A Novel Fuzzy Switching Median Filter to Remove Salt and Pepper Noise

Major Project submitted in partial fulfillment of the requirements for the award of degree of

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(2011-2013)

Certificate

This is to certify that **Ms. Jaya Gupta (2K11/ISY/22)** has carried out the major project titled "**A Novel Fuzzy Switching Median Filter to Remove Salt and Pepper Noise**" as a partial requirement for the award of Master of Technology degree in Information Systems by Delhi Technological University. The major project is a bonafide piece of work carried out and completed under my supervision and guidance during the academic session **2011-2013**. The matter contained in this report has not been submitted elsewhere for the award of any other degree.

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Abstract

Image processing consists of basic and important step of impulse noise removal. Impulse noise is frequently introduced into images while transmitting and acquiring them over an unsecure communication channel. TV or Satellite images may be corrupted by atmospheric disturbances. In other applications noise can be introduced by strong electromagnetic fields, transmission errors, etc. Human visual system is very sensitive to the high amplitude of noise signals, thus noise in an image can result in a subjective loss of information. Various techniques have been introduced for the removal of impulse noise based on the properties of their respective noise models. Performance of some recent filters is evaluated and compared to that of the proposed filter.

This study introduces an iterative filter for images corrupted with salt and pepper noise, typically in the range of 10-50%. It is a novel technique for detecting salt and pepper noise while preserving the image details and textures. The application of Fuzzy Derivative approach with Powerful noise detection mechanism in detection phase provides optimal results. By extensive simulation results and comparisons with other filters, it is observed that the proposed algorithm outperforms several methods.

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List of Acronym

p	*Probability*
S	*size of window*
SPN	*Salt & Pepper Noise*
MSE	*Mean Square Error*
PSNR	*Peak Signal to Noise Ratio*
SMF	*Standard median filter*
MMF	*Min-Max Median Filter*
CWMF	*Center Weighted Media Filter*
AMF	*Adaptive Median Filter*
WM	*Weighted median filter*
SWM	*Switching median filter*
DWM	*Directional weighted median filter*
NAFSM	*Noise Adaptive Fuzzy Switching Median Filter*
FSM	*Fuzzy Switching Median filter*
EEPA	*Efficient edge-preserving algorithm*

Chapter 1

Introduction

1.1 Preview

An image is the representation of the outer appearance of a person or thing. Nowadays, images are the most relevant and convenient means of transmitting information and emotions around the world.

Over the web, daily millions of images are exchanged to facilitate the better understanding of the environment, to educate the masses and to spread the knowledge in a very interactive and interesting way. Therefore, processing of the images by the digital media has become very popular and significant. The process of receiving and analyzing visual information by digital computer is called digital image processing.

A digital image is represented as a two-dimensional function, $f(x, y)$, where x and y are *spatial* (plane) coordinates, and the amplitude of f at any pair of coordinates (x, y) is called the *intensity* or *gray level* of the image at that point[1].

An image with a finite and discrete value of spatial coordinates and amplitude value is referred as Digital Image. Generally, Digital image is represented using small unit elements which are called picture elements, image elements or pixels. Each and every pixel is denoted using a row and column value pair. The first component r (the row) increases downward, while the second component c (the column) increases to the right. Pixel coordinates are integer values and range between 1 and the length of the row or column.

Digital images are of different types such as binary, gray-scale and colour images, which are described below[2]:

1.Binary images:

Binary images are very simple images. Only two discrete values are used to represent these images. Binary images are also called *Bi-level, Two-level or Black and White images*. This means that each pixel is stored as a single bit (0 or 1). Black and white colour is represented by ‘0’and ‘1’ respectively. Binary images often arise as the result of certain operations such as segmentation, thresholding , and dithering. The field of computer vision needs the kind of images in which the general shape or outline information is needed. Bi-level images are the most suitable images for such applications.

2.Gray-scale images:

Gray scale images are called black and white or monochrome images. Each pixel location holds a value to the gray level of image. Basic 8-bit image has 256 gray levels where ‘0’ denotes Black and ‘255’ represents White. The span of gray level between black and white is made up of very fine steps.

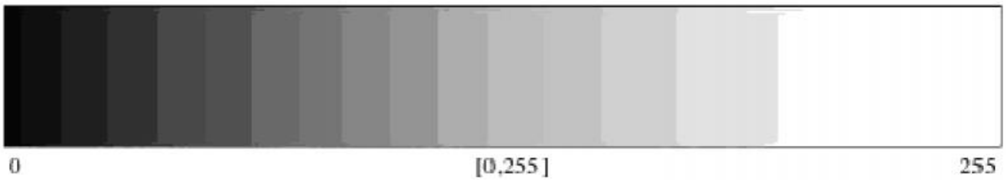


Figure 1.1 : Gray-Scale-Band for an 8-bit image

3.Colour Images:

A colour image is a combination of three colours red, green and blue. These colours hold particular pixel locations in an image. White light is a mixture of primary colours correspondingly red, green and blue (RGB). Any colour could be formed from the different combination of RGB. If 256 levels are taken for each primary colour, then each colour pixel is made up of 24bits.This gives an idea of 16.7 million different possible colour combinations approximately.

(a) (b) (c)

Figure 1.2: (a) Binary Image, (b) Gray-Scale-Image, and (c) Colour Image

If a same size gray scale and colour image is taken, gray scale image takes less memory space than colour. This study is basically for gray scale images, several gray scale images are used for experimental purposes.

Natural images are first converted into digital form using the process of Digitization. The digitization process is accomplished using scanner, Digi-cam or video camera connected to personal computer or laptop. After that the digital images are saved on some storage media such as hard disk or CD-ROM. Once the image is converted into Digital form, various operations can be performed on it as per use.

Digital Image processing involves several steps to process the image. Digital image processing operations can be broadly divided into following classes:

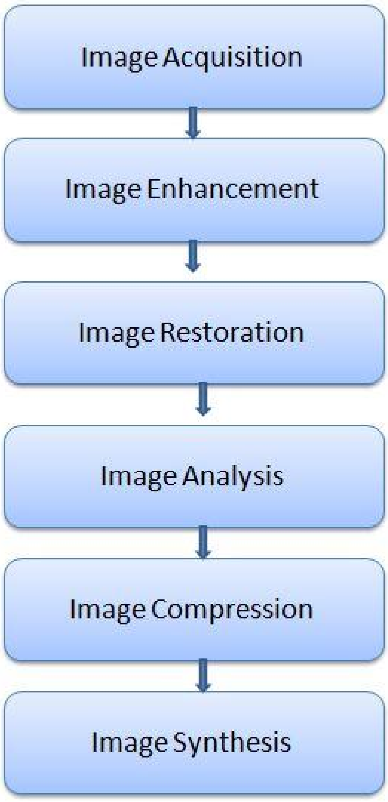


Figure 1.3: Image Processing Steps

- **Image Acquisition**: Sampling and quantization to convert image in digital form.
- **Image Enhancement**: Brightness adjustment, contrast enhancement, image averaging, convolution, frequency domain filtering, and edge enhancement.
- **Image restoration**: Photometric correction, inverse filtering, and noise removal
- **Image analysis**: Segmentation feature extraction, object classification
- **Image compression**: Lossless and lossy compression
- **Image synthesis**: Topographic imaging, 3-D reconstruction

Out of the five classes of digital image processing, cited above, this study focuses on image restoration. To be precise, the thesis devotes on a part of the image restoration i.e. impulse noise removal from images, stated in the Problem Definition. Further, this thesis also discusses how noise removal can be utilized for high quality image enhancement.

1.2 Problem Formulation

The basic idea behind this study is the restoration of image corrupted by Salt and Pepper noise. The process is referred as image “Denoising”. An image containing salt-and-pepper noise will have dark pixels in bright regions and bright pixels in dark regions. Most widely CCD (Charge Coupled Device) image sensors are used to capture images in professional, medical, and scientific applications. They convert Analog-signal to digital domain. Sometimes due to some erroneous analog-to-digital conversion or bit transmission, the images get contaminated by impulse noise.

1.3 Objective

The objective of the proposed research is the discovery of new technique for the restoration of corrupted image. Digital images are contaminated by unwanted noise during image acquisition and transmission. The process of removing unwanted noise from an image is called Denoising. The application of image denoising is in the field of astronomy, medical imaging and forensic science, where the requirement of high quality images is needed for the analysis of unique events. Therefore, a good denoising algorithm is required for pre-processing steps.

During image acquisition in hazy medium and transmission through an improper channel or errors in storage media, various kind of noise affects the image details. Salt & Pepper noise is one of such kinds. There are various methods and techniques which help to restore the image from impulse noise. Some techniques are briefly discussed in further chapters. Various algorithms in a literature are proposed to remove impulse noise from the images. There are many algorithms which remove low as well as high percentage of ‘Salt & Pepper’ noise. They are discussed as follows: Tri-state median filter (TSM)[3] , Fuzzy Switching Median Filter(FSM)[4], Noise Adaptive Fuzzy Switching Median Filter(NAFSM)[5], An Efficient Edge Preserving Algorithm using AFSM[9], Boundary Discriminative Noise Detection Filter (BDND)[7], Modified Decision Based Unsymmetrical Trimmed Median Filter Algorithm (MDBUTMF) [6] etc.

This study provides an efficient algorithm for Salt & Pepper Noise Removal along with edge preserving strategy. The Algorithm is divided in two phases, first is noise detection phase and other one is noise cancellation phase. The proposed algorithm is implemented in MATLAB and tested on some standard image to show the effective and efficient results of an algorithm. It also presents the comparison of results with some existing methods.

1.4 Organization of Thesis

The rest of this thesis is organized as follows.

In Chapter 2 Impulse noise is discussed in detail. An overview of impulse noise detection and removal with literature survey is discussed. Various noise models are also described briefly.

Chapter 3 Illustrates the proposed algorithm for the removal of noisy pixels using fuzzy derivative approach. The design of the proposed algorithm is explained with the aid of flowchart. Fuzzy Derivative Approach and FSM filter is explained briefly. Further, demo of the operation of the algorithm in the form of example is presented.

Chapter 4 provides the comparative results with some recent as well as state of art techniques. The implemented code has been tested on various standard images. Results for varying noise level typically from 10% to 50% are shown for different test images. The quantitative results of comparison are also tabulated by calculating the Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) of the output image.

Chapter 5 comprises the conclusion of the study.

Chapter 2

Impulse Noise

Image Acquisition is the first essential and important step in the field of Digital Image Processing. There are numerous ways to acquire images. One way to acquire the images is to generate the digital image from sensed data. To create a digital image is required to convert the sensed data into digital form. The output of most of the sensors is a continuous voltage waveform whose amplitude and spatial behaviour is related to physical phenomena being sensed. It involves two phenomena: Sampling and Quantization [1]. The basic idea behind Sampling and Quantization is to convert a continuous image in a digital form. Sampling is the process of digitizing the coordinate values of an image (i.e. x- and y-coordinates of an image) and Quantization refers to the digitization of the amplitude value.

At every step there are some fluctuations and disturbance present in the medium that inserts some random values in the image. These disturbances are the noise. Noise is of several kinds such as Gaussian noise, Impulse noise, Rayleigh Noise etc [1].Salt & Pepper noise is a kind of impulse noise.

The main motto of this study is to remove Impulse noise from the image while preserving the image details. Impulse noise affects the image at the time of acquisition due to noisy and faulty sensors or at the transmission time due to channel errors or due to faulty storage hardware. It is a kind of Sharp and sudden disturbance. It is a randomly scattered white and black pixel over the image. Due to this reason is called 'Salt & Pepper' Noise.

(a) **(b)**

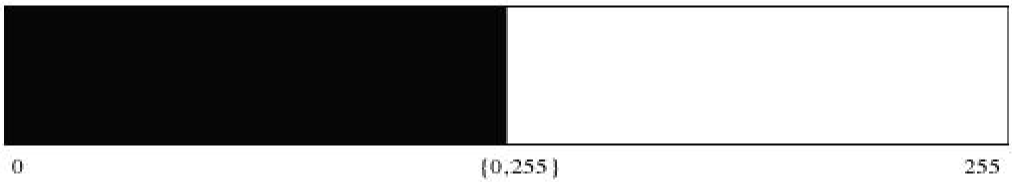
Figure 2.1 :(a) Original Image (b) Noisy Image

Impulse noise are of two kinds:

1.Salt & Pepper Noise (SPN):

For images corrupted by salt-and-pepper noise, the noisy pixels can take only the maximum and the minimum values in the dynamic range i.e.

When $R(i, j) = \{N_{\min}, N_{\max}\}$



Nmax=0 **Nmax = 255**

Figure 2.2 : salt and Pepper Noise dynamic range

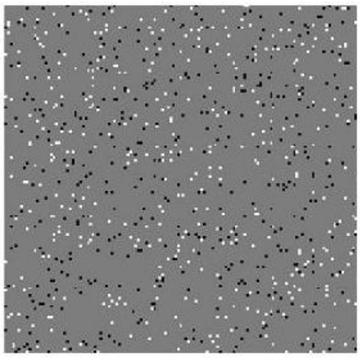


Figure 2.3 : Salt and Pepper Noise

2.Random Valued Impulsive Noise (RVIN):

For images corrupted by Random-valued noise, the noisy pixels can take any random value in the dynamic range i.e. can vary between the specified range as discussed below:

$R(i, j) = \{N_{\min}, N_{\max}\}$

In this study our focus is to remove Salt & Pepper noise (Fixed valued impulse noise).

2.1 Literature Survey

Noise Reduction from corrupted noisy images is still a spectacular area of research. Several algorithms are suggested over a decade by many researchers. Impulse noise removal can be classified into two broad categories:

2.1.1 Linear Techniques

Liner techniques follow noise reduction formula for all pixels of image linearly without classifying pixels into noisy and non-noisy pixels. Drawback of linear algorithm is blurring of edges and image details as they are not able to effectively eliminate the impulse noise. Basic linear filters are Average, Mean Filters, Median Filters [1] etc.

- **Average Filter :**

Initially a square window of size (*2N +1)*x(*2N +1)* is selected centred on a pixel *(x, y)*. Value of N varies from 1 to n. Window size (*2N +1)*x(*2N +1)* must be selected as odd number so that the central pixel is computed easily. Whole image matrix is scanned by the window. At each scan, value of central pixel of window is replaced by the average value of its neighbouring pixels computed within the window.

- **Mean Filter :**

Mean Filter works in same manner as Average Filter with some modified concept of central pixel replacement. Here central pixel value is replaced by the mean value of its neighbouring pixels within the window.

- **Median Filter :**

Working of Median Filter is same as Average filter but here central pixel value is replaced by the median value of its neighbouring pixels computed within the window.

2.1.2 Non Linear Techniques

Non-Linear noise reduction is done in two steps:

- Noise Detection
- Noise Cancellation

In first step, location of noise is detected and in second step, detected noisy pixels are replaced by estimated value.

Many non-linear noise removal techniques are reported in the literature. Some of the earliest operators for removal of salt-and-pepper noise are conventional median filters. They are established as reliable method to remove the salt and pepper noise without damaging the edge details. They exploit the rank-order information of pixel intensities within a filtering window and replace the centred pixel with the median value. Due to its effectiveness in noise suppression and simplicity in implementation, various modifications of the SM filter have been introduced, such as the *weighted median* (WM) filter [1] and the *centre weighted median* (CWM) filter [11].

Conventional median filtering approaches apply the median operation to each pixel unconditionally, that is, without considering whether it is uncorrupted or corrupted. As a result, the image details contributed from the uncorrupted pixels are still subject to be filtered, and this causes image quality degradation.

An intuitive solution to overcome this problem is to implement an impulse-noise detection mechanism prior to filtering; hence, only those pixels identified as "corrupted" would undergo the filtering process, while those identified as "uncorrupted" would remain intact. By incorporating such noise detection mechanism or "intelligence" into the median filtering framework, the so-called *switching median filters (SMF)* are proposed by S. Zhang and M. A. Karim, [5]. In switching median filters, a noise detection mechanism has been incorporated so that only those pixels identified as "corrupted" would undergo the filtering process, while those identified as "uncorrupted" would remain intact [7].

Nonlinear filters such as adaptive median filter (AMF) which are provided by H. Hwang and R. A. Hadded, [12-17] can be used for discriminating corrupted and uncorrupted pixels and then apply the filtering technique. Noisy pixels will be replaced by the median value, and uncorrupted pixels will be left unchanged. AMF performs well at low noise densities since the corrupted pixels that are replaced by the median values are very few. The major drawback of this method is that defining a robust decision measure is difficult. These filters will not take into account the local features as a result of which edge details may not be recovered satisfactorily, especially when the noise is high.

Fuzzy techniques in image processing are promising research field. Fuzzy techniques have already been applied in several domains of image processing (e.g., filtering, interpolation, and morphology), and have numerous practical applications (e.g., in industrial and medical image processing etc.).

Several modifications in SMF filters are proposed to remove high density impulse noise. Kenny Kal Vin Toh [5] developed the extensions of Switching median filters using Fuzzy logic and reasoning, such filters are *FSM Filters and NAFSM filter[7]*. They effectively remove noise from the image but cannot handle high density of impulse noise. Dong-Sheng Jiang, Xun-Bo Li, et.al presented an *Adaptive Fuzzy Switching Median Filter* [13]. This is a based on fuzzy switching median filtering with an adaptive initialization of the filtering window. It is a good filter to remove the high density noise but not able to produce smooth results. P. E. Ng and K. K. Ma proposed a *BDND filter* [5] which is a switching median filter with boundary discriminative noise detection approach .These filters can achieve good edge preserving performance employing fuzzy sets. With the fuzzy theories it is useful and effective to removal salt and pepper noise in image processing compared to the conventional median based filters. Iyad F. Jafar, et.al. represented *Some Efficient Improvements in BDND Filtering*[14]. Most fuzzy techniques in image noise reduction mainly deal with fat-tailed noise like impulse noise. These fuzzy filters are able to outperform rank-order filter schemes (such as the median filter). Nevertheless, most fuzzy techniques are not specifically designed for Gaussian (-like) noise or do not produce convincing results when applied to handle this type of noise. But the major drawback of these filters that the image details get blurred when the noise density is very high. Therefore, some new techniques are proposed for filtering narrow-tailed and medium narrow-tailed noise by a fuzzy filter.

One such filter is developed by Dimitri Van De Ville and Dietrich Van der Weken et.al.[15] These filters can preserve the image details and do fuzzy smoothing in the image while removing impulse noise. But this filter handles very low noise density.

There is a common problem seen while processing of images is blurring of edges due to linear filtering. To deal with blur J. K. Mandal and Somnath Mukhopadhyay[16] has developed efficient filters using evolutionary techniques. To preserve edges, an edge preserving fuzzy filter for colour images developed by Verma *et al*.[8] provides efficient results. It is a novel technique to detect and remove impulse noise in colour images. More sophisticated algorithms have been developed using fuzzy reasoning as well as non fuzzy mechanisms to provide better detection of noise resulting in accurate restoration. There are several impulse noise detection and removal filters [25-29], which are based on Evolutionary algorithms such as *Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO)* etc. These Filters are able to produce good results at high noise densities but takes a lot time in processing.

Therefore this study presents a novel Fuzzy switching median filter with a fuzzy derivative approach, which not only removes a high density Salt and Pepper noise but also preserves image details being less sensitive to local variation due to image structures, such as edges but also smoothens the image textures using fuzzy smoothing operation.

2.2 Performance Measures

Various methods for measuring perceptual image quality attempt to quantify the visibility of deference between an original digital image and its distorted version using a variety of known properties of the human vision system. A fundamental task in many image processing applications is the visual evaluation of a distorted image. There are many measures for examining image quality, such as the mean structural similarity, mean absolute error, mean square error (MSE), and peak signal-to-noise ratio (PSNR).

2.2.1 Mean Square Error (MSE)

The simplest and the most widely used full reference quality measure is the MSE. It is computed by averaging the squared intensity difference of distorted and original image pixels.

$$MSE = \frac{\sum\sum\left(Y(i,j)-\hat{Y}(i,j)\right)^2}{M\times N} \tag{1}$$

$M\times N$ is size of the image, $Y(i,j)$ represents the original image, and $\hat{Y}(i,j)$ denotes the restored image. In ideal conditions the value of Standard MSE should be zero, but in real time scenarios, it is not feasible. Therefore lower the value of MSE better the quality of restored image.

2.2.2 Peak Signal-To-Noise Ratio (PSNR)

PSNR (peak signal-to-noise ratio) measures the quality of reconstruction of image statistics.

PSNR analysis uses a standard mathematical model to measure an objective difference between the original and reconstructed image after noise removal.

It is closely related to Mean Square Error (MSE).

$$PSNR\ in\ dB = 10\log_{10}\left(\frac{255^2}{MSE}\right) \tag{2}$$

The PSNR value tends-to infinity as the MSE approaches zero; this shows that a higher PSNR value implies higher image quality. At the other end of the scale, a small PSNR value provides high numerical differences between images.

Chapter 3

The Proposed Approach

The proposed method is a detail preserving FSM filter using Fuzzy Derivative approach to remove Salt and pepper noise from the contaminated image. It can remove the noise while maintaining image boundaries and textures. From the literature survey it is clear that efficient removal of impulse noise mainly depends on the detection phase. The detection stage of the proposed algorithm efficiently identifies the location of corrupted pixels so that the edges and fine image details remain intact.

The proposed study deals with fuzzy derivative based approach in combination with boundary discriminative approach for noise detection in the contaminated image. The double detection process is very effective to find the corrupted pixels in the image. When the matrix of corrupted pixels is generated, FSM filter is applied to restore the corrupted pixels.

The proposed algorithm performs image restoration in two steps :

- Noise Detection Step
- Noise Cancellation Step

3.1 Noise Detection Step

The noise detection step comprises of two methods one is Fuzzy Derivative Based Method, which is developed to make a difference between an edge pixel and a Salt & Pepper noise, present in the greyscale image and other one is Powerful Noise Detection method, which is a derivative free method for noise detection.

3.1.1 Fuzzy Derivative based Method:

Consider the neighbourhood of a pixel (x, y) as shown in Figure 3.1. A derivative at the central pixel position (x, y) in the direction D (D = {NW, W, SW, S, SE, E, NE, N}) is defined as the difference between the pixel of interest and its neighbour in the corresponding directions.

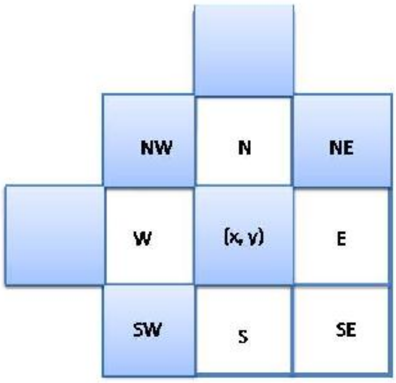


Figure 3.1: Pixel values indicated in gray are used to compute the "fuzzy derivative" of the central pixel (x, y)

For an example the derivative at the central pixel position (x, y) in the direction D is defined as the difference between intensity of the pixel at (x, y) and its neighbour in the direction D as:

$$\nabla(x, y) = |I(x-1, y-1) - I(x, y)| \quad (1)$$

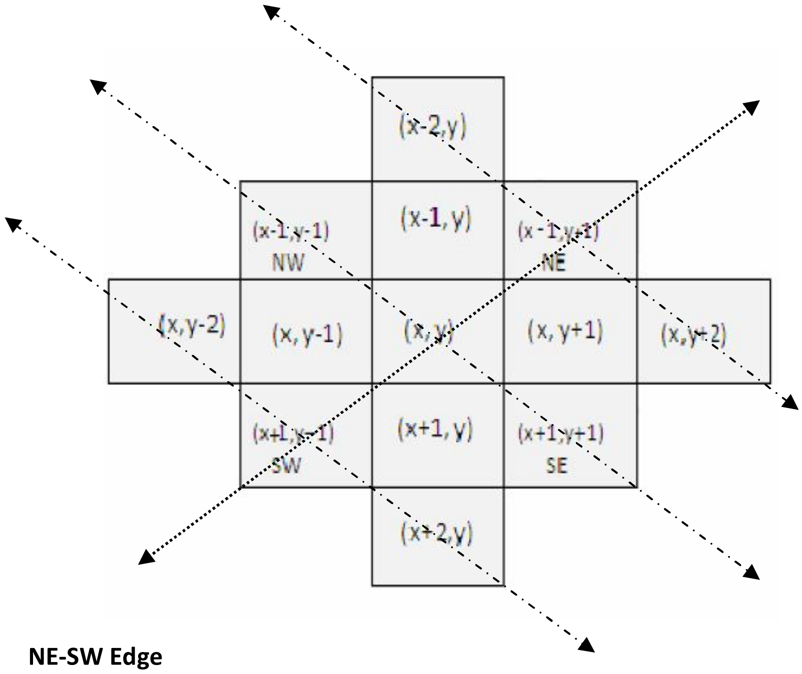
Next, the principle of derivative is based on the following observation. Consider an edge passing through the neighbourhood of a pixel (x, y) in the NE-SW direction as shown in Figure 3.2. For edge in the NE-SW direction, the three absolute derivatives in the NW direction can be defined as:

$$\nabla_{NW}(x, y) = |\ I(x-1, y) - I(x, y)\ | \quad (2)$$

$$\nabla_{NW}(x-1, y+1) = |\ I(x-2, y) - I(x-1, y+1)\ | \quad (3)$$

$$\nabla_{NW}(x+1, y-1) = |\ I(x, y-2) - I(x+1, y-1)\ | \quad (4)$$

The derivative value in the NW and SE directions will be large, but also the derivative values of neighbouring pixels perpendicular to edge direction can expected to be large. The idea is to cancel out the effect of one derivative value which turns out to be high due to noise. Therefore, if the derivative value of pixel (x, y) is large than other two derivative values in NW and SE direction then it is safe to assume that no edge is present in the considered direction. This is a robust approach to estimate the noisy pixels by applying fuzzy rules.



NE-SW Edge

Figure 3.2 : The pixels to be considered for the derivative calculation in NE-SW direction

The maximum value out of three derivatives is calculated in all directions.

$$\nabla_{NW} = \max(\nabla_{NW}(x,y), \nabla_{NW}(x-1,y+1), \nabla_{NW}(x+1,y-1)) \quad (6)$$

$$\nabla_{SE} = \max(\nabla_{SE}(x,y), \nabla_{SE}(x-1,y+1), \nabla_{SE}(x+1,y-1)) \quad (7)$$

Similarly 16 maximum values are calculated in all the directions D = {NW, W, SW, S, SE, E, NE, N} to detect whether centred pixel is noisy or not.

Rule : IF ($(\nabla_{NW}(x,y) == \nabla_{NW})$ AND $(\nabla_{SE}(x,y) == \nabla_{SW})$) OR ($(\nabla_{N}(x,y) == \nabla_{N})$ AND $(\nabla_{S}(x,y) == \nabla_{S})$) OR ($(\nabla_{SW}(x,y) == \nabla_{SW})$ AND $(\nabla_{NE}(x,y) == \nabla_{NE})$) OR ($(\nabla_{E}(x,y) == \nabla_{E})$ AND $(\nabla_{W}(x,y) == \nabla_{W})$)

THEN p(x, y) is NOISY.

The pixels which detected to be noisy are restored using FSM Filter.

Fuzzification :

In fuzzy image processing, there are a numerous ways for Salt and Pepper noise detection. The simplest technique is to define a membership function indicating the degree of variation in pixel intensities in each neighbourhood. This can be achieved by fuzzifying the relevant pixel intensity values into a membership function values that indicates the degree of variation between noisy and true image pixels. In the proposed approach the derivative matrix describing the maximum of the derivative values are fuzzified into MF values using triangular membership function $\text{«}_{Triangular}\left(\nabla(i)\right)$

$$\text{«}_{Traiangula\ r}\left(\nabla(i)\right)=\begin{cases}\dfrac{\nabla(i)-a}{b-a} & ,if\ \ a\le\nabla(i)<b\\ 1 & ,if\ \ \ \ \ \nabla(i)=b\\ \dfrac{c-\nabla(i)}{c-b} & ,if\ \ b<\nabla(i)\le c\end{cases}\qquad(8)$$

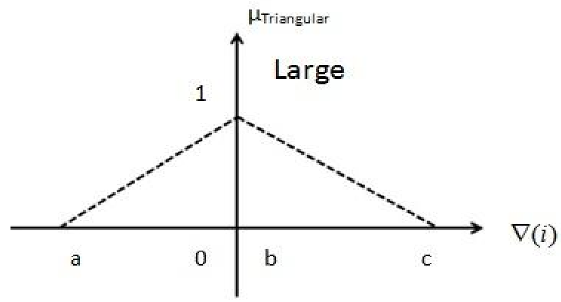


Figure 3.3 : Triangular Membership Function

where a, b, c are the three parameters that can be varied to control the shape and range of the membership function.

3.2 Noise Cancellation Step

Specifically for removal of salt-and-pepper noise, conventional median filters and other classes of modified median filters are widely used. However, median filtering would simply restore the processed pixel even when the pixel is a noise-free pixel. With the growing appeal of fuzzy logic, employing fuzzy theories as an extension to the existing classical filters may prove useful and effective in the domain of noise removal in image processing.

3.2.1 Fuzzy Switching Median Filter:

The FSM filter is able to remove salt-and pepper noise in digital images while preserving image details and textures very well. By incorporating fuzzy reasoning in correcting the detected noisy pixel, the low complexity FSM filter is able to outperform some well known existing salt-and pepper noise fuzzy and classical filters.

The FSM filter is composed of two semi-dependent modules, namely the salt and-pepper noise detection module and the fuzzy noise cancellation module. The fuzzy set used for noise cancellation does not require time-consuming tuning of parameters and thus no training scheme is required. In the proposed filter main concern is the noise cancellation step.

Assume for a 256 gray levels image, normally L_{upper} = 255 and L_{lower} = 0 , because while traversing a histogram form left to center and from right to center respectively the local maximum intensities are respectively are L_{lower} and L_{upper} ; although L_{upper} and L_{lower} can assume some other intensities in general. Once the two impulsive intensities are found, the filtering action would begin by windowing the noisy image starting from the upper-left corner to the bottom-right corner of the noisy image. Defining the filtering window *Wi,j* of size 3x3 shown below :

$$W_{i,j} = \{x_{i-1,j-1} \cdots , x_{i,j} \cdots , x_{i+1,j+1}\} \tag{9}$$

The central pixel $x_{i,j}$ in the 3×3 filtering window is compared with L_{upper} and L_{lower}. If the central pixel $x_{i,j}$ in processing matches one of the two impulsive intensities, then $x_{i,j}$ is more likely to be a noisy pixel. In order to perform a correction on $x_{i,j}$, or to handle an exception when $x_{i,j}$ is noiseless but matches one of the impulsive intensities, the second action module resorting to fuzzy reasoning is executed.

As long as $x_{i,j}$ equals any of the two salt-and-pepper noise intensities, the absolute luminance difference $g_{i+k,j+l}$ between the neighbouring pixels and the central pixel in 3×3 window is calculated using :

$$g_{i+k,j+l} = \left| x_{i+k,j+l} - x_{i,j} \right| \text{ with } k,l \in (-1,0,1) \text{ and } x_{i+k,j+l} \neq x_{i,j} \tag{10}$$

Next, the fuzzy input variable $G_{i,j}$ is determined. $G_{i,j}$ is the maximum fuzzy gradient value in the 3×3 filtering window and is given by:

$$G_{i,j} = \max\{g_{i+k,j+l}\} \tag{11}$$

The fuzzy set (see Fig. 2) processes the neighbourhood information represented by the input fuzzy variable $G_{i,j}$ to estimate a correction term which aims at cancelling the noise.

Mathematically, the fuzzy set $f_{i,j}$ is given by:

$$f_{i,j} = \begin{cases} 0 & : 0 \le G_{i,j} < T_1 \\ \dfrac{G_{i,j} - T_1}{T_2 - T_1} & : T_1 \le G_{i,j} \le T_2 \\ 1 & : otherwise \end{cases} \quad ..... (12)$$

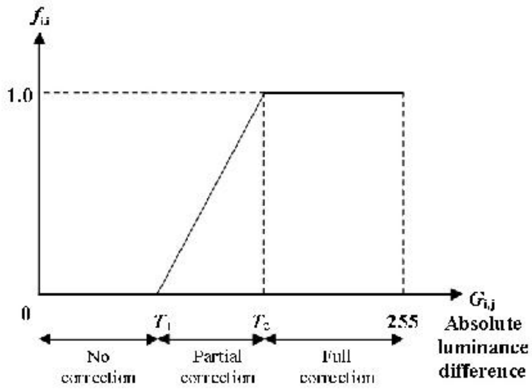


Figure 3.4: Right-Open Trapezoidal function

where T_1 and T_2 are the thresholds to perform partial correction. Here the value of T_1 and T_2 are calculated using powerful detection method.

The correction term $y_{i,j}$ for replacing the current pixel $x_{i,j}$ is given in equation:

$$y_{i,j} = (1 - f_{i,j})x_{i,j} + f_{i,j}m_{i,j} \quad (13)$$

Here to calculate the value of median $m_{i,j}$ the value of maximum and minimum intensities is removed. The value of $m_{i,j}$ in NxN window is given by:

$$m_{i,j} = \sum_{k=-N}^{N} \sum_{l=-N}^{N} x(i-k, j-l) / num \quad (14)$$

Where, $x(i-k, j-l) \ne L_{lower} \ or \ L_{upper}$

where *num* means the total number of pixels that not equal to maximum L_{upper} or minimum L_{lower} in filtering window.

3.3 Proposed Method:

The proposed algorithm named as "A *novel Fuzzy Switching Median filter to remove Salt and Pepper noise"* is a novel technique for the restoration of images corrupted with impulse noise. The algorithm is iterative in nature and preserves the fine details of an image in an efficient manner. The application of Fuzzy Derivative Method in the detection phase provides efficient results.

From the literature survey it is clear that efficient removal of impulse noise mainly depends on the detection phase. The detection method of the proposed algorithm efficiently identifies the location of noisy pixels so that the fine details of the image are not altered.

Proposed algorithm has two detection stages. Double stage detection efficiently locates the noisy pixels and does not alter the value of noise free pixels.

Algorithm basic steps are explained as follows:

Step 1 Select a window of size 21×21 which is centred on each pixel of an image.

Step 2 Sort the pixels in the window according to the ascending order and find the median of the sorted vector $V_{i.}$.

Step 3 Compute the intensity difference between each pair of adjacent pixels across the sorted vector and obtain the difference vector $V_{d.}$.

Step 4 For the pixel intensities between 0 and median in the V_i, find the maximum intensity difference V_d in the of the same range and mark its corresponding pixel in V_i the as the boundary b_1 .

Step 5 Likewise, the boundary b_2 is identified for pixel intensities between *med* and 255.

Step 6 If the pixel lies between b_1 and b_2, it is classified as "uncorrupted" pixel, and the classification process stops; else, the second iteration will be invoked in the following.

Step 7 Select a window of size 5x5 being cantered on the concerned pixel.

Step 8 Calculate derivative in NW, W, SW, S, SE, E, NE, N directions.

Step 9 If the derivate of central pixel(x, y) and its neighbours is maximum than other two for NW-SE, N-S, E-W, NE-SW directions then p(x', y') = p(x, y) is a noisy pixel else Pixel (x', y') is an edge pixel .

Step 10 Select a 3x3 window on center pixel (x, y).

Step 11 Repeat the step 2-5 to get the more specified boundary values $_{b11}$ and $_{b22}$.

Step 12 If the pixel b_{22}< p(x, y) < b_{11} OR p(x, y) == p(x', y') then Restore noisy pixel using equation (12) else leave that pixel because it is uncorrupted.

Step 13 Follow the algorithm for whole image matrix.

3.4 Illustration of Work

An illustration of proposed method is discussed in detail for better understanding of the algorithm.

3.4.1 Noise Detection Step:

Here the window size is taken as 7x7 in first detection phase for better illustration, instead of 21x21 window size:

0	155	155	158	162	162	160
152	154	155	159	164	165	162
149	149	156	163	164	161	160
144	149	0	255	164	162	160
138	149	156	163	164	163	162
137	150	157	163	165	164	163
141	151	157	164	166	165	164

Central Pixel

All 7x7(= 49) values are sorted in ascending order to get the boundary values to divide the pixels in two broad corrupted and uncorrupted categories based on initial raw analysis.

The sorted matrix V_i is :

{0 0 137 138 141 144 149 149 149 149 150 151 152 154 155 155 155 156 156 157 157 158 159 160 160 160 161 162 162 162 162 162 163 163 163 163 163 164 164 164 164 164 164 164 165 165 165 166 255}

The median value of above 7x7 window is 160. This median value is used to calculate the boundary values using Step 4 and Step 5 with the help of difference matrix V_d.

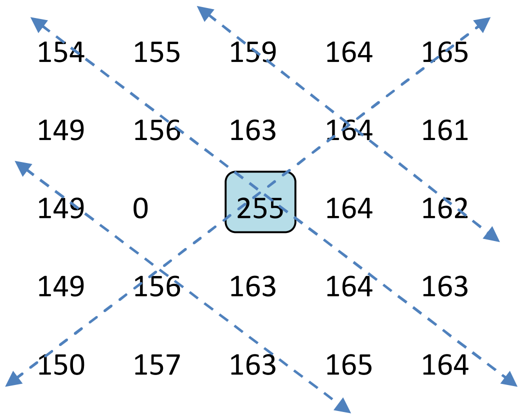
Difference matrix V_d is:

{0 137 1 3 3 5 0 0 0 1 1 1 2 1 0 0 1 0 1 0 1 1 1 0 0 1 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 1 89}

After processing step 4 and step 5, the boundary values b_1 and b_2 are calculated respectively, as 0 and 160. If the pixel belongs between b_1 and b_2 then it is an uncorrupted pixel and does not need further processing or restoration.

A 5x5 window is taken on the central pixel to judge that pixel is noisy pixel or edge pixel.

The gradient is taken in NW and SE direction, as shown below:



NE-SW Edge

$$\nabla_{NW}(x,y) = |\ I(x-1,y) - I(x,y)\ | = 99$$
$$\nabla_{NW}(x-1,y+1) = |\ I(x-2,y) - I(x-1,y+1)\ | = 7$$
$$\nabla_{NW}(x+1,y-1) = |\ I(x,y-2) - I(x+1,y-1)\ | = 5$$

The above calculated values are used to compute maximum gradient in all directions:

$$\nabla_{NW} = \max(\nabla_{NW}(x,y), \nabla_{NW}(x-1,y+1), \nabla_{NW}(x+1,y-1)) = 99$$

Similarly, the gradient is calculated in all directions D and the maximum value out of three is produced to apply Fuzzy Rule.

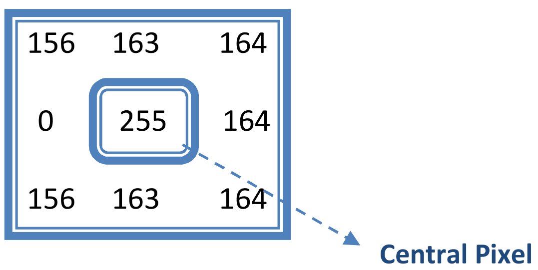
Rule: IF ($(\nabla_{NW}(x,y) == \nabla_{NW})$ AND $(\nabla_{SE}(x,y) == \nabla_{SW})$) OR ($(\nabla_{N}(x,y) == \nabla_{N})$ AND $(\nabla_{S}(x,y) == \nabla_{S})$) OR ($(\nabla_{SW}(x,y) == \nabla_{SW})$ AND $(\nabla_{NE}(x,y) == \nabla_{NE})$) OR ($(\nabla_{E}(x,y) == \nabla_{E})$ AND $(\nabla_{W}(x,y) == \nabla_{W})$)

THEN p(x, y) is NOISY.

So, the value of central gradient is LARGE in comparison to other gradients. The Fuzzy Rule is applied to get efficient results. The Noise Detection Procedure to get the correct information about the noisy pixels, which improves the performance of the detection phase and provide effective results after Noise cancellation.

3.4.2 Noise Cancellation Step:

A 3x3 window is taken for sake of image restoration as shown below:



To calculate boundary values b11 and b22, again the sorted matrix V_i and difference matrix V_d is calculated as:

V_i = {0 156 156 163 163 164 164 164 255}

V_d={156 0 7 0 1 0 0 91}

The median value of above 3x3 windows is 163. This median value is used to calculate the boundary values b_{11} and b_{22} repeating Step 4 and Step 5 using difference matrix V_d.

Here the value of b_{11} and b_{22} is 0 and 255. These values plays very important role in noise cancellation process.

To perform the noise cancellation, initially the luminance difference $g_{i+k,j+l}$ is calculated using equation (10):

99	92	91
255	**255**	91
99	92	91

Luminance Difference Matrix

After that Maximum value of luminance difference G is calculated per kernel (window) for further processing. Here the value of G is 255. The boundary values b_{11} and b_{22} are taken as threshold T_1 and T_2 for restoration purpose. Hence the value of $f_{i,j}$ is 1 for this particular window. This value is used to calculate the replaced pixel $y_{i,j}$ using equation (12), where the value of $m_{i,j}$ is calculated using above equation. Here approximate value of $m_{i,j}$ is 161 .Therefore the pixel $X_{i,j}$ = 255 is replaced by $y_{i,j}$ = 161.

0	155	155	158	162	162	160
152	154	155	159	164	165	162
149	149	156	163	164	161	160
144	149	0	161	164	162	160
138	149	156	163	164	163	162
137	150	157	163	165	164	163
141	151	157	164	166	165	164

Restored Pixel

3.4 Flow Chart

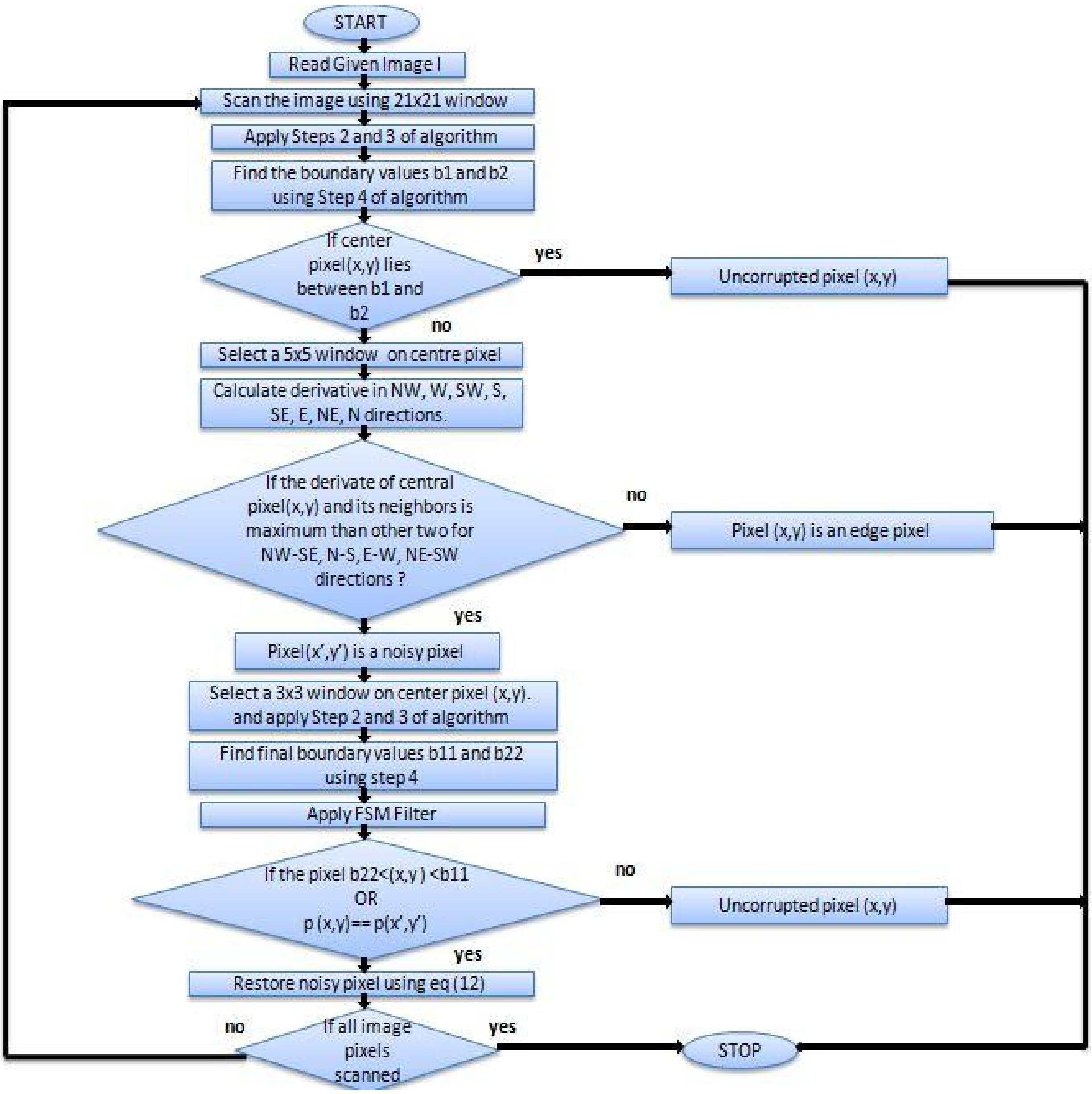


Figure 3.5: Flow Chart

Chapter 4
Experimental Results

4.1 Results using Proposed Approach

The proposed algorithm and all the techniques used for comparison with our approach have been implemented on Intel(R) Core(TM) i3- 2330M at 2.20 GHz using MATLAB version 2009b. The proposed scheme is simulated on some standard images like *Lena, Mandrill, Living room, Woman blonde* and *Pirate*.

(a) Lena ***(b) Pirate*** ***(c) Living Room***

(***d) Woman Blonde*** ***(b) Mandrill***

Figure 4.1: Original Standard Images used for simulation results

(a) (b)

Figure 4.2: Result for *Lena* image at 10% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.3: Result for *Lena* image at 20% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.4: Result for *Lena* image at 30% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.5: Result for *Lena* image at 40% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.6: Result for *Lena* image at 50% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.7: Result for *Pirate* image at 10% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.8: Result for *Pirate* image at 20% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.9: Result for *Pirate* image at 30% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.10: Result for *Pirate* image at 40% noise level

(a) noisy image (b) restored image

(a) (b)

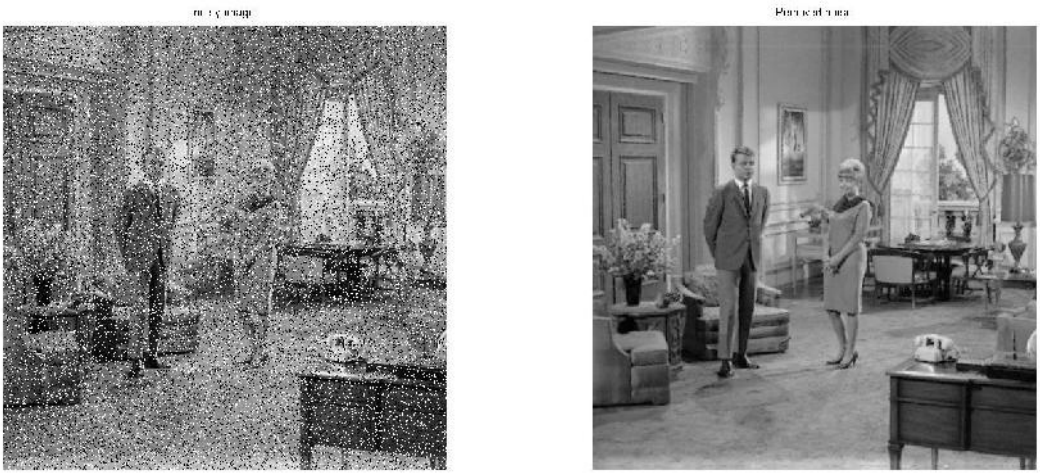
Figure 4.11: Result for *Pirate* image at 50% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.12: Result for *Living Room* image at 10% noise level

(a) noisy image (b) restored image



(a) (b)

Figure 4.13: Result for *Living Room* image at 20% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.14: Result for *Living Room* image at 30% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.15: Result for *Living Room* image at 40% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.16: Result for *Living Room* image at 50% noise level

(a) noisy image (b) restored image

(a) (b)

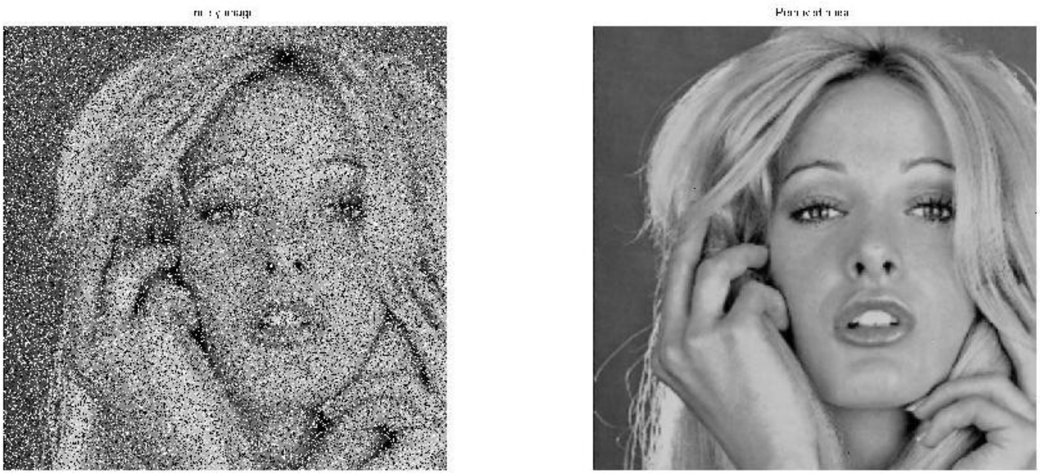
Figure 4.17: Result for *Woman Blonde* image at 10% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.18: Result for *Woman Blonde* image at 20% noise level

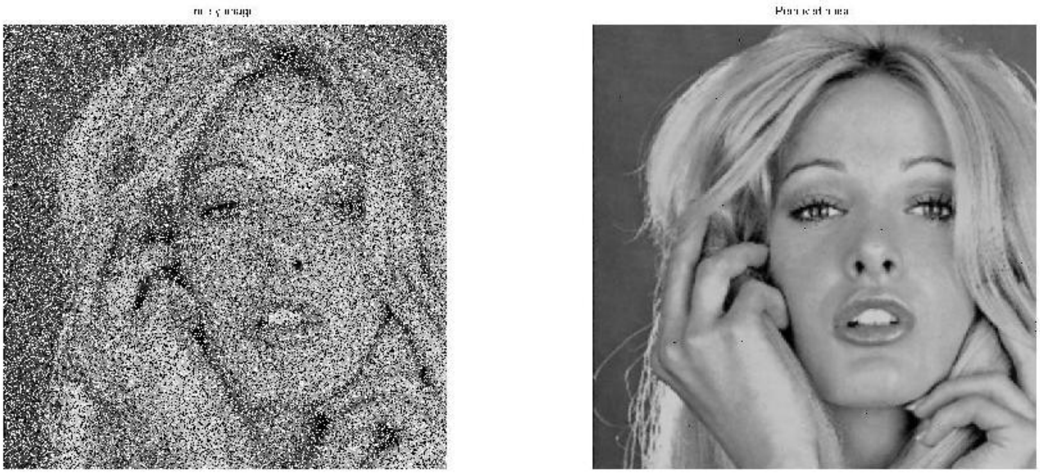
(a) noisy image (b) restored image



(a) (b)

Figure 4.19: Result for *Woman Blonde* image at 30% noise level

(a) noisy image (b) restored image



(a) (b)

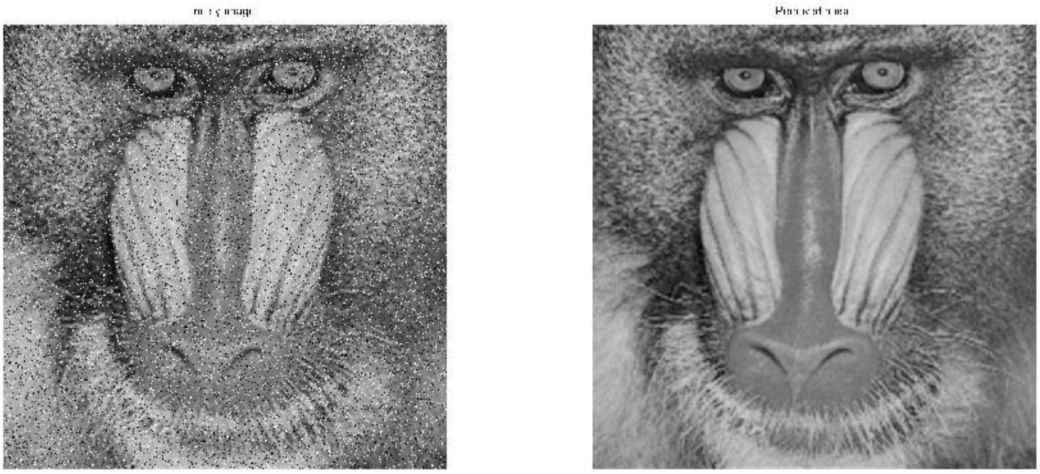
Figure 4.20: Result for *Woman Blonde* image at 40% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.21: Result for *Woman Blonde* image at 50% noise level

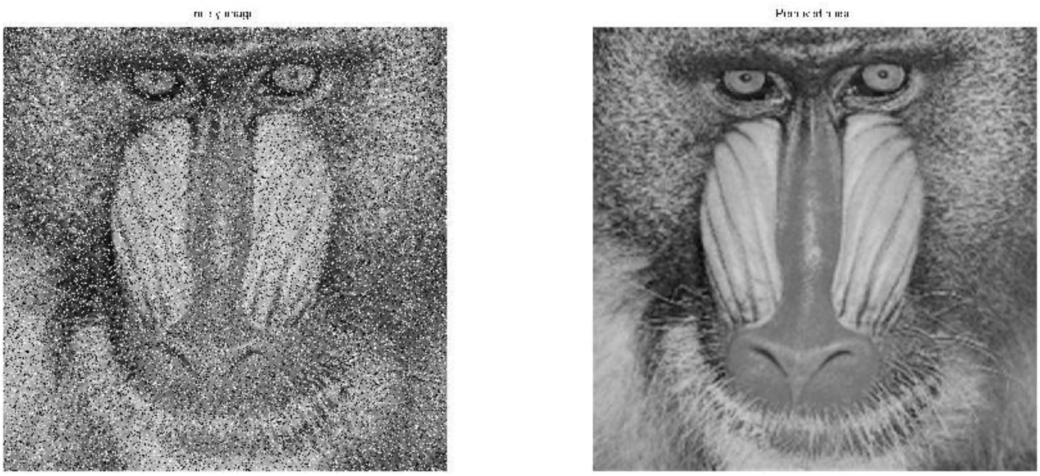
(a) noisy image (b) restored image



(a) (b)

Figure 4.22: Result for *Mandrill* image at 10% noise level

(a) noisy image (b) restored image



(a) (b)

Figure 4.23: Result for *Mandrill* image at 20% noise level

(a) noisy image (b) restored image

(a) (b)

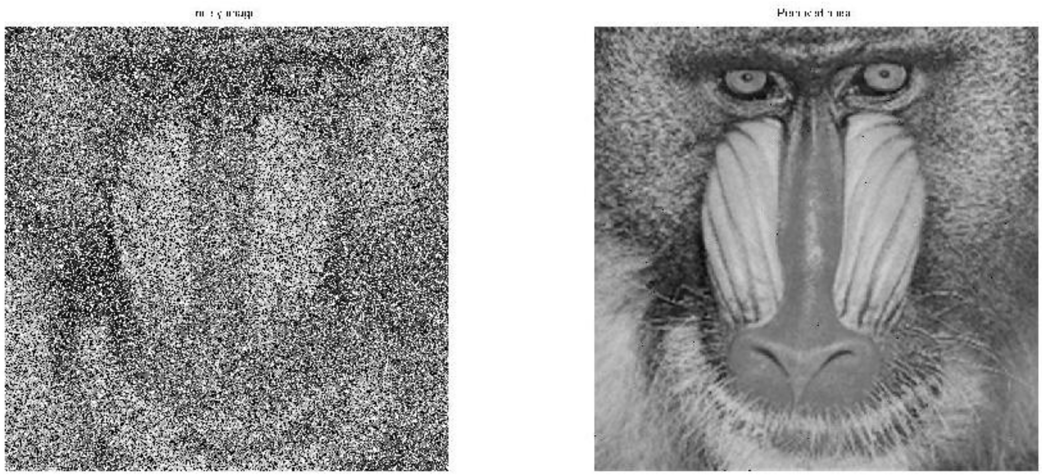
Figure 4.24: Result for *Mandrill* image at 30% noise level

(a) noisy image (b) restored image

(a) (b)

Figure 4.25: Result for *Mandrill* image at 40% noise level

(a) noisy image (b) restored image



(a) (b)

Figure 4.26: Result for *Mandrill* image at 50% noise level

(a) noisy image (b) restored image

Apart from the available standard images, one test image has been simulated from real world to test the feasibility of proposed work. This image was taken from CCTV Camera in a moving metro.

Figure 4.27: Original *Test-Image*

(a) (b)

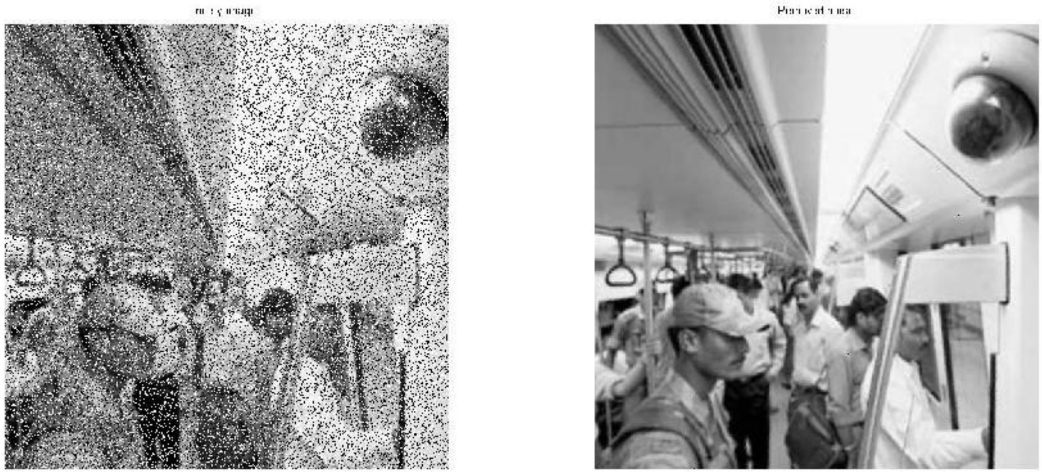
Figure 4.28: Result for *Test-Image* image at 10% noise level

(a)noisy image (b) restored image

(a) (b)

Figure 4.29: Result for *Test-Image* image at 20% noise level

(a)noisy image (b) restored image



(a) (b)

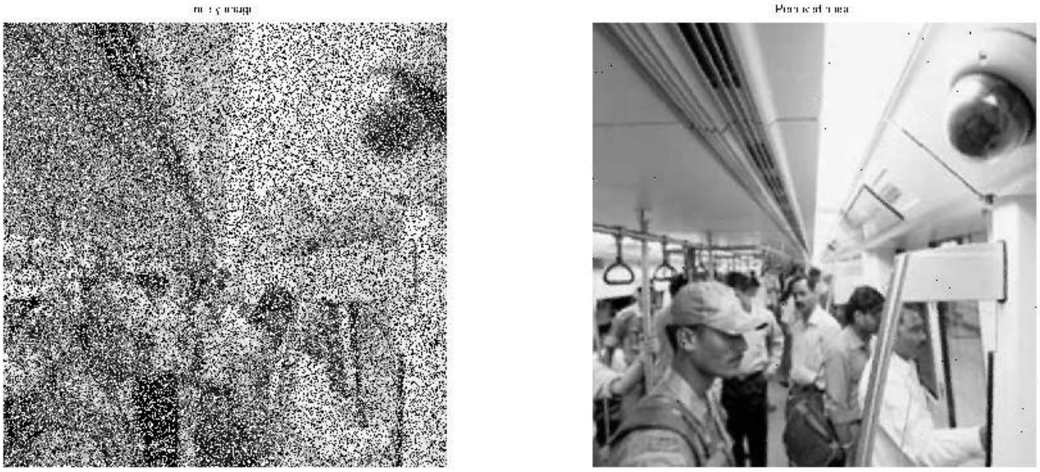
Figure 4.30: Result for *Test-Image* image at 30% noise level

(a)noisy image (b) restored image

(a) (b)

Figure 4.31: Result for *Test-Image* image at 40% noise level

(a)noisy image (b) restored image



(a) (b)

Figure 4.32: Result for *Test-Image* image at 50% noise level

(a)noisy image (b) restored image

Table 4.1

Comparison of PSNR (db) values for different images using Proposed Algorithm

	Noise Percentage				
Image Used	**10%**	**20%**	**30%**	**40%**	**50%**
Lena	36.7750	34.0308	32.3548	31.1092	30.1636
Pirate	36.6645	33.9349	32.2868	31.0567	30.1382
Living Room	36.5315	33.8888	32.2112	31.0753	30.1240
Woman Blonde	36.9522	34.0770	32.3751	31.1414	30.1936
Mandrill	36.7611	33.9975	32.2992	31.0946	30.1676
Test Image	36.9713	34.0669	32.3477	31.1231	30.1968

Table 4.2

Comparison of MSE values for different images using Proposed Algorithm

	Noise Percentage				
Image Used	**10%**	**20%**	**30%**	**40%**	**50%**
Lena	13.6642	25.7037	37.8093	50.3685	62.6212
Pirate	14.0162	26.2777	38.4057	50.9815	62.9877
Living Room	14.4522	26.5583	39.0805	50.7632	63.1951
Woman Blonde	13.1178	25.4320	37.6331	49.9966	62.1903
Mandrill	13.7077	25.9018	38.2970	50.5379	62.5637
Test Image	13.0603	25.4913	37.8714	50.2074	62.1441

4.2 Comparison with Other Techniques

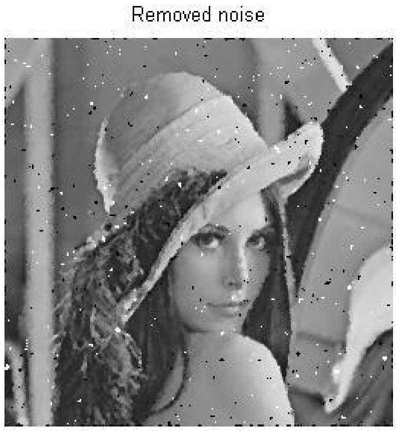
The Proposed approach has been compared with some existing techniques present in literature. For the comparison standard test image *Lena* corrupted with 30% noise density is used. The techniques used for the comparison have been implemented on Intel(R) Core(TM) i3- 2330M at 2.20 GHz using MATLAB version 2009b.

Techniques used for comparison in our work are as follows:

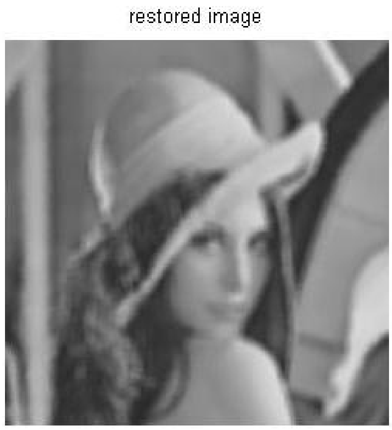
- Salt-and-Pepper Noise Detection and Reduction Using Fuzzy Switching Median Filter (FSM)[4].
- Removal of High Density Salt and Pepper Noise Through Modified Decision Based Unsymmetric Trimmed Median Filter (MDBUTMF)[6].
- An efficient Edge-Preserving Approach Base on Adaptive Fuzzy Switching Median Filter [13].
- A switching median filter with boundary discriminative noise detection for extremely corrupted images (BDND)[7].

A Lena image contaminated with 30% noise density is shown below. The comparison with stated filters is given at the next page:

Figure 4.33: image contaminated with 30% noise density



(a) (c)



(b) (d)

(e)

Figure 4.34 :Comparison of Proposed Algorithm with other techniques on image *Lena* at 30% noise level (a) MDBUTMF (b) BDND (c) FSM (d) EEPA (e) Proposed Filter

Table 4.4

Comparison of PSNR (db) values for "*Lena*" images

	Noise Percentage				
Image Used	**10%**	**20%**	**30%**	**40%**	**50%**
MDBUTMF	40.1044	37.0377	35.4140	34.2523	33.5169
BDND	39.2616	36.6219	34.9418	33.8168	32.9707
FSM	38.7382	36.2401	34.6774	33.6227	32.7409
EEPA	29.5953	29.8175	29.3604	29.2169	28.8150
Proposed	36.7750	32.3548	31.1092	30.1636	36.7750

Table 4.5

Comparison of MSE values for "*Lena*" images

	Noise Percentage				
Image Used	**10%**	**20%**	**30%**	**40%**	**50%**
MDBUTMF	6.3480	12.8620	18.6930	24.4260	28.9331
BDND	7.7076	14.1542	20.8399	27.0021	32.8101
FSM	8.3480	15.4549	22.1481	28.2363	34.5933
EEPA	71.3762	67.8154	75.3424	77.8733	85.4241
Proposed	131.6642	25.7037	37.8093	50.3685	62.6212

The performance analysis of each technique is done in terms of MSE and PSNR values as shown in Table 4.4 and Table 4.5 respectively.

The comparison of the proposed algorithm with the above mentioned techniques shows that the proposed algorithm outperforms several techniques. Both quantitative and qualitative results are shown. The drawback with other methods introduced to handle high noise density fails as we increase the noise level. In comparison with other filters the proposed algorithm is producing optimal results. The proposed algorithm is able to maintain the smoothness of the image while dealing with high density Salt & Pepper noise. The main advantage of proposed algorithm is that its performance is not degraded with increasing noise level.

Chapter 5

Conclusion

Images generally are affected by impulse noise during image acquisition and image transmission. . Most widely CCD (Charge Coupled Device) image sensors are used to capture images in professional, medical, and scientific applications. They convert Analog-signal to digital domain. Sometimes due to some erroneous analog-to-digital conversion or bit transmission, the images get contaminated by impulse noise. Many techniques have been introduced in the literature to remove impulse noise. At low noise density many algorithms perform well but as soon as the noise levels are increased, performance of the method degrades. Therefore, a new filter is developed which provides consistent results.

Experimental results show that the proposed algorithm significantly outperforms existing well-known techniques. The main advantage of our algorithm is that its performance is not degraded with increasing noise level. It is easy to understand as it has uncomplicated structure and takes less time in image restoration. It provides good results on different images even in real world applications. The application of Fuzzy Derivate Technique in combination with FSM filter provides optimal results and makes it a novel technique.

In future, the current thesis work will be extended for RGB images as well as video images.

The main focus will be on the correct detection of noisy pixels so that the restoration provides optimal results.

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