JAIDM
Journal of AI and Data Mining
Vol.1, No.1, 2013, 13-17.

An enhanced median filter for removing noise from MR images

S. Arastehfar[1], A. A. Pouyan[2*], A. Jalalian[1]

1. National University of Singapore (NUS)
2. School of Computer Engineering, Shahrood University of Technology, Iran

Received 01 August 2012; accepted 09 February 2013
**Corresponding author: apouyan@shahroodut.ac.ir (A.A. Pouyan)*

Abstract
In this paper, a novel decision based median (DBM) filter for enhancing MR images has been proposed. The method is based on eliminating impulse noise from MR images. A median-based method to remove impulse noise from digital MR images has been developed. Each pixel is leveled from black to white like gray-level. The method is adjusted in order to decide whether the median operation can be applied on a pixel. The main deficiency in conventional median filter approaches is that all pixels are filtered with no concern about healthy pixels. In this research, to suppress this deficiency, noisy pixels are initially detected, and then the filtering operation is applied on them. The proposed decision method (DM) is simple and leads to fast filtering. The results are more accurate than other conventional filters. Moreover, DM adjusts itself based on the conditions of local detections. In other words, DM operation on detecting a pixel as a noise depends on the previous decision. As a considerable advantage, some unnecessary median operations are eliminated and the number of median operations reduces drastically by using DM. Decision method leads to more acceptable results in scenarios with high noise density. Furthermore, the proposed method reduces the probability of detecting noise-free pixels as noisy pixels and *vice versa*.

Keywords: *Median filter, Impulse noise, Magnetic Resonance Image.*

1. Introduction
Digital images play an important role in some medical issues especially in detecting cancers, internal organs' diseases and injuries. Some medical images are acquired based on Magnetic Resonance (MR) phenomenon used to investigate brain, liver and other soft tissues [1]. The investigation depends on the energy absorbing and emitting in the radio frequency range of the electromagnetic spectrum. MR images may be corrupted by some degrading phenomena during the acquisition process. Some degrading phenomena may contaminate MR images. It is based on the characteristics of MR phenomenon, image capturing equipment and some environmental influences. In this regard, impulse noise has an important corrupting influence impact on MR images, while the image is capturing.

Removing noise from degraded images is a challenging research field in image processing. It involves estimation procedure of the image corrupted by noise [1]-[3]. Over the years, several filtering techniques have been reported for restoring image, each of which has its own assumptions, advantages and disadvantages [1]. In this regard, nonlinear filters such as median filter are preferred as they can cope with the nonlinear property of the image model [2], [4]. Generally, some properties of the image under corruption process, such as the complexity of the image scene, the applied filter based on the nature of the corruption process, and the parameters and properties of the filter, affect the success of drawing an image close to it [5].

The main approach of this paper is to remove impulse noise from MR images through a median-based filter. Before enhancing MR images, it is substantially important to remove noise from the images. Intensive work has been conducted on the restoration of images degraded by impulse noise. Median filter is the most widely used filter for removing impulse noise because of its good noise suppressing power and computational efficiency [1], [4]-[8]. Median filters are nonlinear filters of rank filters and have highlighted some new promising research avenues in recent years [4], [5]. A median filter is also the most popular filter for removing impulse noise.

Median filter is an effective method for eliminating certain kinds of noise, specifically, impulsive noise. This nonlinear filter is simple, robust, repeatedly applicable and particularly adapted to suppress impulse noise. Based on these advantages, the median filter becomes a popular filter for image processing applications. Although the median filter is well suited for suppressing noise, under the median operation, fine details may be erased and the result may be similar to capillarity when the objects in the image are close enough [4]. Moreover, rounding the corners and mapping texture region to a uniform shade are the other deficiencies of the median filter. To mitigate these disadvantages, various approaches of median filter have been developed such as stack filters, multistage median, weighted median [6], [9], rank conditioned rank selection, and relaxed median [4].

However, this paper has proposed, a novel method for removing impulse noise from gray-level images. The new method is capable of attenuating impulse noise, while it can preserve the high portion of noise-free pixels. In this work, an effective noise detecting method for enhancing the median filter is introduced. It is called decision method (DM) filter. The DM is very simple technique, and does not need an extensive calculation. Conducting intensive simulation reveals that the proposed filter may outperform significantly the standard techniques widely used in image processing. It will be demonstrated that the filter is capable of reducing the impulse noise even in situations with noise density.

The remaining sections of this paper are as follows. Impulse noise is described in section 2. Section 3 represents some types of median filter and their advantages and disadvantages. Section 4 focuses on, the introduced proposed median-based filter. Section 5 is devoted to the analysis of the proposed method depending on the density of impulsive noise. This section also contains a number of simulations, tests and filtering results. Finally, the conclusion and the suggestions for the future research domain are summarized in the last section.

2. Impulse noise

Noise is a phenomenon that contaminates an image (generally a signal). Some kinds of noise affect images during some process of image capturing. In fact, noise can limit the quality of an image during acquisition, formation, storage, and transmission processes [3], [10]. In acquisition process noise can affect the image so that the captured image would not clearly reflect the real scene. Moreover, noise can be produced due to the discrepancies in the hardware such as thermal excitation of CCD sensors, and dirt and scratches on the lenses [3]. Furthermore, noise is added to images when the acquired signal is converting to a digital signal in order to be stored and processed.

Images are often degraded by impulse noise [10] because of malfunction in the CCD sensors, faulty memory locations in hardware, and transmission in a noisy channel [6]. Impulse noise is mathematically given in (1).

$$I_{noisy}(i,j) = \begin{cases} R(i,j), & with \quad probability \quad r \\ I(i,j) & with \quad probability \quad 1-r \end{cases} \tag{1}$$

Where, I, I_{noisy}, and R are the noise-free image, noisy image, and random numbers, respectively. The parameter r is noise ratio [7], [8], [10], [11]. To characterize Equation 1 completely, R component can be any number between n and m as long as [n, and m] are the dynamic range of I. Salt-and-pepper noise and random valued noise are the two common types of impulse noise. Providing that noisy pixels take just n or m, the impulse noise will be called salt-and-pepper noise. Otherwise, the noise is called random valued noise [7], [8], [11].

3. Median filter

Various filtering schemes have been introduced over the last two decades to address impulse noise removal. In this regard median filter is the most popular filter [4]-[8], [10] and significant developments of this filter have been reported such as adaptive median filter [5], weighted median filter (WMF) [6], [9], and recursive weighted median (RWM) filter [6]. Standard median operator ranks the intensities of the pixels within a filtering window and replaces the center pixel with the median value. Despite changing some characteristics of an image, the impulse noise will be significantly suppressed by median filter. However, if the noise level is high (over 50%), the filter will smear the details and edges and may lose in noise removing [6]. To limit this deficiency, first, noisy pixels should be identified and then replaced by the filter operator, while other pixels remain unchanged [5]. Based on this fact, different remedies of the median filter, called decision-based [5], [11], [12] and switching filter [2], good at detecting noise even at a high noise density, have been introduced. In this paper, a novel median-based filter is proposed, which is capable of differentiating among noisy pixels and noise-free pixels which is simple and needs few computations.

4. Proposed method (DBM Filter)

The ideality of the proposed filter is designing a filter in such a way that the identity operator acts on the noise-free samples and noisy pixels are affected by the filter operation. In order to provide a trade-off between the identity filter and the median filter, the proposed method DBM is equipped with a novel significantly simple noise detecting method, namely DM.

In this paper, an image is considered as a vector, made of the rows of the image. In the vector scheme, the followed pixels in the same row are still the followed pixels and the pixel before the last pixel of the row is the followed pixel of the second pixel of the next row. Note that the first row, the last row, the first column, and the last column are skipped in the vector scheme. Therefore, the image $I_{n\times m}$ will be $V_{N\times 1}$ in the vector scheme, where N = (n-2) × (m-2). A window $W_i(p)$ is a two-dimensional array of pixels with the size i×i, where i is an odd integer and p is the center pixel of the window.

For detecting the noise in DM, the difference between two followed pixels in V is compared with a threshold (*d*) and the following algorithm is used. The threshold d is not constant and can be changed based on the algorithm provided below. The parameter 'Step' is a predefined value, added to (*d*) depending on the condition (|vi-1-vi|) >*d* is satisfied. In some cases, especially when the noise density is less than 50 percent, the probability, which shows how many noisy pixels are immediate neighbors, is very low. Then, providing that a pixel is detected as a noisy pixel, the condition for detecting the next pixel as a noisy one is getting harder by increasing *d*. Otherwise, parameter (*d*) is changed to the pre-defined threshold. The role of 'Step' is very important in detecting noises more accurately and preserving edges.

- Threshold=*d*
- If ($|v_{i-1}-v_i|>d$) {v_i= median (W_3 (v_i)), *d*= *d* + Step}
- Else {*d*= Threshold}

Where, |·| denotes absolute operator, v_i denotes i^{th} component of V, and W_3 is the filtering window with the size 3×3. Based on the algorithm, if the difference between two followed pixels is greater than the threshold (*d*), the pixel is noisy and the median operation must be applied to it. Otherwise, the pixel is noise-free and the identity operation can be applied.

5. Simulations and Experimental Results

To evaluate the DBM method in removing noise from MR images, several simulations on an original MR image, shown in Figure 1, are carried out. In this paper, the original image is degraded by impulse noise with the presence of 10 and 20 per cent of noise density shown in Figure 2(a) and Figure 2(b). To set the initial values, the window size is kept 3×3 and the threshold (*d)* varies from 1 to 180 in order to obtain the best result. Additionally, the parameter 'Step' is 5 in all the experiments. The results, shown in Figure 3 and Figure 4, imply that the method is successful in removing noise and obtaining acceptable result. Moreover, as these results and studies taken up on the other MR images, optimum threshold (*d)* is in the range of 55-65.

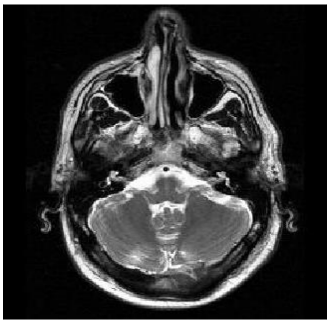
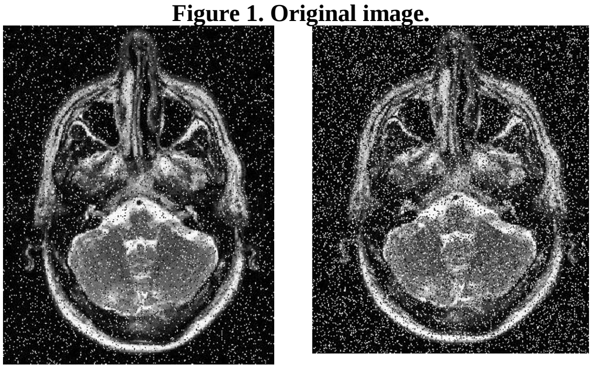


Figure 1. Original image.

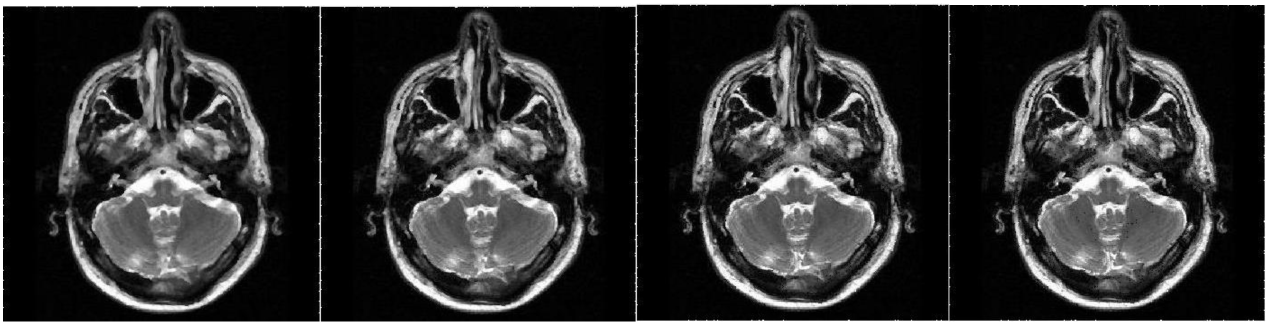


(a) **(b)**

Figure 2. Degraded images, (a) 10 per cent noise density; (b) 20 per cent noise density.

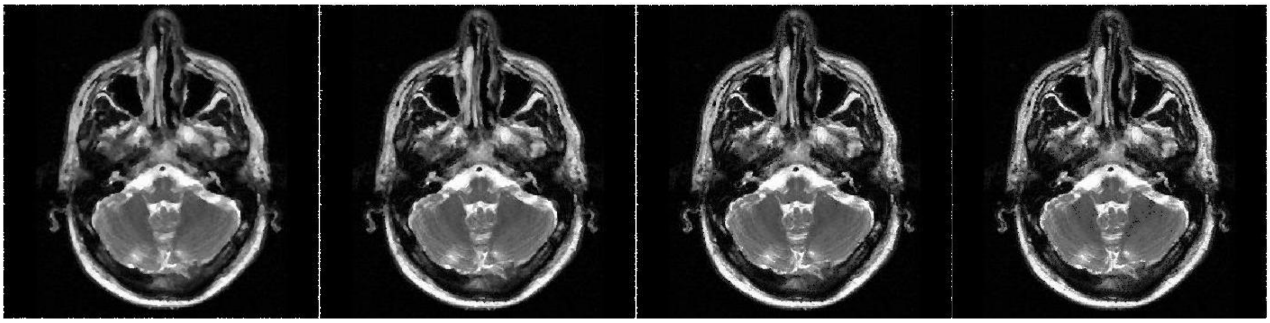
Figure 3 (a) and Figure 3 (b) indicate, when the threshold d is less than 35, the edges are not preserved and the image is blurred. In this case, although the noise is removed from noisy pixels visually-acceptable, some other characteristics of the image are faded. Figure 3 (c), shows the noisy pixels become noise free and the characteristics of the image are remained unchanged. Figure 3 (c) also shows the best result among other results where the threshold is in the range of 55 to -65. Regarding Figure 3 (d), where the thresholdis larger than 65, some small spots expanding the size are clear, when the threshold become larger. Consequently, preserving the characteristics of the image and preventing some undesired changes the threshold should be chosen in the range [55, 65]. According to the results shown in Figure 4, all the above-mentioned results can be gained. In addition, based on our previous study finding and the result in this study shows, the optimum threshold is in the range [55, 65], where the noise reduction rate is maximum.

Figure 5 (a) and Figure (b) show that how many noisy pixels remain after applying the method for 10 and 20 per cent noise, respectively. It is clear that the best thresholds can be obtained in the range [55, 65]. The experiment has been repeated for 50 times and the plots shown in Figure 5(a) and Figure5(b) are the average of the experiments. In addition, all experiments are shown in a small plot on the top of the average plot. According to Figure 5(a) and Figure 5(b), the dynamic of all experiment results are almost the same for each noise density.



(a) (b) (c) (d)

Figure 3. The experimental results of the 10 per cent noisy image, (a) d=10; (b) d=30; (c) d=60; (d) d=75.



(a) (b) (c) (d)

Figure4. The experimental results of the 20 per cent noisy image, (a) d=10; (b) d=30; (c) d=60; (d) d=75.

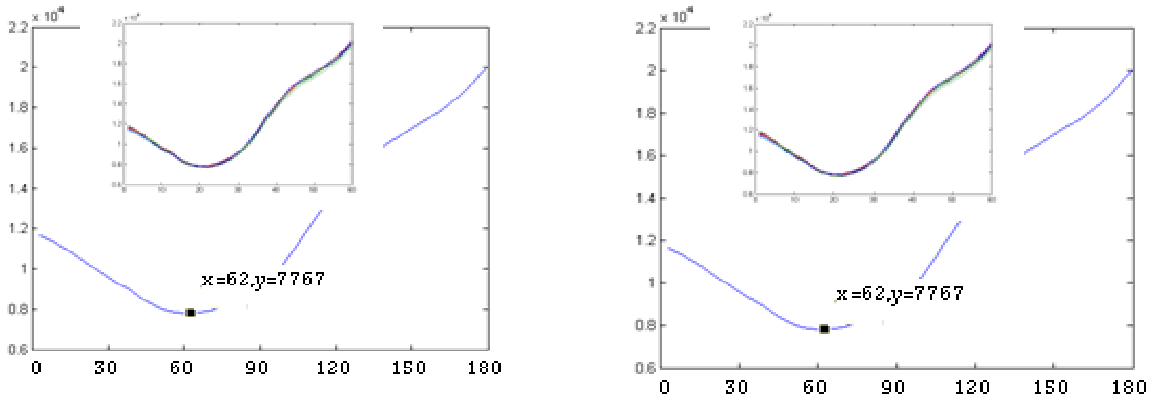


Figure 5. The number of remained noisy pixels by varying the threshold d (a) noise density 10%, (b) noise density 2.

6. Conclusion

In this paper, we have proposed a novel method for impulse noise removing in MR images. A new approach is introduced with a novel method, called decision method, for detecting noisy pixels. The proposed decision based on the median filter, applies the median operation to noisy pixels and leaves healthy pixels unchanged. Consequently, redundant operations will be eliminated. In turn, it leads to a fast and accurate approach.

The proposed method attempts to differentiate between noisy and healthy pixels, but this is not guaranteed in all cases. In other words, the method may detect a healthy pixel as a noisy pixel and vice versa. Further studies should be conducted to adjust parameters *d* and *Step* both locally and adaptively, in order to improve the results in the future domain of the research.

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