ABSTRACT
An interpolation technique with edge sensing and adaptive window size is proposed for restoration of images that are highly corrupted by salt and pepper noise. The new technique shows significantly better image quality than Standard Median Filter, Adaptive Median Filter, Decision Based Algorithm, Progressive Switched Median Filter, Decision Based Unsymmetric Trimmed Median Filter and Modified Decision Based Unsymmetric Trimmed Median Filter. The Proposed technique is tested against different images and it gives better Peak Signal-to-Noise Ratio.

General Terms
Impulse Noise, Interpolation.

Keywords
Median Filter, salt and pepper noise, Adaptive Interpolation.

1. INTRODUCTION
Impulse noise in images is present due to channel transmission errors or introduced during the signal acquisition stage. There are two types of impulse noise, namely salt and pepper noise and random valued noise. Salt and pepper noise represents itself as randomly occurring white and black pixels. Number of nonlinear filters has been proposed for restoration of images contaminated by salt and pepper noise. Among these standard median filter is introduced to remove the salt and pepper noise. In median filter, the corrupted pixel is replaced by its median value. The major drawback of standard Median Filter is that the filter is not effective for high noise densities [1], [2]. That is, when the noise level is too high the edge details of the original image will get lost and also the standard median introduced too much distortion in the processed image. So Adaptive Median Filter [3], [4] is introduced. But at higher noise densities, both the corrupted and uncorrupted pixels in the neighborhood of an impulse corrupted pixel are considered to determine the noise replacing value, so the window size has to be increased which may lead to blurring the image.

In progressive switching median filter [5] the difference of the median value in the filtering window and the current pixel value is compare with a pre-defined threshold to decide about the presence of impulse in an image. The major drawback of this method is taking a robust decision is difficult. To overcome the above drawback, Decision Based Algorithm is proposed [6], [7]. In this, at high noise density, the neighboring pixel is used repeatedly for replacing the noisy pixel which degrades the quality of restored images, called streaking effect. In order to avoid this drawback, Decision Based Unsymmetric Trimmed Median Filter is proposed [8]. If the processing pixel in the window takes either the value of 0 or 255, then the corresponding pixel values are trimmed from the window & the median of the remaining values are calculated. At high noise densities, the trimmed median value cannot be obtained. So this algorithm can be also not suitable for high noise density. The Modified Decision Based Unsymmetric Trimmed Median Filter algorithm is introduced to remove this drawback. At high noise density the mean value is taken into account if the selected window contains all 0's or 255's or both [9]. The proposed interpolation technique with edge sensing and adaptive window size remove this drawback at high noise density and gives better Peak Signal-to-Noise Ratio.

The rest of the paper is structured as follows. Section 2 describes about the existing system. Section 3 describes about the proposed algorithm. Section 4 & 5 describes about the noise detection and the determination of replacing the noisy pixel. Section 6 describes about the results and discussion, and Section 7 describes the conclusion.

2. EXISTING SYSTEMS
2.1 Standard Median Filter
The standard median filter [1], [2], [12] is a reliable method to remove salt and pepper noise without damaging the edge details.

This filtering requires arranging the pixel values either in increasing or decreasing order and replaces the noisy pixel by the median of its neighborhood values.

Center pixel corrupted by impulse noise
the noise the median filter may arger neighborhood, which leads to a loss of edge details.

2.2 Adaptive Median Filter
In adaptive median filter [3], [4] the pixel of the corrupted image is retained if the median and the processing pixel itself are strictly between the minimum and the maximum value of the filtering window. If the median lies between that minimum and the maximum value of that window and the processing pixel does not lies between that minimum and the maximum value, the pixel is replaced by the median value;
otherwise when the median does not lies strictly in between that minimum and the maximum value of that window, the size of the window is increased and the pixel is replaced by the median of the increased size window, provided, this new median is also strictly between the minimum and the maximum value of the window, otherwise, the window size is again increased by without changing the central pixel.

The main drawback of the adaptive median filter is that at high noise density the adaptive nature increases the window larger and larger to obtain a valid median value. Also, there is a possible that the median value obtained from larger window will not be accurate one.

2.3 Progressive Switching Median Filter
In Progressive Switching Median Filter [5], [10] to determine the presence of impulse in an image, the difference of the median value, \( M(i,j) \) of the pixels in the filtering window and the current processing pixel, \( P(i,j) \) is calculated and then it is compared with a threshold. If the difference is greater than the threshold, then the noisy pixels are replaced by the median of the noise free pixels.

\[
X(i,j) = \begin{cases} 
    M(i,j) & \text{if } |M(i,j) - P(i,j)| > \text{Threshold} \\
    P(i,j) & \text{Otherwise}
\end{cases}
\]

The drawback of this process is that the estimation of the optimum threshold is very difficult. Also some time the impulse may be wrongly identified as original pixel and the original pixel may be identified as impulse.

2.4 Decision Based Algorithm
In decision based algorithm [6], [7] the pixel value inside the window are sorted in ascending order and the middle element of the window is consider as median value of that window. If the processing pixel takes the value of minimum and maximum gray levels, then it is consider as corrupted pixel and it is replaced by median of its neighborhood pixels. If the median of the neighborhood pixels also takes the value of 0 or 255, then the processing pixel is replaced by the value of its neighborhood pixel value.

\[
\text{Window selected} \quad \text{Row Sorting}
\]

\[
\begin{array}{cccc}
255 & 255 & 255 & 0 \\
122 & 223 & 255 & 255 \\
132 & 255 & 121 & 124 \\
120 & 250 & 255 & 255 \\
250 & 255 & 200 & 125 \\
\end{array}
\]

\[
\text{(0<255≤255) processing pixel is noisy so replaced by median value.}
\]

\[
\text{Column Sorting} \quad \text{Right diagonal Sorting}
\]

\[
\begin{array}{cccc}
120 & 132 & 255 \\
121 & 223 & 255 \\
122 & 250 & 255 \\
\end{array}
\]

\[
\text{Median, which is used for replacing the processing pixel}
\]

The drawback of this algorithm is at high noise density the neighboring pixel is used repeatedly for replacing the noisy pixel which degrades the quality of restored images, called streaking effect.

2.5 Decision Based Unsymmetric Trimmed Median Filter
In decision based unsymmetric trimmed median filter [8], the pixel values inside the window are sorted and if the processing pixel takes either the value of 0 or 255, then the corresponding pixel values in the window are trimmed from the window & the median of the remaining values are calculated, which is then used for replacing the noisy pixel.

\[
\text{Window Selected} \quad \text{median} = \frac{(120 + 158)}{2} = 139
\]

\[
\begin{array}{cccc}
121 & 122 & 223 & 255 \\
222 & 0 & 125 & 255 \\
167 & 158 & 0 & 0 \\
224 & 0 & 255 & 123 \\
\end{array}
\]

\[
\text{(0<255≤255) processing pixel is noisy.}
\]

\[
\text{Current noisy pixel in the window is replaced by median value calculated.}
\]

The main drawback of the decision based unsymmetric trimmed median filter is, at high noise density, the trimmed median value cannot be obtained because the selected window contains all 0’s or 255’s or both.

2.6 Modified Decision Based Unsymmetric Trimmed Median Filter
In modified decision based unsymmetric trimmed median filter [9], if the processing pixels takes either the value of 0 or 255, then two cases are possible. If the selected window contains
all the element as 0’s or 255’s, then replace the processing pixel with the mean of the element of the window.

\[
\begin{bmatrix}
0 & 255 & 0 \\
255 & 0 & 255 \\
0 & 255 & 0
\end{bmatrix}
\]  
\((0<255<255)\) processing pixel is noisy, also all the remaining elements are 0’s & 255’s, so calculate mean and replace the processing pixel with the mean value.

If the selected window contains not all the element as 0’s and 255’s, then eliminate 255’s & 0’s and find the median value of the remaining elements. Replace the processing pixel with the median value.

\[
\begin{bmatrix}
120 & 255 & 110 \\
0 & 220 & 150 \\
255 & 0 & 255
\end{bmatrix}
\]  
\((0<255<255)\) processing pixel is noisy but not all the elements are 0’s and 255’s, so calculate median and replace the processing pixel with the median value calculated.

3. PROPOSED ALGORITHM

The proposed interpolation technique with edge sensing and adaptive window size algorithm processes the corrupted images by first detecting the impulse noise. The processing pixel is checked whether it is noisy or noisy free. That is, if the processing pixel lies between maximum and minimum gray level values (i.e.) 0< \(P(i,j)\)<255; the pixel being processed is left unchanged. Otherwise, \(P(i,j)\) is a corrupted pixel.

1) A 2-D window of size 3x3 is selected. Assume the pixel to be processed is \(P(i,j)\).
2) The \(P(i,j)\) is an uncorrupted pixel if \(P(i,j)\) lies between minimum and maximum grey level values (i.e.) 0< \(P(i,j)\)<255; the pixel being processed is left unchanged. Otherwise, \(P(i,j)\) is a corrupted pixel.
3) If \(P(i,j)\) is a corrupted pixel, then the neighboring pixel values are taken into account and compared with the threshold value.
   a) If the value is less than threshold then increase the window size.
   b) Otherwise, the processing pixel is replaced with the interpolated value.

The pictorial representation of each step of the proposed algorithm is shown in Fig. 1.

4. NOISE DETECTION

In order to distinguish the salt and pepper noise from an original image first the corrupted pixels should be detected from the uncorrupted pixels. For that a simple algorithm [11] is used as follows:

The algorithm consists of two phases namely phase I and phase II.

Phase I:
1) Consider a 5x5 window with center processing pixel as \(P_{ij}\).
2) Sort all the pixels inside the window in ascending order \((S)\), so that the minimum value lies at the beginning of \(S\) and the maximum value lies at the end of \(S\), then find the median \((med)\) of \(S\).
3) Calculate the intensity difference \((D)\) between each adjacent pixel in \(S\).
4) Now, from the first value to the med in \(S\), find the maximum intensity difference in \(D\) of the same range & mark its corresponding pixel in \(S\).
5) Also, from the med to the last value in \(S\), find the maximum intensity difference in \(D\) of the same range & mark its corresponding pixel in \(S\).
6) Now, three ranges namely minimum, medium and maximum ranges are obtained.
7) If the processing pixel belongs to the medium range, then it is considered as uncorrupted pixel & hence no further processing is required.
8) Otherwise, if it lies in minimum or maximum range, the phase II will be starts.

Phase II:
1) Consider a 3x3 window, with processing pixel \(P_{ij}\) as center & proceed the step 2 to step 6.
2) If the processing pixel belongs to the medium range, then it is considered as uncorrupted pixel & else it is considered as corrupted.

Consider an example of 5x5 window with center processing pixel as 255.

\[
W_{5x5} = \begin{bmatrix}
255 & 150 & 255 & 255 & 255 \\
155 & 0 & 220 & 255 & 155 \\
0 & 22 & 255 & 0 & 126 \\
12 & 0 & 45 & 134 & 255 \\
255 & 160 & 255 & 0 & 0
\end{bmatrix}
\]
Sort the window in ascending order & find the median (med) as 150, i.e., \( S = [0 0 0 0 0 0 0 12 22 45 126 134 150 155 160 220 255 255 255 255 255 255 255 255] \). The intensity difference between each adjacent pixel in \( S \) is calculated as \( D = [0 0 0 0 0 0 12 10 23 81 8 16 5 5 50 60 35 0 0 0 0 0 0] \).

For the pixel with intensities between 0 & med in \( S \), the corresponding maximum difference in \( D \) is 81, which is obtained from taking the difference of 45 & 126 in \( S \).

For the pixel with intensities between med & 255 in \( S \), the corresponding maximum difference in \( D \) is 60, which is obtained from taking the difference of 0 & 126 in \( S \).

Thus the minimum, medium & the maximum ranges are \{0, 0, 0, 0, 0, 0, 0, 12, 22, 45\}, \{126, 134, 150, 155, 160\} & \{220, 250, 255, 255, 255, 255, 255, 255, 255, 255, 255\} respectively.

Since the processing pixel 255 lies in maximum range, the phase II starts. For that a 3×3 window is selected with 255 as center processing pixel.

\[
W_{3 \times 3} = \begin{bmatrix}
0 & 0 & 220 \\
22 & 255 & 0 \\
0 & 45 & 134
\end{bmatrix}
\]

Sort the window in ascending order & find the median (med) as 22, i.e., \( S = [0 0 0 0 22 45 134 220 255] \).

The intensity difference between each adjacent pixel in \( S \) is calculated as \( D = [0 0 0 22 23 81 8 16 5 5 50 60 35 0 0 0 0 0] \).

For the pixel with intensities between 0 & med in \( S \), the corresponding maximum difference in \( D \) is 22, which is obtained from taking the difference of 0 & 22 in \( S \).

For the pixel with intensities between med & 255 in \( S \), the corresponding maximum difference in \( D \) is 60, which is obtained from taking the difference of 160 & 220 in \( S \).

Thus the minimum, medium & the maximum ranges are \{0, 0, 0, 0\}, \{22, 45\} & \{134, 220, 255\} respectively.

At the end of phase II, the center processing pixel 255 is detected as “corrupted” pixel, since it belongs to the maximum range.

5. **DETERMINATION OF REPLACING THE NOISY PIXEL**

In the proposed method, the corrupted pixel is processed by using interpolated value. For that first the horizontal and vertical gradient is calculated as shown below

<table>
<thead>
<tr>
<th></th>
<th>( P_{up} )</th>
<th>( P_{down} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{left} )</td>
<td>( P_{up} )</td>
<td>( P_{down} )</td>
</tr>
<tr>
<td>( P_{right} )</td>
<td>( P_{down} )</td>
<td></td>
</tr>
</tbody>
</table>

Horizontal gradient \( L^H = (P_{left} - P_{right}) \)
Vertical gradient \( L^V = (P_{up} - P_{down}) \)

If \( L^H \) and \( L^V < \text{ethresh} \), then there exists smooth region

Calculate \( P(i,j) = (P_{left} + P_{up} + P_{right} + P_{down}) / 4 \) \hspace{1cm} (4.1)

If \( L^H > \text{ethresh} \), then there exists a sharp horizontal edge

Calculate \( P(i,j) = W1 ((P_{left} + P_{right})/2) + W2 ((P_{up} + P_{down})/2) \), \( W1 > W2 \) & \( W1 + W2 = 1 \) \hspace{1cm} (4.2)

If \( L^H < \text{ethresh} \), then there exists a sharp vertical edge

Calculate \( P(i,j) = W1 ((P_{up} + P_{down})/2) + W2 ((P_{left} + P_{right})/2) \), \( W2 > W1 \) & \( W1 + W2 = 1 \) \hspace{1cm} (4.3)

If any two consecutive pixels \( P_{up}, P_{down}, P_{left}, P_{right} \) takes minimum or maximum grey level values, then replace \( P_{left}, P_{up}, P_{down}, P_{right} \) by \( P_1, P_2, P_3, P_4 \) respectively.

Where

\[
W1 \text{ & } W2 - \text{ weights and based on various analysis the best values chosen for weights are 0.13 and 0.87 respectively.}
\]

---

**Fig 2: Block diagram for replacing the Noisy pixel**

The step is as follows

1) First, the horizontal and vertical gradients are calculated to determine the existence of sharp horizontal and vertical edges.

2) If the horizontal and vertical gradient values are lesser than the threshold, then there is no edge exists and the region is consider to be smooth. The processing pixel \( P(i,j) \) is processed by bilinear interpolation using the equation (4.1).
3) If the horizontal and vertical gradient values are greater than the threshold, then there exists an edge.

Two cases are possible:
   a) If the horizontal gradient $L^H$ is greater than the vertical gradient $L^V$, then there is a sharp horizontal edge and the processing pixel $P(i,j)$ is processed by using the equation (4.2).
   b) If the vertical gradient $L^V$ is greater than the horizontal gradient $L^H$, then there is a sharp vertical edge and the processing pixel $P(i,j)$ is processed by using the equation (4.3).

4) At higher noise density, the interpolation doesn’t perform well; as a result some noises are seen in the restored image. In that case after getting the restored image, smoothing technique is applied to that particular noisy positions.

The pictorial representation of replacing the noisy pixel is shown in Fig. 2.

6. RESULTS AND DISCUSSION

The performance of the proposed algorithm is tested with different grayscale images. The noise density is varied from 10% to 90%. Denoising performances are quantitatively measured by the PSNR as defined in (1)

$$\text{PSNR} = 10 \log_{10} \left( \frac{255^2}{\text{MSE}} \right) \text{ (dB)} \quad (1)$$

Here 255 is the maximum pixel (signal) value of the image.

$$\text{MSE} = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} |u(i,j) - I(i,j)|^2$$

where PSNR stands for peak signal to noise ratio, MSE stands for mean square error, $M \times N$ is the size of the image, $u(i,j)$ represents the original image, $I(i,j)$ represents the denoised image. Fig.3 displays the original and corrupted images of Flower.jpg image. Fig.5 displays the original and corrupted images of Cameraman.jpg image.

In Fig.4, Fig.6, the first column represents the output of standard median filter (SMF) [2], second column represents the output of Adaptive median filter (AMF) [3], third column represents the output of Progressive switching median filter (PSMF) [4], fourth column represents the output of Decision based algorithm (DBA) [5], fifth column represents the output of decision based unsymmetric trimmed median filter (DBUTMF) [6], sixth column represents the output of Modified decision based unsymmetric trimmed median filter (MDBUTMF) [7] and seventh column represents the output of the Proposed Algorithm (PA).

The MSE, PSNR values of the proposed algorithm are compared against the existing algorithms by varying the noise density as shown in Table 1, Table 2, Fig 7 & Fig 8. From the Fig.7 & Fig.8 it is observed that the proposed algorithm provides better PSNR when compared with the existing algorithms at both low and high noise densities.
Table 1. MSE of the restored flower image corrupted by various noise densities

<table>
<thead>
<tr>
<th>Noise Ratio %</th>
<th>SMF</th>
<th>AMF</th>
<th>PSMF</th>
<th>DBA</th>
<th>TMF</th>
<th>MDBUTMF</th>
<th>PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5.87</td>
<td>4.36</td>
<td>4.40</td>
<td>4.34</td>
<td>4.29</td>
<td>4.24</td>
<td>4.13</td>
</tr>
<tr>
<td>20</td>
<td>39.22</td>
<td>37.32</td>
<td>34.95</td>
<td>30.32</td>
<td>29.74</td>
<td>28.36</td>
<td>17.81</td>
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<td>30</td>
<td>156.1</td>
<td>151.6</td>
<td>156.9</td>
<td>140.3</td>
<td>140.2</td>
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<td>57.13</td>
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<td>40</td>
<td>587.3</td>
<td>574.5</td>
<td>519.6</td>
<td>484.1</td>
<td>474.4</td>
<td>460.51</td>
<td>138.6</td>
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<tr>
<td>50</td>
<td>1462</td>
<td>1452</td>
<td>1394</td>
<td>1351</td>
<td>1299</td>
<td>1067.8</td>
<td>303.2</td>
</tr>
<tr>
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<td>2908</td>
<td>2828</td>
<td>2810</td>
<td>2151</td>
<td>2648</td>
<td>2597.4</td>
<td>506.2</td>
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<tr>
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<td>5166</td>
<td>5078</td>
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<td>4207</td>
<td>5274</td>
<td>4834.7</td>
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<tr>
<td>80</td>
<td>8800.3</td>
<td>84901</td>
<td>8474.1</td>
<td>8170.9</td>
<td>7294.1</td>
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<td>1575</td>
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<tr>
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<td>12781</td>
<td>11939</td>
<td>11992</td>
<td>10758</td>
<td>2395</td>
</tr>
</tbody>
</table>

Table 2. MSE of the restored cameraman image corrupted by various noise densities

<table>
<thead>
<tr>
<th>Noise Ratio %</th>
<th>SMF</th>
<th>AMF</th>
<th>PSMF</th>
<th>DBA</th>
<th>TMF</th>
<th>MDBUTMF</th>
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<td>167.8</td>
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<tr>
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<td>569.6</td>
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<td>491.46</td>
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<tr>
<td>50</td>
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<td>1187</td>
<td>1161</td>
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<td>13256</td>
<td>12288</td>
<td>10021</td>
<td>99571</td>
<td>2677</td>
</tr>
</tbody>
</table>

Fig 7: PSNR analysis of the various filters on Flower image for various noise levels

Fig 8: PSNR analysis of the various filters on Cameraman image for various noise levels

7. CONCLUSION

A new algorithm is proposed to restore the image corrupted by salt and pepper noise, which employs the sharp edge and smooth region detection and the adaptive interpolation technique. From the results and discussion, it is seen that the proposed algorithm preserve details at high noise densities and has a better performance than the existing algorithms.

8. ACKNOWLEDGMENTS

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9. REFERENCES