ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol. 3 , No.1, Pages : 316 – 321 (2014)

Special Issue of ICETETS 2014 - Held on 24-25 February, 2014 in Malla Reddy Institute of Engineering and Technology, Secunderabad– 14, AP, India

Rank-ordered Image Statistic & Decision Based Algorithm for Eliminating of High Percentage Impulse Noise

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*Abstract***— Digital Images are contaminated by noise during acquisition and/or transmission over communication channel. Elimination of Impulse noise from images without losing their features is an important aim in digital image processing applications. The median filter is a good process for eliminating impulse noise; however, it fails to preserve the image details when the window size is made larger. In this paper, two filtering schemes, Rank-Ordered image statistic, are introduced for cleaning the images confounded by impulse noise. These Decision Based modified Rank ordered mean filter & Rank-ordered based nonlinear 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. This is quite efficient in eliminating uniform noise and impulse noise. Simulation results show that the proposed filter is superior in terms of eliminating impulse noise as well as preserving edges and fine details of digital images and results are compared with other existing nonlinear filters. The performance of the filtering technique has been evaluated by applying it on several test images corrupted by different levels of impulse noise and the results obtained are presented and compared with that of the existing filtering techniques.**

*Keywords***—Median filter, Image statistics, Decision Based Algorithm, impulse detection, impulse noise and order-statistics.**

I. INTRODUCTION

IMAGES are nonstationary processes and are often contaminated by the heavily impairing impulse noise during their acquisition and/or transmission over the communication channels. Removal of this additive impulse noise is a significant task in image restoration. In images, edges contain valuable information and are important for visual perception. Fine detail retention is an essential in many applications where the preservations of signal structures are not to be compromised. Therefore, the filters designed for image processing are required to attenuate noise without losing edges and fine details [1]-[4].

Median filtering, suggested by John Tukey in 1971, is an effective technique for discarding outliers (impulses), since its Asymptotic Relative Efficiency with respect to mean estimator, $ARE\{med(x_i), \overline{x}\}$ is 2 for long tailed distribution [5]. Median filter preserves edge structures quite well but fails to retain fine details satisfactorily when window size is enlarged [6]. Weighted median filters [7]-[8] and, particularly, Center weighted median filters [9]-[10] are the important extensions of median filters suitable for detail preservation and noise filtering. However, there exists a clear trade-off between detail preservation and noise removal properties of these filters. Moreover, the weights to be assigned to the samples inside the window are to be chosen carefully depending on the characteristics of both the input image and noise, which is not an easy task.

A variety of switching median filters has been reported in the literature for the removal of impulse noise with feature preservation properties [11]-[13]. The impulse noise detection mechanisms employed in these filtering techniques are complex and time consuming. In order to eliminate impulse noise effectively without destroying the image edges, thin lines structures and fine details, a new image statistic technique, referred to as rank-ordered statistic, has been introduced [14]. This technique performs noise detection, which takes the output from sum of the rank-ordered absolute difference between the central pixels value with neighborhood pixel values within the window size of noisy image. It is good two-dimensional statistic for detecting impulse noise and useful for impulsive noise elimination in images. This image statistic exhibits satisfactory performance on images corrupted by low levels of impulse noise, i.e., upto 30%. However, rank-ordered image statistic filter fails to perform adequately and produced blurring when applied on images confounded by high levels of impulse noise.

In this paper, two nonlinear filtering schemes, Rank-Ordered Logarithmic/Absolute Difference image statistic& Decision based algorithm [15-16] are introduced for cleaning the images corrupted by outliers (impulses). The presence of impulse noise is detected & eliminated by Decision based algorithm, if the pixel is noisy; and is detected by comparing the sum of rank-ordered logarithmic difference between the central pixel and its neighborhood pixels inside the window with a preset threshold value if the pixel is noisy free. If the pixel under consideration is detected as an outlier by the ROLD statistic than median filter can be used to eliminate the outlier.

The outline this paper is organized as follows. In Section II, rank-ordered image statistic & Decision based Algorithm filtering techniques for detecting and eliminating of impulses is described. In Section III, simulation results are presented to demonstrate the performance of the proposed filtering techniques. The results are discussed and compared with those obtained using conventional filters. Conclusions are summarized in Sect. IV.

II. DECISION BASED ALGORITHM & RANK ORDERED STATISTIC FILTERING TECHNIQUES

A. *Noise Image Modeling*

The performance of an image restoration filter depends on the image and noise model. The assumption underlying the definitions of the filters is that the image to be filtered is locally smoothly varying and separated by edges. The noise considered is an impulsive noise in which only some pixels are corrupted and others are noise-free. The image and noise have been modeled on this basis for investigating the performance of the proposed filters.

Consider an image {x} of u rows and v columns. When this image is acquired and transmitted it may be corrupted by impulse noise. This noisy image is described as

$$y(i,j) = x(i,j) + n(i,j) \quad (1)$$

where $n(i,j)$ is impulse noise with random values. The noise is assumed to be uniformly distributed with a probability

$$y(i,j) = \begin{cases} n(i,j), & \text{with probability } p \\ x(i,j), & \text{with probability } 1-p \end{cases} \quad (2)$$

where $i = 1, 2.....u,\ \ j = 1, 2.....v,\ \ 0 \le p \le 1$ and $n(i,j)$ is the gray-level value of the noisy pixel. For 8 bit images, if a pixel is corrupted, it is replaced by positive or negative impulse noise. This impulse noise is caused by malfunctioning pixels in camera sensors, faulty memory locations in hardware, or transmission in a noisy channel. Mainly, there are two types of impulse noise contaminating images. They are the salt-and-pepper noise and the random-valued impulse noise. For images corrupted by salt-and-pepper noise (respectively, random-valued noise), the noisy pixels can take only the maximum and the minimum values (respectively, any random value) in the dynamic range. For example, the noisy pixel takes '0' for a negative impulse and '255' for a positive impulse in the case of fixed valued impulse noise (salt and pepper noise).

B. *Eliminating of Impulse Noise*

Eliminating of impulse noise is achieved in two steps. In the first step, impulse detection and corrects are used to identify the corrupted pixels within the sliding window using decision based modified rank-ordered mean filter if the noisy pixel is 0 or 255. In the next step, Rank-ordered image statistic is used to identify the corrupted pixels within the sliding window using rank-ordered image statistic, median or median based filtering is performed on the identified noisy pixels from the noise free pixels.

1. Impulse Detection and correction for noise pixels is 0 or 255: The Decision based modified Rank ordered mean filter (DBMROMF) initially detects impulse and corrects it subsequently. All the pixels of an image lie between the dynamic ranges [0,255]. If the processed pixel holds minimum (0) or maximum (255), pixel is considered as noisy and processed by Rank ordered mean filter else as not noisy and that pixel is unaltered. The brief illustration of this is as follows. Step 1: Choose 2-D window of size 3x3. The processed pixel in current window is assumed as $\{y(i,j)\}$. Step 2: Check for the condition 0 < $\{y(i,j)\}$ < 255, if the condition is true then pixel is considered as not noisy and ROAD/ROLD is used to detect presence of noise from even this noisy free pixel. Step 3: If the processed pixel $\{y(i,j)\}$ holds 0 or 255 i.e. ($\{y(i,j)\}$ =0 or $\{y(i,j)\}$ =255) then pixel $\{y(i,j)\}$ is considered as corrupted pixel. Convert 2D array into 1D array. Sort the 1D array which is assumed as $\{s(i)\}$. Step 4: Initialize two counters, forward counter (F) and reverse counter (L) with 1 and 9 respectively. When a 0 or 255 are encountered inside the window, F is increased by 1 or L is decremented by 1 respectively. If the processing pixel is noisy and the current processed window $\{s(i)\}$ contains few 0's and 255's. So check for 0 or 255 in sorted array $\{s(i)\}$, simultaneously counters would propagate along the $\{s(i)\}$ array thereby eliminating outliers retaining only the pixel that hold values other than 0 and 255. After checking all the pixels F and L would hold a particular value indicating the number of outliers eliminated on either sides. The noisy pixel is replaced by the midpoint of the sorted array.

The Decision based modified Rank ordered mean filter (DBMROMF) is defined as follows: In the selected window, the processed pixel holds 0 or 255. So the processed pixel is considered as noisy. Initialize forward counter F=1 and reverse counter L=9. Convert the 2D array into 1D array and sort the converted array. F and L counter moves in forward and reverse directions respectively.

$$\begin{pmatrix} 86 & 255 & 255 \\ 0 & 255 & 172 \\ 255 & 0 & 250 \end{pmatrix} \longrightarrow \begin{pmatrix} 86 & 255 & 255 \\ 0 & 168 & 172 \\ 255 & 0 & 250 \end{pmatrix}$$

Original neighborhood Restored image

Unsorted array $\{y(i,j)\}$: 86 255 255 0 255 172 255 0 250

Sorted array $\{s(i)\}$: 0 0 86 172 250 255 255 255 255

Now check for the presence of 0 or 255 in the sorted array. Every time a 1 is detected F is incremented by 1 and 255 is detected L is decremented by 1. In the above example there are two 0 and four 255. Hence F is incremented by two times and L is decremented by four times. Now finally F is holding 2 and L is holding 7. Now the corrupted pixel is replaced with midpoint of the trimmed array i.e. corrupted pixel is replaced by (S(3)+S(5))/2 = (86 +250)/2= 168.

2. Impulse Detection and correction for noise pixels range is [1, 254]: The performance of the impulse detection is a crucial factor in the filtering, because the whole denoising process depends on its efficacy. The ROAD/ ROLD image statistic detects the presence of an impulse by comparing the sum of rank-ordered absolute/logarithmic difference between central pixel inside the window and its neighboring pixels with a preset threshold value. This impulse detection mechanism can detect the presence of both positive and negative impulses. The ROAD/ROLD image statistic is defined as follows:

Consider a 3x3 matrix from the noisy image $\{y(i,j)\}$

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$$\begin{pmatrix} y(i-1,j-1) & y(i-1,j) & y(i-1,j+1) \\ y(i,j-1) & y(i,j) & y(i,j+1) \\ y(i+1,j-1) & y(i+1,j) & y(i+1,j+1) \end{pmatrix} \quad (3)$$

ROAD image statistic: The absolute difference between the gray-level values $y(i+s, j+t)$ where $-1 \le (s,t) \le 1$ and $y(i, j)$ is defined as

$$d_{st}\{y(i,j)\} = |y(i+s, j+t) - y(i,j)|; \quad -1 \le (s,t) \le 1 \quad (4)$$

The values of $d_{st}\{y(i, j)\}$ are arranged in ascending order

$$r_1\{y(i,j)\} \le \cdots \le r_8\{y(i,j)\} \quad (5)$$

The definition of ROAD Statistic is given by

$$ROAD_m\{y(i,j)\} = \sum_{k=1}^{m} r_k\{y(i,j)\} \quad (6)$$

The values of m can be chosen from the range, $2 \le \mathrm{m} \le (2\mathrm{N}+1)^2 - 2$.

The computation of ROAD is illustrated as shown bellow. Consider a 3×3 matrix form noisy image $y(i, j)$ and let the value of m be 4.

$$\begin{pmatrix} 213 & 171 & 88 \\ 216 & 16 & 107 \\ 218 & 202 & 139 \end{pmatrix} \longrightarrow \begin{pmatrix} 27 & 6 & 27 \\ 55 & - & 54 \\ 57 & 39 & 32 \end{pmatrix}$$

Original neighborhood Absolute differences

The absolute differences $d_{st}\{y(i, j)\}$ are arranged in ascending order upto first four values as m is equal to 4.

$$r_1 = 6,\ r_2 = 27,\ r_3 = 27 \ \text{ and } \ r_4 = 32 \quad (7)$$

Finally, the ROAD Statistic for the central pixel $y(i, j)$ is

$$ROAD = \sum_{i=1}^{4} r_i = 6 + 27 + 27 + 32 = 92$$

ROAD provides a measure of how close the center pixel value is to its four closest neighbors in a 3×3 window. Noise-free pixels including edge pixels should have at least half of the neighbors having similar intensity (i.e. their ROAD values will be small). Thus the value of ROAD can be used to the detect impulse noise. If the ROAD value of a pixel is greater than a preset threshold, then the central pixel is declared a noisy pixel; otherwise the pixel is considered noise-free. For random-valued impulse noise, some noise values maybe close to their neighbor values, in which case, the ROAD values may be in the middle of range and not large enough to distinguish them.

ROLD image statistic: The logarithmic function absolute difference between the gray-level values $y(i+s, j+t)$ where $-1 \le (s,t) \le 1$ and $y(i, j)$ is defined as

$$d_{st}\{y(i,j)\} = \log_a |y(i+s, j+t) - y(i,j)|; \quad (8)$$

Clearly for any $a > 1$, the number $d_{st}\{y(i, j)\}$ is always in $(-\infty, 0]$. In order to keep it in the dynamic range [0, 1], we use a truncation and a linear transformation

$$d_{st}\{y(i,j)\} = 1 + \max\{\log_a |y(i+s, j+t) - y(i,j)|, -b\}/b \quad (9)$$

where, a, b are positive numbers to be chosen. The value of a controls the shape of the curve of the logarithmic function and the value of b decides the truncation position. The selections of the numbers a and b have great effects on the accuracy of this detection. To choose this detection properly, consider the function $h_{a,b}(x)$ defined as

$$h_{a,b}(x) = 1 + \max\{\log_a x, -b\}/b, \ (x \ge 0) \quad (10)$$

From the definition of $h_{a,b}(x)$, it find that the range of x for $h_{a,b}(x)$ to be zero is $[0, 1/a^b]$. Here, the choosing of a and b is the main problem which decides detection range. This is just another good reason for using the logarithmic function: it converts the problem about the shape of the transformation function into one about the truncation point. Recall that x denotes the absolute difference between a pixel value and that of its neighbors. In general, for an 8-bit gray level image, if this absolute difference is less than 8, it is not noticeable. So, it set $h_{a,b}(x) = 0$ in [0, (8/255)]. Since $8/256 = (1/2)^5$, a and b are chosen as 2 and 5. Accordingly, the $d_{st}\{y(i, j)\}$ is defined as

$$d_{st}\{y(i,j)\} = 1 + \max\{\log_2 |y(i+s, j+t) - y(i,j)|, -5\}/5; \quad (11)$$

The values of $d_{st}\{y(i, j)\}$ are arranged in ascending order

$$r_1\{y(i,j)\} \le r_2\{y(i,j)\} \le --- \le r_8\{y(i,j)\} \quad (12)$$

(7)

The definition of ROLD statistic is given by

$$ROLD_m\{y(i,j)\} = \sum_{k=1}^{m} r_k\{y(i,j)\} \quad (13)$$

where the value of m can be chosen from the range $2 \le m \le (2N+1)^2 - 2$ and $(2N+1) \times (2N+1)$ is the size of the two-dimensional window slid over the noisy image for impulse detection.

The computation of ROLD is illustrated as shown bellow. Consider a 3×3 matrix from noisy image $\{y(i, j)\}$ and let the value of m be 4.

$$\begin{pmatrix} 213 & 171 & 88 \\ 216 & 186 & 107 \\ 218 & 202 & 139 \end{pmatrix} \longrightarrow \begin{pmatrix} 1.95 & 1.78 & 2.32 \\ 1.98 & - & 2.26 \\ 2 & 1.8 & 2.11 \end{pmatrix}$$

Original neighborhood Logarithmic function on absolute differences

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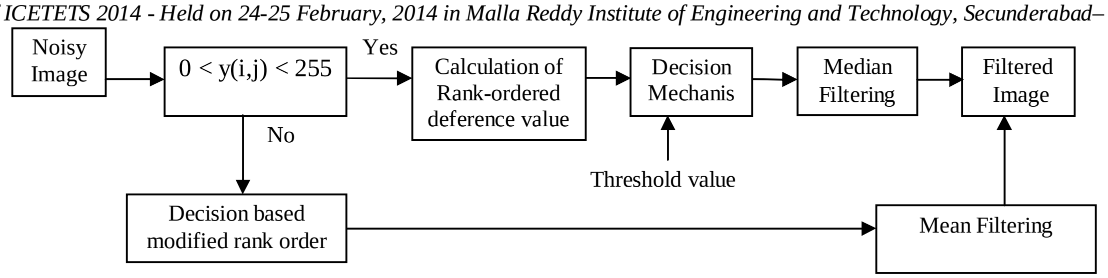

Fig.1 Block diagram of rank ordered Statistic based filtering strategies.

The absolute differences $d_{st}\{y(i, j)\}$ are arranged in ascending order upto first four values as m is equal to 4.

$$r_1 = 1.78,\ r_2 = 1.8,\ r_3 = 1.95,\ \text{and}\ r_4 = 1.98 \quad (9)$$

Finally, the ROLD statistic for the central pixel $y(i, j)$ is

$$ROLD = \sum_{i=1}^{4} r_i = 1.78 + 1.80 + 1.95 + 1.98 = 7.51 \quad (10)$$

If the ROLD value of a pixel is greater than a preset threshold, then the central pixel is declared a noisy pixel; otherwise the pixel is considered noise-free. For random-valued impulse noise, some noise values may be close to their neighbor values, in which case, the ROLD values may be in the middle of range and large enough to distinguish them.

Filtering model: The impulse noise, upon its detection, is eliminated using one among a variety of nonlinear order-statistic filters. Fig.1 illustrates filtering strategy using Rank-ordered image statistic for eliminating impulse noise. In this scheme, image statistic and DBA is employed for detection and median/ mean filters are used for eliminating impulse noise.

The sum of rank-ordered logarithmic difference between the central pixel value and surrounding pixel values within window at point/pixel over the noisy image is compared with the threshold value at decision mechanism. The impulse detection and elimination are carried out by the filtering strategy as described below:

if $\{y(i, j)\}$ is 0 or 255, then

$\{y(i, j)\}$ is a noisy pixel, mean filtering

else

if $\{y(i, j)\}$ is not o or 255, then

$ROAD / ROLD\{y(i, j)\} \geq T$

$\{y(i, j)\}$ is a noisy pixel,

Median filtering is employed on $\{y(i, j)\}$

else

$\{y(i, j)\}$ is a noise-free pixel,

no filtering is performed on $\{y(i, j)\}$

end; end;

where, T is the threshold value and the efficacy of detection process depends on the choice of the threshold value. Upon proper selection of threshold values, the ROLD statistic filtering scheme offers improved visual quality of filtered images in addition to much reduced Mean Square Error values.

The performance of ROLD statistic detection is affected by threshold values. If threshold value is set to zero, then the noise removing ability of this detection is, as good as that of standard median filter. In this case, the filtering is performed on all input pixels (noisy as well as noise-free). When the threshold value is increased, more and more noise-free pixels are left unfiltered. At a particular threshold value is called optimal threshold value; the filtering is performed only on noisy pixels. If the threshold value is increased any further, the noise removing ability of the ROLD based filtering decreases, because the filtering is not performed on some noisy pixels also. The filter, when operated at optimal threshold value, preserves thin lines and other detailed features satisfactorily.

III. Results

Performance of proposed filtering techniques, namely, RADBMF and RLDBMF are compared with their conventional counterparts, that is, MF, ROLD/ROAD statistic based filters. The filtering techniques are tested by applying them on Lena image of size 256 x 256 corrupted with different levels of impulse noise. The window size of the filters is chosen to be 3x3. 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.

$$\text{MSE} = \frac{\sum |x(i, j) - f(i, j)|^2}{\text{number of rows} \times \text{number of columns}} \quad (11)$$

$$\text{PSNR} = 10 \log_{10} \left[\frac{255^2}{\text{MSE}} \right] \quad (12)$$

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where, $x(i, j)$ represents the pixel intensities of the original (noise-free) image and $f(i, j)$ represents the pixel intensities of the filtered image.

The proposed RADBMF and RLDBMF filters are found to perform quite well on images corrupted with the impulse noise levels up to 60%. The PSNR values obtained using different filtering techniques on Lena image at different levels of impulse noise are summarized in Table.1. A filter producing a lower MSE and a higher PSNR value is considered to be superior filter in terms of noise elimination and restoration of image features. Higher PSNR values are achieved when the images are processed using ROLD based filters as seen from Table.1.

In addition, Fig.2 illustrates that the RLDBMF statistic filters perform better than conventional filters in terms of noise elimination and feature preserving characteristics. In the images restored by conventional filers, the impulses are filtered out but the loss of fine details results in blurring. The images filtered by the RLDBMF based filters are more pleasant for visual perception due to their superior edge and detail preserving characteristics. Among the Rank-ordered based filters, RLDBMF generally exhibits better performance than RADBMF as seen from Table.1 and Fig.2. Fig.3 graphically depicts the PSNR values achieved using different filtering techniques on Lena image at different levels of impulse noise. The RLDBMF of the window size 3x3 offers the best possible performance compared to all other filtering schemes.

TABLE I

PSNR VALUES OBTAINED USING DIFFERENT FILTERING ON LENA IMAGE AT DIFFERENT LEVELS OF IMPULSE NOISE

Type of Filters	**Impulse Noise**							
	5%	***10%***	***20%***	***30%***	***40%***	***50%***	***60%***	***70%***
MF	31.46	30.91	28.74	27.63	26.05	24.06	21.58	19.21
RADMF	37.74	34.26	30.25	27.95	26.27	24.43	21.97	18.75
RLDMF	39.07	34.73	30.96	28.42	26.56	24.85	22.39	19.22
DBMROMF	40.37	36.73	34.66	29.42	29.06	24.85	21.39	18.22
RADDBMF	41.39	37.93	33.74	31.67	28.73	25.31	19.19	16.65
RLDDBMF	42.83	39.65	35.65	33.45	28.46	26.23	21.34	17.03

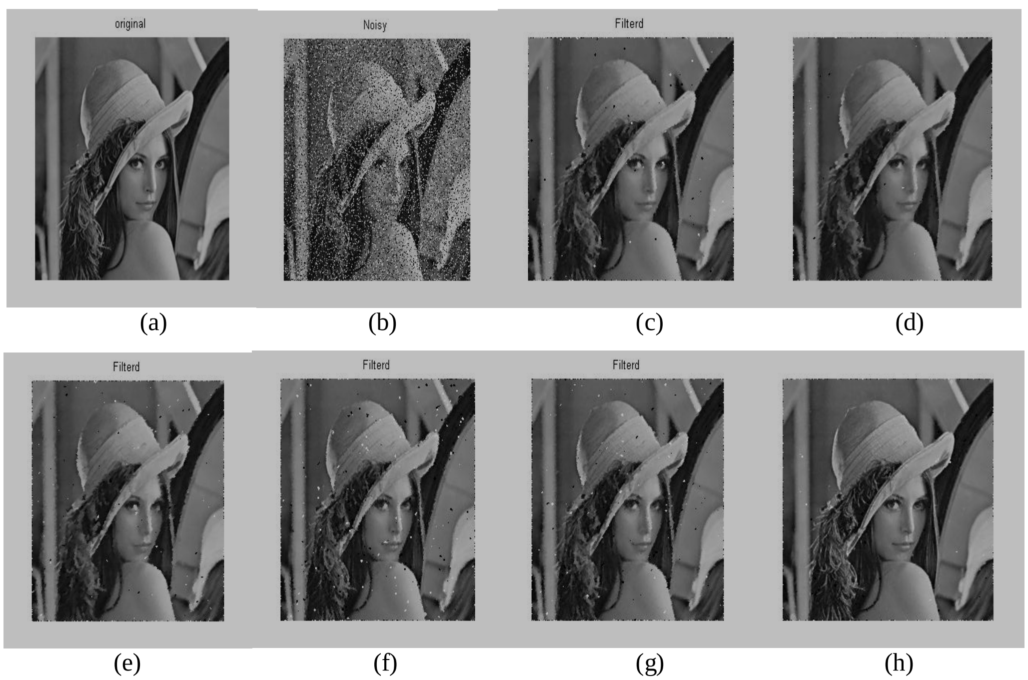

Fig.2 Performance of ROLD based filters (a) Original image; (b) Image corrupted with 30% mixed impulses; Restored images by (c) MF, (d) RADMF (e) ROLMF, (f) DBMROMF, (g) RADDBMF, and (h) RLDDBMF

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Extensive simulation studies conducted on the Lena test image contaminated by different levels of impulse noise show that RLDBMF is superior to the Rank-ordered based filters and conventional filters in terms of filtering characteristics including feature preservation properties. RLDBMF can be chosen to be the best possible filtering strategy for the removal of impulse noise. The RLDBMF is found to perform quite well on images corrupted with the impulse noise levels up to 60%. However, RLDBMF statistic based filters are computationally more complex than their RADDBMF statistic based counterparts. This is the price paid for achieving the improved performance using RLDBMF statistic based filters.

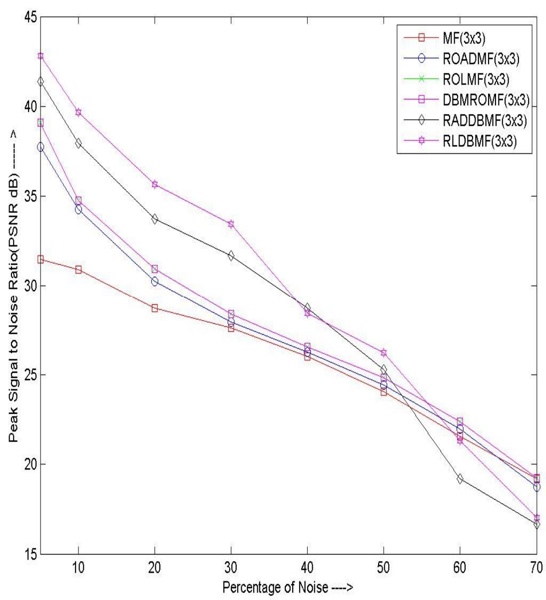

Fig. 3. PSNR values obtained for Lena image corrupted by various levels of impulse using different rank-ordered based filtering techniques

IV. CONCLUSION

Restoration of edges and fine details of image while filtering out the impulse noise is a critical requirement in image processing applications. Uniform application of nonlinear median filtering, irrespective of the fact whether the pixels are corrupted ones or not, results in considerable loss of fine details. Rank-ordered image statistic with decision based algorithm based nonlinear techniques, introduced in this paper is shown to perform filtering on the corrupted pixels. The uncorrupted pixels are also checked whether it's corrupted or not based on surrounding pixels. The two proposed filtering schemes are found to be effective methods\ in eliminating the impulse noise besides preserving the image features quite satisfactorily. Performances of the proposed image statistic filtering schemes are quantitatively evaluated using mean square error (MSE), peak signal to noise ratio (PSNR) and image enhancement factor (IEF) by applying the filters on test image corrupted by different levels of impulse noise. A fairly good number of processed images are presented for visual perception and subjective evaluation. RLDDBMF based nonlinear filters exhibit better performance than their conventional counterparts both in terms of objective and subjective measures. The proposed filter is found to perform quite well on images corrupted with the impulse noise levels upto 70%.

ACKNOWLEDGMENT

The authors acknowledge with thanks, the department of Electronics and Communication Engineering, Mallreddy Institute of Engineering & Technology, Hyderabad, India for providing facilities and support to carry out this research work.

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