IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 7, Issue 8, August2020

DOI 10.17148/IARJSET.2020.7810

Non-linear Filters for Removal of Gaussian Noise

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Abstract: Images are very often degraded by Gaussian noise during image acquisition. Gaussian noise is evenly distributed over the image and characterized by adding to each image pixel a value from a zero-mean Gaussian distribution. It is necessary to remove Gaussian noise from the image while keeping its features intact. A review of non-linear bilateral filter, trilateral filter, fast and efficient algorithm, modified fuzzy filter and fast guided filter is presented in this paper. This study shows that computational complexity and performance of filters for flat & busy regions and at edges plays vital role in overall assessment of the filter.

Keywords: Gaussian Distribution, Domain, Range, ROAD, Threshold, Weighting Coefficient.

I. INTRODUCTION

An image carries large amount of information and is a medium of communication between people. Images are likely to be degraded by noise. For digitally acquired images, noise can be summarized as the visible effects of an electronic error in the final image [1]. The noise gets added in digital images mainly during image acquisition and/or transmission.

A variety of environmental factors and the quality of the sensing elements determines the performance of imaging sensors during image acquisition [2]. For example, when CCD camera is used, light levels and sensor temperature greatly decides amount of noise present in the resulting image. At the time of transmission, interference in the transmission channel degrades the quality of image. For example, an image transmitted wirelessly, might get corrupted due to lightning or other atmospheric disturbance. Noise interference degrades the quality of image and leads to loss of information. Hence removal of noise is important for extraction of reliable & accurate information before subsequent image processing operations image segmentation, edge detection, feature extraction, object detection and classification etc.

Noise having Gaussian-like distribution is very often encountered while acquiring image. Thermal motion of electrons causes the photoelectric sensors to introduce Gaussian noise in an image during the acquisition process [3]. The electromagnetic interferences may also introduce Gaussian noise during the transmission. High temperature and/or poor illumination will also induce Gaussian noise in an image. Gaussian noise is evenly distributed over the image. Gaussian noise is characterized by adding to each image pixel a value from a zero-mean Gaussian distribution. Let Oij be pixel intensity at location (i, j) of original image O of size M * N, then corresponding pixel of noisy image Xij is

$$Xij = Oij + Gij$$

where each noise value G is drawn from zero-mean Gaussian distribution. Since Gaussian noise is evenly distributed over the image, its removal is important. Various researchers have proposed various types of linear and non-linear filters for removal of Gaussian noise. Review of some of these non-linear filters is presented in section II and conclusion is drawn in section III.

II. LITERATURE REVIEW

The zero-mean property of the distribution allows such noise to be removed by locally averaging pixel values. Conventional spatial domain linear filters such as arithmetic mean filters operate in a neighbourhood window and replace processing pixel by weighted average of neighbouring pixels. Here the intuition is that images typically vary slowly over space, so neighbouring pixels are likely to have similar values. When noise gets added, noise values are mutually less correlated than the original pixel values. So, when pixel is replaced by weighted average, noise gets averaged away. But assumption of slow spatial variation fails at edge and hence due to spatial domain filtering edges are blurred.

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The Wiener filter is the mean square error-optimal stationary linear filter which requires some 'a priori' knowledge about the spectra of noise and the original signal. This information is necessary to perform the optimal choice of parameter values and/or threshold selections. Unfortunately, such information is very often not available in real time applications. Also, without considering busy and flat regions, Wiener filter uniformly filters the image, resulting in unacceptable blurring of fine detail across edges and inadequate filtering of noise in relatively flat areas [1]. To overcome these limitations of linear filters, many researchers have proposed many non-linear methods for Gaussian noise removal.

C. Tomasi et al. have proposed a simple, noniterative filtering scheme for gray and colour images for edge preserving smoothing [4]. Authors have combined spatial domain filtering and range filtering. This combined approach is called as bilateral filtering. Two pixels are close to one another, when they occupy nearby spatial location and two pixels are similar to one another, when they have nearby values, possibly in a perceptually meaningful fashion. So, closeness refers to closeness in the spatial domain while similarity refers to vicinity in the pixel values range. In domain filtering, pixel is replaced by weighted average of neighbouring (close) pixels, thereby enforcing closeness. In range filtering, pixel is replaced by weighted average of similar pixel values. This domain filtering and range filtering is combined in bilateral filter. In bilateral filter, final weights to be applied are obtained by product of weights obtained from domain component and range component. Pixel is replaced by weighted average of similar and nearby pixels. It is shown that, in smooth regions, bilateral filter essentially works as domain filter averages away small, weakly corelated differences between pixels caused by noise. At the edges, good filtering is achieved due to domain component while edges are preserved due to range component. This bilateral filter can also be applied on colour images.

In order to remove effectively, both Gaussian noise and impulse noise, R. Garnett et al. have proposed trilateral filter [5]. Bilateral filter removes Gaussian noise. Along with spatial component and range component of bilateral filter, authors have incorporated one more impulsive component (weight) to determine final weights. Impulsive weights determine how much impulse-like each pixel is. Rank-Ordered Absolute Differences (ROAD) statistics is used to determine these impulsive weights. When image is having only Gaussian noise, trilateral filter effectively shuts off impulsive component and only uses spatial component and radiometric i.e. range component to filter out Gaussian noise (in other words, trilateral filter works as bilateral filter). If the image is having both Gaussian and impulse noise, for the regions without impulses, radiometric weights are applied heavily and impulsive weights are applied very lightly and for the regions with impulses, radiometric weights are applied very lightly and impulsive weights are applied heavily.

Main drawbacks of bilateral and trilateral filters are, it takes more computation time and complex hardware to implement. So, V. R. Vijaykumar et al. have proposed fast and efficient algorithm to remove Gaussian noise in digital images [6]. In this algorithm Immerkaer's fast method is used to estimate Gaussian noise standard deviation which is used as a measure of the extent of noise corruption for the purpose of setting a threshold. The threshold is defined as the product of noise standard deviation and a smoothing factor. The value of smoothing factor is chosen as two for optimal performance. In the filtering window, the absolute difference between the centre pixel and surrounding pixels is obtained. The difference will be large if image is highly corrupted. This difference is compared with threshold. The pixels for which difference is less than threshold, are used for further processing. If number of such pixels are greater than or equal to 5 then centre pixel is replaced by mean of these pixels else window size is increased and above procedure is repeated. This algorithm is applied for all pixels of noisy image to obtain filtered image. Experimental results show that performance of this filter in terms of MAE and PSNR is better than mean filter, Wiener filter, alpha trimmed filter, K means algorithm, bilateral filter and tri lateral filter. Because of less computational time and complexity, this algorithm can also be implemented in hardware.

T. Rahman et al. have proposed a modified fuzzy filter for reduction of Gaussian noise [7]. According fuzzy filtering strategy, the output Yij at point (i, j) is given by

$$\mathrm{Yij} = \frac{\sum \mathrm{Fij\,Xij}}{\sum \mathrm{Fij}}$$

where Fij is general 8 neighbour function proportional to fuzzy membership function. For 8-bit image, pixel intensities are ranging from 0 to 255. When pixel intensity is 0 or 255 i.e. at the boundary, value of neighbour function is taken as one. For other pixel intensity values, membership value is calculated using $exp\left(-\frac{(Xij-Xmax)^2}{2*8*\sigma}\right)$

where Xmax is maximum intensity value within 8 neighbours of current pixel and σ is standard deviation of all intensity values within the window. While determining degree of corruption of each pixel, in order to reflect effect of 8 neighbours, fuzzy function is divided by 8. Therefore, the 8-neighboring function for each pixel can be determined by the following equation

$$\mathrm{Fij} = 1, \qquad \text{for Xij} = 0 \text{ or } 255$$

$$\mathrm{Fij} = \exp\left(-\frac{(\mathrm{Xij}-\mathrm{Xmax})^2}{2*8*\sigma}\right), \qquad \text{otherwise}$$

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S. Shaik Majeeth et al. have proposed a new Gaussian noise denoising algorithm is proposed using the combination of Fast Guided filter and its method noise thresholding using wavelet transform [3]. In this algorithm, noisy image I_N is denoised using Fast Guided filter. Fast guided filter uses a guidance image which can be the image itself or different depending on application. In fast guided filter, linear coefficients are calculated by sub sampling input image and guidance image. Then linear coefficients are up sampled and adopted on guidance image to produce the output I_D. The filtered image is local linear transformation of guidance image. The fast-guided filter removes noise along with fine details of the image. To recover fine details, from the difference of noisy image I_N and filtered image I_D, method noise MN is obtained. This method noise consists of high frequency components and noise. Then discrete wavelet transform of method noise is obtained to yield noisy coefficients. Noisy coefficients comprise of coefficients of details and coefficients of Gaussian noise. BayesShrink technique is used to compute threshold and soft thresholding is applied on decomposed coefficients to estimate coefficients of details. Then inverse discrete wavelet transform is performed to obtain estimated detail image. This estimated detail image is added with the filtered image I_D to get denoised image whose quality is superior compared to filtered image obtained from fast guided filter.

III. CONCLUSION

Gaussian noise corrupts each pixel of image, so its removal is important before sub sequent image processing operations. A review of non-linear filters, namely bilateral filter, trilateral filter, fast and efficient algorithm, modified fuzzy filter and fast guided filter is presented in this paper. This study demands for comparison of quantitative and qualitative performance of these filters for flat regions, at edges & for busy regions and computational complexity for same input images so that filter with good performance and less computational complexity can be implemented in hardware and can also be used in real time applications.

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