Removal of Salt & Pepper Impulse Noise from Digital Images Using Modified Linear Prediction Based Switching Median Filter

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Abstract - This paper proposes the switching based median filter for preserving the image details while reducing the streaking problem in gray scale images corrupted by salt and pepper noise at high noise ratios. It effectively suppresses the noise in two stages. First, the noisy pixels are detected by using the signal dependent rank-ordered mean (SD-ROM) filter. In the second stage, the noisy pixels are first substituted by the first order 1D causal linear prediction technique and subsequently replaced by the median value. The algorithm is further modified compared to the existing algorithm by choosing a larger window size and following an iterative procedure to enhance the performance of noise removal capability. Extensive simulations are carried out to validate the claim. Experimental results show improvements both visually and quantitatively compared to that of the state-of-the art switching based median filters at high noise ratios.

Index Terms *- Impulse noise; Linear Prediction; Median value ; Noise density; SD-ROM filter; Streaking effect; Switching median filter*

1 INTRODUCTION

Impulse noise plays a predominant role in corrupting the digital images very frequently during the process of Image acquisition and/or transmission. There are two types of impulse noise, namely, the salt-and-pepper noise also known as the fixed valued impulse noise and the random-valued impulse noise. Salt and pepper noise produces two gray level values 0 and 255 while Random Valued Impulse Noise produces impulses whose gray level value lies within a predetermined range. Impulse noise is primarily caused by faulty camera sensors, faults in data acquisition systems, and transmission in a noisy channel. It is established that the linear filters do not perform well for removal of impulse noise while on the other hand non-linear filters have been found to be superior and provide good results.

Median filtering has been established as a reliable method to remove impulse noise without damaging edge details. The most basic nonlinear filter is the standard median (SM) filter [1]. It replaces every pixel in the image by the *median* value of the corresponding neighborhood window centered at this pixel. But the main drawback of SM filter is that it is effective only at low noise densities and has poor performance for higher noise densities. In order to overcome this problem, Weighted Median (WM) filter was proposed which gives more weight to some values within the window than others. The special case of the WM filter is the center weighted median (CWM) [3] filter which gives more weight only to the center value of the window. However, these filters have poor performance at higher noise densities.

Some kind of decision making process or switching action in the filtering framework is a better strategy to overcome this drawback. At each pixel location, it is first determined whether the current pixel is contaminated or not. Then filtering is applied on the pixel only if it is corrupted by noise. The corrupted pixels are replaced by the median values, while the noise-free pixels are left unaltered. Since not every pixel is filtered, undue distortion can be avoided. Switching-based median filters are well known. Identifying noisy pixels and processing only noisy pixels is the main principle in switching-based median filters. Some of the state-of the-art switching based median filters are the Rank Conditioned Mean (RCM) [4], the Signal-Dependent Rank Ordered Mean (SD-ROM) [5], the Tri-State Median (TSM) [6], the Adaptive Center Weighted Median (ACWM) [7], the Directional Weighted Median (DWM) [8], the Adaptive Switching Median (ASWM) [9], and the New Switching Based Median (NSWM) [10] filters.

The Signal-Dependent Rank Ordered Mean (SD-ROM) filter excludes the current pixel itself from the sliding operational window. In this filter, multiple thresholds are considered in detection of the corrupted pixels and subsequently, the corrupted pixels are replaced by the Rank-Ordered Mean (ROM) value of the pixels in the current window. The detection technique of the SD-ROM filter has been found to be superior even at high noise density than other switching based median filters. However, the filtering output of the SD-ROM filter is poor at high noise ratio due to its simple prediction and replacement technique. Another recently proposed switching based median filter with better preservation of details on images corrupted by the salt and pepper noise at high noise densities is the new switching based median (NSWM) filter. The NSWM filter has been found to perform well for the removal of salt and pepper noise at high noise ratios (e.g. 70 % or above). But NSWM filter applies a very simple technique for the detection of the noisy pixels. In NSWM filter there is a probability that some of the uncorrupted pixels in the image may also be regarded as the noisy pixels, thereby, leading to false detection and replacement by the NSWM filter. This causes the *streaking effect* at higher noise ratios though the prediction and replacement technique has been found to be superior to other

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switching based median filters for the removal of salt and pepper noise. So, a better impulse detection technique may be adopted instead of the one in the NSWM filter for the reduction of the streaking effect at the filtered output and also better preservation of the image details including thin lines and edges.

In this paper, we present a switching based nonlinear filtering technique to remove the impulse noise from highly corrupted images with better preservation edge and other image details. The algorithm is mainly based on the *detection, prediction* and *replacement* strategy. To minimize the streaking effect and false detections of corrupted pixels at high noise ratios, we adopt the detection stage of the SD-ROM filter to identify the noisy pixels. This paper also studies the overall computational complexity of the proposed algorithm, particularly at high noise ratio. Experiments are carried out in detail to evaluate the proposed method for the removal of salt and pepper noise.

I. IMPULSE NOISE MODEL

Consider an 8-bit gray scale image **X**. Let $Y(i,j)$ be the gray value of the noisy image **Y** at pixel (i,j) and $W(i,j)$ be a window centered at (i,j). We assume here the following impulse noise model

$$\text{Y(i,j)} = \begin{cases} X(i,j), \text{ with probability } 1-r \\ R(i,j), \text{ with probability } r \end{cases} \tag{1}$$

where $X(i,j)$ and $R(i,j)$ denote the pixel values at location (i,j) in the original image and the noisy image, respectively and r is the noise ratio/density. For example, in an 8-bit gray scale image, the salt and pepper noise $R(i,j)$ can take either 0 or 255 whereas for the random-valued impulse noise, $R(i,j)$ is uniformly distributed in [0, 255].

II. PROPOSED ALGORITHM

The algorithm of the proposed scheme is discussed in this section. The modification that is incorporated to the proposed method to that of the earlier method [12] is that the size of the window chosen is 3x3 and an iterative procedure is applied so as to achieve good performance and the better preservation of edges. The algorithm consists of two stages. In the first stage, the noisy pixels are detected by the impulse detection stage of the SD-ROM filter. SD-ROM filter is used because of its ability to detect an impulse with very good accuracy even in the presence of multiple impulses within the sliding window. It applies four distinct rank-ordered differences to detect an impulse. The rank-ordered differences are then individually compared with four increasing thresholds, to be discussed later in this section. In the second stage, if a pixel is considered to be noisy, it is substituted by performing a first-order 1D causal linear prediction from the neighborhood pixels in the current window prior to estimation [10]. Then the noisy pixel is replaced by the median value of the pixels within the current window. This strategy is found to be very effective than the conventional method of replacing an impulse by the median value as practiced in the switching based filter. This is because the center pixel in the current window is the corrupted pixel and is not being considered at all in the filtering stage to compute the median value. Instead, it is first smoothed by predicting its value from its 1D causal neighborhood prior to the estimation. A similar practice was also adopted in the filtering strategy of the SD-ROM filter where the noisy pixel is estimated by the rank-ordered mean (ROM) of the neighborhood pixels in a small window without considering the center pixel itself. The uncorrupted pixels in the image are kept unaltered.

The proposed scheme mainly executes the following three steps recursively until all the pixels in the image Y are processed [12]:

1) ***Detection of the noisy pixel***:

Since the proposed scheme uses the impulse detection stage of the SD-ROM filter, a brief review of this filter is give below. The SD-ROM filter consists of the following two stages [12]:

- Consider a 3×3 window **W** centered at $Y(i,j)$. Define an observation vector containing the pixels in the neighborhood of $Y(i,j)$ and obtained by a left-right, top-to-bottom scan of the window: $\mathbf{w} = [w1\ w2 \ldots\ldots w8]$.
- Arrange the observation vector **w** by their ranks **Δ** given by $\mathbf{\Delta} = [\Delta1, \Delta2, \ldots, \Delta8]$ such that $\Delta1 \le \Delta2 \le \ldots\Delta8$. Define the rank-ordered mean (ROM) by $M = (\Delta4 + \Delta5)/2$.
- Obtain the rank-ordered differences τd, where

$$\tau\text{d} = \begin{cases} \Delta\text{i} - Y(i,j), \text{if } Y(i,j) \le M \\ Y(i,j) - \Delta9 - \text{i}, \text{otherwise} \end{cases} \tag{2}$$

for $i = 1, \ldots. 4$

- Consider $Y(i,j)$ to be noisy if $\tau i^{\text{d}} > \text{Ti}$ where T1,T2,T3 an T4 are threshold values such that Ti < Ti+1 , for i =1,...,4.

2) ***Prediction of the noisy pixel:***

If $Y(i,j)$ is detected as a corrupted pixel, it is substituted by a predicted value as follows:

- If the current pixel lies in the range of 0 and 255 then keep the pixel value unaltered and shift the window to the next pixel location in the image.
- Otherwise, store the elements of the window **W** in an 1D array **Y***a* and sort them in an ascending order.
- Take a left-to-right scan of the 1 D array, if any value of **Y***a* is found to be equal to255, substitute it by its causal linear prediction given by:
  $\text{Ya(n)} = \alpha * \text{Ya(n-1)}$, where $\alpha = RYY(1) / RYY(0)$, $0 < \alpha < 1$, $RYY(1)$ is the autocorrelation for lag 1 and $RYY(0)$ is the autocorrelation for lag 0.

Define, $RYY\ (1) = \{Ya(n-2) * Ya(n-1)\}$ and $RYY\ (0) = \{Ya(n-1)\}^2$. If $\alpha = 0$, substitute Ya(n) by Ya(n-1).

- Next, consider a right-to-left scan of **Y***a* . If a value of 0 appears at any location, substitute it by its predicated value given by:
  $Ya(n) = \alpha * Ya(n+1)$, where $RYY\ (1) = \{Ya(n+2) * Ya(n+1)\}$ and $RYY\ (0) = \{Ya(n+1)\}^2$. If $\alpha \geq 1$, substitute Ya(n) by Ya(n+1).

3) *Estimation of the noisy pixel:*

- Obtain a new array **Z***a* resulting from the substitutions in **Y***a* discussed in the previous step and again sort its elements in ascending order. Therefore, **Z***a*= $\{Za(1), Za(2), \ldots, Za(8), Za(9)\}$, such that $Za(1) < Za(2)$, $Za(2) < Za(3)$, and so on.
- Find the median value of **Z***a* .
- Replace the current pixel under processing by the *median* value.

IV. ILLUSTRATION OF THE PROPOSED ALGORITHM

Each and every pixel of the image is checked for the presence of salt and pepper noise pixel. During processing if a pixel element lies between "0 and 255", it is left unchanged. If the value is 0 or 255, then it is a noisy pixel and it is substituted by a substitution pixel. [10]

Array labeled *Y*1 displays an image corrupted by salt and pepper noise.

Array labeled *Y*2 depicts the current processing window and a pepper noise pixel. The square shown in solid line represents the window; and element inside the circle represents a pepper noise pixel:

$Y_1 =$

20	189	178	160	199
210	200	205	188	234
168	169	255	255	0
0	255	255	255	0
0	0	255	0	255

$Y_2 =$

200	189	178	160	199
210	200	205	188	234
168	199	255	255	0
0	255	255	255	0
0	0	255	0	255

If the current pixel under processing is between 0 and 255, it is left unchanged. Otherwise it will be replaced by a new pixel value estimated using the proposed algorithm. For this purpose, the elements inside processing window are arranged as an array *YA* and sorted in ascending order.

$Y_A =$

169	188	200	205	255	255	255	255	255

$Z_A =$

169	188	200	205	200	255	255	255	255

Check for the pixel elements of value "255" starting from the left. If the pixel value is "255", then that value will be substituted by a predicted value from the immediate neighborhood pixel. Array *ZA* illustrates this. The element inside the circle is the substitute pixel for the pepper noise pixel. This is repeated for all the pixels having the value "255". Array *ZA* is sorted again to find the median. This is shown as array *ZD*. The element encircled is the median.

$Z_D =$

169	188	200	200	200	200	205	205	205

$Z_P =$

200	189	178	160	199
210	200	205	188	234
168	199	200	255	0
0	255	255	255	0
0	0	255	0	255

Finally, the current noisy pixel in the window in array *Y*2 is replaced with the new median value. The final processed array is shown as *ZP*. The element encircled in array *ZP* is the final estimate of the pepper noise pixel of array *Y*2. In the proposed algorithm, a 3×3 window will slide over the entire image. Computation complexity is minimal with a 3 × 3 fixed window. This procedure is repeated for the entire image. Similar procedure can be adopted for the salt noise substitution, estimation, and replacement.

V. SIMULATION RESULTS

In this section, results are presented to illustrate the performance of the proposed algorithm. Images are corrupted by uniformly distributed salt and pepper noise at different densities for evaluating the performance of the algorithm. The image selected is that of "cameraman". A quantitative comparison is performed between several filters and the proposed algorithm in terms of Peak Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE), Image Enhancement Factor (IEF), Structural Similarity (SSIM) Index. The results show improved performance of the proposed algorithm in terms of these measures. Matlab R2007b on a PC equipped with 2.21 GHz CPU and 2 GB RAM has been used for evaluation of computation time of all algorithms. The performance of the algorithm for various images at different noise levels from 70% to 90% is studied, and results are shown in Figures. The metrics for comparison are defined as follows:

$$\mathrm{PSNR} = 10\log 10 \frac{255}{\mathrm{MSE}} \qquad (3)$$

$$\mathrm{MSE} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(rij - xij)^2 \qquad (4)$$

$$\mathrm{IEF} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(nij - rij)^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}(xij - rij)^2} \qquad (5)$$

$$\mathrm{SSIM}(r,x) = \frac{\left(2\mu_r\mu_x + C1\right)\left(2\sigma_{xy} + C2\right)}{(\mu_r^2 + \mu_x^2 + C1)(\sigma_r^2 + \sigma_x^2 + C2)} \qquad (6)$$

where *rij* is the original image, *xij* is the restored image, and *nij* is the corrupted image. The Structural Similarity index between the original image and restored image is given by SSIM where μr and μx are mean intensities of original and restored images, σr and σx are standard deviations of original and restored images, *rp* and *xp* are the image contents of *p*th local window, and *G* is the number of local windows in the image.

Table I. Performances of various filters on "Cameraman" image at different noise densities. (A) PSNR in dB and (B) MSE

(A)

Method	% of Noise		
	50	70	90
SM	14.26	9.46	6.18
CWM	20.09	14.27	10.56
PSM	22.7	18.24	15.07
Proposed	25.24	21.69	17.60

(B)

Method	% of Noise		
	50	70	90
SM	2479.63	7363.96	15499
CWM	932.05	7228.47	15420.53
PSM	568.43	3016.29	12818.31
Proposed	569.77	596.15	901.50

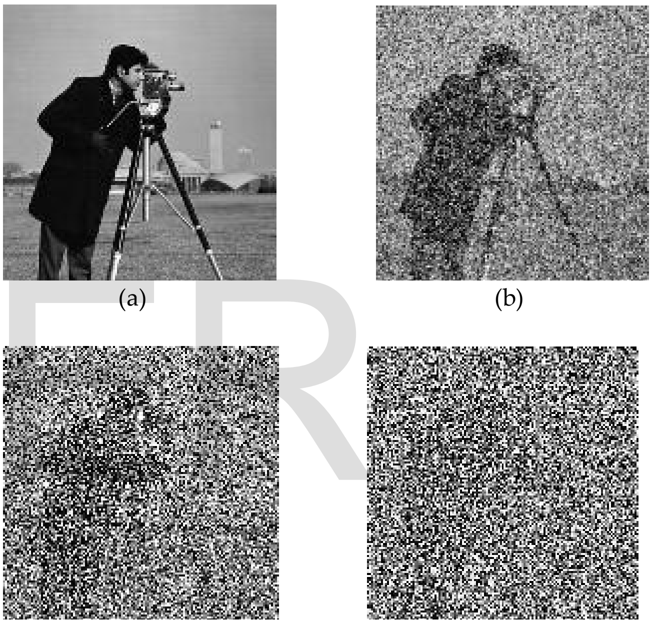
Table II. Performances of various filters on "Cameraman" image at different noise densities. (A) IEF and (B) SSIM

(A)

Method	% of Noise		
	50	70	90
SM	0.288	0.260	0.494
CWM	16.43	4.60	1.45
PSM	10.47	1.91	1.16
Proposed	17.49	24.66	18.21

(B)

Method	% of Noise		
	50	70	90
SM	0.246	0.068	0.017
CWM	0.647	0.213	0.027
PSM	0.564	0.066	0.015
Proposed	0.694	0.690	0.596

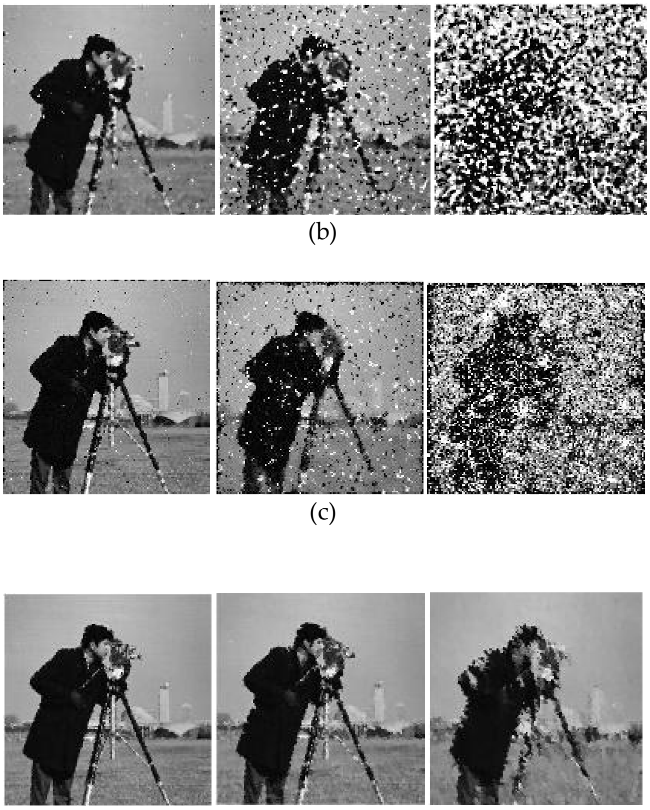


(a) (b)

(c) (d)

Figure 2. (a) Original "Cameraman" image (b) Corrupted by 50% noise (c) Corrupted by 70% noise (d) Corrupted by 90% noise

(a)



(b)

(c)

(d)

Figure 3. Result of different filters on "Cameraman" image using (a) SM (b) CWM (c) PSM (d) Proposed filter at noise ratios of 50%, 70%, 90% respectively.

VI. CONCLUSION

A modified median filtering scheme and an algorithm for removal of high-density salt and pepper noise in images is proposed. The algorithm is based on a new concept of substitution prior to estimation in contrast to the standard switching-based nonlinear filters. Noisy pixels are substituted by prediction prior to estimation. A simple novel recursive linear predictor is developed for this purpose. A subsequent optimization by median filtering results in final estimates. The performance of the algorithm is compared with that of SMF, PSMF, in terms of Peak Signal-to-Noise Ratio, Mean Square Error, Mean Structure Similarity Index, and Image Enhancement Factor. Both visual and quantitative results are demonstrated. The results show reduced streaking at high noise densities. The proposed algorithm can be a good compromise for salt and pepper noise removal in images at high noise densities. However, further reduction in computational complexity is desirable.

REFERENCES

[1] W. Pratt, *Digital Image Processing*. John Wiley & Sons Inc, 1978.

[2] D. R. K. Brownrigg, "The weighted median filter," *Commun. ACM*, vol. 27, pp. 807–818, August 1984.

[3] S.-J. Ko and Y. Lee, "Center weighted median filters and their applications to image enhancement," *IEEE Transactions on Circuits and Systems*, vol. 38, no. 9, pp. 984–993, September 1991.

[4] R. C. Hardie and K. E. Barner, "Rank-conditioned rank selection filters for signal restoration," *IEEE Transactions on Image Processing*, vol. 2,pp. 192–206, 1994.

[5] E. Abreu and S. Mitra, "A signal-dependent rank ordered mean (SDROM) filter-a new approach for removal of impulses from highly corrupted images," in *ICASSP*, vol. 4, pp. 2371 –2374, 1995.

[6] T. Chen, K. K. Ma, and L. H. Chen, "Tri-state median filter for image denoising," *IEEE Transactions on Image Processing*, vol. 8, no. 12, pp. 1834–1838, Dec. 1999.

[7] T. Chen and H. R. Wu, "Adaptive impulse detection using center weighted median filters," *IEEE Signal Processing Letters*, vol. 8, no. 1, pp. 1–3, January 2001.

[8] Y. Dong and S. Xu, "A new directional weighted median filter for removal of random-valued impulse noise," *IEEE Signal Processing Letters,* vol. 14, no.3, pp. 193-196, 2007.

[9] S. Akkoul, R. Ledee, R. Leconge, and R. Harba, "A new adaptive switching median filter," *IEEE Signal Processing Letters*, vol. 17, pp. 587-590, 2010.

[10] V. Jayaraj and D. Ebenzer, "A new switcing-based median filtering scheme and algorithm for removal of high-density salt and pepper noise in images," *ERASIP Journal on Advances in Signal Processing*, vol. 2010, pp. 50:1-50:11, 2010.

[11] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," *IEEE Trans. On Image Processing*, vol. 13, pp. 600-612, 2004.

[12] Bhabesh Deka and Dipranjan Baishnab, "A Linear Prediction Based Switching Median Filter for the Removal of Salt and Pepper Noise from Highly Corrupted Image", *IEEE CISP proceedings*, vol.14, pp. 99-103, 2012.