Review on High Performance Median Filter for Salt and Pepper Noise Removal

Antima Bajpai[1], Shweta Agrawal[2] and Prashant Badal[2]
[1]Research scholar,[2] Assistant Professor,
Dept of Electronics and Comm., SRCEM Banmore, Morena, India

Abstract— **As the noise may introduced anywhere within image, a filter is the essential part of the image processing units. The noise may corrupt the desired signal which may result in degradation in quality of the image. Among the different noises, the salt and pepper noise is also the frequently occurred noise within the image due to transmission error. In order to eliminate the effect of noise within the image, a special filter called median filter is used. As the noise density increases, the conventional median filter fails to provide noise-free image. Therefore, different algorithm that uses some decision to reduce the salt and pepper noise is proposed in the literature. This paper provides a comprehensive literature review on the different median filter algorithm and architectures.**

Keywords— **Salt and Pepper Noise, Median Filter, Digital Signal Processing (DSP), Image Processing, Integrated Circuits, VLSI, Low Power Design.**

I. Introduction

With the advancement in the very large scale integration (VLSI) technology, there is the exponential usage of the portable devices exhibiting multimedia application, in the recent years. This integration of huge functionality is imposing several challenges to the VLSI designer as increasing functionality increases the complexity which in turn increases failure probability. Further as area, power and delay are main area of concern and at the same time it is very difficult to achieve optimal value of these parameters. Image processing application is the prime component of the multimedia applications. The image processing tasks are the area and performance inefficient and demands architecture that exhibits low computational complexity. Thus, a high performance image processing is the requirement of modern devices to work with the real-time applications.

In the VLSI design the area, power and delay are the three primary parameter that designer wants to improve. But these parameters form a tradeoff triangle i.e. improving one parameter damages the other. The conventional approach of VLSI design provides accurate results i.e. follow the given specification. However, in real scenario it is not always required. There are many applications where minor error can be tolerated called as error tolerant applications.

The image/video processing applications are error tolerant applications. In these applications, small error is tolerable as these applications produce output for human consumption as human have limited visual perception. Along with the multimedia applications, several other applications such as that exhibit probabilistic computations and iterative computation also exhibits error tolerance. Thus, the accurate designs for these applications are the waste of power/area and performance. For these applications, accuracy can be seen as the new design parameter that can be traded to improve all design parameters.

Filtering is the process that is commonly used most of the image processing cores as noise may occur anywhere in the image. From different types of noise [1-4], Salt and pepper (SAP) noise is the noise that occurs due to incorrect computations. Median filter is the most commonly used filter for reducing the SAP noise. In median filtering noisy pixel is replaced by the median of its neighbour. As the noise density increases, the conventional median filter fails to provide image of good quality. Further large size image sub-matrix is required that increases the computational complexity. There are different efficient algorithms for median filtering is developed such as modified decision based trimmed median filter. Although, these algorithms remove high density SAP noise, their complexity is large. There is demand of low complexity median filter design.

In this paper, existing median filter designs are implemented and then evaluated using design and error metrics and compared with the well-known existing architectures.

II. Literature Review

This section details different types of noises, their sources and severity on the image.

2.1 Noises in the image

Noise is unwanted signal which corrupts the desired information in the image. The noise may come from either while sampling the input, incorrect computations, transmission error, or while storage. This noise may have additive or multiplicative nature i.e. it may corrupt original signal in way that noise is added to the original signal or it may multiply with the original signal. Although, the multiplicative noise is very severe compared to the additive, it is rarely occurred and most noises are of additive nature. The mathematically the noisy signals may be expressed by

$$In_a(x,y) = I(x,y) + n(x,y) \quad (1)$$

$$In_m(x,y) = I(x,y) * n(x,y) \quad (2)$$

Where, $In_a(x,y)$, $In_m(x,y)$, $I(x,y)$ and $n(x,y)$ are the additive-noisy, multiplicative-noisy, original signal and noisy signal respectively.

As the most of the noise affects the image signal at the pixel level and therefore signal manipulation or filtering is done at pixel level and image morphing is application where it is commonly employed. The noise mainly affects the brightness of the original signal. The following subsections provide detailed discussion on different noises where it starts with the Gaussian noise followed by Speckle Brownian noise and "Salt and pepper" noise.

2.1.1 Gaussian Noise

It is a noise which exhibits Gaussian distribution [1] over the location at which noise is introduced therefore it is called as Gaussian noise as shown in Figure 1. The pixel at which noise is cantered will be affected more as compared to the farther pixels noise intensity reduces exponentially. Its distribution of probability can be represented by a bell shaped graph. The mathematical model of the Gaussian noise can be represented by the Equation 1 given below.

$$F(g) = \frac{1}{\sqrt{2\pi\sigma^2}}\,\varepsilon^{-(g-m)^2/_{2\sigma^2}} \qquad (3)$$

Where, m, g and σ represent the mean or average, gray level and the standard deviation of the noise respectively.

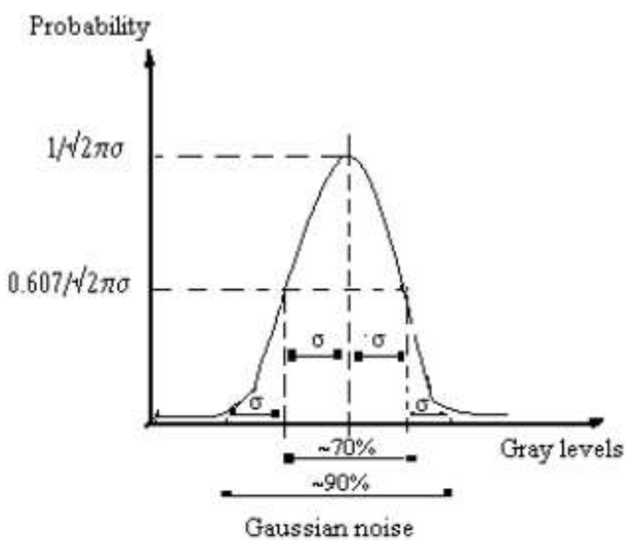


Figure 1: Illustration of Gaussian noise distribution for varying mean and standard deviation

The noise density is very high at the pixel and reduces exponentially. Thus noise effect is seen only on the few neighbour pixels.

In order to remove the effect of Gaussian noise from the image and smoothing filter is commonly employed. The smoothing filter provides a weighted average value of the considered neighbouring pixels. Therefore, the smoothing filter spread out the noise to the widow and makes it less severe at a given pixel. Various energy efficient Gaussian smoothing filter architectures are present in the literature.

2.1.2 Speckle Noise

The Speckle noise [2] is multiplicative in nature i.e. it affects the signal value severely. The prime sources of this noise the coherent returns of randomness in the coherent system such as synthetic aperture radar imagery, LASER and acoustic etc. A fully developed speckle noise has the property of multiplicative property.

2.1.3 Brownian Noise

Brownian noise [3] also called flicker noise exhibits inverse relationship with the frequency i.e. its magnitude is severe at lower frequencies compared to the higher frequencies. The Brownian motion represents the behaviour of the 1/f noise. A stochastic process which is non-stationary and exhibiting normal distribution is the Brownian noise. Mathematically the 1/f noise can be achieved by integrating white noise.

2.1.4 Salt and Pepper (SaP) Noise

It is the impulse noise where noisy pixels achieve either maximum or minimum value. Therefore, Salt and pepper noise [4-14] is kind of noise which exhibits maximum error in the original signal i.e. it either makes the pixel value to 0 or 255. This kind of error occurred in the image due to error in the data transmission. Let the probability of the error is *a* and *b* as shown in Fig. 2. This minimum or maximum setting of input image value is called as Salt and pepper noise due the fact that maximum value will be represented as white point while the minimum value will be represented by the black pixel. The SaP noise may also occurs due to the faulty memory locations or improper digitization process. The image containing SaP noise is shown in Fig. 3.

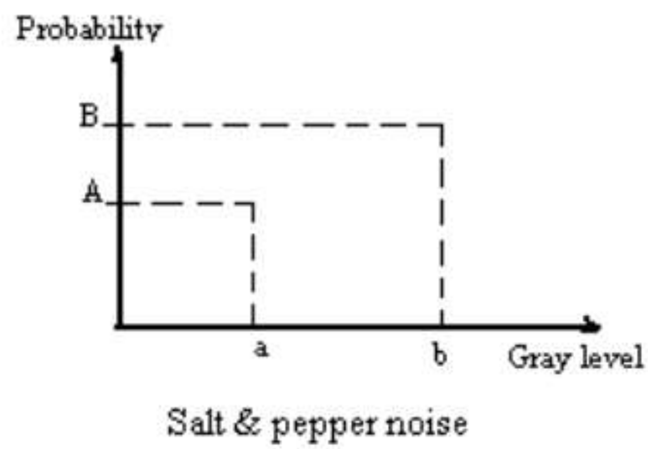


Figure 2: PDF for salt and pepper noise

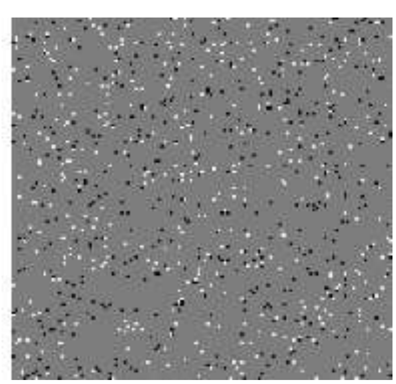


Figure 3: Salt and pepper noise

2.2 Filter Algorithms and Architectures

This subsection details different median filter design to eliminate Salt and Pepper noise.

2.2.1 Principle of median filtering

A median filter is a nonlinear filter different to that of the mean filter. It follows same moving window principle as mean filter. In this filter kernel size of 3x3, 5x5, or 7x7 are consider at once and median of the sub-image matrix of kernel size is taken as the output as shown in Fig. 4. In other words, the pixels of the selected window sizes are sorted and the central element is considered as the output of the median filter as compared to mean filter where the mean of the selected window is taken as output.

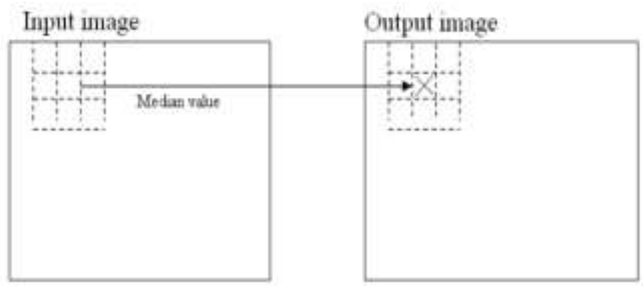


Figure 4: Illustration of median filtering operation

The example shown in Fig. 5 illustrates that window size of 3x3 exhibits median value of 124 which will replace the central noise pixel (red colour) of value 255. Thus the median filter can easily eliminate the effect of noise as the noisy pixels will always fall on the boundaries.

122	124	125	129	139
121	123	125	126	134
117	119	255	124	133
118	114	148	122	132
110	115	109	119	129

114 119 122 123 124 125 126 148 255

Figure 5: Median filtering concept

As the noisy pixel does not affects the neighbour pixels in the salt and pepper noise, the median filter provides better filtering compared to the mean. Further, in the median filter, the noisy pixel is replaced by the one of its neighbour pixels; it does not create false value which cannot occur in the image. Therefore, the median filter provide image which exhibits good edge characteristics over the mean filter which generates new pixels from the mean of its neighbours.

In the MATLAB, tool of image processing contains medfilt2(). The function takes input image and the window size as input parameters. The image can be loaded into the a variable using **imread()** function. The noise in this image can be added to make noisy image by using inbuilt function **imnoise()**. This noisy image can be filter using median filter function **medfilt2()** existing in the MATLAB toolbox. The function **imnoise()** have feature to allow noise of different mean and standard deviation while **medfilt2()** can filter image with different kernel size. Fig. 6 shows the filtered image using median filter. From the filter image it can be seen that edges in the image are not spoiled and are very sharp.

(a) Input to median filter

(b) Output from median filter

Figure 6 Cameraman image with (a) Salt and pepper noise (b) filtered image

Although, the median filter provides noise free image with higher quality over the mean and other filter at low noise density, its performance degrades with increasing the noise density. The median of a given kernel will always a noisy pixel if the noise is very high. To achieve high image quality even under present of high noise, different decision based median filter algorithm and their architectures are developed in the literature.

2.2.2 Modified decision based asymmetric trimmed median filter (MDBATMF) algorithm

An asymmetric trimmed median filter algorithm [15] employing decision making circuitry such that the filter can eliminate noise of colour or gray scale image even under higher salt and pepper (SAP) noise. Algorithmic step can be understood by the flow chart as shown in Figure 7 below.

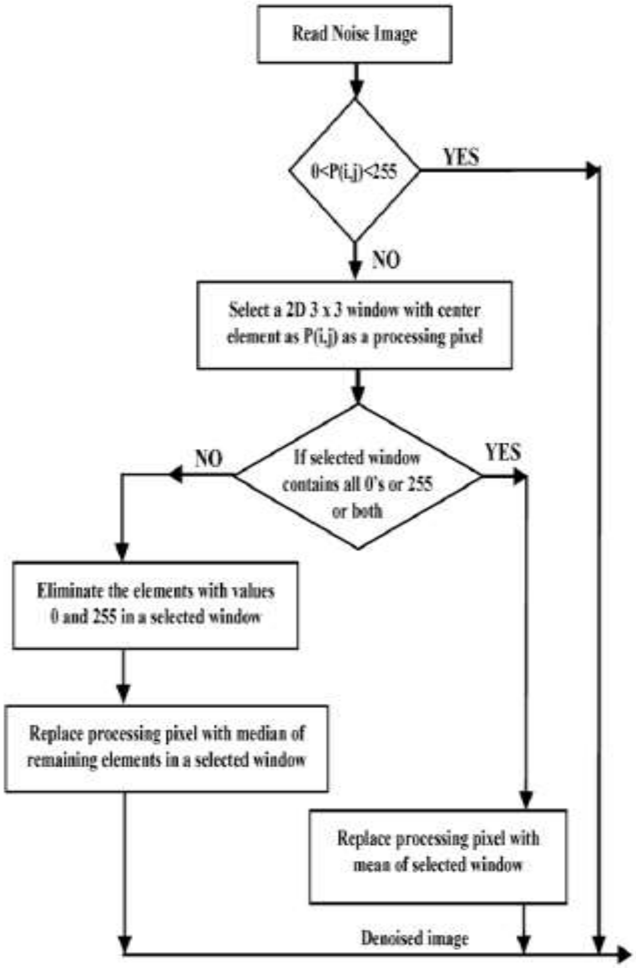


Figure 7: Flow chart of the proposed algorithm

In the proposed algorithm the noisy pixel is replaced by the median of the trimmed window where pixels having value 0 or 255 are eliminated. Further in the algorithm if all the pixels are having value 0 or 255, then the noisy pixel is replaced by the selected window mean value. It is observed that proposed technique provides better noise reduction over the prevailing for different gray-scale and colour images. The MDBATMF algorithm first detects the noisy pixels and if the entire pixels are noisy then the selected window mean will be the resulting pixels otherwise the algorithm eliminates the noisy pixels and performs the median operation on the remaining pixel.

IV. EXPERIMENTAL RESULT & ANALYSIS

In order to evaluate the quality metrics, MATLAB tool is to model the proposed and existing architectures of the median filters. These implemented designs on MATLAB. The noisy images are created and then filtered via proposed and existing median filters. The filtered images are extracted and compared.

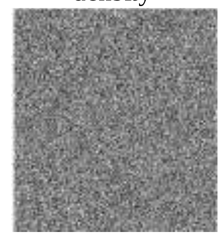
4.2 Simulation results on MATLAB

To evaluate the quality metrics, in the original image [16], salt and pepper noise is first introduced with different noise density using MATLAB inbuilt function. The noisy images having different noise density are shown in Fig. 7 while the filtered images using various filters are shown in Fig. 8.

(a) Image with 2% noise density

(b) Image with 20% noise density

(c) Image with 50% noise density



(d) Image with 100% noise density

Figure 7: Original and noisy images with varying noise density

(a) Filtered via CMF with 20% noise

(b) Filtered via CMF with 50% noise

(c) Filtered via MDBTMF with 20% noise

(d) Filtered via MDBT-MF with 50% noise

Figure 8: Filtered Lena images using CMF (a), (b), MDBTMF (c), (d) and proposed MF (e), (f).

The error between the original image and the filtered output image is extracted for different image median filters as shown in Table 1.

Table 1: Comparison error metrics for different median filter architecture

Metrics	CMF		MDBTMF	
	20%	50%	20%	50%
PSNR	85.81	77.01	88.44	84.44
SSIM [17]	0.938	0.314	0.980	0.934

The simulation results of the conventional and MDBTMF filters show that MDBTMF filter provides higher quality (SSIM) value over the conventional median filter. Similarly it can also observed that MDBTMF median filter provides much higher PSNR metrics over the conventional median filter architecture as shown in Figure 9.

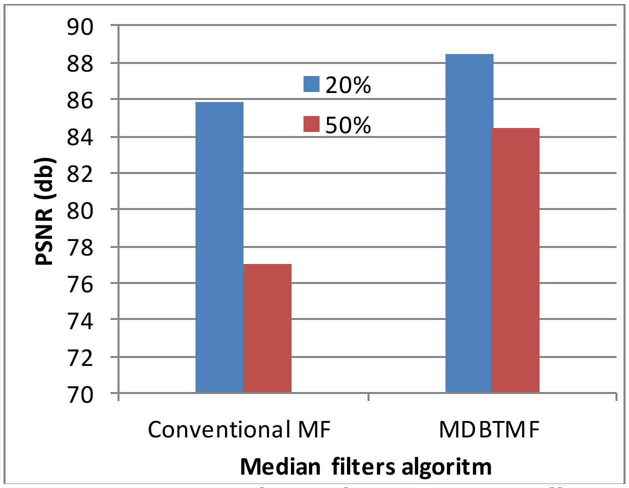


Figure 9: Comparison of PSNR for various MF at different noise density

It can be concluded from the quality metrics and the image obtained after filtering is that the proposed median filter performs better noise filter over the existing median filter architectures.

V. CONCLUSION

There are different types of the noises that corrupt the images. The salt and pepper noise the common noise which occurs due to transmission error. The median filter is commonly used to reduce the salt and pepper noise compared to the mean filter. In this work existing techniques of the median filters are explored and analyzed.

REFERENCES

[1] Foi, Alessandro, et al. "Practical Poissonian-Gaussian noise modeling and fitting for single-image raw-data." *Image Processing, IEEE Transactions on*17.10 (2008): 1737-1754.

[2] Racine, René, et al. "Speckle noise and the detection of faint companions."*Publications of the Astronomical Society of the Pacific* 111.759 (1999): 587.

[3] Mao, Xuerong, Glenn Marion, and Eric Renshaw. "Environmental Brownian noise suppresses explosions in population dynamics." *Stochastic Processes and Their Applications* 97.1 (2002): 95-110.

[4] Arce, Gonzalo R., Peter J. Warter, and Russell E. Foster. "Theory and VLSI implementation of multilevel median filters." *Circuits and Systems, 1988., IEEE International Symposium on*. IEEE, 1988.

[5] Hosseini, Hossein, Farzad Hessar, and Farokh Marvasti. "Real-Time Impulse Noise Suppression from Images Using an Efficient Weighted-Average Filtering." *Signal Processing Letters, IEEE* 22.8 (2015): 1050-1054.

[6] Oflazer, Kemal. "Design and implementation of a single-chip 1-D median filter." *Acoustics, Speech and Signal Processing, IEEE Transactions on*31.5 (1983): 1164-1168.

[7] Karaman, Mustafa, Levent Onural, and Abdullah Atalar. "Design and implementation of a general purpose VLSI median filter unit and its applications." *Acoustics, Speech, and Signal Processing, 1989. ICASSP-89., 1989 International Conference on*. IEEE, 1989.

[8] Lu, Ching-Ta, and Tzu-Chun Chou. "Denoising of salt-and-pepper noise corrupted image using modified directional-weighted-median filter." *Pattern Recognition Letters* 33.10 (2012): 1287-1295.

[9] Wan, Yi, Jiafa Zhu, and Qiqiang Chen. "On the nature of variational salt-and-pepper noise removal and its fast approximation." *Image Processing (ICIP), 2012 19th IEEE International Conference on*. IEEE, 2012.

[10] Chen, Ren-Der, Pei-Yin Chen, and Chun-HsienYeh. "A low power architecture for the design of a one-dimensional median filter." *Circuits and Systems II: Express Briefs, IEEE Transactions on* 62.3 (2015): 266-270.

[11] Diaz-Sanchez, Alejandro, and Jaime Ramirez-Angulo. "Analog VLSI weighted median filters." *Circuits and Systems, 2000. Proceedings of the 43rd IEEE Midwest Symposium on*. Vol. 1. IEEE, 2000.

[12] Chen, Chun Te, et al. "Design and VLSI implementation of real-time weighted median filters." *Circuits and Systems, 1994. APCCAS'94, 1994 IEEE Asia-Pacific Conference on*. IEEE, 1994.

[13] Aiswarya, K., V. Jayaraj, and D. Ebenezer. "A new and efficient algorithm for the removal of high density salt and pepper noise in images and videos."*Computer Modeling and Simulation, 2010. ICCMS'10. Second International Conference on*. Vol. 4. IEEE, 2010.

[14] Monajati, M., S. M. Fakhraie, and E. Kabir. "Approximate arithmetic for low-power image median filtering." *Circuits, Systems, and Signal Processing*34.10 (2015): 3191-3219.

[15] Esakkirajan, S., et al. "Removal of high density salt and pepper noise through modified decision based unsymmetric trimmed median filter." *Signal Processing Letters, IEEE* 18.5 (2011): 287-290

[16] Benchmark images available at http://saliency.mit.edu/datasets.html

[17] Wang, Zhou, et al. "Image quality assessment: from error visibility to structural similarity." *Image Processing, IEEE Transactions on* 13.4 (2004): 600-612.

