A Simplified Fuzzy Filter for Impulse Noise Removal using Thresholding

Roli Bansal, Priti Sehgal, and Punam Bedi

Abstract— **This paper presents a simplified fuzzy filter to remove impulse noise in an image with the combined ability of the RCM filter and fuzzy thresholding technique to preserve edges and fine details. The pixels lying outside the trimming range after ranking in the RCM filter are further tested for being noisy by the process of fuzzy thresholding. The algorithm uses range of threshold values rather than a crisp threshold value as the level of contamination varies from pixel to pixel. The modified value for the noisy pixel is calculated depending on the impulse noise present in it. The better performance of the filter is demonstrated on the basis of PSNR values calculated from the original and restored images respectively.**

Index Terms— **Fuzzy logic, Image filtering, Impulse noise, Median filter, noise detection.**

I. INTRODUCTION

Filtering is the most fundamental operation in image processing and computer vision. The filtered image at a given location is a function of values of the input image in a small neighborhood of the same location. Assuming that images vary slowly over space, near pixels are likely to have similar values. But this assumption fails at regions that contain edges and image details (e.g. corners, lines, end of lines etc.) Most of the classical linear filters like the averaging low pass filters tend to blur and destroy the lines, edges and other fine image details. The median filter is the most important non-linear order statistic filter [1]. Though simple and computationally efficient, the median filter causes an appreciable loss in image details [2], because it replaces all the pixels of the noisy image with the median of the pixels from the local neighborhood, irrespective of them being corrupted or not.

To trade off detail preservation against noise reduction, Ko and Lee proposed the centre weighted median filter (CWM)[3]. In this method they applied a weight adjustment to the centre or origin pixel within the sliding window and the filter outputs the median of the extended set. It is observed that the performance of the CWM filter with a larger centre weight is superior to the one with a smaller centre weight in detail preservation but inferior in noise reduction.

In order to effectively remove impulse noise while preserving image details, ideally the filtering should be applied only to the corrupted pixels and the noise free pixels should be kept unchanged. An effective way to improve the performance of the CWM filter was conditioning the pixel replacement to their ranks in the ordered set without specifying any weights. In the rank conditioned median filter RCM [4], pixels with extreme ranks i.e. outside the trimming range, are substituted by the sample median, while the others are left unaltered. This is because of the usual assumption that the corrupted pixel in a window appears at one of the extremes after ranking in median filtering.

However, it is very difficult, if not possible to set the conditions under which a certain filter should be chosen, because the local conditions can be evaluated only vaguely in some parts of the image. For this reason the filtering system should be capable of performing reasoning with uncertain information, which is a common usage of fuzzy logic.

To obtain improved performance many generalizations of median filters have been proposed in the literature including the switching median filter(SM) [5], the centre weighted median filter [3], the RCM filter [4], the tri-state median filter(TSM) [6], the multi-state median filter(MSM) [7] , Adaptive two pass rank order filter [8] etc. Several fuzzy filters [10] – [16] such as Fuzzy median filter (FMF), fuzzy weighted mean filter, adaptive weighted mean filter, (AWMF), FIRE filters, fuzzy switching filters, etc. have also been studied for the removal of impulse noise. The proposed filter gives better performance than FMF, AWMF and FIRE filters because it uses the ability of the RCM filter prior to fuzzy thresholding. Normally fuzzy filters can be classified into two broad categories i.e. one, in which the fuzzy filter is purely based on fuzzy techniques and two, in which the fuzzy filter is based on the fuzzification of one or more classical methods of filtering. This paper presents a simple fuzzy filter which belongs to the latter category. It firstly detects impulses based on the rank conditioned median algorithm and then further tests the presence of impulsive pixels by comparing them with a range of threshold values using an S – shaped fuzzy membership function.

Results show that the proposed filter is able to suppress impulse noise while preserving image details largely and gives an improved performance over most of the above filters, yet being computationally efficient and algorithmically very simple to implement.

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The remainder of this paper is organized as follows. Section II describes the proposed filter. The simulation results and discussion is presented in section III. Section IV contains the conclusions.

II. PROPOSED FILTER

The proposed filter is composed of two parts. The first determines if the central sample of pixels lies in the trimming range in the rank order set. If so, it is left unchanged. Otherwise, the second part compares it with its neighboring pixels that lie in the trimming range. The differences between these pixels determine the amount of impulse present in the central sample. The algorithm works on the fact that the difference between an impulse and its neighbor is usually larger than the difference between a pixel on an edge with any of its neighboring pixels. As this difference increases the impulsiveness goes on increasing. Finally by fuzzy switching [9], the output pixel is correspondingly changed depending on the level of corruption of the input pixel.

The formulation of the proposed technique is as follows:- Let $X = \{ x = (x_1, x_2) \mid 1 \le x_1 \le H, 1 \le x_2 \le W\}$ be the pixel coordinates of an input image and let $Y = \{ y = (y_1, y_2) \mid 1 \le y_1 \le H, 1 \le y_2 \le W\}$ be the pixel coordinates of the corresponding filtered output image where, H and W denote the height and width respectively. At each location $x \in X$, a filter window is defined whose size is $N = 2n + 1$ where, n is a non-negative integer.

A. Checking if the sample lies in the trimming range in the rank order set.

Let $\mathbf{w}(x)$ denote a sample vector of all the pixels in a filter window including the central pixel $w(x)$ i.e.-

$$\mathbf{w}(x) = [w_1(x), w_2(x), \ldots\ldots w_N(x)]^T \tag{1}$$

where, $w_1(x)$ is the upper left value in the window, $w_N(x)$ is the lower right value and the pixels are scanned from left to right and top to bottom as $w_1(x), w_2(x), \ldots. w_N(x)$. The ordered or the sorted sample vector is then given by :-

$$\mathbf{w}_s(x) = [w_{(1)}(x), w_{(2)}(x), \ldots\ldots\ldots w_{(N)}(x)]^T \tag{2}$$

where, $w_{(1)}(x), w_{(2)}(x), \ldots\ldots\ldots w_{(N)}(x)$ are arranged in ascending order as $w_{(1)}(x) \le w_{(2)}(x) \le \ldots\ldots\ldots w_{(N)}(x)$, N being the maximum rank possible. Let M represent the median value of the ordered sample vector.

If w(x) lies in the trimming range it is left unaltered i.e.-

$$w(y) = w(x) \quad \text{if } i \le r(x) \le N+1-i \tag{3}$$

where, w(y) is the corresponding pixel in the output image and r(x) is the rank of the centre sample in the ordered sample vector $\mathbf{w}_s(x)$ and [i, N+1-i] represents the trimming range. If w(x) does not lie in the trimming range, perform the next part.

B. Modifying the current pixel by fuzzy switching.

For the current pixel define rank difference D as follows :-

$$D(x) = \max\{ w_{(i)}x - w(x), w(x) - w_{(N+1-i)}(x) \} \tag{4}$$

where, i = 1,2,..or N.

If $\mu[D(x)] \in [0, 1]$ is the membership function of D(x) that indicates how much the pixel x looks like an impulse, we give the following fuzzy rules :-

[*Rule 1*] If D(x) is large, then $\mu[D(x)]$ is large.
[*Rule 2*] If D(x) is small, then $\mu[D(x)]$ is small.

With these rules we have used the *S*-function to describe the membership function of the impulse noise corruption extent of the current pixel.

$$\mu[D(x)] = \begin{cases} 0 & \text{if } D(x) \le a \\ 2\left(\dfrac{D(x)-a}{c-a}\right)^2 & \text{if } a \le D(x) \le b \\ 1 - 2\left(\dfrac{D(x)-a}{c-a}\right)^2 & \text{if } b \le D(x) \le c \\ 1 & \text{if } D(x) \ge c \end{cases} \tag{5}$$

where, a and c are predefined thresholds such that if D(x) is less than a , the pixel is considered as noise free and if D(x) is greater than b the pixel is considered as definitely impulsive. Here $b = (a + c) / 2$.

The filter based on the above fuzzy rules generates the following output value:-

$$y = (1 - \mu[D(x)]) * x + \mu[D(x)] * M \tag{6}$$

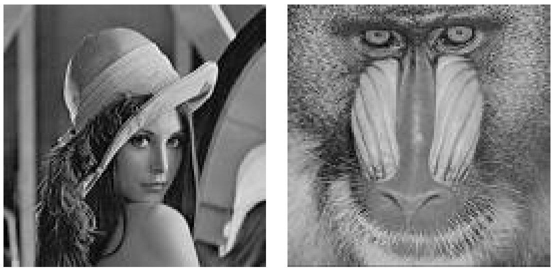
If $\mu[D(x)] = 0$ then, y = x i.e. no filtering is required and the pixel remains unaltered. If $\mu[D(x)] = 1$ then, y = M i.e. the pixel is definitely impulsive and it is replaced by the median of the neighboring values. If $0 < \mu[D(x)] < 1$ then, the pixel is somewhat impulsive and the filter will output the weighted average of the input pixel and the median value.

III. IMPLEMENTATION AND RESULTS

The performance of the proposed filter has been evaluated and compared with those of several existing median type filters based on fuzzy and non-fuzzy techniques for image restoration. In our implementations, a group of 512 X 512 grayscale images were corrupted by impulsive noise with various occurrence probabilities. The objective quantitative measure used for comparison is the peak signal-to-noise ratio (PSNR) in dB between the original and restored images, defined by

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} 255^2}{\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\left[I(i,j)-Y(i,j)\right]^2}\right) \quad (8)$$

where I(i, j)and Y(i, j) are the original and restored images, respectively.



(a) (b)

Fig 1. Test images used in this paper (a) Lena image (b) baboon image.

Table1: Comparative results in PSNR of different filtering methods for various percentages of impulse noise in the Lena image.

	Noise ratio				
Filters	5%	10%	15%	20%	25%
Median	33.2	32.5	32.0	31.5	30.8
CWM	37.0	34.8	32.9	30.5	29.0
RCM	38.36	37.20	35.28	34.27	32.6
TSM	39.1	37	35.7	32.0	30.9
MSM	39.9	37.5	35.9	32.32	31.8
AWFM	33.6	32.9	31.7	31.4	30.9
FIRE	35.8	33.83	30.9	28.3	24.4
FMF	37.9	35.6	33.28	31.8	29.5
Proposed	37.29	37.36	37.09	36.76	35.96

Table2: Comparative results in PSNR of different filtering methods for various percentages of impulse noise in the Baboon image.

	Noise ratio				
Filters	5%	10%	15%	20%	25%
Median	22.7	22.6	22.46	22.39	21.8
CWM	28.1	26.1	24.8	24	23.6
RCM	26.67	26.37	25.78	25.1	24.29
TSM	28.8	26.7	25.5	24.5	23.7
MSM	30.0	27.5	26.0	25.2	24.4
AWFM	24.6	24.52	24.34	24.22	24.1
FIRE	26.3	25.45	24.1	22.86	20.8
FMF	29.7	27.12	26.83	24.58	22.9
Proposed	28.36	28.40	28.28	28.11	27.91

Table 1 and 2 give comparative restoration results in PSNR of filtering two images corrupted by different percentages of salt and pepper noise. It is observed that the results of the fuzzy thresholding algorithm proposed in this paper are better than other methods in terms of detail preservation as well as noise reduction. All implementations have been done using Matlab 7.0.

IV. CONCLUSIONS

A novel fuzzy framework of switching scheme for median filtering, called the fuzzy thresholding filter has been proposed in this paper. In this scheme the output is selectively switched based on predefined thresholds on the differences of the current pixel with the noise free pixels in its neighborhood. Implementations have shown that the proposed filter gives better results than other median based fuzzy and non-fuzzy filters, especially in case of lower impulse noise. The algorithm can be extended for higher noise ratios. Results of this investigation would be reported further.

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