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An Outline of Various Non-Linear Median Filters for Impulse Noise Removal in Images

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Abstract— Images are often contaminated by noise and degradations of quality of digital data due to flawed exchange mean of communication or noisy channels or flawed camera in the transmission of images over channels. Removal of noise is one of the most vitally necessary and exigent tasks in signal and image processing. Digital images are degraded by impulse noise which has two models namely, random valued impulse noise and salt & pepper noise. In imagery, high frequency components carry precious information such as edges and fine points of imagery. Linear filters are not able to preserve edges in images corrupted by non-Gaussian noise. Non linear filters are thus used for the removal of non-Gaussian noise with edge and fine detail preservation. The paper focuses on testing the functioning of various non-linear median filters for the removal of impulse noise that focused around past studies & compared using Peak Signal to Noise Ratio (PSNR). The non-linear filters were able to identify corrupted pixels from noisy image and then filter those noisy pixels. The outcomes of filters is tested on gray scale images that are degraded with variable percentage of salt and pepper noise and random valued impulse noise.

Keywords— Impulse noise, Image denoising, filtering, noise detection, Non-linear filters

I. INTRODUCTION

Mostly images are corrupted by the impulse noise. The major cause of impulse noise is malfunctioning of pixels in camera sensors, or due to fault in memory locations in hardware and also transmission in a noisy channel. The quality of the image hence can be severely degraded and cause some loss of data and information. So it is very vital to filter such type of noise in the images before some further image processing such as edge detection, image segmentation in the image. Impuse noise can further be extended into two models that are random valued impulse noise and salt and pepper noise[1]. Random valued impulse noise produces the noisy pixels whose gray level lies within a preset range. For an instance, if gray level exceeds a value Tmax, it produces high intensity impulse noise(Tmax to 255); and if gray level is less than Tmin, then it produces an impulse noise with low intensity(Tmin to 0). While on the other hand the images that are degraded with salt and pepper noise, can take only two values i.e. maximum(255) and minimum(0) values. So filtering is introduced in order to remove the impulses so that the noise free image is fully retrieved with minimum signal alteration. Even though noise removal can be achieved by using various existing filtering techniques but the linear filtering techniques are not so effective in removing the impulse noise. Therefore the need is to use non-linear filtering techniques such as the median filter.

The segment 2 defines the noise that can be incorporated in an image and its types. The extensions to nonlinear median filtering are sketched out in this paper in Segment 3, which incorporates Basic non-linear median filters namely, Standard Median Filter(SMF), Decision Based Algorithm(DBA), Switching Median Filter (SMF), Progresssive Switching Median Filter(PSMF), Modified Decision Based Algorithm(MDBA), Adaptive Median Filter(AMF), Modified Decision Based Unsymmetric Trimmed Median Filter (MDBUTMF). Segment 4 contains comparison of algorithms and segment 5 will give the conclusion.

II. NOISE & ITS TYPES

A. Noise

Noise is a random variation of brightness or image intensity or color information [2] and originates as undesirable signal. It represents unwanted details which deteriorates image quality. Noise may be arised at the time of transmitting or clicking or taking images.Whenever noise is introduced, the pixels present in the image show different values of intensity rather than the true pixel values.

B. Types of Noise

The undesirable effects produced in the image leads to noise. The noise can effect the image upto different extent depending on the type of disturbances.

Image noise can be categorized as Impulse Noise (Salt & Pepper noise), Gaussian Noise (Amplifier noise), Multiplicative Noise (Speckle Noise), Poisson Noise (Photon Noise).

1) *Impulse Noise*: Impulse noise alters at random values of some pixels.Impulse noise affects signal positions of a digital image that are random during accomplishment stage when faulty sensors are used to acquire images in poor imaging conditions or during image transmission when they are transmitted through faulty radio channels[3].

   Appearance of black and white dots is found in the image[4] as a result of this noise and therefore it is also called as salt and pepper noise. Over heated faulty components or sharp and sudden changes in image signal can cause this type of noise.

2) *Gaussian Noise*: Noise having Gaussian like distribution affects all the pixel values. This noise model is basically additive in nature[6] and follow the Gaussian distribution. It means that each pixel in the corrupted image is the summation of the true pixel value and a random Gaussian distributed noise value. The noise here is independent of the intensity of pixel value at every point.

   Gaussian noise can be removed easily by taking average of the pixels inside the window locally and then sustituting the processing pixel with that average value[5].

3) *Speckle Noise*: Speckle noise also known as multiplicative noise can be modelled by random value multiplications with pixel values of the image and it can be expressed as

   $N = I + n*I$

   Where, 'N' is called the speckle noise distribution image, 'I' is for input image and 'n' is the uniform noise image of mean' *o'* and variance '*v'*. This noise disintegrates the quality of active radar and Synthetic Aperture Radar (SAR) images[7], satellite images and medical images.

   Speckle noise is basically originated because of the consistent processing of back scattered signals from multiple distributed points. In conventional radar system this type of noise is noticed when the returned signal shows sudden disturbances from the object having size less than or equal to a single image processing unit.

4) *Poisson Noise*: Poisson Noise also known as shot photon noise is the noise that is produced when the number of photons sensed by the sensor are not sufficient to provide the statistical information that is detectable.

   The root mean square value is proportional to square root intensity of the image in this type of noise. Different pixels are infulenced by independent noise values. The photon noise including the other sensor based noise corrupt the signal at different proportions at practical basis.[8].

III. IMAGE DENOISING

A. *Filtering*

The image filtering technique filters a new image from an original by operating on the pixel values[9]. Filters are used to supress noise, enhance contrast, find edges, locate features etc. They play a major role in image restoration process.

Denoising methods can be either linear or non-linear. The linear filters are fast enough but they are not able to preserve the details of the images. Where as on the other hand the non-linear filters preserve the details of the images.

B. *Basic Concept Of Image Denoising*

The flow chart shows the basic sequence of steps required for removing the noise in images:

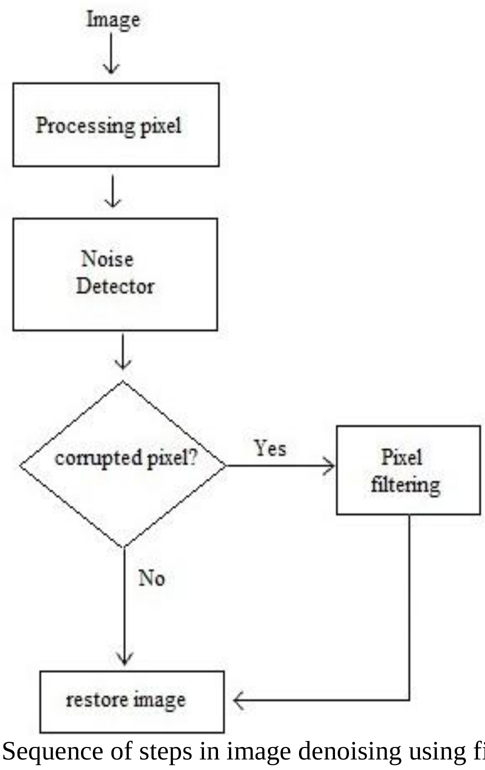

Fig. 1: Sequence of steps in image denoising using filtering

Image denoising emphasizes on removing noise from an image while keeping its fundamental structure comprising of edges, corners, etc., undamaged as much as possible[10]and retain the important signal features.

The parameters required to assess the performance of the filters are defined as follows:

1) *Mean Square Error(MSE)*: The two major error metrics that are used to compare the various image compression methods are the PSNR (Peak Signal to Noise Ratio) and the MSE (Mean Square Error).

MSE is the accumulative squared error[11] between compressed image and original image. Mathematically, it is given by:

$$MSE=\frac{1}{RS}\sum_{Y=1}^{R}\sum_{X=1}^{S}[I'(x,y)-P'(x,y)]^2$$

where $I'(x, y)$ refers to actual image, $P'(x, y)$ is the noisy image and R, S are the dimensions of the images.

2) *Root Mean Square Error(RMSE)*: RMSE is mathematically denoted as:

$$RMSE=\sqrt{\frac{1}{RS}\sum_{i,j}(Y_{ij}-X_{ij})^2}$$

where, *Yij* and *Xij* represent the pixel values of the restored and original image respectively and R.S is the size of the image.

3) *Peak-Signal-to-Noise-Ratio(PSNR)*: PSNR is a matehematical term to estimate the quality of reconstructed image as compared to that of original image[12]. It is defined as ratio between maximum power of signal(original data) and power of corrupting noise(error in reconstruction).

Peak signal to noise ratio is commonly calculated in terms of logarithmic decibel scale. Higher PSNR indicates that image reconstruction is of higher quality.

Mathematically, it is expressed as:

$$PSNR=20\ log\ 10\left(\frac{255}{RMSE}\right)$$

where RMSE is the root mean square error and 255 is the maximum possible value of pixel of the image when we represent pixels using 8 bits per sample.

There is an inverse relation between MSE and PSNR. A lower value of MSE means less error. So accordingly, higher value of PSNR is good enough as it shows that the signal to noise ratio is higher where ‘signal’ is the original image and ‘noise’ is the error in reconstruction.

C. Various Non-Linear Median Filters

In linear filtering, value of an output pixel is the linear combination of neighborhood values, which ultimately can produce blur in the image. Thus various smoothing techniques have been developed that are non linear. Linear filter blur the edges and are not able to preserve other image details.For impulse noise removal, non linear filters are thus used as they tend to preserve edges and other fine details of the image.

1) *Standard Median Filter (SMF):* Median filter performs better job than the mean filter by preserving the useful details in the image.

The median filter focusses on each pixel in the image and sees at its close neighbours to decide whether or not it is representator of its surroundings[11]. Rather than simply exchanging the pixel value with the mean of nearby pixel values, it substitutes it with the median of those values.

For calculating the median, firstly arrange the entire pixel values from the surrounding into numerically ascending order and replace the pixel being considered with the middle value of the pixel. If the considered neighbourhood contains an even number of pixels, then use the average value of two middle pixel values.

The noise is removed and image details are well preserved and edges are not blurred as in the case of mean filter.

2) *Adaptive Median Filter (AMF):* The adaptive median filtering finds which pixels in an image are affected by impulse noise by performing spatial processing. It removes the impulsive noise by modifying the gray levels to minimum extent, and resulting in maximum preservation of the original information[13]. AMF classifies the pixels as noise by comparing each pixel to its neighbourhood pixels in the image. The size here, of the neighbourhood is adjustable, also of the threshold for the comparison[14].

If the processing pixel is found corrupt in the 3x3 window taken from image matrix, median of processing block window is taken and replaced with the processing pixel value. The size of the window can be modified to 5x5 during this operation if median of the window comes out to be a corrupt value.The Adaptive median filter can better handle the impulse noise at high noise density as compared to standard median filter.

3) *Switching Median Filter*: The Switching Median Filters (SMF) divides the filtering process into two sequential steps i.e. Noise detection and Filtering[15]. By utilizing the analytical knowledge obtained from the noise detection step, the filtering step could be more intended and does not need to emphasize on the uncorrupted pixels. It aims to provide solid basis for subsequent filtering. The decision taken is based on a preset and predetermined threshold value.

SMF is performed only on noisy pixels, noise free pixels are undisturbed. As a result this filter outperforms existing filters in terms of feature preservation and noise elimination properties.

4) *Progresssive Switching Median Filter (PSMF)*: PSMF is a median based filter, used to remove salt and pepper impulse noise[16].The name progressive is attributed to its window by window processing. The algorithm is developed using the two following schemes namely switching scheme in which the algorithm representing the

detection of impulse is used before filtering. Therefore, filtering will be done only on proportion of all the pixels and progressive method in which, both the detection of impulse and the noise filtering procedure are progressively applied through several iterations.

The main advantage of PSMF is that some impulse pixels located in the middle of large irregular shaped noise spots can also be properly detected and filtered. Thus, better restoration results [17] come especially when the images are highly corrupted.

5) *Decision Based Algorithm (DBA)*: To overcome the drawback of robust decision making and effective edge & details recovery in the Switching Median Filter, Decision Based Algorithm(DBA)was devised[18]. In this, image is filtered by using a 3x3 window. If the current pixel value is zero or 255 it is proceeded next otherwise it does not go for any futher change. If the processing pixel is corrupted and all the elements in the window are 0's and 255's. Then substitute the processing pixel with the mean of the window element. And if all elements are not 0's and 255's, then remove 255's and 0's and find the median value of the remaining elements. Now replace the processing pixel with the median value. This algorithm gave better PSNR value as compared to existing algorithms.

6) *Modified Decision Based Algorithm (MDBA)*: The Modified decision based median filtering approach is defined for restoring the images that are highly degraded and despoiled by salt and pepper noise. It consists of various phases where noisy pixels are detected based on threshold value and is an enhanced form of decision based algorithm[19]. The noisy pixels here are replaced by median in which median value is calculated without considering zero and 255. Thus, at high density noisy situation it is very proficient to find noise free median value.

In MDBA, 3x3 window is selected for corrupted processing pixel. If all elements are noisy, the processing pixel is removed and substituted by last processed pixel that is noise free. And If this last processed pixel is noisy, then a filtering window with newer dimension will be created. Standard Median Filtering is used to find the probable intensity value. If median value is noisy then mean value of all pixel values in the window will be calculated. Thereafter, robust estimation method is applied in order to remove the pixel intensity discontinuity and for smoothing the restored image. Thus MDBA provides high quality restored images[20], specially at higher noise density.

7) *Modified Decision Based Unsymmetric Trimmed Median Filter (MDBUTMF)*: In decision based algorithm using a 3x3 window, at high density of noise the median value will be either zero or 255 which is corrupted and hence the neighboring pixel is used for replacement. This produces the streaking effect due to repeated substitution of neighbouring pixels. Due to this limitation, Decision Based Unsymmetric Trimmed Median Filter (DBUTMF) was proposed. But in case of high noise densities, if the selected window consists of all zero's or 255's or both then, median value(trimmed value) cannot be obtained. Thus this algorithm does not give much better results at very high noise density like at 80% & 90% noise density. So the MDBUTMF (Modified Decision Based Unsymmetric Trimmed Median Filter) [21] eliminates this limitation of DBUTMF and gives better PSNR (Peak Signal-to-Noise Ratio) at high noise density and thus improved visual qualty of images.

This filter is called trimmed median filter as the noisy pixel values 0's and 255's are removed from the window that is selected. This technique only removes those pixels from the image that contains salt & pepper noise[22] and does not trim uncorrupted pixels.

IV. COMPARISON OF THE ALGORITHMS

This section compares all the above explained algorithms according to the PSNR values at low, medium and high noise densities respectively. Table 1 shows the comparison.

V. CONCLUSION

In this paper, we have discussed different types of noise incorporated in images. The third section focused on the denoising of images using various nonlinear filtering techniques. Non-linear filtering is performed using various non linear median filters. These filters are mainly used for removing noise that are impulsive in nature, i.e., salt & pepper noise.

The functioning of the algorithms has been tested against low, average and high noise densities on the images that are gray scale.

On the basis of PSNR value results, it insists us to conclude that MDBUTMF provides better retrieval of images even at higher noise density as compared to other non linear median filters.

Table I: Comparison of non-linear filtering algorithms

SERIAL NO.	NAME OF AUTHOR	YEAR	ALGORITHM	METHODOLOGY	PSNR ACHIEVED (NOISE in % & PSNR in DB)
1.	Megha J Mane and M S Chavan	2013	SMF	Better than mean filter as it preserves blurring of edges and useful image details.	Pepper image: 10%- 32.5680 50%- 15.2730 80%- 8.0034

2.	T.K.Thivakaran, Dr.RM.Chandrasekaran	2010	AMF	It gives better results at high noise density as compared to SMF.	Elina image: 10%- 99.8234 30%- 99.2028
3.	R.Puspavalli, G.S Ivaradje	2012	Switching Median Filter	performed only on corrupted pixels, uncorrupted pixels are not disturbed. Thus give better results than existing algorithms.	Lena image: 10%- 51.29 50%- 33.07 90%-18.72
4.	Kavita Tewari, Maanorama V. Tiwari	2012	PSMF	impulse pixels located in the middle of large irregular shaped noise spots can also be properly detected and filtered.	Cameraman image: 10%- 25.14 50%- 18.72 80%- 7.68
5.	Ms. Rutuja N.Kulkarni1, Prof. P.C.Bhaskar	2013	DBA	overcame the drawback of robust decision making and effective edge & details recovery used by the Switching Median Filter.	Cameraman image: 10%- 42.69 50%- 34.84 80%- 30.43
6.	Priyanka Shrivastava et al	2014	MDBA	an enhanced form of decision based algorithm.provides high quality restored image at high noise density.	Lena image: 10%-36.75 50%-26.25 80%-20.40
7.	S. Esakkirajan et al	2011	MDBUTMF	trimmed median value cannot be obtained at high noise densities in DBUTMF. So MDBUTMF was proposed.	Lena image: 10%- 37.91 50%- 28.18 80%- 21.70 90%- 34.23

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