CHAPTER 4
ADAPTIVE ALGORITHMS FOR SIMULTANEOUS REMOVAL OF ADDITIVE MIXED NOISE IN IMAGES WITH FINE DETAIL PRESERVATION AND BLUR REDUCTION

4.1 INTRODUCTION

Two non linear adaptive algorithms based on LMMSE of the observed signal and a combining technique to get the reconstructed image has been introduced in this chapter. The proposed algorithms along with the combiner remove mixed noise with both the edge and detail information preserved. In the theoretical analysis of median filters several unrealistic assumptions were made about the image signal. It was assumed that signal was of constant value or that it was an ideal step edge. Fine details are removed by the ordering process of the median filter (Fitch et al 1985). Blurring increases with an increase of the window size. Since median and max operators satisfy the monotonicity property, the threshold decomposition is possible as explained by Arce and McLoughlin (1987). Nieminen et al (1987) have proved that the performance of the filter could be improved if median operation employed in the place of max operation and, for this purpose, he introduced multistage median operators. These filters are less biased towards large values.
The output of a bidirectional multistage median filter is obtained by the operation

\[ y_{i,j} = \text{med}\{ z_{12}, z_{34}, x_{ij} \} \]  

(4.1)

where

\[ z_{12} = \text{med}(\{x_{i,j-v}, \ldots, x_{i,j}, \ldots, x_{i,j+v}\} \cup \{x_{i-v,j}, \ldots, x_{i,j}, \ldots, x_{i+v,j}\}) \]

\[ z_{34} = \text{med}(\{x_{i+j-v}, \ldots, x_{i+j}, \ldots, x_{i+j+v}\} \cup \{x_{i-j-v}, \ldots, x_{i,j}, \ldots, x_{i+j+v}\}) \]

Since this filter is sensitive to horizontal, vertical and diagonal directions, this filter is a two stage filter and it can preserve details in all the directions.

The mean filter fails to preserve steps and mean filter renders images blurry. The results of the median filter show that many important details are lost even though sharpness is retained. A good compromise between the two can be achieved by alpha trimmed mean filter. The edges and noise in homogeneous region are taken care of by the alpha trimmed mean filter. The idea behind alpha trimmed mean filter is to reject the most probable outliers - some of the very smallest and largest values and after rejection averaging is carried out Bedner and Watt (1984).

It has been noted that an adaptive non linear filter is needed to rectify the following problems encountered in filtering process:

i) To eliminate mixed noise of additive Gaussian, positive and negative impulses.

ii) To apply the filtering process only to the corrupted pixels so that the smearing of edges is avoided.

iii) To preserve edges and thereby reducing blur due to averaging of intensity values. Edge preservation is necessary since edges are the important information bearing signals.
iv) To preserve fine and low spatial order details.

v) Even if the size of the window is increased, the edges and details are to be preserved.

In order to achieve all the above requirements, the following two adaptive algorithms are proposed.

### 4.2 PROPOSED FILTERING ALGORITHMS

#### 4.2.1 New Filter I

The new adaptive non linear filter algorithm is based on the variance of the corrupted image and LMMSE of the signal corrupted by the noise. The original image is corrupted by a mixed noise and the noise model used in this algorithm is given below:

\[
s(k,l) = x(k,l) + n(k,l) \quad \text{with a probability } 1-(p_1+p_2)
\]

\[
= s_{\text{max}} \quad \text{with a probability } p_1
\]

\[
= s_{\text{min}} \quad \text{with a probability } p_2
\]  \hspace{1cm} (4.2)

The image consists of homogeneous and heterogeneous regions in which the long tailed noise in the heterogeneous region is filtered by the bidirectional median operation and the noise in the homogeneous region is filtered by the alpha trimmed mean of the pixels inside the window.
4.2.1.1 Principle of operation of the proposed algorithm

The block diagram of the new filter I is depicted as below.

![Block Diagram of New Filter I](image)

**Figure 4.1 Block Diagram of New Filter I**

The homogeneous regions in the corrupted signal are processed by alpha trimmed mean filter and the corrupted pixels in the heterogeneous regions are alone processed by a new adaptive filter (NAF) which incorporates bi directional median filter.

4.2.1.2 Deviation operators

Deviation operators are used to obtain the deviation estimates of observed corrupted signal and noise signal. They are computed using moving window of size \( n \times n \), \( w_s \) and \( w_n \) respectively.

\[
\begin{align*}
\sigma_s &= \frac{1}{n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} (s(i, j) - E[s(k,l)])^2 \\
\sigma_n &= \frac{1}{n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} (n(i, j) - E[n(k,l)])^2
\end{align*}
\]

In equation (4.3), \( \sigma_s \) and \( \sigma_n \) are the signal and noise variance respectively and \( E[s(k,l)] \) and \( E[n(k,l)] \) are the mean estimates of the signal and noise respectively.
In the homogeneous regions, $v_s = v_n$ and hence it is found that if the ratio $v_n/v_s$ is greater than 0.35, corrupted signals are processed by alpha trimmed mean filter (ATMF). This facilitates the removal of white Gaussian noise and also the preservation of edges. The result of the ATMF is as follows

$$y(k,l) = \frac{1}{m \times n(1-2\alpha)} \sum_{i=\text{even}+1}^{m-\text{even}} \sum_{j=\text{even}+1}^{n-\text{even}} s(i, j)$$ (4.4)

If all the pixels in the heterogeneous region are processed and if the window size is increased, it leads to smearing of edges. Hence the pixels which form the edges are isolated and they are tested if they are corrupted by noise or not. The corrupted pixels alone are processed by the bidirectional median filter. In order to isolate the corrupted pixels, a threshold is incorporated and is calculated based on the value of estimated noise and signal variance.

It is known that $v_s$ is greater than $v_n$ in the edge region and experimentally it has been found that if the ratio of $v_n/v_s$ within the window is lesser than the threshold value 0.35, then those pixels are to be processed by the filtering algorithm. Hence heavy tailed noise is reduced by a bidirectional median filter. In order to preserve edges and fine details, the pixels are isolated and processed separately by the ATMF and NAF. The resultant of the two filters is combined to get the reconstructed image by using a combining algorithm.

4.2.2 New Filter II

The quantitative and qualitative results of New filter I shows its better performance in removing noise with fine detail and edge preservation properties even if the window size is increased from $3 \times 3$ to $7 \times 7$. From the
subjective analysis, it is found that there is a slight blurring in the reconstructed image. This has been rectified by an adaptive filter with edge detection technique, as described in the diagram.

![Diagram](image.png)

**Figure 4.2  Block Diagram of New Filter II**

### 4.2.2.1 Principle of operation of New Filter II

Stage I: Adaptive alpha trimmed mean filter

The first stage of the filter incorporates adaptive alpha trimmed mean filter. The value of alpha is determined by the variance of the corrupted image. The steps involved in the detection and elimination of impulses are as follows:

Step1: Let \( s(i,j) \) be the pixel values considered inside the window \( N \times N \). The mean, median and alpha trimmed mean of the pixels inside the window of size \( N \times N \) are given by

\[
Mean[s(i,j)] = \frac{1}{N \times N} \sum_{i=1}^{N} \sum_{j=1}^{N} s(i,j)
\]  

(4.5)
Step 2: Mean of the pixels inside the window \((N\times N)\) and \((N\times N)-2\) are calculated.

Step 3: If the absolute difference between the mean of pixels with the window size \((N\times N)\) and \((N\times N)-2\) is lesser than the threshold ‘t’, then all the \((N\times N)\) pixels are considered for the next stage. If it is greater than ‘t’, then it is considered as the presence of impulses.

Step 4: Next the difference between the mean of the \((N\times N)-2\) pixels and the \((N\times N)-4\) pixels is determined. This process is continued till the difference is less than the threshold; once that condition is satisfied, the pixels inside the larger window among the two are transferred to the next stage.

Thus stage 1 is used to detect and remove impulse noise. Experimentally the best value of the threshold ‘t’ has been calculated as 0.02.

Stage 2: Preservation of Edges

Stage 2 is used to preserve the edges of an image. It is known that the variation between consecutive pixels is very high, if there is an edge. Hence, the variance of a set of neighbourhood pixels containing an edge will be high. The edges are preserved as follows:

Step 1: The variance of the set of pixels obtained from the previous stage is calculated and is compared with a threshold value ‘th’. If it is less than the ‘th’, it can be considered as the absence of edge and are passed on to the third stage.

Step 2: It is to be noted that the set of pixels obtained from the first stage is free from impulse noise. Hence, the centre pixel is compared with each of the pixels of the set obtained from the first stage. If it equals any one of the pixels in the set, it is considered that the center pixel is not corrupted by
impulse noise. Hence it is left unaltered, and is retained in the resultant image. Otherwise, the set of pixels from the first stage is passed on to the third stage. It must be noted that during edge preservation, the Gaussian noise is not removed.

The threshold value ‘th’ has been determined experimentally as 0.003 for less amount of Gaussian noise and for high amount of Gaussian noise, a high value of th = 0.3 is chosen. Thus this stage preserves edges and retains the center pixel if it is an edge.

Stage 3: Reduction of Blur

The arithmetic mean filter averages the image pixels to reduce Gaussian noise. In this process the neighbourhood pixels get blurred. Reduction of blurring and elimination of Gaussian noise is considered in stage 3.

In stage 3, the following steps are carried out:

Step 1: The variance of the pixels that are obtained from the previous stage is calculated and is compared with a threshold value.

Step 2: If the variance is less than the threshold ‘pt’, then the mean of the pixels inside the window is used to replace the centre pixel of the window. Otherwise lower number of pixels is involved in the mean operation. This process is continued till the condition is satisfied, and then the mean of the final set of pixels is calculated to replace the center pixel.

A larger threshold value ensures better removal of Gaussian noise at the expense of increased blurring of the image. Here, again, the threshold value must be chosen as a large number for large Gaussian noise, as removal of the noise becomes more important when compared to blurring.
It has been determined experimentally that a low value of ‘pt’ offers the best results for removal of Gaussian noise at lower densities. The value of ‘pt’ is equal to 0.0001 for a Gaussian noise of variance of 0.01 and is 0.08 for Gaussian noise of variance 0.2. The image can be made smoother if the value of the threshold ‘pt’ is increased. In this way the third stage of the filter eliminates Gaussian noise and reduces the blurring effect.

4.3 RESULTS AND DISCUSSION

The original image is corrupted by the addition of white Gaussian noise of different variances and impulse noise of different noise densities. The performance analysis of the proposed filter is done in terms of MSE/pixel, IEF and PSNR and the performance is compared with that of general mean, median, bidirectional median and adaptive alpha trimmed mean filters.

The IEF for the proposed new adaptive filter is found to be greater than mean, median filters, which shows significant removal of noise with edge preservation. The Image enhancement factor has been calculated for various filters with window sizes of 3×3 and 5×5 and they are compared with the results of New filter I in Table 4.1. It is clear that the Image Enhancement Factor increases with the increase of window size which shows a significant reduction in the noise and improvement in edge preservation.

Figure 4.3 shows the relation between the variance of mixed noise and the PSNR of various filters. The noise is a mixture of impulse noise density of 0.03 and Gaussian noise at different amounts of variance. It is to be noted that the new filter I shows superior performance in comparison with mean, median and bidirectional median filters in terms of PSNR.
The qualitative performance of the new filter I is shown in Figures 4.4(a) to 4.4(e) and are compared with the results of the other filters. In this analysis, the original image is corrupted with a mixed noise of impulse noise of density 0.03 and Gaussian noise of variance 0.03. Figures 4.5(a) to 4.5(e) show the comparative performance of the filter if the original image is contaminated by a mixture of impulse noise of density 0.04 and Gaussian noise of variance 0.1. The results are shown in Figures 4.4 and 4.5 using a ‘remote sensing’ image as the test image with window sizes of 3×3 and 5×5 respectively.

The New Filter II algorithm has been tested using the ‘Lena’ image and ‘remote sensing’ image. Table 4.2 shows the relative performance of the filter with that of the mean, median and MATMF in terms of IEF. In this analysis the image is corrupted by an impulse noise of 5% density and at different variances of Gaussian noise. The value of IEF decreases with a increase in the added amount of Gaussian noise.

The impulses are eliminated while the edges are preserved. Objective analyses of the filter performance shows that the mixture of white Gaussian noise and impulses is eliminated and edges are preserved leading to reduction in blur. Figure 4.6(a) to Figure 4.6(g) are used for the performance illustration of the proposed adaptive filter for various amounts of noise with the window size of 3×3. Figure 4.6(a) shows the original test image. Figure 4.6(b) is the image corrupted with the mixture of Gaussian noise of variance 0.1 and impulse noise of an amount of 4% and the corresponding filtered result is shown in Figure 4.6(c). Figure 4.6(d) is the image corrupted by the mixture of impulse noise of 5% and Gaussian noise of variance 0.1 and
its corresponding filtered image is shown in Figure 4.6(e). Figure 4.6(f) represents the image corrupted by the mixture of impulse noise of an amount of 10% and Gaussian noise is of variance 0.2. The corresponding filtered image is depicted in Figure 4.6(g). It could be inferred that the results of the filter are subjectively appealing since the blur is reduced and the edges are preserved even if the image is corrupted with a noise at higher densities.

Table 4.3 shows the relative performance of the filter with that of the mean, median and MATMF in terms of IEF. In this analysis the image is corrupted by various amounts of impulse noise and a fixed Gaussian noise of Variance 0.1. The highest value of IEF shows the excellent performance of the new filter II in terms of blur reduction and edge preservation capabilities.

Figure 4.7 shows the comparison of the results of the proposed blur reducing adaptive new filter II with that of the results of the general mean, median and alpha trimmed mean filters. These results are shown for different amounts of impulse noise and fixed Gaussian noise of variance 0.4. The comparison of the results of various filters for various amount of Gaussian noise mixed with an impulse noise density of 20% is shown in Figure 4.8. It is found that IEF for the proposed filter increases as the amount of impulse noise increases and is greater than the IEF of other filters. The IEF decreases as the corrupted amount of Gaussian Noise increases.
Table 4.1 Effect of window size on to the performance of the New Filter I

<table>
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<tr>
<th>Impulse noise density</th>
<th>Variance of Gaussian noise</th>
<th>Window size</th>
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Figure 4.3 Noise Variance Vs PSNR for various Filters
Figure 4.4  Qualitative illustration of the proposed New filter I (with window size of 3×3) (a) Original test image. (b) Original image corrupted with a noise mixture of Gaussian noise of variance 0.03 and impulse noise density 0.03 (c) Result of General Mean Filter (d) Image filtered by bidirectional median Filter (e) Image filtered by the New Filter I
Figure 4.5 Qualitative illustration of the proposed New filter I (with window size $5 \times 5$) (a) Original test image. (b) Original image corrupted with a noise mixture of Gaussian noise of variance 0.1 and impulse noise density 0.04 (c) Result of General Mean Filter (d) Image filtered by bidirectional max/median Filter (e) Image filtered by the New Filter I
Table 4.2  Comparison of the performance of the New Filter II in terms of IEF with that of the various filters

<table>
<thead>
<tr>
<th>Variance of Gaussian Noise in %</th>
<th>Impulse noise density in %</th>
<th>IEF of Mean filter</th>
<th>IEF of median Filter</th>
<th>IEF of MATMF</th>
<th>IEF of New Filter II</th>
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Figure 4.6  Results of the New Filter II for various amounts of noise added to the original image.
Table 4.3  Comparison of the performance of the New Filter II in terms of IEF with that of the various filters

<table>
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<tr>
<th>Percentage of impulse noise (mixed with Gaussian noise of var 0.1)</th>
<th>IEF of Mean filter</th>
<th>IEF of Median filter</th>
<th>IEF of MATMF</th>
<th>IEF of proposed new filter II</th>
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Figure 4.7  Performance comparison of the New Filter II with that of other filters in terms of IEF (for fixed Gaussian noise variance)
Figure 4.8 Performance comparison of the filter II with that of other filters in terms of IEF (for fixed impulse noise density)
4.4 CONCLUSION

AMMF proposed in chapter 3 is efficient in removing the additive mixed noise and preserves low spatial information by involving all the pixels in the de-noising process. It is found that the edges are smeared due to averaging of all the pixels inside window. In order to preserve fine details and edges, two filtering algorithms namely New Filter I and New Filter II are proposed in this chapter. New Filter I is used to preserve edges and fine details by processing the corrupted pixels separately and then combined by a combiner algorithm. Even though the objective analysis shows better results, the subjective analysis shows blurring in reconstructed images.

New Filter II has three stages namely a stage 1, stage 2 and stage 3. Stage 1 is used to detect and remove impulse noise. Edges are detected and removed by stage 2. Blur and Gaussian noise are removed by stage 3.

Various evaluation measures namely MSE/pixel, IEF and PSNR are used to analyse the performance of the proposed filters. IEF is calculated with various window sizes. The subjective analysis and objective analysis are made. A mixture of Gaussian and impulse is removed and edges are preserved leading to reduction in blur. The results are compared with various adaptive filters and higher value of IEF shows the removal of noise with edge preservation even at higher window size.