Comparative Study on Noise Removal Techniques in Digital Images

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Abstract

A visual image is rich in information. Digital images plays very significant role in our day today life. The influence and impact of digital images on modern society, science, technology and art are tremendous. Image Processing is a popular field from Medical to Robotics and the list pretty endless. Digital images are corrupted with various types of noises during acquisition and transmission. The main challenge in digital image processing is to remove noise from the original image. There have been several published algorithms and each approach has its assumptions, advantages, and limitations. The scope of the paper is to focus on different types of noises and denoising techniques which are encountered in digital images.

Keywords: *Image Denoising, Filters, Transform Domain, Wavelet Thresholding.*

1. INTRODUCTION

Digital Images play an important role in all areas of our day to day applications. Image processing is a field that continues to grow, with new applications being developed at an ever increasing pace. The images that are collected from various image sensors by noisy images because imperfect devices and problem with data acquisition process introducing interference. Some of the reasons which causes noises are poor sensors, defects in optical lenses, motion of the object, wrong focus, atmospheric turbulence, temperature of the environment and poor light levels. Moreover, transmission errors and compression introduces noise. So the data can degrade in terms of quality[1]. Thus, it is necessary to denoising the data, before images data is analyzed. Denoising technique is useful to get efficient output from corrupted data. It still remains a challenge for researchers. This paper presents a review of some noise models and various existing image denoising techniques. Image Denoising is an important technology in image analysis and the first step to be taken before images are analyzed [2].

2. TYPES OF NOISES

Various types of noises have their own characteristics and are inherent in images in different ways. The most common noises in digital images are

- Gaussian noise (Amplifier noise)
- Poisson Noise (Shot Noise / Photon Noise)

- Impulse Noise (Salt-and-pepper noise) and
- Speckle Noise

3. CLASSIFICATION OF IMAGE DENOISING TECHNIQUES

Denoising is the process of constructing the original image by removing unwanted noise from a corrupted image. There are three basic approaches to denoising images. They are,

- Spatial Filtering,
- Transform Domain Filtering and
- Wavelet Threshold Method.

The objectives of any filtering approach are: to suppress the noise effectively in uniform regions, to preserve edges and other characteristics of image and to provide a visually natural appearance [3].

4. SPATIAL FILTERING

A traditional way to remove noise from image data is to employ spatial filters. Spatial filtering term is the filtering operations that are performed directly on the pixels of an image. Spatial filter consists of two things. First one is neighborhood, typically a small square or rectangle and its size is much smaller than that of f(x,y), the image. The second one is a predefined operation performed on the image pixels in the neighborhood. Spatial filtering is the method of choice in situations when only additive noise is present. It can be further classified into Linear and Non Linear Filters.

4.1. LINEAR FILTERS

It is the method of choice in situations when only additive noise is present [2]. Mean filter is optimal for Gaussian noise in the sense of mean square error. The disadvantage of using linear filter is that it blurs sharp edges, destroy lines and other fine details of image. The two methods in the linear spatial filtering are the *correlation* and *convolution*.

Correlation is a function of displacement of the filter and is represented as follows

$$g(i,j) = w(i,j) \bullet f(i,j) = \sum_{s=-K/2}^{K/2} \sum_{t=-K/2}^{K/2} w(s,t) f(i+s, j+t) \quad \text{-----------(1)}$$

Convolution is the same as correlation except that the filter is first rotated by 180^0. It is denoted as

$$g(i,j) = w(i,j) * f(i,j) = \sum_{s=-K/2}^{K/2} \sum_{t=-K/2}^{K/2} w(s,t) f(i-s, j-t) \quad \text{-----------(2)}$$

Where $g(i,j)$ is the denoised image, $f(i,j)$ is the image with noise and $w(i,j)$ is the filter mask of size *(* **K X K** **.** The Mean filter and Wiener filter are two types of linear filters.

The ***Mean Filter*** or average filter provides smoothness in an image by reducing the intensity variations between the adjacent pixels. It uses a mask over each pixel in the signal. Each of the components of the pixels which fall under the mask are averaged together to form a single pixel. Generally linear filters are used for noise suppression. The main disadvantage is that edge preserving criteria is poor in mean filter [4].

The ***Wiener Filter*** takes statistical approach to reduce the amount of noise in a signal. This is done by comparing the received signal with an estimation of a desired noiseless signal. Desired frequency response can be acquired using this filter. This 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, whose output will be as close as original signal as possible [5].

4.2. NON LINEAR FILTERS

It is the method of choice in situations when multiplicative and function based noise is present [2]. 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. 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 .

In ***Median Filter***, the 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 [5]. It is a robust filter. Median filters used for providing smoothness in image processing and time series processing [4]. 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. One of the major problems with the median filter is that it is relatively expensive and complex to compute. Median filters perform very well on images containing salt and pepper noise but perform poorly when the noise is Gaussian.

5. TRANSFORM DOMAIN FILTERING

The transform domain filtering can be divided according to choice of basic functions. For image smoothing we implement low pass filters while for image sharpening we implement high pass filters.

5.1 SPATIAL FREQUENCY FILTERING

Frequency domain filtering of digital images involves conversion of digital images from spatial domain to frequency domain. Fast Fourier transform(FFT) is a specific tool for spatial domain to frequency domain conversion. Image smoothing or blurring in low pass filter is achieved in frequency domain by attenuation of high frequency or high intensity transition. The output of low pass filter contains small or less intensity transition in to a particular group of pixels. The sharpening of images in high pass filter is achieved in frequency domain by attenuation of low frequency or low intensity transition. The output of high pass filter contains high intensity transition in to a particular group of pixels. It refers the use of low pass filters using FFT. 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 [10]. The main disadvantage of 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. The key to this technique is to identify edges. Edges are identified as features that have signal peaks across many scales[6].

5.2 WAVELET DOMAIN FILTERING

Wavelet Transform is a mathematical procedure that break up signal into different frequency components and then each component is analyzed with a resolution matched to its scale. 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 [7]. A major advantage is that it provides time and frequency localization simultaneously.

6. WAVELET BASED THRESHOLDING

To overcome the weakness of other filtering, Donoho and Johnstone proposed the wavelet based denoising scheme[3]. 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. There are several studies on thresholding the Wavelet coefficients. The process, commonly called Wavelet Shrinkage[8], consists the following main stages:

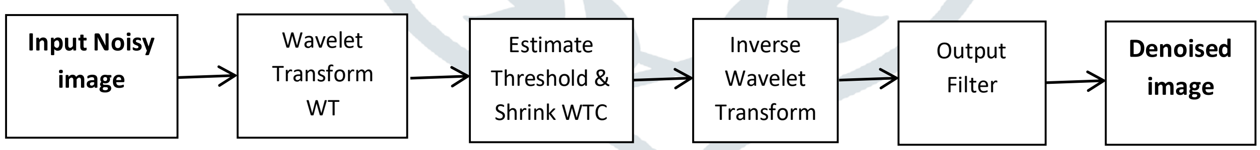

Figure1. Block diagram of Image denoising using Wavelet Thresholding

6.1 Thresholding Method

There are various thresholding techniques are used in 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. The threshold λ is chosen according to the signal energy and the noise variance σ. If a wavelet coefficient is greater than λ, we assume that it is significant and attribute it to the original signal. Otherwise we consider it to be due to the additive noise and discard the value. The mathematical representation is as follows [10].

$$f(x) = \begin{cases} x & if\ x \geq \lambda \\ 0 & otherwise \end{cases} \quad \text{-----------(3)}$$

The soft thresholding function has a somewhat different rule form the hard thresholding function. It shrinks the wavelet coefficients by λ towards zero, which is the reason why is it also called the wavelet shrinkage function. The mathematical representation is as follows [10].

$$f(x) = \begin{cases} x-\lambda & if\ x \geq \lambda \\ 0 & if\ x < \lambda \\ x+\lambda & if\ x \leq -\lambda \end{cases} \text{-----------(4)}$$

6.2 Threshold Selection Rules

In image denoising applications, the selection of threshold value should be such that Peak Signal to Noise Ratio (PSNR) is maximize. 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. Threshold selection is based on non adaptive and adaptive threshold.

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. The drawback is that it can only deal with additive noise. Threshold λ can be calculated using the formulae,

$$\lambda = \sigma\sqrt{2logn^2} \text{-----------(5)}$$

Adaptive Threshold

The two types of adaptive threshold are ***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 [8]. The Bayes Shrink method has been attracting attention recently as an algorithm for setting different thresholds for every sub band. Here sub bands are frequency bands that differ from each other in level and direction [9]. The purpose of this method is to estimate a threshold value that minimizes the Bayesian risk assuming Generalized Gaussian Distribution (GGD) prior.

7. CONCLUSION

This paper is to present a comparative study of digital image denoising approaches. As images plays a vital role in this digital era, image denoising is an important pre-processing task to produce better results on image processing and analysing. Every technique regarding denoising has its own characteristics, merits and limitations are discussed in this paper. The denoising algorithms performance were measured using quantitative performance measures such as peak signal-to-noise ratio, minimum mean square error as well as in terms of visual quality of the images. The study of existing denoising techniques for digital images shows that wavelet filters outperforms the other standard spatial domain filters. Spatial domain 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 prominent properties such as multiscale, multiresolution and sparsity nature. The wavelet domain filter is superior filter because of its edge and feature-sensitive selectivity in passing certain high-frequency data. The complete overview of this paper take the researcher to next level of choosing the appropriate technique for their application.

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