Performance Evaluation of Spatial Domain Filtering with Brute Force Thresholding Algorithm for Image Denoising

Juhi Mishra
M.Tech Scholar
Dept of Electronics & Communication Engineering,
Dr. C.V. Raman University,
Kargi Road, Kota, Bilaspur (C.G.), India

Saurabh Mitra
Assistant Professor
Dept of Electronics & Communication Engineering,
Dr. C.V. Raman University,
Kargi Road, Kota, Bilaspur (C.G.), India

Abstract- For researchers the extraction of noise from the original image is still a problem. Several algorithms have been developed and they all have their own merits and demerits. This paper is focused on the denoising of image which is a pre processing step for an image before it can be used in image processing applications. In this work to achieve these denoising, filtering approach and thresholding with wavelet based approach are used and their comparative performances are studied. Image filtering algorithms are applied on images to remove the different types of noise that are either present in the image during capturing or injected into the image during transmission. Here wavelet approach and special domain filter are used for the image reconstruction and denoising. In this paper, we propose an efficient algorithm for denoising of digital images.

Keywords - Spatial Filters, Denoising, Brute Force, Thresholding, Wavelet Sub bands.

INTRODUCTION-
Image signals are often corrupted by acquisition channel or artificial editing. The main goal of image restoration techniques is to restore the original image from a noisy observation of it. Image noise problems arise when an image suffers with fluctuation or random variation in intensity level. Images may suffer with many of problems like additive multiplicative or impulse noise. It is undesirable because it degrades image quality and makes an image unpleasant to see. The several reasons due to which an image can reduce its quality or get corrupted are - motion between camera and object, improper opening of the shutter, atmospheric disturbances, misfocusing etc. Preprocessing can be done with image denoising and inpainting. Noise is the result of image acquisition system whereas image inpainting problems occur when some pixel values are missing. Denoising is a process of extracting useful information of image and to enhance the quality of image. Denoising is an enhancement technique to reconstruct a noiseless image which is better than the input image.

Generally in case of image denoising methods, the characteristics of the degrading system and the noises are assumed to be known beforehand. The image \( i(x,y) \) is added with noise \( n(x,y) \) to form the degraded image \( d(x,y) \). This is convolved with the restoration procedure \( g(x,y) \) to produce the restored image \( o(x,y) \).

Fig. 1 Denoising Concept

Denoising is a necessary step to be taken before the image data is analyzed for further use. Because after introducing the noise in image, the important details and features of image are destroyed. It is necessary to apply efficient denoising technique to compensate for such data corruption. So the main aim is to produce a noise free image from the noisy data. In this paper denoising of images which contain noise is defined by studying the actions of different special domain filters such as regular median filter, adaptive median filter, Gaussian filter and Bilateral filter. Also a thresholding technique called as brute force thresholding is used.

The organization of this paper is as follows: Section 2 is describes a noise models, Section 3 discusses about the filtering approach and thresholding technique, Section 4 describes simulation results on an image and Finally Section 5 gives conclusion.

NOISE MODELS-
Noise can affect an image by different ways upto different extent depending on type of disturbance. Generally our focus is to remove certain kind of noise. So we identify certain kind of noise and apply different algorithms to remove the noise. The common types of noise that arises in the image are: a) Impulse noise, b) Additive noise, c) Multiplicative noise. Different noises have their own characteristics which make them distinguishable from others.

(i). Impulse noise- This term is generally used for salt and pepper noise. They are also called as spike noise, random noise or independent noise. In image at random places black and white dots appears which makes image noisy. Over heated faulty component and dust particles on image
acquisition system is the main cause of such noise. Occurrence of such noise is independent of pixel values.

(ii) Additive noise - Gaussian noise comes under the category of additive noise. This noise model follows Gaussian distribution model. The resultant noisy pixel is a sum of original pixel value and randomly distributed Gaussian noise value. This can be expressed by following equation:

\[ w(x, y) = i(x, y) + n(x, y) \]  (1)

its probability distribution function can be given by:

\[ f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-m)^2}{2\sigma^2}} \]  (2)

where \( \sigma \) is standard deviation, \( g \) is gray level of image and \( m \) is mean.

(iii) Multiplicative noise - This type of noise occurs in almost all coherent imaging systems such as laser, acoustics and SAR (Synthetic Aperture Radar) imagery. Speckle noise is a multiplicative noise. The source of this noise is attributed to random interference between the coherent backscattered signals. Fully developed speckle noise has the characteristic of multiplicative noise. Speckle noise follows a gamma distribution. It can be given as

\[ w(x, y) = i(x, y)\times n(x, y) \]  (3)

**SPATIAL FILTERING AND THRESHOLDING APPROACH FOR IMAGE DENOISING -**

(i). Spatial domain filters - Enhanced images can be reconstructed via filtration process. Image filters may be used to highlight parts or edges of image or boundaries. Filters provide an image better visualization. Image denoising is the process of obtaining original image from the degraded one. It helps to retain the edges and other major detail without modifying the visual information of image. Filtering in image processing is used to accomplish many things, including interpolation, noise reduction, and resampling. The choice of filter is often determined by the nature of the task and the type and behaviour of the data. Noise, dynamic range, color accuracy, optical artifacts, and many more details affect the outcome of filter functions in image processing.

A traditional way to remove noise is to employ spatial filters. Spatial filtering is commonly used to clean up the output of lasers, removing aberrations in the beam due to imperfect, dirty or damaged optics. The special filtering works directly on image plane and manipulates the pixel value of corrupted pixel by applying various algorithms of filters. The values of neighbourhood pixels decide the value of processed pixel therefore it is also known as neighbourhood process. Spatial filters can be further classified into non-linear and linear filters. In linear filters output values are linear function of the pixels in the original image. Linear methods are easy to analyse mathematically than the nonlinear filters. Non-linear filters have accurate results because they are able to reduce noise levels without blurring the edges. Some of the filtering techniques have been discussed below:

(A) Gaussian filter - Gaussian filters are linear low pass filters. It is basically a smoothing filter. Smoothness depends upon the deviation. To get intensive smoothness deviation must be larger.

(B) Regular median filter - Median filter is one of the most popular non-linear filters. It is very simple to implement and much efficient as well. In median filter a central pixel which appears to be noisy is replaced with the median values of neighbouring pixel values. Median filtering tends to remove image detail such as thin lines and corners while reducing noise. A limitation of median filter is that it acts as a low pass filter so it passes low frequencies while attenuates high frequency components of image like edges and noise. So it blurs the image.

(C) Adaptive median filter - Images affected by impulse noise can be denoised by the application of adaptive median filters. Its algorithm is simple and easy to implement. It is being used to remove high density of impulse noise as well as non-impulse noise while preserving fine details. Its algorithm works on two levels. In first level it the presence of residual impulse in a median filter output is tested. If there is an impulse then it will increase window size and repeat the test. If no impulse is present in median filter output then second level test is carried out to check whether central pixel is corrupted or not. If yes then the value of central pixel will be replaced with the median value.

Bilateral filter - Bilateral filter smooth the image as well as preserves edge information. It extends the concept of Gaussian smoothing by weighting the filter coefficients with their corresponding relative pixel intensities. Pixels that are very different in intensity from the central pixel are weighted less even though they may be in close proximity to the central pixel. This is effectively a convolution with a non-linear Gaussian filter, with weights based on pixel intensities. Its formulation is very simple.

(ii) Discrete Wavelet Transform

A ‘wavelet’ is a small wave which has its energy concentrated in time. It has an oscillating wavelike characteristic & it as time-scale and time-frequency analysis tools have been widely used in topographic reconstruction and still growing. Working in the wavelet domain is advantageous because the DWT tends to concentrate the energy of the desired signal in a small number of co-efficients, hence, the DWT of the noisy image consists of a small number of coefficients with high Signal Noise Ratio (SNR) and a large number of coefficients with low SNR. After discarding the coefficients with low SNR (i.e., noisy coefficients) the image is reconstructed using inverse DWT. As a result,
noise is removed or filtered from the observations\cite{3}. The DWT is identical to a hierarchical sub band system where the sub bands are logarithmically spaced in frequency and represent octave-band decomposition. By applying DWT, the image is actually divided i.e., decomposed into four sub bands and critically sub sampled as shown in Figure 1(a). These four sub bands arise from separable applications of vertical and horizontal filters. The sub bands labeled LH1, HL1 and HH1 represent the finest scale wavelet coefficients, i.e., detail images while the sub band LL1 corresponds to coarse level coefficients, i.e., approximation image. To obtain the next coarse level of wavelet coefficients, the sub band LL1 alone is further decomposed and critically sampled. This results in two-level.

(iii) Brute force thresholding- brute force is

Finding an optimized value ($\lambda$) for threshold is a major problem. A small change in optimum threshold value destroys some important image details that may cause blur and artifacts. So, optimum threshold value should be found out, which is adaptive to different sub band characteristics. Here we proposed a Brute Force Thresholding technique which gives an efficient threshold value for noise to get high value of PSNR as compared to previously explained methods. Threshold follows the same concept as in basic electronics, Brute force Threshold is given 5 times the maximum pixel intensity, which will be 127 in most of the images. Brute force thresholding always outclass other existing thresholding techniques in terms of better results. Algorithm for brute force thresholding is given

- Input wavelet sub band.
- Find maximum (max) and minimum (min) value of sub band coefficients.
- loop through (threshold= min to max) and execute desired algorithm
- save the results in array for each loop such that $F= [\text{threshold, result}]$
- When loop completed, select the (threshold) that gives best result.

(iv) Flow diagram for proposed algorithm-

![Flow diagram of proposed algorithm](image)

PERFORMANCE EVALUATION AND SIMULATION RESULTS-

This work has been implemented using MATLAB as a simulation tool. The proposed method is tested on image ‘SAR Image.JPG’ of size 1232 X 803. The image is corrupted by different type of noises like salt and pepper noise, random noise and Gaussian noise at various noise densities and the performance of algorithm is evaluated on the basis of peak signal to noise ratio, mean square error and root mean square error.

(i) Mean Square Error- Mean square error or MSE is the average square difference of pixels between orginal and denoised image throughout the image. Lower the MSE better will be the system response.

$$\text{MSE} = \frac{\sum (|I_o(r,c) - I_d(r,c)|)^2}{R \times C}$$

(ii) Peak Signal To Noise Ratio- the phrase peak signal to noise ratio abbreviated as PSNR represents the ratio between maximum possible power of signal and power of corrupting noise. Because of wide dynamic range
PSNR is usually expressed in logarithmic decibel scale. PSNR may be expressed as:

$$\text{PSNR} = 20 \log_{10} \frac{\text{MAX}_i}{\text{MSE}}$$

(iii) Root Mean Square Error- The term root mean square error also known as root mean square deviation, also referred as standard deviation as it is the square value of variance. It represents the square root of the mean/average of the square of all of the error. The use of RMSE is very common and it makes an excellent general purpose error metric for numerical predictions.

$$\text{RMSE} = \frac{255}{\text{PSNR}} 10^{-20}$$

Take an example of SAR image. The stimulation results and data are shown in below and Table respectively.
In this work image denoising is achieved by various special filtering approach with a thresholding method named as brute force thresholding. Simulation is performed on image with various types of noises that are either present during acquisition or transmission of image. In this work three types of noises are added to image and special domain filtering is performed on each of them. The performances of the filters are compared using the Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE). The performance of brute force thresholding algorithm is very efficient in denoising.

CONCLUSION-

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