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A REVIEW OF IMAGE RESTORATION TECHNIQUES FOR SALT-AND-PEPPER NOISE WITH TEST RESULTS

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Abstract— *A review of image restoration techniques in the presence of salt –and- pepper noise is presented. Bipolar salt- and-pepper noise is impulse like noise consisting of high intensity positive and negative impulses. In an image, these manifest themselves as white (salt) and black (pepper) spots. This noise appears during image acquisition process where quick transients such as faulty switching take place during imaging. Linear and non-linear filter have been traditionally used to remove this type of noise. Among linear filters, contra-harmonic filters and Weiner filters are commonly used, whereas median and adaptive median filters are extensively used in the non-linear filters category. The latter give better performance as compared to the former. Decision based algorithms (DBA) have also been successfully used in the removal of impulse noise. In these a pre-defined decision rule is used to replace the intensity of the pixel under consideration. Newer techniques like various DWTs (Discrete Wavelet Transforms) have been recently used to remove salt-and-pepper noise from an image. This paper presents a theoretical background of all these techniques along with some comparative performance results/analysis.*

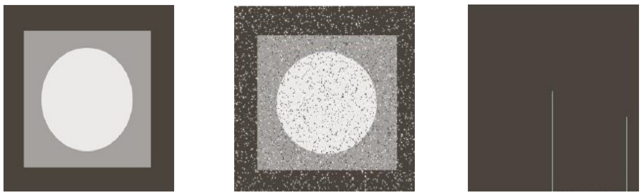
Index Terms— Adaptive median filter, Decision based filter, Median filter, Weiner filter, Salt-and-pepper noise.

1.INTRODUCTION

Salt-and-pepper noise is a bipolar impulse like noise i.e. the noise impulses can take very high positive (or negative) values. Since scaling is a part of image digitizing process, the corrupted intensity values (very high positive and negative) are digitized as extreme values i.e. either 255 (pure white - salt) or zero (pure black - pepper) in the 8-bit gray scale digitizing process.. Noise reduction methods are based on the probability density function (pdf) of the type of noise present. In the case of salt-and-pepper noise the pdf is given by

$$P(z) = \begin{cases} P_a, & \text{if } z = a \\ P_b, & \text{if } z = b \\ 0, & \text{otherwise} \end{cases} \qquad (1)$$

The appearance of this noise and its pdf are shown in Fig 1 along with the uncorrupted image.



(a) (b) (c)

Fig 1 Characteristics of salt-and-pepper noise
(a) Original test image, (b) the degraded image with salt-and-pepper noise and (c) PDF of the salt-and-pepper noise. [1].

The process of denoising the image is shown in Fig 2.

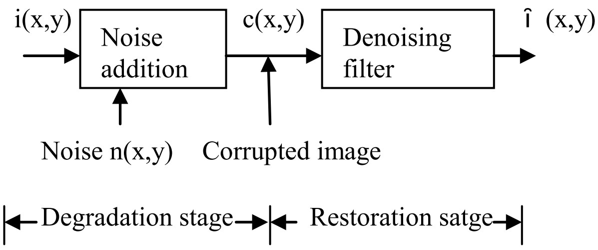


Fig 2: Process of corruption of the original image and its denoising.

where i (x, y) is the original image
n (x, y) is the salt-and-pepper noise
c (x, y) is the corrupted image and
î (x, y) is the estimate of the original image i (x, y) after denoising.

Usually images in bionics i.e. x-ray and ultrasound images get corrupted with high density salt-and-pepper noise. It is very difficult to remove this noise from the degraded image using image processing methods like morphology and histograms equalization techniques.

Various filtering techniques are used for removal of salt-and-pepper noise. These include:

a) Linear filters: (i) Harmonic mean filter
(ii) Contra-harmonic mean filter
(iii) Weiner filter

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b) Non-linear filter:
(i) Median filter
(ii) Max filter
(iii) Min filter
(iv) Adaptive median filter
(v) Decision based filter

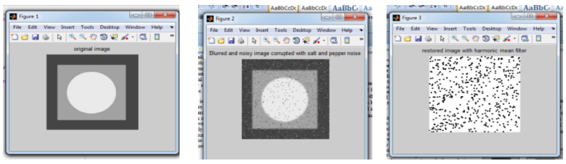
c) Discrete wavelet transforms (DWT):
(i) Haar wavelets
(ii) Daubechies wavelets

The aim of all these techniques is to remove the noise while retaining the original information present in the image along with the edges and boundaries. However, it is difficult to achieve both these together. In this paper, we will present an overview of the various filtering techniques for denoising the image affected by salt-and-pepper noise along with some comparative results/analysis.

2. LINEAR FILTERING METHODS:

2.1 Harmonic Mean Filter:

In this filter, the value of the restored image î (x, y) at the point (x, y) is the harmonic mean value of the corrupted pixels in the window. This techniques is successful against the salt noise but not against pepper noise. It also removes Gaussian noise. Fig 3 shows the results of the harmonic mean filter, on a part in the presences of salt-and-pepper noise.



(a) (b) (c)

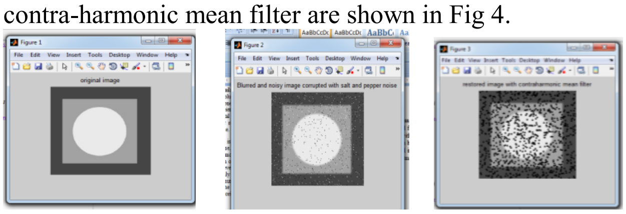
Fig 3 Image restoration using harmonic mean filter (a) Original image (without salt-and-pepper noise) , (b) noisy image (with 0.025 (2.5% of the pixels are noise affected) salt-and-pepper noise added) and (c) output of the Harmonic mean filter
Mean square error (MSE) = 1.89, Peak signal to noise ratio (PSNR) = 5.3

2.2 Contra Harmonic Mean Filter:

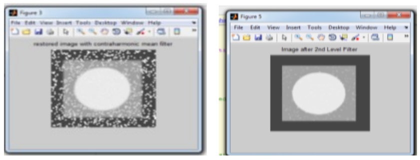
It yields a restored image based on the expression

$$\hat{\imath}\ (x,y) = \sum_{(s,t)\in Sxy} c(s,t)^{Q} + 1/\sum_{(s,t)\in Sxy} c(s,t)^{Q} \quad (2)$$

This filter is well suited for reducing the effect of salt-and-pepper noise. For positive values of Q, it eliminates pepper noise, while for negative Q values it eliminates salt noise. It cannot do both simultaneously. Both salt-and-pepper spots can be removed by using a cascade of filters first stage having positive Q value and the following stage having negative values of Q. Sample results with cascaded contra-harmonic mean filter are shown in Fig 4.



(a) (b) (c)

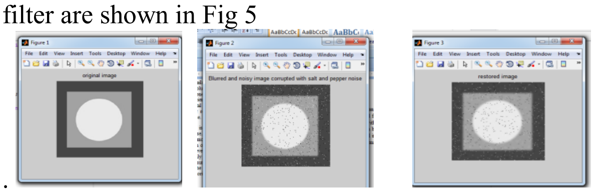


(d) (e)

Fig 4 Image restoration using contra-harmonic mean filter (a) Original image (without salt-and-pepper noise) , (b) noisy image (with 0.025 salt-and-pepper noise added), (c) result with positive Q value, (d) result with negative Q value and (e) output of the cascaded contra-harmonic mean filter
MSE = 4.52, PSNR = 2.29

2.3 Weiner Filter:

Wiener filter is a linear adaptive filter, tailoring itself to the local image variance. Where the variance is large, Wiener filter performs little smoothing, where the variance is small, it performs more smoothing. This approach often produces better results than other linear filters. It is more selective than a comparable linear filter, preserving edges and other high-frequency parts of an image. However, Wiener filter requires more computation time compared to other linear filters. The Wiener filtering is optimal in terms of the mean square error, i.e it minimizes the overall mean square error and noise smoothing. Wiener filtering is a linear estimation of the original image. **However, Wiener filtering is usually used to remove additive noise and not the impulsive noise.** With Wiener filter alone, we cannot remove the salt-and-pepper noise efficiently. The results with Weiner filter are shown in Fig 5



(a) (b) (c)

Fig 5 Image restoration using weiner filter (a) Original image (without salt-and-pepper noise) , (b) noisy image (with 0.025 salt-and-pepper noise added) and (c) output of the Weiner filter
MSE = 22.31, PSNR = 34.64

3. NON-LINEAR FILTERS:

3.1 Median Filter:

The median filter is a non-linear digital filtering technique, often used to remove noise from images or other signals. The idea is to examine a sample of the input and decide if it is representative of the signal. This is performed using a window consisting of an odd number of samples. The values in the window are sorted into numerical order; the median value, the sample in the center of this order (ranking) is selected as the output. The earlier sample is discarded, a new sample acquired, and the calculation repeats i.e.

$$\hat{\imath}\ (x,y) = \underset{(s,t)\in Sxy}{\text{median}}\,[c(s,t)] \quad (3)$$

Median filtering is a common step in image processing. It is particularly useful to reduce speckle noise and salt and pepper noise. Its edge preserving nature is quite effective. However,

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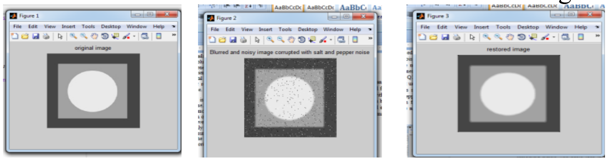
the major drawback of Median Filter (MF) is that the filter is effective only at low noise densities. When the noise level is over 50% the edge details of the original image will not be preserved by this filter. If the pixel being currently processed has a value within the minimum and maximum values in the window of processing, then it is an uncorrupted pixel and no modification is made to that pixel. If the value doesn't lie within the range, then it is a corrupted pixel and will be replaced by either the median pixel value or by the mean of the neighborhood processed pixels (if the median itself is noisy), this will ensure a smooth transition among the pixels. The results with median filter are shown below in Fig 6



(a) (b) (c)

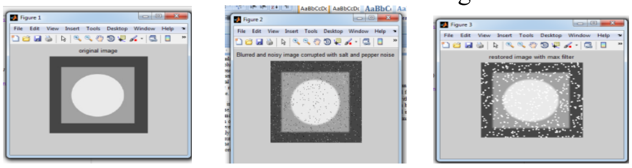
Fig 6 Image restration using median filter (a) Original image (without salt-and-pepper noise) , (b) noisy image (with 0.025 salt-and-pepper noise added) and (c) output of the Median filter
MSE = 10.17, PSNR = 38.01

3.2 Max Filter:

This is also an order statistic filter. While in the median filter 50^{th} percentile value of a set of neighbourhood values are taken, in the max filter, 100^{th} (max) percentile value is taken. The estimated value of the processing center pixel is given by

$$\hat{f}(x,y) = \max_{(s,t)\in S_{xy}}[c(s,t)] \qquad (4)$$

This filter is useful for finding the brightest points in an image. Also, because pepper noise has very low values, it is reduced by this filter as a result of the max selection process in the subimage area Sxy.
The results with Max filter are shown in Fig 7.

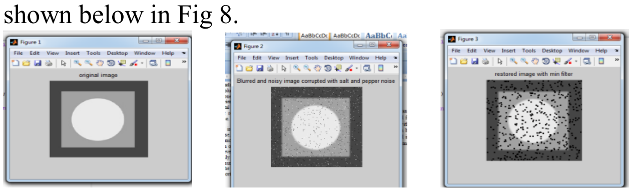


(a) (b) (c)

Fig 7 Image restoration using max filter (a) Original image (without salt-and-pepper noise) , (b) noisy image (with 0.025 salt-and-pepper noise added) and (c) output of the Max filter
MSE = 2.10, PSNR = 14.90

3.3 Min Filter:

This filter is useful for finding the darkest points in an image. Also, it reduces salt noise only. The results are shown below in Fig 8.

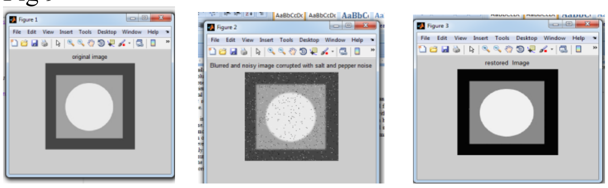


(a) (b) (c)

Fig 8 Image restoration using min filter (a) Original image (without salt-and-pepper noise), (b) noisy image (with 0.025 salt-and-pepper noise added) and (c) output of the Min filter
MSE = 2.44, PSNR = 14.23

3.4 Adaptive Median Filter:

The adaptive median filtering has been applied widely as an advanced method compared with standard median filtering. The Adaptive Median Filter performs spatial processing to determine which pixels in an image have been affected by impulse noise. The Adaptive Median Filter classifies pixels as noise by comparing each pixel in the image to its surrounding neighbor pixels. **The size of the neighborhood is adjustable, as well as the threshold for the comparison.** A pixel that is different from a majority of its neighbors, as well as being not structurally aligned with those pixels to which it is similar, is labeled as impulse noise. These noise pixels are then replaced by the median pixel value of the pixels in the neighborhood that have passed the noise labeling test.
Adaptive Median Filter (AMF) performs well at low noise densities, but at high noise densities the window size has to be increased which may lead to blurring the image. Non-linear filters can be used for discriminating corrupted and uncorrupted pixels and then apply the filtering technique. Noisy pixels will be replaced by the median value and uncorrupted pixels will be left unchanged. AMF performs well at low noise densities since the corrupted pixels which are replaced by the median values are relatively few. At higher noise densities, window size has to be increased to get better noise removal which will lead to less correlation between corrupted pixel values and replaced median pixel values. This filter type is adaptive in nature, that is here, the mask is applied to only those pixels that are corrupted whereas in simple median filter, mask is applied to all the pixels whether corrupted or not. The adaptive structure of the filter ensures that most of the impulse noise is detected even at a high noise level provided that the window size is large enough. Here, the noise pixels are replaced by the median value while the remaining pixels are left unaltered. However, the replacement methods in this denoising scheme cannot preserve the features of the images; in particular the edges are smeared. The results with median filter are shown below in Fig 9



(a) (b) (c)

Fig 9 Image restoration using adaptive median filter (a) Original image (without salt-and-pepper noise) , (b) noisy image (with 0.025 salt-and-pepper noise added) and (c) output of the Adaptive median filter
MSE = 0.417, PSNR = 51.94

3.5 Decision Based Filter:

This is name given to a group of filters which use different algorithms. For achiving median filtering [6, 8]. They differ in the way the window size, threshold and other paramerters are varied. Results in respect of one of these algorithms are shown in Fig 10.

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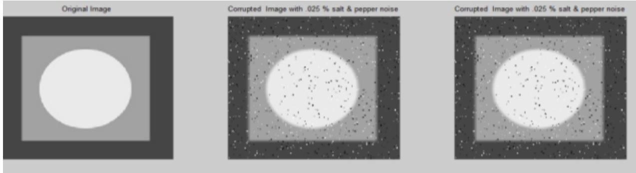
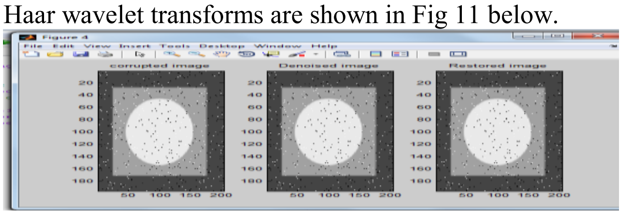


(a) (b) (c)

Fig 10 Image restoration using decision based filter (a) Original image (without salt-and-pepper noise) , (b) noisy image (with 0.025 salt-and-pepper noise added) and (c) output of the Decision based algorithm.
MSE = 10.18, PSNR = 38.05

4. Discrete Wavelet Transforms (DWTs):

Over the last few years wavelet transforms have been used for image de-noising. A discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. A key advantage it has over Fourier transforms is temporal resolution: it captures both frequency and location information (location in time). The DWT of image signals produces a non-redundant image representation which provides better spatial and spectral localization of image formation compared with other multi scale representations such as Gaussian and Laplacian pyramid. The DWT can be interpreted as signal decomposition in a set of independent, spatially oriented frequency channels [3, 1]. The results with Haar wavelet transforms are shown in Fig 11 below.



(a) (b) (c)

Fig 11 Image restoration using haar wavlet transforms (a) Original image (without salt-and-pepper noise) , (b) noisy image (with 0.025 salt-and-pepper noise added) and (c) output of the Discrete wavlet transforms.
MSE = 1.5010, PSNR = 73.9154

5. CONCLUSIONS

This paper reviews techniques for removal of salt-and-pepper noise from images. Salt-and-pepper noise is a frequently encountered noise during image acquisition. Salt-and-pepper noise is impulsive in nature. It can be removed/reduced using linear and non-linear filtering techniques. Recently DWT techniques have also been used to remove this noise. Among linear filters are harmonic filter, contra-harmonic mean filter and Weiner filter. While among non-linear filters are median filter, max filter, min filter, adaptive median filter, decision based filter use. Among DWT techniques we have various wavelets techniques like haar and daubechies wavelets.

Non-linear filters, in general, produces better results in reducing salt-and-pepper noise. Among linear filters contra -harmonic mean filters give good performance. In non-linear filters, adaptive median filter and decision based median filters produce very good results.

Recently, discrete wavelet transforms have also been used to remove salt-and-pepper noise. Sample results have been presented for all the afore-mentioned restoration techniques.

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