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Restoration of Digital Images by Removing Impulsive Noise-A Review

[1] Subhadarshini Mishra, [2] C. S. Panda
[1][2] PG. Dept. of Comp. Sc. and Applications, Sambalpur University, Jyoti Vihar, Burla, Odisha, India

***Abstract* - Noise detection and its removal is one of the biggest challenges in the field of digital image processing and impulse noise removal is one of them. Image may be corrupted by noise during image acquisition and transmission. To reduce the impulse noise level we use various restoration filters. Restoration is the process of reconstruction of an uncorrupted image from a blurred or noisy image. Various restoration techniques like wiener filter, adaptive median filter, alpha trimmed median filter, novel median filter, hybrid median filter, cloud model filter, Iterative non-local means filter, adaptive dual threshold median filter are described. However, this paper presents a comprehensive review of some proposed methods and techniques used for restoration along with its advantages and limitations of each approach.**

Keywords — Impulsive noise, restoration, degradation model, Weber's law, adaptive median filter, alpha trimmed median filter, novel median filter, hybrid median filter, cloud model filter, Iterative non-local means filter, adaptive dual threshold median filter.

I. INTRODUCTION

An image is used to record some useful information or details of a specimen in an environment. It is generally a picture which has a similar appearance of some physical object or a person or a thing. An image can be defined as a two dimensional function f (x, y) where x and y are spatial coordinates and the amplitude of f at any pair of coordinates (x, y) is called the intensity or gray level of the image at that point. When x, y and the amplitude values of f are all finite, discrete quantities we call the image as a digital image.

1.1 IMAGE NOISE:

Image noise is a random, usually unwanted distortion in brightness or color information in an image. It is an undesirable byproduct of image capture that adds spurious and extraneous information to an image. Noise in digital images arises during image acquisition or transmission. During image acquisition, the performance of imaging sensors is affected by a variety of factors like the quality of sensing elements, the environmental conditions etc. Images are also corrupted during transmission due to interference in channel used for the transmission. There are different types of noise that can affect the originality of an image. Here we consider the impulsive noise. The US National Institute for Occupational Safety and Health (NIOSH) defines impulsive noise as a noise with sharp rises and rapid decay, 1sec or less in duration [2]. Impulsive noise can be classified mainly in to two categories.

1. Salt and Pepper Noise (SPN)
2. Random Value Impulsive Noise (RVIN)

Let $Y_{i,j}$ be the gray level of an original image Y at pixel location (i, j) and $[n_{min}, n_{max}]$ be the dynamic range of Y. Let $X_{i,j}$ be the gray level of the noisy image X at pixel (i, j) location. Impulse noise may then be defined as

$$X_{i,j} = \begin{cases} Y_{i,j} \text{ with } 1-P \\ R_{i,j} \text{ with } P \end{cases} \qquad (1)$$

Where $R_{i,j}$ is the substitute for the original gray scale value at pixel location (i, j) . 'P' is the probability of distortion. In case of SPN the pixel substitute in the form of noise may be either n_{min} (0) or n_{max} (255) where as in RVIN situation it may range in between n_{min} and n_{max} [3].

1.2 IMAGE RESTORATION:

To keep the originality of an image we must try to remove the noise from an image. Thus image restoration is the process of reconstruction or estimation of uncorrupted image from a blurred or noisy image. Restoration tries to perform an operation on the image which is the inverse of imperfection in the image formation system. The restoration of images tries to diminish the effects of degradation by means of filters. The priory knowledge about the original image and the degradation function can help us to get the exact result i.e. close towards the original image, while it depends on how much the degradation function is accurate and with what accuracy it can be implemented.

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1.2.1 DEGRADATION MODEL:

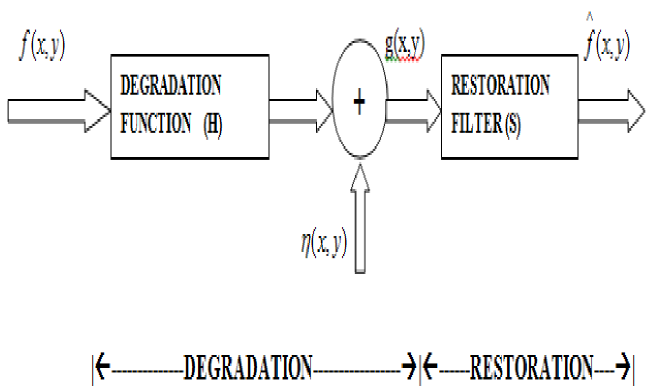

Fig. 1. Model of The Image Degradation /Restoration Process

The degradation process modeled above is defined as a degraded image g(x, y) is produced when a degradation function H and an additive noise $\eta(x,y)$ operate on the input image $f(x,y)$. The objective of restoration is to obtain an estimate $\hat{f}(x,y)$ of the original image by using some restoration filters. We always want to estimate $\hat{f}(x,y)$ be as close as possible to the original input image $f(x,y)$.This can only be possible, the more we know about H and η.

1.2.2 CLASSIFICATION OF IMAGE RESTORATION TECHNIQUE:

Image restoration technique can be broadly classified into two types depending on the knowledge of degradation. Deterministic method of image restoration is applied when we have the prior knowledge about the degradation and if it is not known then stochastic method has to be implemented [4].

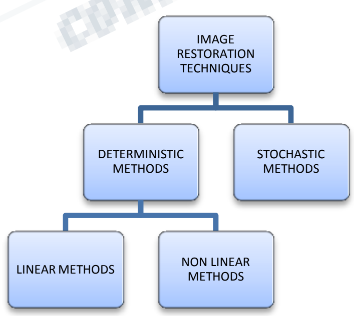

Fig.2. Image Restoration Flow

1.3 FILTER:

Image restoration usually employs different filtering techniques. Filtering may be done either in spatial domain or in frequency domain. Here we only consider filtering techniques in spatial domain. Mainly, filters can be classified in to two categories: linear and non linear. In linear filtering the value of an output pixel is a linear combination of the values of the pixels in the input pixel's neighborhood. Nonlinear filters locate and remove data that is recognized as noise [5]. Linear filters are low pass filters and tend to blur the edges and other details of image. On the other hand, non-linear filters remove the impulse noise without edge blurring and results in better image quality thereby causing more complexity in the system.

1.4 PERFORMANCE MEASURE:

The metrics used for performance comparison of different filters are described below.

(a) Peak Signal to Noise Ratio (PSNR) :

PSNR analysis uses a standard mathematical model to measure an objective difference between two images. It estimates the quality of a reconstructed image with respect to an original image. The basic idea is to compute a single no. that reflects the quality of reconstructed image. Reconstructed images with higher PSNR are judged better. The original image Y of size (M x N) pixels and a reconstructed image , the PSNR (dB) is defined as :

$$\text{PSNR(dB)} = 10\log_{10}\left(\frac{255^2}{\frac{1}{MXN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(Y_{i,j}-\hat{Y}_{i,j}\right)^2}\right) \quad (2)$$

(b) Percentage of Spoiled Pixels (PSP):

PSP is a measure of percentage of non-noisy pixels changes their gray scale values in the reconstructed image. In other words it measures the efficiency of noise detectors. Hence, lower the PSP value better is the detection, in turn better is the filter performance.

$$\text{PSP}=\frac{number\ of\ non-noisy\ pixels\ changed\ their\ gray\ value}{total\ no.\ of\ non-noisy\ pixels}x100 \quad (3)$$

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(c) Mean Square Error (MSE):

The MSE is the cumulative squared error between the compressed and the original image.

$$MSE= \frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}\left[I(x,y)-I'(x,y)\right]^2 \quad (4)$$

Where I(x, y) is the original image, I'(x, y) is the approximated version (which is actually the decompressed image) and M, N are the dimensions of the images. A lower value for MSE means lesser error.

(d)Subjective or Qualitative Measure:

Along with the above performance measure subjective assessment is also required to measure the image quality. This can be done by image enhancement. In a subjective assessment measures characteristics of human perception become paramount and image quality is correlated with the preference of an observer or the performance of an operator for some specific task. Hence the image enhancement there is no qualitative performance evaluation measure because no ideal image can be used as reference. Hence human observer is the only way by which enhanced image quality can be measured. All the proposed schemes are hence compared with the subjective results of well accepted schemes to measure the image quality [6].

2. LITERATURE REVIEW:

Noise removal from a contaminated image is a prominent field of research and many researchers have suggested a large number of algorithms with its merits and demerits. The main aim of all such algorithms is to remove impulsive noise while preserving the image details. There are no. of proposed methods for filtering process to restore an image. In this section an attempt has been made for a detailed literature review of the reported articles and described as below.

Vikas Gupta et. al. , 2014 used the concept of adaptive dual threshold for the detection of random valued impulsive noise and used the simple median filter for the removal of noise. This method utilizes the windowing technique for the detection of noise. In this technique a test window is defined and the central pixel of the window is checked with respect to some defined threshold for identifying the existence of noise. Averages of rows and columns of filtering window are used for threshold computation. The noisy pixels are identified in a relatively narrow range and thus can reduce the probability of incorrect detection. After the detection of noisy pixel simple median filter is used to remove the noise. In this proposed method quality of noise detection is very much dependent on the selection of threshold value. It improves vastly the denoised image quality of simple median filter from 16.38% to 33.89% for 70% noise density [7].

Hussain Dawood et.al., 2014 Weber law is an efficient way to identify noise, as it describes the information of the neighbor pixels to the central pixel. Thus it can identify impulse noise in the current block with improved accuracy. Here Mr. Dawood et al. proposed a robust noise detection method by considering the phenomena of Weber's Law known as Weber's Law Noise Identifier (WLNI). By using switching techniques based on WLNI binarization , the pixels of the noisy image are classified as either noisy or noise free pixels. The classified noisy pixels are then processed by the proposed Modified Switching Median Filter (MSMF). This MSMF replaces the noisy pixels in two ways. In first case the central value is replaced by the median value of the current block where as in second case, the central value is replaced by the mean value of the current block. The proposed WLNI method outperforms the state-of-the-art image denoising methods in visual quality, structural similarity (SSIM) and PSNR quality [8].

Xianquan Zhang et al., 2014 the proposed method is based on the theory of image inpainting. The algorithm takes noisy pixels as missing data for inpainting. First of all, they use a prewindow and current window to find the noisy pixels. This can reduce the false detection and miss detection. After the detection of noisy pixels they use a convolution mask along the four directions and adaptively select a convolution mask according to the dominant direction of the region of the noisy pixels for filtering. During restoration, this method keeps the noise free pixels unchanged and inpaints the noisy pixels by iterative convolution. This method has a fast speed because detection of noise is simple and fast and they use different strategies for different noisy regions. Specifically, the use of four dimensional masks makes it more accurate in textural and edge regions. This algorithm is better than other algorithms in visual quality and not only removes the salt and pepper noise but also preserves image details as at high noise density [9].

Xiaotian Wang et al., 2016 they proposed an iterative non local means filter for image salt and pepper noise removal. The concept of iterative nonlocal means filter (INLM) is based on the fact that there exists lots of similar patches with repeat patterns in natural images and the central pixels of these similar patches share the same gray value distribution. They integrate the NLM algorithm and carried out the weighted average scheme. The proposed method contains mainly three stages. Firstly, a preprocessing procedure based on noise detection to construct a noise map . Secondly, patch matching procedure in NLM performed on each noisy pixel centered on the local window and finally an iterative frame work which contains the weighted mean of centered pixels in similar patches is used to approximate the optimal value. Here, instead of local estimation non local information is exploited to preserve the image details. It can be seen that the proposed method outperforms other state of art filters by having the highest PSNR values in different noise levels and texture reliability at a wide range of salt and pepper noise densities. This method is capable of restoring images with good visual effects even in strongly corrupted cases like some blurring edges in some local areas [10].

Easwara et al., 2013 proposed a detail preserving filter based on the cloud model (CM) to remove impulse noise at high density. CM is an uncertain conversion model which integrates the concept of randomness and fuzziness. The CM filter performs better as compare to the traditional switching filters. There are three major differences between the traditional detectors and the CM filter. First, for the detection of a pixel it takes all the pixels within the window. Secondly, the CM filter does not discard the extreme values in the detection window. Thirdly, the proposed detector identifies the detected pixel is noisy or not and replaced the noise candidate. The CM filter is a switching fuzzy mean filter, which restores the image and preserves the details well without any jagged edges. Hence the cloud model filter is helpful to remove severe impulse noise while preserving the image details at high density noise level. The CM filter is a moderately fast denoising filter with good detail preservation [11].

Rakesh M.R. et al., 2013 proposed hybrid median filter which is an improved version of median filter. It is a windowed filter of non linear class that removes impulse noise while preserving edges. The basic idea behind filter is to apply median technique several times varying window shape and then take the median of the got median values. Hybrid median filter can be implemented through a three step ranking operation. Data along the different spatial directions are considered and ranked separately. Three median values are calculated along the horizontal, vertical and diagonal pixels. The filtered value is the median of the two median values and the central pixel. In hybrid median filtering the image can be extended symmetrically to fill up the gap by adding lines at the top and at the bottom of the image and add columns to the left and to the right of it. This filter is adaptive in nature and performs better on fast moving picture information of small spatial extent. It has also shortcomings like it only removes impulsive noise and its computation cost is high [12].

H. Gangadhar et al., 2014 here two filtering schemes, Rank ordered image statistics are introduced for cleaning the impulse noise. These decision based modified rank ordered mean filter and rank ordered based non linear filtering techniques perform the filtering function on the basis of sum of rank ordered logarithmic / absolute differences & decision based algorithm between central pixel inside the window and its neighboring pixels. In this paper, two non linear filtering schemes, rank ordered logarithmic (RLDBMF) / absolute difference (RLDDMF) image statistic and decision based algorithm are introduced for cleaning the images corrupted by impulses. The presence of impulse noise is detected and eliminated by decision based algorithm, if the pixel is noisy and it detected by comparing the sum of rank ordered logarithmic difference between the central pixel and its neighborhood pixels inside the window with a present threshold value if the pixel is noise free. If the pixel under consideration is detected as noisy then median filter can be used to eliminate the impulses. The values of Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) have been estimated from the filtered image at different level of noise and with various threshold values. RLDBMF is superior to the rank ordered based filters. RLDBMF is found to perform quite well on images corrupted with the impulse noise levels up to 60% [13].

Geeta Hanji et al. , 2014 proposed a Novel median filter (NMF) and its application to image restoration problem. The restoration problem considered here is an impulse noise cleaning of the noisy and degraded gray scale images. Novel median filter, a spatial domain approach use an overlapping adaptive window to filter the images. For each position of the window, a median is computed for all the pixels and is checked to see if it is an impulse or not. If it is unaffected by an impulse noise, it is confirmed as an appropriate median otherwise a more representative value is considered and used as an appropriate median for the replacement of noisy pixels. The proposed novel median filter performed best in terms of impulse noise removal in a corrupted image as compared to the standard median method and the adaptive median filter methods [14].

Mr. Praveen kumar B.T et al. , 2013 done a comparison of adaptive median filters based on homogeneity level information, discrete wavelet based filter, continuous wavelet based filter and fuzzy based noise filter for the removal of salt and pepper noise. Homogeneity level is defined for pixel values based on their global and local statistical properties. Adaptive median filter based on homogeneity level information is a decision based, signal adaptive median filtering algorithm. This algorithm achieves accurate noise detection and high SNR measures by preserving the fine details and edges in the image. Wavelet based filters are classified as discrete wavelet transform and another is continuous wavelet transform. The continuous wavelet transform is best suited to signal analysis and the discrete wavelet transform have been used for signal coding applications, including image compression, image filtering and various tasks in computer vision. Fuzzy logic based filters used to remove uncertainty present in the information as introduced by the noise while uncorrupted pixels are left unchanged. The fuzzy based filter performs the highest PSNR rate rather than the other types of filters [15].

Minakshi et al. , 2017 they used median filtering technique for removing salt and pepper noise from various types of compound images. Here an alpha trimmed mean filter is used as a non linear class window filter which is a hybrid of the mean and median filters. The basic idea behind filter is for any element of the signal look a glance of neighborhood pixel, discard the most atypical elements and find the mean value using the rest of them. Alpha is a parameter responsible for the number of trimmed elements. To get the alpha trimmed mean value discard the elements at the beginning and at the end then calculate average value using the rest. They focus on three parameters which are the back bone of this paper are PSNR, MSE and Image Enhancement Factor (IEF). The proposed method performs more desirable than the median filter and other conventional edge preserving method. The PSNR, MSE is low. The proposed method is a fast method for removing salt and pepper noise [16].

Isma Irun et al. , 2014 implemented an noise adaptive filter which aims to estimate the original image pixel values in presence of impulse noise in monochromatic images. This takes place in two stages, one is impulse noise detection and other is impulse noise reduction or cancellation. First stage is based on mean and median distance and thresholding i.e. a pixel contaminated by any other impulse noise has a relatively high intensity values from its neighborhood. To check whether a pixel is contaminated or not its distance is measured from median and mean of its neighborhood. After experimenting two threshold values 20 and 30 have been decided for accurate detection of noise. In the second stage reconstruction of image using the values of neighboring pixels of the pixels under consideration detected as contaminated pixel by first stage. This noise detection can be compared with other existing methods using the ratio of miss detection (MD) and false detection (FD). MD refers to a situation when a contaminated pixel is detected as uncorrupted where as FD refers to a situation when an uncorrupted pixel is detected as a contaminated one. Performance of this method is very well for all impulsive noise models with almost zero MD and FD for all impulsive noise models and highest PSNR values [17].

Iyad F. Jafar et al. , 2013 proposed two modifications to the filtering step of the Boundary Discriminative Noise Detection(BDND) algorithm. BDND method is an example of the switching median filter. BDND algorithm filters the noisy image in two steps. First, it detects the noisy pixels in a localized window based on clustering. It differentiates the noisy and non noisy pixels using the intensity differences in the ordered set of pixels in the window. Secondly in the filtering step, a strict condition is applied on the size of the filtering window and it uses the median filter technique. The proposed method made some modifications to the BDND method and the median filter. They modified it by loosening the condition in the expansion of the filtering window. One another modification has made to incorporate the spatial information of the uncorrupted pixels in the filtering window and the deviation of their intensities from the median when computing the estimated value of the noisy pixel. The proposed method produces higher quality images with high noise density which is visually sharper and more distinctive as compared to the BDND method [18].

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3. TABULATION:
Table -1 : Summary of all the literatures

MOTIVATION	REFERENCE	FILTER USED	TECHNOLOGY USED	FINDINGS
Random-Valued Impulse noise Removal using adaptive dual threshold median filter.	Vikas Gupta et al.[7]	Median Filter	Adaptive Dual Threshold	Depending on the selection of threshold value it improves the denoised image quality of simple median filter from 16.38% to 33.89% for 70% noise density.
Removal of high-intensity impulse noise by Weber's law Noise Identifier.	Hussain Dawood et al.[8]	Modified Switching Median Filter (MSMF)	Weber's Law Noise Identifier (WLNI)	Identifies 100% of impulse noise and effectively replaces the noisy pixel values. Highly edge preserving and better PSNR and SSM values with other state-of-the-art algorithms by varying noise intensities ranging from 50% to 90%.
Salt and Pepper noise Removal with image inpainting.	Xianquan Zhang et al.[9]	Iterative Filtering	Iterative convolution i.e. used K x K mask for smooth region and directional convolution mask for textual regions to remove noise.	Reduces Miss Detection (MD) and False Detection (FD). Also iteratively removes S & P noise in the textual and edges at high density and with better visual quality.
Iterative non-local means filter for salt and pepper noise removal.	Xiaotian Wang et al.[10]	Switching based Median Filter (SMF)	Noise Map, Patch Matching, Iterative Weight calculation	Blurring edges in local areas are restored with good visual effects. Also good in texture reliability at a wide range of S & P noise densities with high PSNR values.
Removal of High Density Impulse Noise Using Cloud Model Filter.	Easwara.M et al.[11]	Switching Fuzzy Mean Filter	Cloud Model (CM) integrates the concept of randomness and fuzziness.	Helpful in detecting and removing the noise and preserves details well without any jagged edges.
Hybrid Median Filter for Impulse Noise Removal of an Image in Image Restoration.	Rakesh M.R et al.[12]	Hybrid Median Filter	Order statistic i.e. three step ranking operation	adaptive nature and preserving corners and edges , perform better on fast moving picture information of small spatial extent, removes only impulse noise.

Rank-Ordered Image Statistics & Decision Based Algorithm for Eliminating of High Percentage Impulse Noise.	H. Gangadhar et al.[13]	Decision Based modified Rank ordered mean filter & Rank-ordered based nonlinear filter	rank-ordered Logarithmic / absolute differences & Decision Based Algorithm	Eliminates the impulse noise besides preserving the image features. RLDBMF perform well on images corrupted with impulse noise levels up to 60%.
Novel Median Filter for Impulse Noise Suppression from Digital Images.	Geeta Hanji et al.[14]	Novel Median Filter (NMF)	Overlapping adaptive window	Performed best to remove impulse noise at higher densities. As compare to SMF & AMF filters, proposed method shows high PSNR and least MSE results.
Comparisons of adaptive median filter based on homogeneity level information and the new generation filters.	Mr. Praveen Kumar B.T et al.[15]	Fuzzy based , Discrete Wavelet based and continuous wavelet based filter, Adaptive Median Filter.	Comparisons among different types of filters.	Fuzzy based filter performs the highest PSNR values rather than other types of filters.
A Review Paper on Novel Approach for Removing Salt and Pepper Noise Using Trimmed Median Filter.	Minakshi et al.[16]	Non- linear window filter	Hybrid of mean & median filter and trimmed elements.	More conventional edge preserving method. The PSNR, SNR is high and MSE is low.
A Noise Adaptive Approach to Impulse Noise Detection and Reduction	Isma Irum et al.[17]	Noise Adaptive Filter	Thresholding based distance from mean and median of pixel under consideration.	Estimate the original image pixel values in presence of impulse noise in monochromatic images where noise models with zero MD and FD & highest PSNR values.
Efficient Improvements on the BDND Filtering Algorithm for the Removal of High-Density Impulse Noise	Iyad F. Jafar et al.[18]	Median filter	Modified BDND method	Visually sharper and more distinctive images are produced as compare to BDND method.

4. CONCLUSION:

This paper reviews and summarizes some existing as well as some innovative filtering techniques to remove the impulsive noise. Some proposed algorithms are efficient in removing SPN and others are to remove RVIN. However, RVIN removal is more challenging than SPN. From the study, we can conclude Dual threshold median filter performs well to remove RVIN. Some works are done to compare the performance between different methods by calculating the PSNR, MSE values. The result is good when PSNR value is high and MSE value is low. Most of the processes illustrated in two stages i.e. noise detection and noise removal. It is found that WLNI method detects a noise free pixel and a noisy pixel more accurately. Instead of local estimation, non local based algorithm seems to be more promising to preserve image details. Hence, further study can be made to improve efficient detectors for identifying contaminated pixels, thresholding techniques and non local based approaches.

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