Impulse Noise Removal using Cloud Model based Filter

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ABSTRACT
This paper presents image processing, enhancement and restoration of images with the aid of Cloud Model (CM) filter capable of removing impulse noise. In this method, a modified decision based unsymmetrical trimmed median algorithm is used to remove noise pixels which are detected by CM based detector. The performance of CM filter is compared with that of Standard Median (SM), Adaptive Median (AM) and Wiener filters. The PSNR study is conducted at different noise levels ranging from 10% to 90% to show the effectiveness of the proposed filter.

Keywords
Cloud Model (CM), Image processing, Impulse noise, PSNR study.

1. INTRODUCTION
Images are informations formed due to the combination of image and noise. Any image can be affected by a certain degree of noise irrespective of thermal, electrical or otherwise sources. Noise being unwanted information can corrupt the fine details present in an image hence determine image quality. Images are frequently corrupted by impulse noise due to errors generated in camera sensors, analog-to-digital conversion and communication channels. The random value noise or uniform noise and fixed value noise or impulse noise are the two major noises determining the image. This paper focus only on impulse noise as it has wide applications in image processing. Grasping the noise characteristics is necessary to remove impulse noise that corrupts the image pixels. Uncertainties are the major feature determining the details preserved in images. Randomness and fuzziness are the two important features of uncertainty. Randomness is based on two aspects, i.e., the pixels are randomly corrupted by the noise and the noise pixels are randomly set to the maximum and minimum values. Fuzziness focuses on the pixels with extreme values whether they are noisy or not.

Many filters are available to minimize impulse noise and improve the clarity of images. Of these, the Standard Median filters [9] are able to remove the noise pixels without identifying the noisy candidates. They can perform only at low noise levels. But due to its simplicity, various modifications are done in SM filters such as Weighted Median Filter (WM), Centre Weighted Median Filter (CWM) and Directional Weighted Median Filter (DWM). Adaptive median filter is a type using adaptive windows to identify noise. It can perform well only below 50%. A switching weighted adaptive median filter for effective suppression of impulse noise was proposed earlier [3]. Switching median filters [8] are able to identify the noise pixels and replace the median values. Compared with median filters these switching filters have great improvement. Switching filters based on fuzzy logic first identify the location of the noise pixels, then remove the noise one by one and scan the noise image twice. This decreases computational efficiency and increases memory spaces. An adaptive fuzzy switching filter based on fuzzy logic for removing impulse noise from the affected image [4] has the better capability of removing the impulse noise from the corrupted images.

Zhe Zhou [1] has proposed a filter called Cloud Model Filter which is based on cloud model process to remove the impulse noise. Here uncertainty based detector is used to identify the noisy pixels first and subsequently weighted fuzzy mean filter is used to remove the noise candidates present in the image. This approach preserves details effectively in images at high noise level of 90%. In Decision Based Algorithm (DBA) the image is restored using a 3×3 window. If the processing pixel value is 0 or 255, it is processed or else it is left unchanged. At high noise density, the median value will be 0 or 255 which is noisy. In such cases, neighboring pixel is used for replacement. This repeated replacement of neighboring pixel produces streaking effect. The Decision Based Unsymmetric Trimmed Median Filter (DBUTMF) [2] when used at high noise densities, if the selected window contains all 0's or 255's or both then, trimmed median value cannot be obtained. So this algorithm does not give better results at very high noise density.

To overcome the above mentioned problems, this paper explains a Modified Decision Based Unsymmetric Trimmed Median Filter/Algorithm (MDBUTMF) based on Cloud Model. First, noise pixels are detected by Cloud Model based detector. Then Modified Decision Based Unsymmetrical Trimmed Median Algorithm is used to replace the noise pixels. Comparisons are made with that of Standard Median, Adaptive Median and Wiener filters. None of the above mentioned filters touched on the heavily corrupted images. But CM filter can remove noise effectively for higher noise densities. Moreover, it can operate on wide range of noise densities from 10 % to 90% and give better PSNR value than the existing filters. The outline of this paper is as follows. Section 2 elaborates the Impulse Noise. Section 3 describes the proposed method. Experimental results and discussion are explained in Section 4. Finally, Section 5 concludes this paper.

2. IMPULSE NOISE
Impulse noise is otherwise called as "Salt and Pepper" noise. They are short duration noises which degrade an image. They

consider only the value of minimal and maximal intensities i.e., pepper value (gray level-0) or salt value (gray level-255) which appear as black and white spots on the images. They may occur during image acquisition, switching, sensor temperature interference in the channel as well as due to atmospheric disturbances during image transmission. The noise model is given as follows. Let $x_{i,j}$ be the gray value of an image X at pixel location (i, j). [S_{min}, S_{max}] be the dynamic range of X and Y be the noisy image.

$$y_{i,j} = \begin{cases} S_{min} & \text{with probability } p \\ S_{max} & \text{with probability } q \\ x_{i,j} & \text{with probability } 1 - p - q \end{cases} \quad (1)$$

3. PROPOSED METHOD

First, an uncertainty based Cloud Model detector identify the pixels corrupted by impulse noise. Then detected noisy pixels are removed and replaced by the median value based on Modified Decision Based Unsymmetrical Trimmed Median algorithm.

3.1 Cloud Model

Cloud model is an uncertain model applied in data mining [5], image processing [6] and other fields [7]. It combines randomness and fuzziness and forms an intermapping between qualitative and quantitative informations. The definition is given below. Let U be a universal set expressed by exact numbers and C be the qualitative concept associated with U. If number x € U exists, which is the random realization of the concept C and the certainty degree of x for C, *i.e.,* μ(x) € [0, 1], is a random value with stabilization tendency, *i.e.,*

$$\mu: U \rightarrow [0, 1] \quad \forall x \in U \; x \rightarrow \mu(x) \quad (2)$$

The distribution of x on U is called the cloud and each x is called a drop. The cloud can be characterized by three parameters, the expected value Ex, entropy En and hyperentropy He. Ex is the expectation of cloud drops distribution. En is the uncertainty measurement of the qualitative concept determined by randomness and fuzziness.

Expected value Ex.

$$Ex = \frac{1}{n} \sum_{x(i+s,j+t) \in w(i,j)} x(i+s, j+t) \quad (3)$$

Entropy En.

$$En = \sqrt{\frac{\Pi}{2}} \times \frac{1}{n} \sum_{x(i+s,j+t) \in w(i,j)} |x(i+s, j+t) - Ex| \quad (4)$$

3.2 Modified Decision Based Unsymmetrical Trimmed Median Filter

The idea behind a trimmed filter is to reject the noisy pixel from the selected 3×3window. Alpha Trimmed Mean Filtering (ATMF) is a symmetrical filter where the uncorrupted pixels are trimmed which leads to loss of image details and blurring of the image. In order to overcome this drawback, an Unsymmetric Trimmed Median Filter (UTMF) is proposed. The selected 3×3 window elements are arranged in either increasing or decreasing order. The pixel values 0's and 255's are removed from the image. Then the median value of the remaining pixels is considered. This median value is used to replace the noisy pixel. This filter is called Trimmed Median Filter. The proposed Modified Decision Based Unsymmetrical Trimmed Median algorithm is based on three cases.

Case i): If the selected window contains 0/255 pixel value as processing pixel and neighboring pixel values contains all pixels that adds salt and pepper noise to the image:

$$\begin{pmatrix} 0 & 255 & 0 \\ 0 & <255> & 255 \\ 255 & 0 & 255 \end{pmatrix}$$

where "255" is processing pixel, *i.e.,* P_{ij}. All the elements surrounding P_{ij} are 0's and 255's. The median value will be either 0 or 255 which is again noisy. To solve this, the mean of the selected window is identified and the processing pixel is replaced by the mean value. Here the mean value is 170, and replace the processing pixel by 170.

Case ii): If the selected window contains salt or pepper noise as processing pixel and neighboring pixel values contain some pixels that adds salt (i.e., 255 pixel value) and pepper noise to the image:

$$\begin{pmatrix} 70 & 90 & 0 \\ 120 & <0> & 25 \\ 96 & 255 & 72 \end{pmatrix}$$

where "0" is processing pixel, *i.e.,* P_{ij}. Eliminate the salt and pepper noise from the selected window. That is, elimination of 0's and 255's. The 1-D array of the above matrix is [70 90 0 120 0 255 96 255 72]. After elimination of 0's and 255's the pixel values in the selected window will be [70 90 120 96 72]. Here the median value is 90. Hence, replace the processing pixel by 90.

Case iii): If the selected window contains a noise free pixel as processing pixel, it does not require further processing. If the processing pixel is 80 then it is noise free pixel.

$$\begin{pmatrix} 73 & 94 & 60 \\ 127 & <80> & 55 \\ 36 & 28 & 12 \end{pmatrix}$$

3.3 Algorithm

Step 1: Initialize N=1 and threshold δ is a positive integer. Denote n as the number of uncorrupted pixels and initialize n=0.

Step 2: Calculate expected value Ex.

Step 3: Calculate entropy En of all the pixels.

Step 4: Calculate w_{max} and w_{min} values.

$$w_{max} = \text{Max}(S_{max}, Ex+3En) \quad (5)$$
$$w_{min} = \text{Min}(S_{min}, Ex-3En) \quad (6)$$

Step 5: If $w_{max} < x_{i,j} < w_{min}$, then $x_{i,j}$ is an uncorrupted pixel and go to step 6.

Step 6: Identify the other noise pixels in $w_{i,j}$. If $w_{max} < x_{i+s,j+t} < w_{min}$, then $x_{i+s,j+t}$ Will remain and n=n+1.

Step 7: If $w_{max} < x_{i,j} < w_{min}$ with $n < \delta$ then set N=N+1 and go to step 2 ; otherwise $x_{i,j}$ is a noise candidate.

Step 8: Select a 3×3 window with center element as processing pixel P_{ij}.

Step 9: If the selected window contains all the elements as 0's and 255's.Then replace P_{ij} with the mean of the element of window.

Step 10: If the selected window contains not all elements as 0's and 255's. Then eliminate 255's and 0's and find the median value of the remaining elements. Replace P_{ij} with the median value.

Step 11: Repeat steps 9 to 10 until all the pixels in the entire image are processed.

4. EXPERIMENTAL RESULTS AND DISCUSSION

For experimental study, several 512 X 512 grayscale images such as Lena.jpg, Barbara.png and House.png affected by the impulse noise with noise occurrence of 10% to 90% are considered. Emphasis is given on two aspects, the accuracy of the noise detection and the quality of the restored image. The images are processed by the fourth generation programming language MATLAB. Matrix Laboratory (MATLAB) is a numerical computing environment which is user friendly and operating system independent simulation tool used widely for image processing applications. The result of the proposed CM filter is compared with Standard Median (SM), Adaptive Median (AM) and Wiener filters. Standard Median filter (SMF) unconditionally fulfill on each pixel without considering whether the pixel is bad or not. As a result, the uncorrupted pixels are altered and may damage the image details at high noise levels. 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 of the image. Wiener filter (WF) is not an adaptive filter. The quantitative measures used for comparison is the Peak Signal-to-Noise Ratio (PSNR) between the original and restored images. PSNR value is evaluated using the following equation:

$$PSNR = 10 \log_{10} \left(\frac{255\times 255}{MSE} \right) \quad (7)$$

$$MSE = \frac{1}{M\times N} \sum_{i,j} (S_{i,j} - Y_{i,j})^2 \quad (8)$$

where

MSE mean square error;
S original image;
M×N size of image;
Y restored image.

Following tables show the comparison of PSNR value obtained for various filters for the test images such as Lena.jpg (Table 1), Barbara.png (Table 2) and House.png (Table 3) at different noise densities.

Table 1. PSNR for various filters for Lena.jpg image at different noise densities

Noise in %	PSNR in dB			
	SMF	AMF	WF	CMF
10	60.4	30.8	30.7	30.8
20	53	25.1	25.1	26.9
30	44.5	21.5	21.4	20.6
40	36.1	18.9	18.8	22
50	37.8	17.1	17	29.2
60	23.6	15.5	15.5	19.8
70	18.9	14.3	14.3	18.5
80	15.3	13.1	13.1	17.1
90	12.3	13.1	13.1	17.1

Table 2. PSNR for various filters for Barbara.png image at different noise densities

Noise in %	PSNR in dB			
	SMF	AMF	WF	CMF
10	54.66	30.54	30.4	30.04
20	49.8	24.76	24.7	26.26
30	43.34	16.64	16.62	19.91
40	35.21	18.65	18.62	21.54
50	28.9	16.76	16.7	20.03
60	23.32	15.3	15.3	18.76
70	19.09	14.04	14.04	13.95
80	15.14	12.91	12.91	12.77
90	12.32	12.93	12.93	16.88

Table 3. PSNR for various filters for House.png image at different noise densities

Noise in %	PSNR in dB			
	SMF	AMF	WF	CMF
10	63.63	31.06	31.02	29.82
20	53.38	24.99	25	27.56
30	44.23	21.51	21	24.58
40	35.93	18.95	18.9	22.41
50	28.98	17.05	17.04	20.68
60	23.4	15.5	15.5	19.3
70	18.81	14.09	14.1	18.07
80	15.18	13.07	13.07	17.18
90	12.2	13.04	13.05	17.08

Table 4. PSNR for various filters for different test images at 95% noise density

Image	PSNR in dB			
	SMF	AMF	WF	CMF
Lena	10.9	13.2	13.2	17.1
Barbara	11.04	12.95	13	16.88
House	11.01	13.02	13	17.2

Tables 1, 2 and 3 show that CMF has better restoration performance in terms of PSNR when compared to other filters particularly at very high noise densities. At low noise densities the PSNR values obtained are similar to that of other filters. But CMF shows better improvement in PSNR value at high noise levels. Table 4 shows that even at 95% of noise level PNSR values obtained for the proposed CM filter are better than that of the other three filters (SMF, AMF and WF) tested/studied.

Fig 1: Output of Lena.jpg image for proposed CM Filter at different noise densities from 10% to 90%.

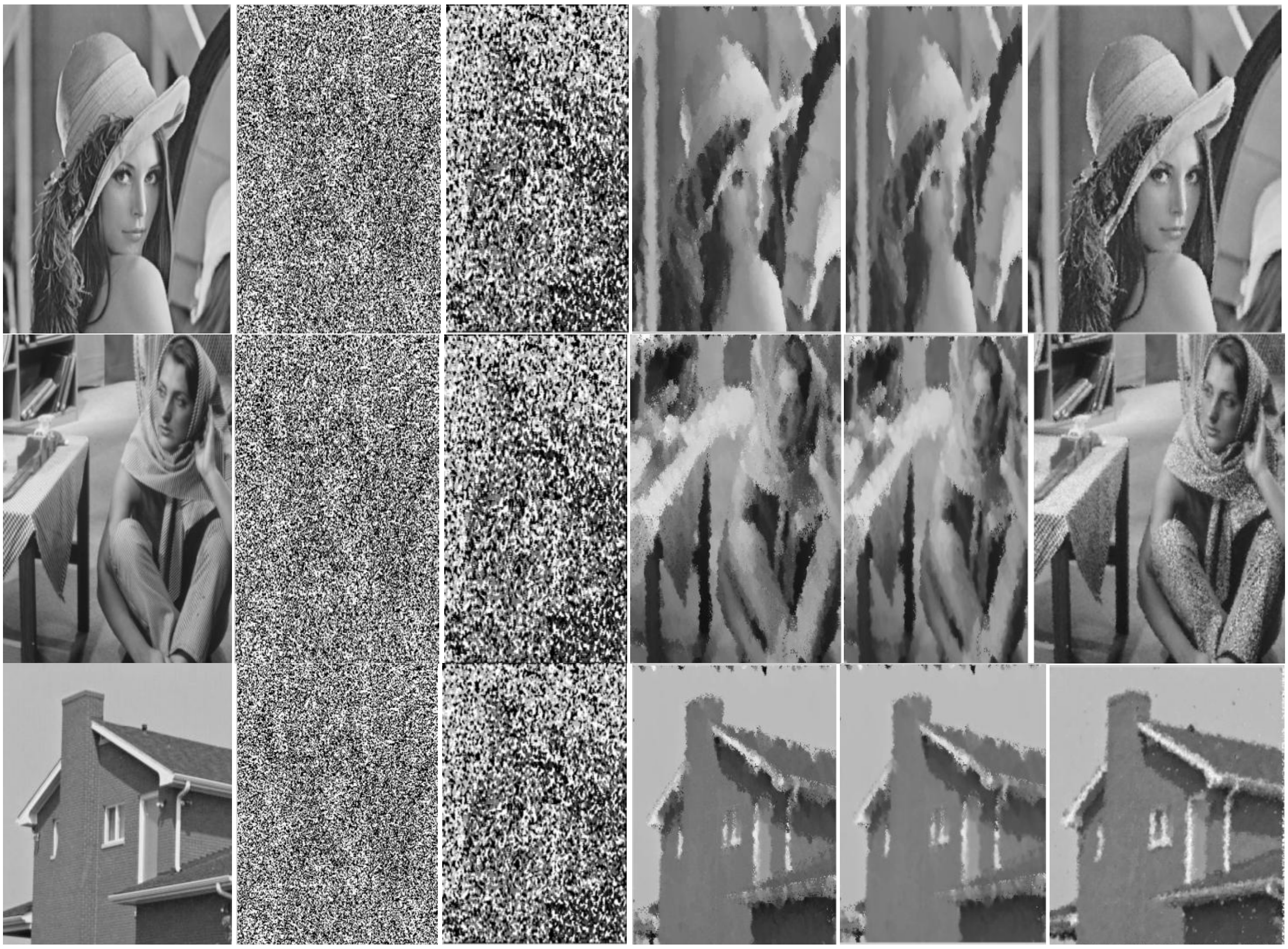

Fig 2: Comparison of different filters for different images. (a) Original image (b) Image corrupted by 90% impulse noise (c)Standard Median Filter (d) Adaptive Median Filter (e) Wiener Filter (f) Cloud Model Filter.

Figure 1 shows the simulation of proposed Cloud Model Filter at different noise levels ranging from 10% to 90% for Lena.jpg image. Figure 2 shows the comparison of CM filter with Standard Median filter, Adaptive Median filter and Wiener filter. Test images corrupted by 90% of impulse noise when compared, it is clearly evident that CM filter is better than the other filters. When the noise density is above 50%, noise removal accuracy and visual clarity of Median, Adaptive Median and Wiener filters are very poor. The compared filters can perform well only below 50% of noise level. But the proposed CM filter gives better restoration performance. Finally, to demonstrate the excellent performance of the CM filter, the filter is tested at the noise level of 95% (see Figure 3). Although the restored images have some blurring edges in some local areas, however, the images have been still restored with good visual effect.

Fig 3: Images with 95% of noise level restored by the CM Filter.

5. CONCLUSION

The process of restoration of an image requires two aspects in impulse noise removal. First, the accuracy of noise detection which will directly influence the restored image. Increasing the accuracy of noise detection is directly proportional to the denoising performance of CM filter. Second, uncertainties exist in the noise. Understanding the uncertainties completely helps to improve the quality of the restored images. In the present study, Cloud Model Filter effectively removed impulse noise and gave better performance in comparison with SMF, AMF and WF in terms of PSNR. The performance of the filter has been tested at low, medium and high noise densities on different gray-scale images. Even at high noise densities the proposed filter can detect and remove the impulse noise effectively. Both visual and quantitative results are demonstrated. The experimental results conclude CM filter is the best one among the tested filters. It made greater improvements both in noise detection and image details preservation. Even if the noise level is closer to 95%, the texture and the details of the images are restored by the CM filter better with good visual effect. However, it needs further studies to improve the performance of CM filter in image processing using different noise detectors or restoration methods and these extensions will be given in forthcoming papers.

6. REFERENCES

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