Two stage noise detection filter for Image Denoising

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Abstract—This paper presents a novel switching filter for removing impulse noise from digital images. Presence of impulse noise is common in digital images which degrades the visual quality. Therefore, it is important to denoise images to enhance their features. We aim at developing a switching filter which can remove impulse noise effectively without degrading the image edges and fine details. The proposed filter consists of noise detection in two stages. In the first stage, we search for those pixels similar with the central pixel inside 3×3 window. If no pixel is found to be similar, the central pixel is considered as noisy and is filtered by median filter. On the other hand, if the central pixel is found to be similar with atleast one pixel, we again increase the search window to 5×5 and search for similar pixels. If the central pixel is found to be similar with more than a predefined threshold number, then it is regarded as original pixel else filtering action is performed. Every pixel in the image is checked for an impulse or not in these stages and corrupted pixels are replaced by the output of switching median filter. The proposed filter gives better results than other well known filters in terms of PSNR, MAE and MSE.

Keywords— impulse, median, denoise, switching filter, intensity.

I. INTRODUCTION

Noise is an unwanted signal which occurs as random variation of pixel values in images. Images are often contaminated by noise during acquisition, transmission through communication channels, storage or due to faulty sensors [1]. Some common noise includes impulse noise, Gaussian noise and Poisson noise. Presence of noise hampers the visual quality and complicates further image processing steps such as edge detection, segmentation, etc. This will degrade the image details and the information contained in the images will be misinterpreted. Images are widely used as a medium for conveying information in our everyday life at homes, offices, and many other fields such as satellite imaging and medical image analysis. Medical images like Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) depict certain anatomical and physiological conditions of patients which are used for diagnosis [2]. Noise may mislead the health specialist during treatment. Therefore, it is necessary to remove noise in the pre-processing stage.

Impulse noise is defined as on off noise which occurs for a short duration [3]. It can be classified as fixed-valued and random valued. Images contaminated by impulse noise appear as white and black dots. For this reason, it is also known as salt (white) and pepper (black) noise. For an 8-bit image, corrupted by impulse noise, the pixel value is either 0 or 255. This type is called fixed-valued impulse noise. In case of random-valued, the pixel value can take any value ranging from 0 to 255. For removing impulse noise, certain filters have been developed [3]. Median filter is the most common filter for handling impulse noise since its impulse response is zero. Other filters include mean averaging filters, min-max based filters, etc. However, these traditional filters have the major drawback that they filter all pixels without checking if they are actually corrupted by noise or not. This causes excessive smoothing and blurring. To overcome this problem, we have proposed a switching filter. By switching, it means that the filter first check for an impulse or not, and switches either to filtering or non filtering action depending on the presence and absence of noise. The noise detection has two stages. In the first stage, the pixel under consideration (the central pixel) inside the 3×3 window is checked if it has atleast one similar pixel among the remaining pixels. The idea behind this detection is that if the central pixel is an impulse, its pixel value should be either very small or large from the neighboring pixels. This is because an impulse value varies greatly from healthy pixels. If the central pixel has no similar pixel, then it is treated as corrupted and is filtered by median filter. If the central pixel has atleast a similar pixel, then it is treated as probably noisy and consider for second stage for noise detection. In this stage, we expand the search range upto 5×5 window and check if the similarity is greater than a pre-defined threshold number. If the similarity fulfills these criteria, then the central pixel is considered as original pixel else filtering operation is performed by median filter. The reason behind second stage of noise detection is that sometimes an impulse may occur among other impulses in the neighboring pixels which succeed the first stage of noise detection leading to misdetection. Therefore, to validate for noise- free pixel, we have considered for second stage of noise detection. The proposed filter is compared with some common filters used in the literature. It is found that our proposed algorithm gives better results in terms of increased Peak Signal to Noise Ratio (PSNR), Mean Absolute Error (MAE) and Mean Square error (MSE). The visual quality of the images is also improved as well.

The paper is organized as follows: Literature review is given in section 2. The proposed filter is described in section 3.

In section 4, we have discussed the experimental results on test images. Finally, the conclusion is drawn in the last section.

II. LITERATURE REVIEW

Numerous filters have been proposed in the literature for impulsive noise removal from digital images. These filters can be classified as linear and nonlinear filters. Linear filters are those which satisfy superposition principle. Since images are nonstationary in nature, nonlinear filters have proved successful in preservation of edges and fine image details. Such filters are also classified into order statistics filters, detection followed by filtering, Peer group filters, vector sigma filters, etc. [4]. Order statistics filters are non linear spatial filters whose response is based on ordering (ranking) the pixels inside the filtering window. The median filter [5], alpha-trimmed median (ATM), min-max filters are some members of this filter. Mean filter belong to linear filter which replace the central pixel by the mean of the pixel values inside the filtering window. It also known as averaging filter. The alpha-trimmed mean (ATM) filter is based on order statistics and varies between a median and mean filter. There are many other well known filters some of them are multistate median filter (MSM) [6], the peak and valley filter [8], signal dependent rank order mean (SD-ROM) filter [9], the pixel-wise MAD (PWMAD) filter [11], modified threshold Boolean filter (TBF), Jarque-Bera test based median (JM) filter , two-output nonlinear filter , iterative median filter mentioned in [12], the adaptive center weighted median filter (ACWM) [7], filter base on conditional signal-adaptive median (CSAM) [10], etc.

III. PROPOSED WORK

The proposed algorithm comprises on two stage impulse noise detection and filtering stage by median filter. In the noise detection, each pixel in the noisy image will be checked for two times through two stages in order to consider as a corrupted. Each stage has different window size, threshold value and intensity range. Let us consider the filtering sliding window in Fig.1

x_{10}	x_{11}	x_{12}	x_{13}	x_{14}
x_{15}	x_2	x_3	x_4	x_{16}
x_{17}	x_5	x_1	x_6	x_{18}
x_{19}	x_7	x_8	x_9	x_{20}
x_{21}	x_{22}	x_{23}	x_{24}	x_{25}

inner 3×3 window

Fig.1 Filtering window

We have considered x_1 as the central pixel. The noise detection is described below:

(a) First stage is to detect any pixel that has a strange value amongst its neighboring pixels in the 3×3 window. We check if the central pixel has atleast a similar pixel with its neighboring pixels. The similarity is based on the difference in pixel intensity between them. For finding the similarity distance, we compute the well known distance measure such as Euclidean distance. It is based on the fact that neighboring pixels should have either similar intensity or slightly different intensity values. The distance is compared with a predefined threshold distance and if it is greater than this threshold distance D_1, then the pixel is considered as noisy and is filtered by median filter. On the other hand, if this distance is smaller than 3×3, it is considered as probably noisy and pass to the second stage.

(b) Second stage is to detect any pixel which has succeeded to pass the first stage. We have expanded the search range to 5×5. In the larger window, we have to find if the central pixel has some threshold number *n* of similar pixels. The idea behind this second stage lies in the fact that inside the 3×3 there can be two or more noisy pixels apart from the central pixel. In such cases, the central pixel has fulfilled the first criteria of noise detection by having atleast two number of similarity with it. This leads to misdetection and noisy central pixel will not be filtered. Hence, to overcome this problem, it is needed to increase the search range. For searching the similar pixels, the same concept applied in the first stage is being used. Based on the fact that increase spatial distance leads to increase in pixel value difference, we have taken a different threshold distance D_2 which is slightly lesser that D_1. If the number of similar pixel is lesser than *n*, then the central pixel is considered as noisy and filtered by median filter else it is left unaltered.

By checking the two stage noise detection stage, we aim at improving the efficiency of the median filter. The proposed filter incorporates a switching scheme to detect if the pixel under consideration is actually noisy or not. If it is found to be corrupted by impulse noise, the median filtering is performed. In median filter, we sort the pixel values present inside the sliding window in ascending order. The median of the sorted array represents the output. This median represents the highest similarity of all the pixels. Also, impulse noise is either very high or very low values, which lies at the extreme or near extreme ends. Therefore, median filter can easily filter the impulses. While, on the other hand, if the central pixel satisfies both the two stages of noise detection, it is considered to be the original pixel and no filtering action is performed. Therefore, the filter switches between filtering and no filtering (identity) operation. This is known as switching filter.

IV. RESULTS AND DISCUSSION

In this section, we have discussed the simulated results on some test images and compared with other filters for removing impulse noise. The impulse noise model considered is defined below:

$$y_{i,j} = \begin{cases} z_{i,j}, & \text{with probability } 1-p \\ g_{i,j}, & \text{with probability } p \end{cases} \quad (1)$$

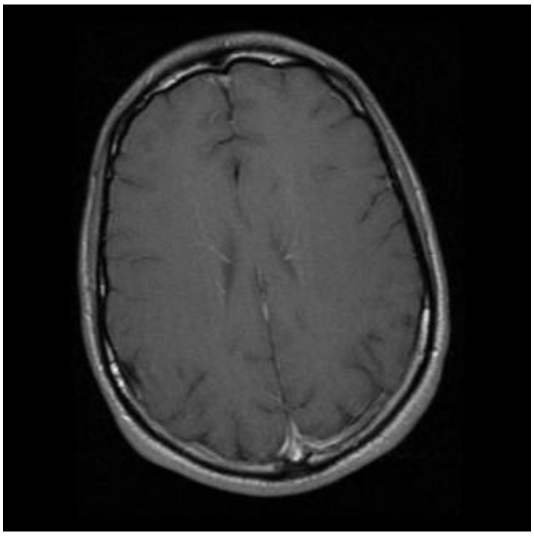
In which $g_{i,j}$ is the gray-level value of the corrupted pixel and $z_{i,j}$ represents the pixel values in the original image at pixel coordinate at (*i*,*j*) with noise corruption probability *p*.
For evaluating the filtering performance, we have used the standard performance metric PSNR, MAE and MSE. PSNR is defined below:

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{255^2}{\frac{1}{MN}\sum_{i,j=1}^{M,N}(z_{i,j}-\hat{x}_{i,j})^2}\right)\ \mathrm{dB} \tag{2}$$

Where $M \times N$ represents the size of the image, $z_{i,j}$ and $\hat{x}_{i,j}$ are the original and restored images at the particular pixel coordinates. PSNR is used to assess the quality of the restored image. It is expected to have higher PSNR for good filter. MSE represents the average of the squares of the errors between the actual image and our restored image. Similarly, MAE compares the true pixel values to the filtered noisy image. For an efficient filter both the MSE and MAE are supposed to be minimum.

We have used standard test images (512 $\times$512) shown in Fig.2 to show the performance of the proposed filter with some existing filters such as Median filter, Mean filter and Elastic Median Filter [13]. Matlab is used for our experimentation. The images are corrupted with impulse noise with noise ration ranging from 10% to 40%. The performance of our filter as compared to other filters are given in Table 1 for Lena image.
Table 1 : Filtering performance of various filters in terms of PSNR, MAE and MSE for Lena.

(a) Lena



(b) Brain

(c) Road

Fig.2. Test images used for simulation.

It is observed that the proposed filter has better filtering performance in trms of PSNR, MAE and MSE. It has the highest PSNR, lowest MAE and MSE. Several simulations have been performed on different images and with different values of D_1, D_2 and *n* for both the first and second stages. It is found that the best optimized results occur at $D_1 = 10$, D_2=15 and *n*=7.

Table 1 : Filtering performance of various filters in terms of PSNR, MAE and MSE for Lena

Filters	10%			20%			30%			40%		
	PSNR	MAE	MSE	PSNR	MAE	MSE	PSNR	MAE	MSE	PSNR	MAE	MSE
Mean	25.70	5.31	11.87	24.60	5.87	14.88	23.60	6.21	15.79	20.56	7.32	19.67
Median	26.60	4.55	10.21	25.79	4.23	13.59	24.61	5.78	14.76	22.11	6.45	16.43
Elastic Median	30.21	2.33	9.222	26.71	3.12	12.80	25.50	4.56	13.54	24.45	5.43	15.66
Proposed Filter	31.32	1.23	8.11	29.30	2.33	10.11	27.59	3.78	12.68	26.33	4.11	14.80

V. CONCLUSION

In this work, we have designed a two stage noise detection filter for removing impulse noise from digital images. The first stage aims at finding atleast one similar pixel of the central pixel in the 3×3 window. If no similar pixel is found, it is treated as noisy and is filter by median value. On the other hand, if it passes the first stage, it goes to the second stage for finding similar pixels in 5×5 window. The same procedure is repeated for this stage also. Finally, the proposed filter is compared with other well known filter and its performance is better in terms of PSNR, MAE and MSE. In the future work, we will extend the proposed filter in color images and design its hardware implementation using Field Programmable Gate Arrays (FPGA).

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