applications that means only a part of the image needs to be processed.

3.1.1.2 Weiner Filter: Weiner filtering requires the spectrum information of noise as well as the original signal. The filtering is optimal in terms of the mean square error that means it reduces the overall mean square error in the process of inverse filtering and noise smoothing. This approach is based on a stochastic framework and is capable of reducing the noise and degrading function.

The fourier domain of the weiner filter is-

$$G(u,v) = \frac{H^*(u,v)}{|H(u,v)|^2 P_S(u,v) + P_n(u,v)} \tag{7}$$

Where, $H(u,v)$ =Degraded function

$H^*(u,v)$ =Complex conjugate of degraded function

$P_n(u,v)$ =Power spectral density of noise

$P_S(u,v)$ =Power spectral density of non-degraded image

3.1.2 Nonlinear Filters: In recent years, non linear like median, weighted median, relaxed median filters have been developed to overcome the disadvantage of linear filter. It can preserve the edge of the image but is able to reduce the noise levels present in it. Though nonlinear filters are powerful, but they are more difficult to design than linear filter.

3.1.2.1 Median Filter: Median filter is efficient in removal of random valued impulse noise and is used for reducing the amount of intensity variation between two pixels. In this filter, the value of the corrupted pixel in the noisy image is replaced by the median value of the corresponding window. The median value is calculated by first sorting all the pixel values into ascending order and then replacing the pixel being calculated with the central pixel value. If the neighboring pixel of the image which needs to be considered contains an even number of pixels, then the average of two middle pixel values is used to replace.

3.1.2.2 Weighted Median Filter: The weighted median filter was introduced to make a generalization of median filter. It is a type of nonlinear filter which gives robustness to the image with edge preserving capability where non- integer weight is assigned to each position in the filter window.

3.2. Transform domain: The principle behind transform domain or frequency domain approach is finding out orthogonal transform of the image rather than taking the image itself. This technique is suitable for the processing of images according to its frequency content. Transform domain is further classified in non-data adaptive and data adaptive technique.

3.2.1 Non-data adaptive transform: Non-data adaptive transform works on the local properties of the data and constructs an approximate representation. The parameters of this transform remain the same for each and every time

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series regardless of its nature. The non-data adaptive representation was drawn by its spectral decomposition. This transformation includes wavelet domain and spatial frequency domain approach.

3.2.1.1 Wavelet Domain[13]: The wavelet analysis is the advanced solution to the flow of the fourier transform. The wavelet based denoising methods depend on the thresholding of the discrete wavelet transform (DWT)coefficients. Image denoising using DWT has three steps. They are image decomposition followed by thresholding of wavelet coefficient and image reconstruction.

Thresholding is a nonlinear technique which operates on one coefficient for a given time. This technique breaks the noisy image into various subband images. By keeping low frequency wavelets fixed the horizontal, vertical and diagonal wavelet coefficients are brought into comparison with the soft threshold. Lastly, the inverse wavelet transform is applied to obtain the reconstructed noise free image. Filtering operation in the wavelet domain can be categorized in linear and non-linear methods.

3.2.1.1.1 Linear Filter: If the corruption of noise in signal is modeled as a Gaussian process and accuracy criterion is the MSE, then linear filter such as weiner filter in wavelet domain can be applied to get optimal result in image denoising.

Though the filtering operation successfully reduces the MSE, but the frequency results in a filtered image which is visually more displeasing than the original signal. So to overcome this problem, usually a spatially adaptive FIR Weiner filtering is proposed.

3.2.1.1.2 Non-linear threshold filtering: Nonlinear coefficient threshold based method takes the use of sparsity property of wavelet transform. It maps white noise in the signal domain into that of the transform domain. In fact, the signal energy becomes more concentrated into fewer coefficients in the transformation but noise energy does not. This knowledge helps for separation of signal from noise.

The process in which small coefficients are removed while others are kept untouched is called hard thresholding but it guarantees artifacts as a result of failure of removing large noise coefficients. To overcome this, soft thresholding is done where the large coefficients are shrunk by the absolute value of the threshold itself. Most of the methods rely on an optimal threshold which can be adaptive or non-adaptive.

3.2.1.1.2.1 VISU Shrink: VISU shrink is a non-adaptive universal threshold which relies on a chunk of data points. It is known to produce overly smoothed images because its threshold choice can be unwarrantly large due to its independence on the number of pixels of image.

3.2.1.1.2.2 Adaptive method: SURE shrink, Bayes shrink and cross validations are examples of adaptive threshold method.

SURE shrink is an adaptive universal threshold which produces combined result of sure threshold and universal threshold and has better performance than visu shrink. Bayes shrink basically reduces Bayes Risk estimator function. Cross validation gives a replacement to wavelet coefficients with the weighted average of neighborhood coefficients. It gives minimization of the cross validation function and provides a maximum threshold for every coefficient.

3.2.1.1.3 Wavelet coefficient model: Wavelet coefficient model utilizes the multi resolution properties of wavelet transform. The modeling can be either deterministic or statistical.

3.2.1.1.3.1 Deterministic modeling: The deterministic method basically creates a tree structure of wavelet coefficients with every level in the tree representing each scale of transformation and nodes represent wavelet coefficients. Optimal tree approximation shows a hierarchical interpretation of wavelet decomposition.

3.2.1.1.3.2 Statistical Modeling: Statistical modeling of wavelet coefficient exploits the properties like multi scale correlation between wavelet coefficients, local correlation between neighborhood coefficients. Marginal and joint probability models fall in this category. Gaussian Mixture Model (GMM) and Generalized Gaussian Distribution (GGD) are usually employed in order to model the wavelet coefficient distribution. The Hidden Markov Model is efficient in capturing interscale dependencies whereas the Random Markov Field (RMM) model is more efficient to capture inter scale correlations.

3.2.1.1.4 Non-orthogonal Wavelet Transform: Un decimated Wavelet Transform (UDWT), Shift Invariant Discrete Wavelet Transforms (SIDWT) are popular transforms of image denoising. Since UDWT comprises of decomposing the signal thus provides a visually better solution. Though the shift invariance property of UDWT avoids visual artifacts but it adds a large overhead of computations thus making it less feasible.

3.2.1.2 Spatial Frequency Filtering: Spatial frequency filtering is basically the use of low pass filters using Fast Fourier Transform(FFT). Frequency smoothing methods is elimination of noise in frequency domain by using a filter which has adaptive cutoff frequency chosen by the fact noise is decorrelated from the useful signal but this method is time consuming and complex because it depends on the adaptive cut-off frequency and function behavior. Sometimes they may produce artificial frequency components in the processed image.

3.2.2 Data Adaptive Transform[14]: As the name suggests, in the data adaptive transform approach the parameters of the transformation are modified depending on the available data. By adding a data sensitive step, almost all non-data adaptive transforms can be made as data adaptive. In recent times, Independent Component Analysis(ICA) is a new

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image denoising adaptive data transform that has recieved much attention. This technique is widely used to remove noise from non-gaussian data.

4. CONCLUSIONS

In this survey, a clear idea of image quality degradation and quality retrieval is produced through the sections discussing noise models and denoising approaches both in spatial and transform domain. Since digital images are used almost in each real life application, thus denoising is an important preprocessing step before further processing like image segmentation, feature extraction etc. The above survey shows various linear and non linear spatial domain filters which can handle various types of noises like salt and pepper, speckle, gaussian etc. But it is also seen that it operates on a fixed window and thus produces artifacts around the image. Also over-smoothing can lead to blurring for thses filtering techniques. In this case transform domain approach specially wavelet transform outperforms utilizing its sparsity, multi resolution and multi scale nature. In recent times, image denoising using various meta heuristic algorithms [15] grabbed researcher's attention with excellent noise level reduction performance kept as a scope of future work.

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