Aerospace Systems (2023) 6:53–59
https://doi.org/10.1007/s42401-022-00160-y

ORIGINAL PAPER

Application of switching median filter with L_2 norm-based auto-tuning function for removing random valued impulse noise

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Received: 10 May 2022 / Revised: 8 August 2022 / Accepted: 13 August 2022 / Published online: 5 September 2022

Abstract
In the field of digital image processing, denoising is one of the basic problems. The challenges faced in image denoising are detecting impulse noise and designing a suitable filter. In this paper, we propose a methodology to remove the random impulse noise on the color image using a novel switching median filter. By using this novel technique, the occurrence of color artifacts has been avoided after noise removal which depends on auto-tuning threshold detection and a vector-type median filter noise remover. In the proposed technique, the random valued impulse noises with uniform distribution have been dealt with switching median filter. L_2 Norm is employed to calculate the distribution distance rather than L_1 Norm which is used to identify the optimal threshold value for auto-tuning filter. The switching auto-tuning detector automatically tunes the noisy pixels based on distance information of pixels distribution. The Normalized Mean Square Error (NMSE) is found to decrease for L_2 Norm when compared with L_1 Norm. The Peak Signal to Noise Ratio (PSNR) value and True Positive Rate (TPR) value improved with L_2 Norm signifying effective noise removal. The efficiency of the present method is verified by conducting experiments on digital images.

Keywords Auto tuning function · L_2 norm · Switching median filter · Image denoising

1 Introduction

Image denoising is an important part of digital image processing. This process effectively removes or reduces the degradations that can creep in while the images are being obtained or transmitted. The impulse noises can be removed by using many different types of non-linear filters [1]. One of the prominent non-linear filters is a median filter. This can be used for the removal of impulse noise since it is having better denoising capability and better computational efficiency. Median filters can be classified as multi-state type [2–4] and pattern classification type filters [5–7].

Among the pattern classification-type filters, Switching Median Filter (SMF) is widely used in many applications [8]. This filter detects the pixel which is noisy based on the

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difference between the original noisy image and the output of the median filter. Median filtering is then carried out only for the detected pixel which is noisy. However, due to this median filtering, color distortions may occur.

To overcome the above problem, Vector Median Filter (VMF) which treats the given input signal as a vector which is having RGB components is widely used [9]. A Robust Switch type VMF (RSVMF) is also proposed in recent years [10]. It has high noise removal ability and high resistance to color distortions. But this is not reliable as the details are sometimes over smoothed.

An improved quantized adaptive switching median filter has been proposed for reducing impulse noise in gray-scale digital images [11]. The proposed filter has been implemented using five processing blocks. The experimental results show the median filter occupied low Mean Square Error (MSE) and high Structure Similarity Index (SSIM) for highly corrupted images. The quality of restored images can be measured using Peak Signal to Noise Ratio (PSNR) value, which is not measured in the quantized adaptive switching median filter.

Several researchers have recommended using Artificial intelligence (AI) for reducing impulse noise in digital images. The impulse noise levels in the digital images have been reduced using different approaches like Fuzzy [12–14], Artificial Neural Networks (ANN) [15–17], Support vector machines (SVMs) [18]. The artificial intelligence method is quite complex, as it takes more parameters for reducing the impulse noise signal which involves more processing time. It requires a large number of input images for the training phase which increases the complexity.

Zhang et al., proposed an adaptive switching median filter based on evidential reasoning for reducing impulse noise signal [19]. An uncertainty that happened in impulse noise detection has been reported using basic belief assignment (BBA) functions. The proposed median filter occupied more noise density and it attained a longer processing time. Therefore, an improved performance median filter is needed for digital images to reduce the impulse noise.

The impulse noise density signal has been removed by the combined filters methods like adaptive vector median filter and weighted mean filter for color images [20]. These filters are applied over noisy and non-noisy pixels in the noise removal process. The proposed filter achieved improved performance in impulse noise density, but it occupied high computational complexity in noise removal procedures. A cluster-based adaptive fuzzy median filter was proposed for reducing impulse noise signals [21]. Directional rank order absolute difference (DROD) method used in the adaptive fuzzy median filter provided effective impulse noise removal. This methodology utilized a smaller number of processing windows, which eventually reduced computation cost but color artifacts might be the problem.

Yan used the L_0 norm to explain the sparsity of the impulse noise, but he handled the L_0 norm by introducing a binary matrix that represents the set of pixels that are not affected by the impulse noise [22, 23].

The proposed methodology reduces random valued impulse noise without generating color artifacts in the processed image. Also, L_2 norm-based distance calculation is employed in the noise detector rather than L_1 norm, this improves the PSNR value and TPR and reduces the NMSE, thereby guarantees the efficient denoising strategy. There are two broad classifications of impulse noise [24]. They are Salt and Pepper Noise, and Random Valued Impulse Noise.

The other name for salt and pepper noise is intensity spikes. This can happen while an image is being transmitted. It can also occur due to faulty pixel elements in the sensors of the acquisition device such as a camera. Sometimes it happens due to defective locations in the memory which happens during the digitization process. The two possible values are 0 and 1. These two values have a probability of less than 0.1. For random valued impulse noise intensity level lies between 0 and 255. The entire image has randomly distributed noise. Any intensity level value can occur as noise which has an equal probability as that of the noise.

Mathematical representation of random valued impulse noise is given in Eq. 1.

$$Y_{ij} = \begin{cases} n_{(i,j)} \text{ with probability } p \\ X_{(i,j)} \text{ with probability } 1 - p \end{cases} \tag{1}$$

where Y_{ij} represents the image affected by random valued impulse noise, $n_{(i,j)}$ represents the intensity of the noise corrupted pixel, $X_{(i,j)}$ represents the original image, p represents the probability of occurrence of the noise.

Based on the switching threshold, random valued impulse noises will be detected by Switching Median Filter (SMF). The absolute difference between the given input image and the output of the median filter is calculated and if it is greater than the switching threshold, that pixel will be considered as a noisy pixel. If it is not the case, the pixel will not be considered as a noisy pixel.

The input signal is considered as vectors unlike component-wise scalar processing [9]. Linear filtering is combined with the vector median operation. By doing so, the noise attenuation is improvised and filtering is done with appreciable edge response [25].

2 Methodology

To remove the random valued impulse, the switching median filter consists of a noise detector with auto tuning threshold function and a noise remover based on a vector median filter.

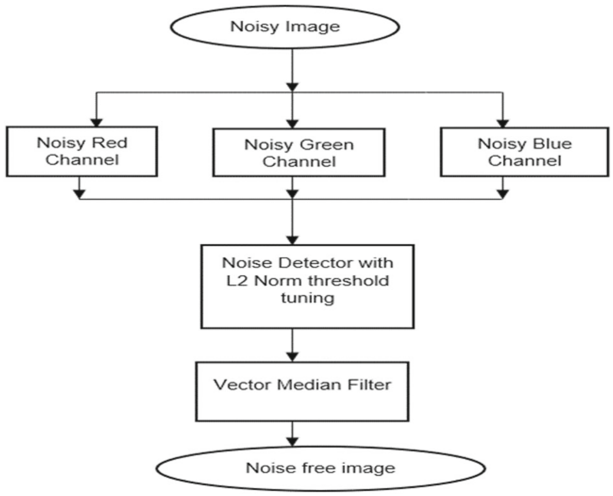

Fig. 1 Block diagram of the proposed methodology

Fig. 2 Noise-free test image

The noisy pixels are identified by calculating the distance between the original image and the noisy image using L_2 norm. The block diagram of the proposed methodology is shown in Fig. 1.

This SMF contains a detector which detects the noise and vector median filter which removes the noise. This detects if the particular pixel is noisy or not in each channel independently. Noise detector has a threshold auto-tuning function which is tuned depending on the performance of the filters. Then, VMF removes the particular detected pixel and replaces it.

2.1 Threshold method

The threshold value differs from image to image based on the image resolution, size, and intensity value and so on. The best threshold value cannot be predicted before noise detection in the spatial domain of color image processing. Best threshold value can be found using auto-tuning detector [8]. The threshold value is called the optimum threshold value for color image.

2.2 Noise detector

In the spatial domain process, the noise pixel detection uses a threshold value. Here, noise detection is based on distance distribution between noisy image and median filtered image. The noise pixel can be identified from the distance between two images based on the defined threshold value (ω).

The noisy position image $g_k(i, j)$ is defined as

$$g_k(i, j) = \begin{cases} 1, & \left|Y_k(i, j) - Y_{k,med}(i, j)\right| \geq \omega \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

where $Y_K(i,j)$ represents the random valued impulse noisy image at the position (i,j), $Y_{K\text{med}}(i,j)$ represents the output of the median filter at the position (i,j), ω represents the threshold value.

In this proposed detector, the optimum threshold value is calculated as

$$\omega^* = \text{argmin}\, J\left(P_{d,(\omega)}, P_u\right) \tag{3}$$

where J is a function to calculate the distance of the distribution. $P_{d,(\omega)}$ represents the probability density function of the detected noise with the threshold ω. P_u represents the uniform distribution of the random valued impulse noise.

To compute the distance of distribution, we employ L_2 norm which is defined as

$$L_2\left(P_{d(\omega)}, P_u\right) = \sqrt{\sum_{m=0}^{255} \left|P_{d(\omega)}(m) - P_u(m)\right|^2} \tag{4}$$

where $P_{d,(\omega)}(m)$ represents the probability density function of the detected noise with the threshold ω for any random m. $P_u(m)$ represents the uniform distribution in the range of 1/256 for any random m.

If the distributions are same to each other, distance becomes less.

2.3 Noise remover

Pixel interpolation is one of the best methods for image signal power with reducing the occurrence of color artifacts. Noisy pixels are replaced by vector median filtered color image pixel in the noisy color image. The pixel interpolation is processed in Red, Green and Blue channels individually. The pixel interpolation can improve the PSNR value and also reduces the occurrence of color artifacts [26–30].

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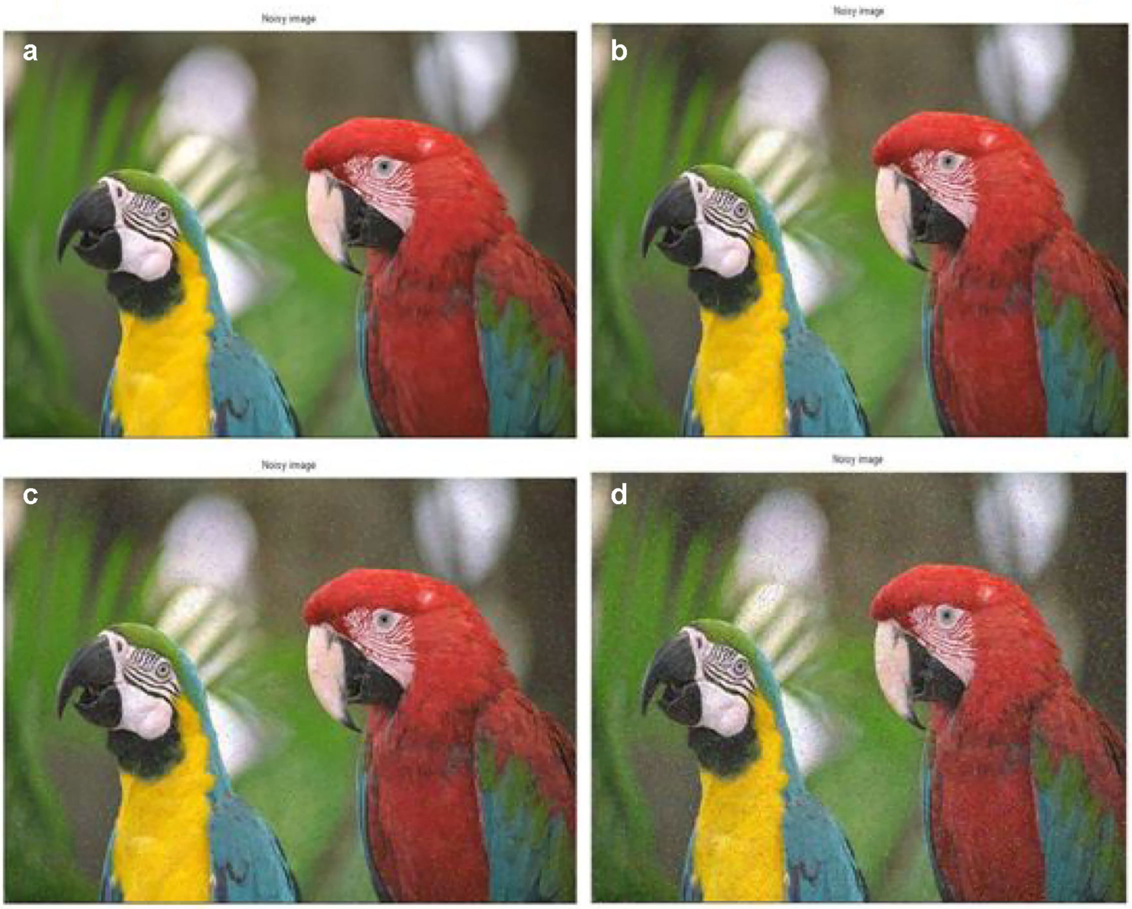

Fig. 3 **a**, **b**, **c** and **d** are the noisy images with noise probabilities 0.01, 0.03, 0.05 and 0.1 respectively

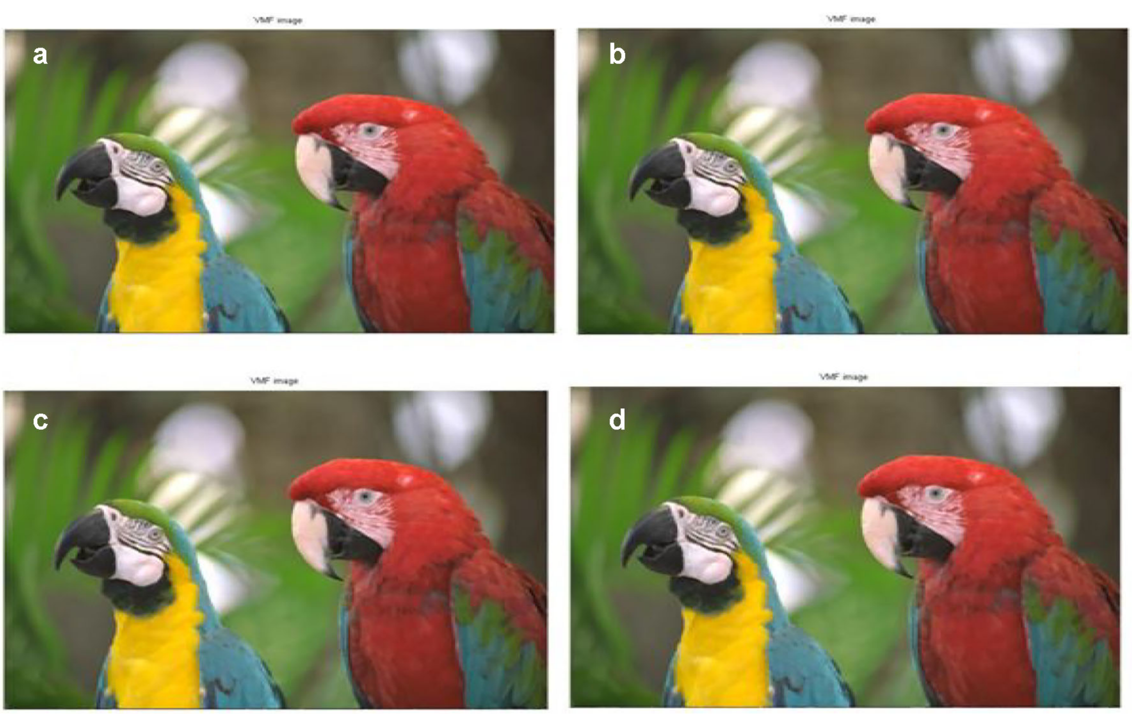

Fig. 4 **a, b, c and d** represent restored images with noise probabilities 0.01, 0.03, 0.05 and 0.1 respectively

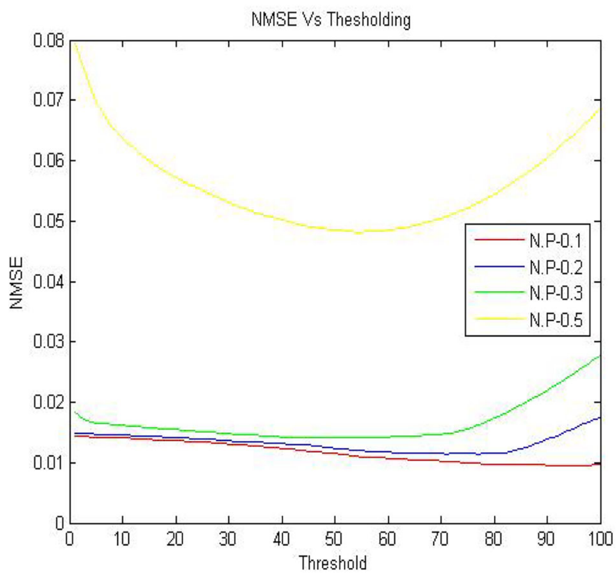

Fig. 5 NMSE obtained between the input image which is noise-free and the output image attained by the detector with changing threshold from 1 to 100

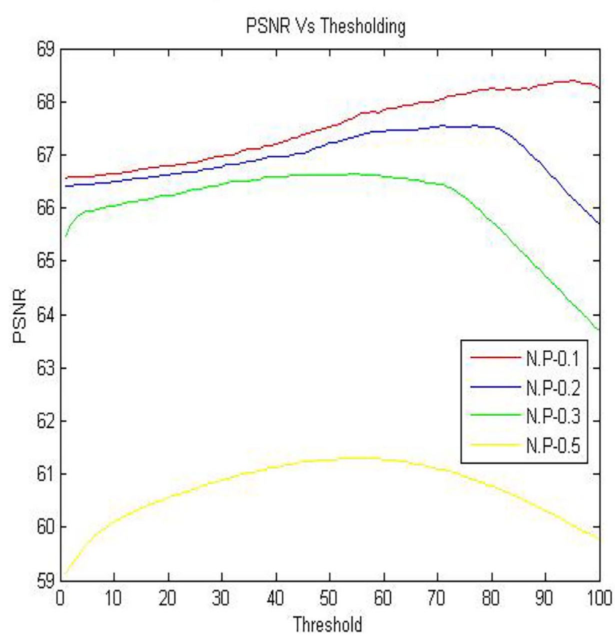

Fig. 6 PSNR obtained with different thresholds for different noise probability restored images

Here, the corrupted noisy pixel $S_R(i,j)$ in the red channel is replaced by VMF output pixel $Y_{vmf,R}(i,j)$. In the same manner, corrupted noisy pixels are removed in green and blue channels. The noise remover is defined by

$$S_k(i,\ j) = \begin{cases} Y_{VMF,k}(i,\ j),\ g_k(i,\ j) = 1 \\ Y_k(i,\ j) otherwise \end{cases} \quad (5)$$

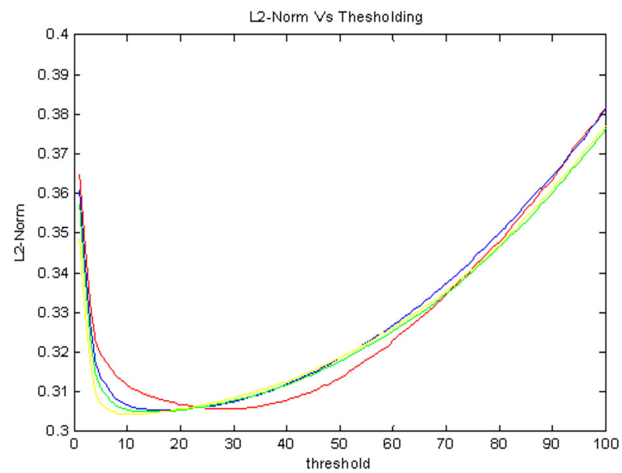

Fig. 7 L_2 norm between noisy image and the detected image by varying threshold from 1 to 100

where $S_k(i,\ j)$ is the output image of our methodology used in the current study with kth component. $Y_{VMF,k}(i,\ j)$ represents the vector median filter output. $Y_k(i,\ j)$ represents the random valued impulse noise.

3 Results and discussions

To carry out the simulation, images from the website called FreeImages were utilized [24]. The efficacy and the soundness of the projected method are confirmed by experiments using a test image which is given in Fig. 2.

Noise is added to the noise-free image with different noise probabilities such as 0.01, 0.03, 0.05 and 0.1 is added to the noise-free image shown in Fig. 2 and the obtained outputs are compared as shown in Fig. 3.

The outcomes obtained after filtering the above images are as follows:

3.1 Assessment of auto-threshold tuning methodology

3.1.1 Normalized mean square error

The normalized mean square error (NMSE) is calculated to validate the projected methodology. It is carried out for the original noise-free image which is shown in Fig. 2. The restored output image is shown in Fig. 4. Whenever the switching threshold is well tuned, NMSE becomes smaller. Figure 5 shows NMSE attained with altering the threshold of the Switching Median Filter.

Table 1 Comparison of L_1 and L_2 norm methods

Noise probability	NMSE		PSNR		TPR	
	L_1 norm	l_2 norm	L_1 norm	L_2 norm	l_1 norm	L_2 norm
0.1	0.0200	0.0093	67.3776	68.4550	0.83	0.84
0.2	0.02481	0.0121	66.3326	67.6965	0.86	0.88
0.3	0.0264	0.0163	65.3101	66.9032	0.87	0.89
0.5	0.0498	0.0385	60.1630	61.2750	0.89	0.91

3.1.2 PSNR

The PSNR is frequently used as a measure of the reconstruction quality of noisy images. It should be high for a good quality restored image. PSNR obtained with changing ω of the Switching Median Filter is shown in Fig. 6.

3.1.3 L_2 Norm

The following Fig. 7 shows the graph between the L_2 norm and the threshold.

The L_2 norm between the presumed noise and the normalized histogram of the noises sensed by the detector with changing threshold is shown in Fig. 7. The minimum L_2 norm represents the tuned value of the threshold which can be computed from Fig. 7.

3.1.4 True positive rate (TPR)

In the field of image denoising, TPR is defined as the number of detected noisy pixels to the total number of noisy pixels available in the image. The value of TPR lies between 0 and 1. If the value of the TPR is larger, it indicates the better performance of the proposed algorithm.

The proposed methodology utilizes L_2 norm for tuning the threshold of the noise detector. The results have been compared with L_1 norm which is employed by Kubota et al., in their research for a similar random valued impulse noise removal problem.

From Table 1, it is understood that L_2 norm outperforms L_1 norm in terms of NMSE, PSNR and TPR. When L_2 norm is used, NMSE gets reduced, PSNR and TPR values get improved as evident from Table 1 for different noise probability values.

4 Conclusion

A modified SMF has been elucidated in this paper. In this methodology, L_2 norm is used to identify the optimal threshold value for auto-tuning the noise detector. It is noted that L_2 norm outperforms L_1 norm by reducing NMSE and increasing PSNR and TPR for tuning the threshold function. Since NMSE is less and PSNR and TPR are high, this methodology is not affected by color artifacts much. This methodology is simple yet powerful in removing random impulse noise without introducing color artifacts and blurring. The efficiency of this method was illustrated using the experimental results. The feature scope of this research work is to employ nature mimic algorithms such as gray wolf optimization, whale optimization techniques for finding the optimal threshold value for auto-tuning the noise detector in SMF. This may improve the PSNR value and TPR value and decrease the NMSE value.

Author contributions All authors contributed to the manuscript. Finally, all authors read and approved the manuscript.

Funding No funds.

Data availability Data used in the current is available on reasonable request to the corresponding author.

Declarations

Conflict of interest The authors declare no conflict of interest.

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