

**A STUDY AND COMPARATIVE ANALYSIS OF VARIOUS
IMAGE ENHANCEMENT TECHNIQUES**

THESIS

**SUBMITTED TO THE
BABASAHEB BHIMRAO AMBEDKAR UNIVERSITY
LUCKNOW**

FOR THE AWARD OF THE DEGREE OF

Doctor of Philosophy

IN

COMPUTER SCIENCE

BY

PUSHPA MAMORIA

Under the Supervision of

DR. DEEPA RAJ

ASST. PROFESSOR

**DEPARTMENT OF COMPUTER SCIENCE
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**BABASAHEB
BHIMRAO
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**प्रज्ञा शील करुणा
ESTABLISHED 1996**

**DEPARTMENT OF COMPUTER SCIENCE
BABASAHEB BHIMRAO AMBEDKAR UNIVERSITY
(A CENTRAL UNIVERSITY)**

**VIDYA VIHAR, RAEBARELI ROAD
LUCKNOW-226025 (U.P.) INDIA**

2018

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SUMMARY

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2018

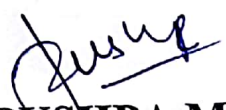
Dedicated
To
My Lovely
Daughter, Husband,
and
Beloved Parents

CANDIDATE'S DECLARATION

I here declare that the work which is being presented in this thesis entitled **A STUDY AND COMPARATIVE ANALYSIS OF VARIOUS IMAGE ENHANCEMENT TECHNIQUES** carried out by me under the guidance and the supervision of **Dr. Deepa Raj, Assistant Professor, Department of Computer Science, Babasaheb Bhimrao Ambedkar University (A central University) Lucknow, India**, is an authentic work. The matter presented in this thesis has not been submitted in part or full for the award of any other degree or diploma in this or any other university/institution.

Date: 30/7/18

Place: Lucknow


(PUSHPA MAMORIA)



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Date

CERTIFICATE

This is to certify that the thesis titled "A STUDY AND COMPARATIVE ANALYSIS OF VARIOUS IMAGE ENHANCEMENT TECHNIQUES" submitted by Ms. Pushpa Mamoria is an original research work and has not been previously submitted in part or full for the award of any degree or diploma to this or any other university.

The thesis submitted to Babasaheb Bhimrao Ambedkar University Lucknow satisfies all the requirements as stipulated in the *Doctor of Philosophy (Ph.D.) regulation – 1999 as amended in 2008/2010/2013* and it is fit for submission and evaluation for the award of the degree of **Doctor of Philosophy** of the University.

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Pushpa Mamoria



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VIVA VOCE CERTIFICATE

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LIST OF PUBLICATIONS

- ***JOURNAL PAPERS***

1. **Pushpa Mamoria**, Deepa Raj, "An Optimized Multiple Fuzzy Membership Functions based Image Contrast Enhancement Technique," **KSII Transactions on Internet and Information Systems**, vol. 12, no. 3, pp. 1205-1223, March 31, 2018. **Impact factor: 0.452 (SCI)**.
2. **Pushpa Mamoria**, Deepa Raj, Comparison of Mamdani Fuzzy Inference System for Multiple Membership Functions", **International Journal of Image, Graphics and Signal Processing (IJIGSP)**, Vol.8, No.9, pp.26- 30, 2016, **MECS** 2016.
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9. **Pushpa Mamoria, Deepa Raj, An Analysis of Fuzzy Contrast Enhancement Methods using Satellite Image, *International Conference on Computing for Sustainable Global Development*, 1st-3rd March 2017, IEEE.**



SUMMARY

SUMMARY

In the present digital era, various kinds of images are needed to be analyzed, enhanced and converted into a suitable form for better interpretation as highly perception quality for human viewers and imaging applications. In the field of digital image processing, image enhancement is one of the challenging research fields in processing the image in such a way that the resultant image is more visually appealing with greater clarity. In recent years, the dynamic range of imaging sensors has increased and the new challenge is the demand for better image quality in low-light conditions and noisy backgrounds.

In this dissertation, various image enhancement methods in the spatial and the fuzzy domain have been studied in details with quantitative and qualitative observations. It has been observed that the classical spatial methods produce the enhanced image which is not natural in visual clarity due to saturated with very bright or dark intensity levels. To overcome this drawback, the fuzzy set theory is used to handle both brightness preserving and contrast enhancement. In a fuzzy domain, the inexactness of gray levels is handled in a better way as compared with classical spatial domain methods. For this, a fuzzy inference system consisting of input membership function, inference system using if-then rules and output membership function, are studied and a range of case studies is performed using different membership functions for gray-scale contrast enhancement. Using this Mamdani fuzzy inference system (FIS), better membership functions based on the observations and findings are identified from comparative results and analysis. A novel fuzzy Mamdani FIS is then proposed utilizing the optimization of fuzzy image quality in order to preserve the brightness and contrast of the image between the combination of membership functions. Our proposed optimization algorithm solves the problem of under-exposed or over-exposed and unnatural enhancement.

Our criterion is to determine the optimum results through the selection of best cases of membership function combinations that are based on the fuzzy quality parameter. The algorithm calculates and compares the fuzzy quality for the different cases and it stops only when minimum fuzzy quality is achieved for given membership functions.

Next study is on edge detection techniques using classical and fuzzy logic approaches for various types of images such as medical images and normal images. Observations and drawbacks found based on the results and analyses are highlighted.

CHAPTER I

This chapter provides the introduction of signal processing, image enhancement, edge detection and their applications. The research challenges in the domain of image enhancement and edge detection are discussed. The existing solutions for both the image enhancement and the edge detection along with advantages, disadvantage and motivations are presented. A brief overview of all the domains in image processing such as spatial, fuzzy and frequency domain is described. The performance metrics used for evaluation are defined with expression at the end of the chapter. These performance metrics are used throughout the thesis for analysis of proposed image enhancement techniques.

CHAPTER II

The second chapter covers the existing literature on histogram-based, fuzzy logic-based enhancement and edge detection technique. It consists of a brief description of research works from various sources in the area of image enhancement. According to the obtained findings, it is observed that a very little information about the image enhancement using fuzzy inference system (FIS) is available. A FIS consists of input membership function, inference system with

fuzzy rules and output membership function based on fuzzy set theory. The various FIS based methods for image enhancement designed in the present research work are efficient, effective and simple in design for various applications. The main goal of this chapter is to discuss the literature on contrast enhancement and on edge detection using classical methods and fuzzy methods.

CHAPTER III

This chapter presents the comparative analysis of various contrast enhancement techniques applied to different types of the images. Contrast enhancement based on classical approach is a technique of image processing for the enhancement of contrast in the spatial domain where the image pixel values are manipulated based on global information obtained from a histogram of the input image. An analysis of contrast enhancement techniques is conducted in details on the basis of performance parameters such as PSNR, MSE, and visibility. Observation findings based on this study are presented at the end of the chapter. The contents of this chapter have been presented and published in the proceedings of:

- **International Conference on Green Computing and Internet of Things, ICGCIoT, 8-10 October 2015, IEEE Explore, Organized by GCET, Greater Noida, India.**

CHAPTER IV

This chapter deals with Image enhancement technique based on fuzzy logic as the motivated by the results and discussions of the previous chapter. It addresses different membership values and fuzzy techniques for contrast enhancement. A fuzzy technique has been designed based on human perception for better improvement of contrast in the given image. As discussions in previous chapters, the contrast enhancement techniques using fuzzy have shown improved image

quality using the method of adjustment of parametric value for different membership functions. To get more insight into it, the different existing methods of classical contrast enhancement techniques have been compared with the fuzzy-based image enhancement method. A detailed results analysis of images has been done using different qualitative attributes of the image in the simulation. The results show that the merits and demerits of image enhancement for both the approaches.

The contents of this chapter have been presented and published in the proceedings of:

- **International Conference on Green Computing and Internet of Things, ICGCIoT, 8-10 October 2015, IEEE, Organized by GCET, Greater Noida, India.**
- **3rd Lucknow Science Congress (LUSCON- 2015), organized by Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow, India.**
- **International Conference on Computing for Sustainable Global Development, 16th-18th March 2016, Organized by Bharti Vidyapeeth University, Delhi, India, IEEE.**
- **International Conference on Computing for Sustainable Global Development, 1st-3rd March 2017, Organized by Bharti Vidyapeeth University, Delhi, India, IEEE.**

CHAPTER V

In this chapter, various case studies have been considered to get more insight into fuzzy enhancement for Mamdani fuzzy inference system (Mamdani FIS) using different shaped membership functions (MFs). In fuzzy set theory, fuzzy inference systems are used as the best-known approach that shows the potential use of different shaped membership functions. It relies on the mapping of input and output membership functions by using the rule-based design for

transforming the input image into an enhanced image. Using different shaped membership functions, a study is presented with the help of fuzzy IF-THEN rules and fuzzy logic operators for image contrast enhancement. The case study based on mapping the rules and different membership functions for both input and output of FIS is presented in details. Results and analysis show that the images with good steps of grays between black and white are commonly the best images for the aim of human perception. The contents of this chapter have been published in:

- **International Journal of Image, Graphics and Signal Processing (IJIGSP), ISSN: 2074-9074(Print), ISSN: 2074-9082 (Online), MECS Publisher, Hong Kong.**

CHAPTER VI

In this chapter, a novel approach is proposed using a Mamdani fuzzy inference system (FIS) for contrast image enhancement through different and multiple shaped membership functions combinations and optimization is done to achieve best-satisfied enhancement. A potential use of different shaped multiple membership functions (MFs) and its combinations in the fuzzy domain are described in details. According to intuitions based on local image quality, an algorithm for generating fuzzy IF-THEN base for Mamdani FIS is also proposed in order to modify the membership functions for achieving overall resultant enhanced image quality. Analysis of this chapter shows that the use of multiple shaped membership functions in the different set of combinations for Mamdani FIS shows the best handling of non-linear pixel modification intensities when optimization is done based on fuzzy quality. Thus, the overall contrast of input image is shown to be improved after applying optimization in the fuzzy domain. The fuzzy quality is determined by the ratio of average fuzzy contrast and fuzzy contrast. The overall

intensity is handled by the average value of fuzzy contrast while fuzzy contrast value indicates the spread of the gradient. The resultant obtained images using our scheme have been measured with the help of statistical matrix parameters so that accuracy of the different combination of contrast enhancement methods can be observed distinctly. The contents of this chapter have been submitted in:

- **An Optimized Multiple Fuzzy Membership Functions based Image Contrast Enhancement Technique”, KSII Transactions on Internet and Information Systems. VOL. 12, NO. 3, March 2018. Impact factor: 0.452 (SCI).**

CHAPTER VII

This chapter is based on various spatial edge detection methods and fuzzy based edge detection methods. It described the spatial edge detection methods and fuzzy if-then-else methods and compared to each other to know which method will be more suitable to determine the edges in a better way. A change of intensity is an important issue of the edge detection. In the spatial edge detection method, various masks are used to detect edges and in the fuzzy domain, masks are used with the fuzzy if-then-else method. Statistically parameters such as PSNR, MSE value detect that fuzzy domain gives better results of edge detection as compared to spatial domain method. It is helpful to analyze an image in various applications. The contents of this chapter have been published in:

- **The IUP Journal of Computer Sciences, ISSN: 0973-9904, India.**
- **International Journal of Information Engineering and Electronic Business (IJIEEB), Vol.8, No.6, pp.62-68, 2016, MECS 2016.**

CHAPTER VIII

In this chapter, the contribution and advantages of the research work presented are highlighted. From the work, it is observed that for finding any anomalies in a specific image or for the purpose of diagnosing, images must be clearly visible, enhanced and sharpened. Otherwise, uses of low contrast, blurred or noisy images are risky and failed to analyze. Throughout work is based on contrast enhancement and edge detection of gray images using classical methods and fuzzy methods in the spatial domain. The experimental results presented in the thesis are analyzed on the basis of statistical matrix parameters, shall be very helpful for further research. The present work can also be extended as a future scope for color images in the spatial domain as well as in frequency domain. Fuzzy edge detection can be extended to implement different filtering techniques. Optimization concept can be extended to different fuzzy methods as well as in neural network and neuro-fuzzy system.

CHAPTER I

Introduction

CHAPTER I

INTRODUCTION

Nowadays, the image capturing devices are in the larger range of utilizing the various technologies. The growing technologies on the internet of world demand the more efficient image enhancement techniques that can process various degraded images for making good perceptual quality. A degraded image can be due to various conditions such as poor illumination, the wrong focus of the camera, noisy background, etc. A good perceptual quality of an image contains the detailed information, which is suitable for human viewers and for computer vision and other applications. Due to various types of degradation in the image, image enhancement plays an important role to make the image looking better in clarity and visualization. It usually makes the selective operations on some pixel of the image without increasing or decreasing the detailed image information. Although many works have been done in order to eliminate the problems towards getting best image enhancement techniques, much attention has been given to the study of image enhancement on various conditions such as under-water images, medical images, satellite images, etc.

Image enhancement can be one of the methods to improve the quality of the original image which can easily be applied to computer imaging problems. The enhancement techniques differ from one application to another according to their enhancement operations include removing blurring and noise, increasing contrast, and revealing. The principles behind these image enhancements are to modify the features of the image like boundaries, edge, and pixel manipulation to make the more clarity of the input image. Image enhancement methods are to serve an input image so that the resultant image is more suited for the particular application.

Image enhancement techniques are classified into two broad domains namely; (i) Spatial Domain; (ii) Frequency Domain. Spatial domain methods directly deal with the image pixels by manipulating them using some operations in order to achieve the desired enhancement in terms of quality or visibility. In this domain, logarithmic transformation, power law transformations are a basic operation for processing on image pixels. Histogram equalization and its variants are also other popular methods of enhancement in this domain. Next, the frequency domain methods are based on the nature of the frequency (and sequence) transformation. The principle behind on the methods of the frequency domain is consisting of computations using Fourier transform, manipulations on transformed coefficients in the frequency domain, the inverse transformation to get back resultant enhanced output.

In most of the classical spatial domain methods, the enhanced images are still degraded due to uncertainty like over-smoothing, blurring, and deformation of edges. To overcome the above problems, another method of image enhancement is called fuzzy image enhancement method. Fuzzy image processing is a collection of different fuzzy approaches to image enhancement that can be understandable, applicable based on human perception or knowledge. These are capable of mimicking the behavior of a human expert to handle the vagueness and uncertainties present in the digital images.

1.1 DIGITAL IMAGES REPRESENTATION

Generally, a digital image is composed of a finite number of elements called pixels, each of which has a particular location and value. We can define the image I as the two dimensional light intensity function $f(x, y)$, where x and y denote spatial coordinates and the value of $f(x, y)$ at any point denotes to the brightness (gray level) of the image at that location. As shown in figure 1.1, a digital image has x rows and y columns of pixels each storing a value

$f(x, y)$ where pixel values are gray levels in the range of 0 - 255 (black-white). A digital image is the output of optical scanner or camera and the processing a digital image using digital computer is called the digital image processing.

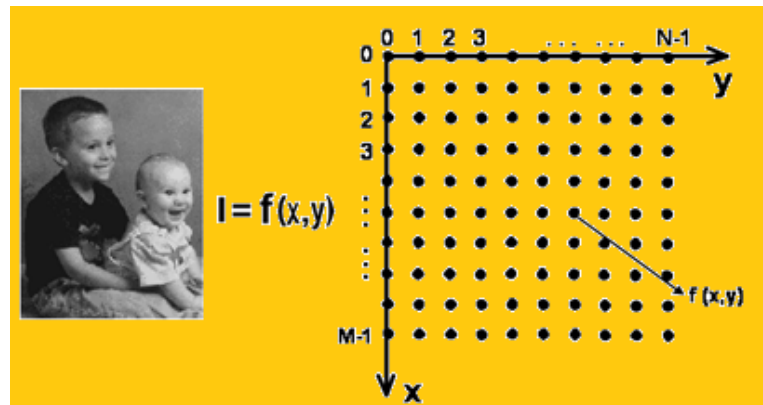


FIGURE 1.1: REPRESENTATION OF DIGITAL IMAGE

A brief overview of different types of images and different methods of image enhancements are given in this chapter. Problems and our solutions along with performance metrics are also discussed. The quality attributes for performance comparison discussed in this chapter are used throughout the thesis for results and analysis. The organization of the thesis is given at the end of the chapter.

1.2 TYPES OF DIGITAL IMAGES

Basically, there are four types of digital images like grayscale images, color images, binary images, and multispectral images.

1.2.1 GRAY SCALE IMAGES

Gray-scale images are referred to as the images of black and white. They contain gray-level information no color information. The number of bits used for each pixel determines the number of different gray levels available. The typical grayscale image contains 8 bits/pixel data, which allows us to have 256 different gray levels.



FIGURE 1.2: GRAY IMAGE

1.2.2 COLOR IMAGES

Color-scale images are referred to as three colors (RGB) images. The actual information stored in the digital image data is the gray level information in each spectral band. They contain 24 bits/pixel data (8-bits for each of the three color bands red, green, and blue). The typical grayscale image contains 8 bits/pixel data, which allows us to have 256 different gray levels.



FIGURE 1.3: COLOR IMAGE

1.2.3 BINARY IMAGES

The binary image is a 1-bit image because it takes only 1 binary digit to represent each pixel. It can often be created from the grayscale image via a threshold operation, where every pixel above the threshold value is turned white ('1'), and those below it are turned black ('0').

1.2.4 MULTISPECTRAL IMAGES

This type of images includes infrared, ultraviolet, X-ray, acoustic, or radar data. These are not images in the usual sense because the represented information is not directly visible to the human. It can be visible through the mapping the different spectral bands to RGB components.

1.3 TYPES OF IMAGE ENHANCEMENT METHODS

A range of image enhancement methods is based on operations, domain conversions. The enhancement of images can be classified into spatial and frequency domain. These types can be further divided based on its used operations or filtering. The processing of the image is simply denoted using three blocks of representation as shown in figure 1.4.



FIGURE 1.4: PROCESS OF IMAGE ENHANCEMENT

The classifications of image enhancement methods are described in the next section.

1.3.1 SPATIAL DOMAIN METHODS

These methods are based on direct manipulation of pixels in an image. These methods are computational efficient with less processing resources for the enhancement. The operation can be formulated by

$$g(x, y) = T [f(x, y)] \quad (1.1)$$

Where $g(x, y)$ is the output image, $f(x, y)$ is the input image and T is an operation on f defined over some neighborhood of point (x, y) as shown in Figure 1.5. It can be divided on

the basis of point operation and mask operation. The point operation is based on the intensity of a single pixel. It is represented by an expression given below.

$$S = T(r) \tag{1.2}$$

Where T is a transformation function which maps a pixel value r into a pixel value s.

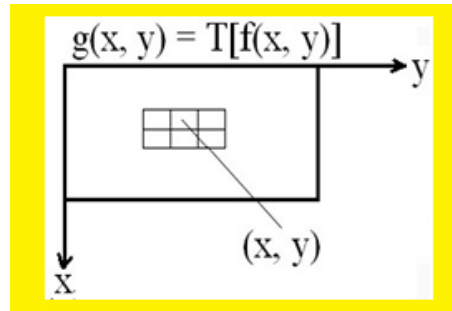


FIGURE 1.5: TRANSFORMATION FUNCTION

This transformation based on point operation is used in the method of image negatives, log transformations, and power-law (gamma) transformation for the image enhancement. Mask operation (spatial filtering) is used to enhance the image by accepting or rejecting certain frequency components. It is also called spatial mask, kernels templates and window based consisting of the neighborhood and predefined operation that are performed on the image pixel. Filtering is getting a new pixel at a coordinate equal to some operation on pixels at neighborhood coordinates. The new pixel value is the result of the filtering operation. The expression of the spatial filtering of an image of size M X N with a filter of size m X n is:

$$g(x, y) = \sum_{s=-a}^a \sum_{t=-b}^b w(s, t) f(x + s, y + t) \tag{1.3}$$

Where x and y are variables, w(s, t) are weights of the mask, f(x, y) is input pixel at the coordinate of (x, y) and g(x, y) is the output value. The most important neighborhood operator is convolution. The expression of the convolution is given as

$$g(x, y) = \sum_{s=-a}^a \sum_{t=-b}^b w(s, t) f(x - s, y - t) \tag{1.4}$$

Another similar method of filtering is a correlation. It is the process of moving a filter mask over the image and computing the sum of the product at each location. The difference from convolution is that this filter is first rotated by 180° in correlation.

1.3.1.1 IMAGE NEGATIVES

In image negatives, the obtained image is the conversion of enhancement of white or gray detail into dark regions. It is useful in many applications such as medical images, photographic images where analysis of negative images is much easier. The negative transformation function is given by the expression:

$$g(x, y) = L - 1 - f(x, y) \quad (1.5)$$

Where intensity levels are the range $[0, L - 1]$.

1.3.1.2 LOG TRANSFORMATIONS

The log function is used to expand dark pixel in an image and the compression is used for higher-level values and vice versa in the case of inverse-log transformation. Log transformation function is given by the expression:

$$g(x, y) = c \log(1 + f(x, y)) \quad (1.6)$$

Where c is a constant and it is assumed that $f(x, y) \geq 0$. It is used for a wider range of spreading/compressing of intensity levels in an image.

1.3.1.3 POWER-LAW (GAMMA) TRANSFORMATIONS

Power-Law (Gamma) transformation is more versatile than the log transformation for the purpose of spreading/compressing of intensity levels in an image. It is given by the expression:

$$g(x, y) = c (f(x, y))^{\gamma} \quad (1.7)$$

Where c and γ are constant.

This transformation is used in a variety of devices for image capturing, printing and display respond according to a power-law. This phenomenon is popular due to the gamma correction.

1.3.1.4 *PIECEWISE LINEAR TRANSFORMATIONS*

Piecewise linear transformation functions require more user input as compare to other functions for the better image enhancement. It is divided into three main methods, namely contrast stretching, intensity level slicing, and bit plane slicing. A contrast stretching method is used to expand the full range of intensity of an image so that the overall brightness of the image can increase. Transformation function used for contrast stretching is given in Equation 1.8. It can enhance the contrast of an image, which shows an equal distribution of intensity.

$$g(x, y) = g_1 + \left(\frac{g_2 - g_1}{f_2 - f_1} \right) [f(x, y) - f_1] \quad (1.8)$$

Here Mapping of gray levels $[f_1, f_2]$ is on new the range $[g_1, g_2]$, f_1 is minimum intensity and f_2 is the maximum intensity of an image.

Next, intensity-level slicing method is based on the intensity of an image on the specific range of interest. Due to this property, it is used in applications like satellite images, X-ray images where enhancing features such as masses of water, flaws are important. Instead of an intensity-level range, bit-plane slicing method shows composed of the intensity of each pixel in a 256-gray image is of 8 bits. So an 8-bit image is considered a group of eight 1-bit *PLANES*, in which each plane is containing an order of bits from lowest to highest.

1.3.1.5 *SMOOTHING FILTERS*

The smoothing filter is used for blurring and for noise reduction. Blurring is used in the pre-processing tasks, such as removal of small detail from an image like reduction of noise from

an image. This filter classified in a low pass or average filter and median filter. Average filtering is used for removal of noise is known as the low pass filter. Also, we can say a filter which preserves low frequency is known as a low pass filter. A Gaussian blur is also a low pass filter and it leads to softened edges. The median filter is used for fast operation for a small neighborhood with noise reduction and blurring of sharp edges function. It is used to smooth the image which suffers from salt and paper noise because of its appearances white and black dots superimposed on an image.

1.3.1.6 SHARPENING FILTERS

It is a filter witch used for removal of fine details. The sharpening of the image is done by spatial differentiation which enhances edges and other discontinuities and de-emphasizes areas with slowly varying intensities. So mainly it is used for edge detection and sharpens of images. It is classified in basic high pass spatial filter and derivative filter. A basic high pass filter preserves high frequency. Low pass filter denotes smoothness and emphasizes on fine edges. The derivative filter is used in the Edge detection as a break off between gray levels. For the edge detection in images, first order derivative and second order derivatives are used. The edge content is increased by the derivative mask. First order derivative is using gradient and the second-order derivative is by the Laplacian.

1.3.2 FREQUENCY DOMAIN METHODS

Frequency domains methods are based on the nature of signals with respect to frequency. These are the transformation of the time domain into the frequency domain via mathematical operator called transform such as discrete cosine transform, Fourier transforms, Fourier series, Laplace transforms, and z-transform etc. The principle consists of computation using Fourier transform, manipulation of transform coefficients in the frequency domain, and then inverse transformation to get the resultant enhanced image.

These are also divided into low-pass filter and high-pass filters. In a low-pass filter, all the frequency components are passed within a given cutoff frequency value. Outside its value, all frequencies are cut off. The characters having distorted shapes in an image can be handled by the smoothing method in the frequency domain. A Gaussian low-pass filter is used to show the visibility of characters or alphabets in an image. Gaussian High pass filters are used for fingerprint types of image enhancements. Similarly, band-pass and band-reject filters are also popular for various applications of image processing.

1.3.3 HISTOGRAM PROCESSING

A statistical feature of an image is obtained by Histogram. For a given image, intensity histogram gives the distribution of gray levels or intensity levels of all the pixels. It is given by

$$h(r_i) = n_i \quad (1.9)$$

Where r_i is i 'th value of intensity level (gray value) and n_i denotes the number of pixels in intensity r_i of the image. A normalized value of the histogram is commonly used in image processing applications. It is a division of each component n_i with the total number of pixels i which is MN . Here M is the row and N is the column of the image. It is given as

$$p(r_i) = \frac{n_i}{MN}, \text{ for } i = 0, 1, 2, \dots, L - 1 \quad (1.10)$$

Where $p(r_i)$ denotes the probability of occurrence of gray level and L denotes the maximum value of gray level. For a 8-bit image, total 256 gray level is the value of L .

1.3.3.1 HISTOGRAM EQUALIZATION

Histogram for image enhancement is useful only within a limited data range because some details of the image are not visible properly. To overcome this problem, the Histogram

Equalization method is proposed to extract the histogram as uniformly distribution fashion. It is also called histogram stretching method. The idea of Histogram Equalization is to get transformed image for which the histogram is uniformly distributed from the gray level transform of the input image.

1.3.3.2 HISTOGRAM MATCHING

Histogram Equalization is a special method of histogram matching. Histogram matching is the method of getting a specified histogram by transforming the input image through the adjustment of its histogram within some gray level range. In the Histogram equalization method, the obtained histogram is a uniform distribution. In histogram matching, image enhancement is obtained by means of matching the accumulative distribution of the original histogram and the desired histogram of the image.

1.3.4 FUZZY IMAGE PROCESSING

The fuzzy set method is also one of the utility tools for an image enhancement with the help of classical mathematics and integral imprecision of the real world. It is one of the techniques which operate on fuzzy set just like spatial domain method operates on pixels. This fuzzy image enhancement method has three main stages, namely fuzzification of images, modification of membership function, and defuzzification.

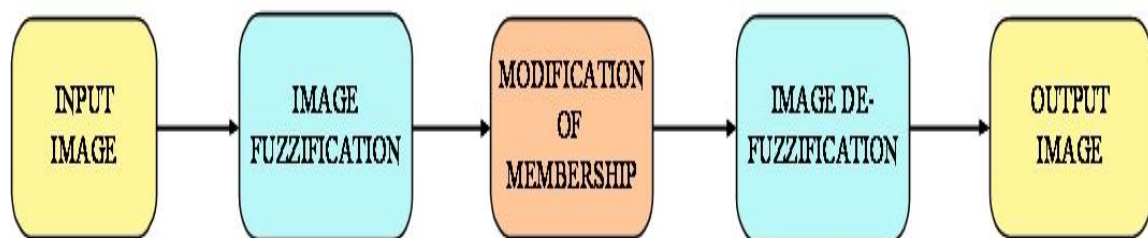


FIGURE 1.6: FUZZY IMAGE ENHANCEMENT MODEL

It is based on the crisp value of gray level mapping into a membership function to get a higher contrast output image than the input image [141, 142].

The human concepts are represented by linguistic variables. The fuzzy modeling can be possible using these variables. To get enhanced output, the model needs to modify the membership. Using the linguistic variables as modifiers, the new fuzzy set is obtained by modifying the shape of membership. For example, linguistic variables for the brightness of the image could be very (new fuzzy set will square of a fuzzy set i.e., $\mu_{\text{new}} = \mu^2$), more or less ($\mu_{\text{new}} = \sqrt{\mu}$), very-very ($\mu_{\text{new}} = \mu^4$) etc [17].

Basically, human perception is different as compared to the machine understanding, that's why fuzzy sets are used to make understating of the machine as like human perception. These are able to handle fuzziness in the image to enhance the contrast of the images and to remove unclerness in edges, boundaries, regions, features of the image. It is also used to remove noise from images by using fuzzy filters to enhance the images. Fuzzy entropy and membership function used for contrast enhancement of images. A general structure is shown in figure 1.7. More knowledge is a need for membership modification in order to get significant image enhancement.

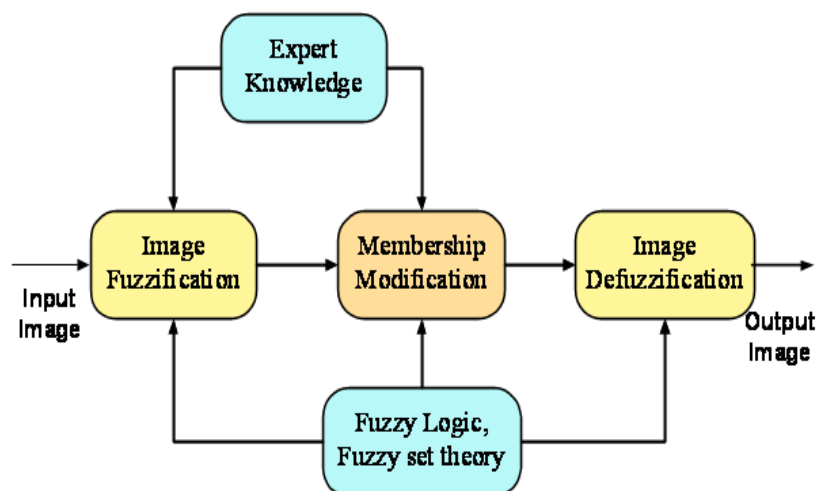


FIGURE 1.7: GENERAL STRUCTURE

1.4 IMAGE QUALITY PARAMETERS

In this thesis, following image quality attributes are used to measure the performance for image enhancement methods.

1. Mean square error (MSE)
2. Peak signal-to-noise ratio (PSNR)
3. Contrast Improvement Index (CII)
4. Index of fuzziness (IOF)
5. Entropy (H)
6. Structural Similarity Index (SSIM)

1.4.1 MEAN SQUARE ERROR (MSE)

It is the cumulative squared error between the compressed and the original image.

$$MSE = \frac{1}{mn} \sum_0^{m-1} \sum_0^{n-1} \left| f(i, j) - g(i, j) \right|^2 \quad (1.11)$$

Where f = matrix data of the original image, g = matrix data of the degraded image, m = no of rows of pixels of an image, i = index of that row, n = no of columns of pixels of an image, j = index of that column.

1.4.2 PEAK SIGNAL-TO-NOISE RATIO (PSNR)

It is the ratio between the maximum power of a signal and power of computing noise. Here the signal is the original data, and the noise is the error. The mathematical formula of PSNR is as follow:

$$PSNR = 10 \log_{10} \left(\frac{255^2}{MSE} \right) \quad (1.12)$$

Where MSE = Mean square error.

So, the quality of the image will be better when the value of PSNR is higher and the value of MSE is minimum.

1.4.3 CONTRAST IMPROVEMENT INDEX (CII)

The Contrast improvement index (CII) is used to measure the quality of contrast in the output image.

$$CII = \frac{C_{processed}}{C_{input\ image}} \quad (1.14)$$

Where the $C_{processed}$ and $C_{input\ image}$ denote the average values of local contrast in the processed and input image respectively. Here the local contrast can be computed by the ratio of the difference of maximum intensity and minimum intensity and the summation of maximum and minimum intensity for a given image.

1.4.4 INDEX OF FUZZINESS (IOF)

It represents equivocalness present in the image by evaluating the space between its fuzzy attribute levels to the nearest ordinary level. Index of fuzziness (IOF) defined as:

$$I(A) = (2/n^k). d(A, \tilde{A}) \quad (1.15)$$

Where $d(A, \tilde{A})$ denotes between fuzzy set A and its nearest ordinary set \tilde{A} . A small value of IOF indicates that the clarity of the image is increased in the enhanced image and it contains minimal noise.

1.4.5 ENTROPY (H)

The entropy gives the overall information contained in the given image. With the higher value of Entropy (H), the output image contains more detailed information as compared to that of the input image. It is given as:

$$H = \sum_{j=1}^M \sum_{k=1}^N p(j, k) \log p(j, k), \quad (1.17)$$

Where $M \times N$ denotes the size of the output image.

1.4.6 STRUCTURAL SIMILARITY INDEX (SSIM)

The overall quality of measurement of the entire image can be evaluated using SSIM values. It is used to reflect the qualitative visual appearance by the measurement of the degree of distortion. The SSIM is given as:

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + c_1)(\alpha_{xy} + c_2)}{(\mu_x^2 + \alpha_x^2 + c_1)(\mu_y^2 + \alpha_y^2 + c_2)} \quad (1.18)$$

Where c_1 and c_2 are constants, μ denotes the mean intensity of the image, and α is the correlation coefficient. These are computed from the dynamic range of the images.

1.5 APPLICATIONS OF IMAGE ENHANCEMENT

Image enhancement is rapidly being made a part of all the applications which require the various kinds of images as an information source for data interpretation and analysis.

Image enhancement contains numerous applications such as medical image processing in the medical field for screening, monitoring patient, processing of chest X rays, tomography images, and for patient diagnosis etc., The use of these images are for detection of tumors, screening and monitoring the patient's health, recognition of various diseases in patients. The ranges of applications include processing for radar, sonar, and acoustic image, automated inspection of industrial parts, remote sensing through satellites or other spacecraft. Images captured by satellite in various environmental conditions are useful in prediction of agricultural crops, weather conditions, image transmission, and storage for business applications.

1.6 THESIS OBJECTIVE

The objective of the thesis is to explore the possibilities of best image enhancement techniques for grayscale images. A study has been done to find out the best solution that will fulfill the requirements of the latest technologies on the Internet of Thing scenarios. Nowadays, image capturing devices are in many ranges from high resolutions to lower resolution in terms of pixels value. In this digital world, the technologies have been grown rapidly for many applications such as internet of thing (IoT) applications; Image enhancement techniques play an important role while processing the data from one device to another, an image enhancement technique could be used to forward the improved image data. Different devices could require different qualities of improved images for processing the data or applications. In different qualities of an image, a device may fail to capture the better image quality and hence a good enhancement technique may be the need to achieve the required quality in the image. This thesis is based on comparative analysis of various techniques of image enhancement for gray-scale images. Based on comparative studies, a novel method of image enhancement is then proposed. Comparative analysis of classical contrast enhancement techniques is presented first then fuzzy image enhancement techniques are studied in details because these techniques show better image contrast enhancement. Use of different fuzzy membership functions is described to show the effectiveness of image contrast enhancement. After this detailed study, we have compared and analyzed various contrast enhancement techniques and edge detection technique for classical and fuzzy domain both and then concluded which method is remarkably better. Based on this comparative analysis, we proposed a method for multiple membership functions of Mamdani fuzzy inference system (FIS). The proposed method is a novel approach to multiple membership functions of Mamdani FIS for contrast enhancement. This method shows that uses of multiple membership functions in different combinations can

lead to non-linear modification pixel intensities. After this, another approach, edge detection of image enhancement is taken. It includes a comparative analysis of classical methods and fuzzy methods. In the next section, an organization of the present thesis is given.

1.7 THESIS ORGANIZATION

The present work is based upon the enhancement of digital images for the better interpretation, investigation, and analysis. The key idea of this thesis is to get better enhancement method to improve the contrast of gray images for better analysis and interpretation. The work done in the present thesis has been organized in the eight chapters.

Chapter 1 describes the various spatial domain, frequency domain, and fuzzy domain image enhancement methods that are used for the contrast enhancement of the images. Individual methods are used to reduce the criticality of analysis of images for the specific applications. This chapter also includes performance quality parameters used throughout thesis for analysis purpose.

Chapter 2 presents the literature on contrast enhancement methods for spatial domain and fuzzy domain and edge detection. Chapter 3 includes the comparative study on various classical contrast enhancement methods like contrast stretching, histogram equalization, Contrast-limited Adaptive Histogram Equalization (CLAHE), Brightness preserving Bi-Histogram Equalization (BBHE), Dualistic Sub-Image Histogram Equalization (DSIHE), Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE), Dynamic Histogram Equalization (DHE), and Brightness Preserving Dynamic Histogram Equalization (BPDHE). A description of these methods is presented first and then the comparative analysis is done.

In chapter 4, various fuzzy contrast enhancement methods are analyzed to draw the performance as compared to classical methods. Both the methods are implemented and compared with the help of various quality attribute parameters for different images.

Chapter 5 is based on the development of contrast enhancement using different membership functions (MFs) for Mamdani fuzzy inference system (FIS). In the proposed method, a fuzzy inference system consisting of input membership function, inference system using if-then rules and output membership function, are studied and a range of case studies is performed using different membership functions for gray-scale contrast enhancement. Using this Mamdani fuzzy inference system (FIS), better membership functions based on the observations and findings are identified using comparative results and analysis.

In chapter 6, a novel fuzzy Mamdani FIS is proposed that uses optimization of fuzzy image quality in order to preserve the brightness and contrast of the image. In this proposed method, the criteria are to determine the optimum results through the selection of best cases of membership combinations that uses fuzzy quality parameter for achieving an overall enhanced contrast of the image.

Chapter 7 includes the study of edge detection techniques using classical and fuzzy logic approaches. The presented work is on comparative analysis of various edge detection techniques for various types of images such as medical images and normal images.

The last chapter 8 concludes the presented work. It highlights the major contribution for gray-scale image contrast enhancement. Some interesting future scope of the image enhancement methods is suggested. Since the present work of the thesis is on grayscale image enhancement so in future, the work may be extended for the color images for the contrast enhancement. It may also extend for the neural network, fuzzy neural networks and for the deep fuzzy neural networks.

CHAPTER II

Review of Literature

CHAPTER II

LITERATURE SURVEY

In this chapter, a brief literature review on image enhancement methods for spatial domain and the fuzzy domain is described. It covers the important related work on contrast enhancement and edge detection methods for the classical and fuzzy domain. During data acquisitions, image data may lose detailed information. Image data can be a collection of various images such as real-life photographic images, medical images, satellite images, sensing images etc. These are suffered from poor contrast or brightness. The image processing on these degraded images becomes important for application point of view [3, 31, 106]. First, the spatial domain based image enhancement methods are described. Both the image contrast enhancement and edge detection methods are given in different sections for spatial domain. Fuzzy domain methods are then presented in the next section of it.

2.1 IMAGE ENHANCEMENT IN THE SPATIAL DOMAIN

The spatial domain includes the operation of image pixels directly for getting enhanced visibility on the output image. Many algorithms and methods have been proposed in the literature to increase the contrast of the image based on image pixel operations. For example, the logarithmic transformation, the power law transformations are used to get improved results. That's why, these are popular as a tool for processing on image pixels [7, 8, 25]. In some spatial operations, identity function and image negative functions are used as a linear function. In the negative image function, the resultant image is of negative transformation, in which black or gray color-converted in white and vice versa.

The logarithmic and the power-law (gamma) transformation are another functions used for image contrast enhancement [7, 31, 47, 124]. The perception of the image can be improved using different enhancement methods as per application requirements. For examples, the medical images need to get increased contrast and sharpness for disease diagnosis, and forensic images require to be improved in resolution for its applications. Thus, one enhancement method suited for one application may not be applicable for other. Therefore, there is not any standard for image quality applicable to image enhancement methods. Image processing for getting an image with good perceptions and detailed information is a necessary requirement for several areas such as computer vision, satellite applications, bio-medical imaging, fault detection etc.

2.1.1 CONTRAST ENHANCEMENT

Contrast enhancement is one of the spatial domain methods to get improved contrast having a visually natural image when an image has degraded due to poor contrast. In poor contrast, the visually appealing area appears dull, so the looking/visually of the image is required to modify using some spatial operations [3, 7, 9]. For both grayscale and color images, contrast enhancement methods can be applied to get the visually appealing image. A simple and effective method of contrast enhancement is histogram equalization [2, 43], which is commonly used in many contrast enhancement applications [6, 24, 29, 105, 107]. Using the histogram function, a statistical feature of an image can be determined that gives the distribution of intensity levels for all the pixels of the given image [6, 24]. Since only histogram method does not handle some details of the image, histogram equalization (HE) is proposed to handle it [105, 107]. HE extracts the histogram as uniformly distributed intensity levels over given pixel range. In histogram equalization, the normalized cumulative histogram is obtained as the grayscale mapping function [110]. Due to its simplicity and global approach, it is popular for many applications [5]. Many variants of HE

are proposed in the spatial domain [4]. Another extension of HE is proposed by combining three accelerative techniques namely local histogram, cumulative histogram function and the use of block size W^2 [143]. However, it is complex in computation and processing time. HE and its variants have own advantages and disadvantage. One of the limitations of HE is that the mean brightness gets affected, so histogram matching or histogram specification methods are used for generating a specific histogram [59, 104]. Histogram specification is well suited for preserving the fast hue and range in color image enhancement and histogram along with fuzzy logic is also applicable effectively enhancement techniques [75, 100]. The histogram matching concept is based on the matching of intensity histogram for getting its smoothed version for image contrast enhancement [61]. For real-time applications, dynamic histogram specification (DHS) algorithm is proposed that includes the range of levels for working in real-time image processing [114]. Other extensions of HE are Adaptive HE (AHE) [146], Exact Histogram Matching (EHM), Brightness Preserving Bi-histogram Equalization (BBHE) [54], Dualistic Sub Image HE (DSIHE), Brightness Preserving Dynamic HE (BPD) [31] and Minimum Mean Brightness Error Bi-Histogram equalization (MMBEBHE) [20] for brightness preservice [33, 21]. Adaptive Histogram Equalization (AHE) [146] uses three accelerative steps. First, using sliding window approach, the local histogram is determined; secondly, cumulative histogram function is computed; thirdly, the multiplication and division operations are modified with fast bitwise shift replacement such that the block size W^2 keeps equal to the product of grey levels and an integral power of 2. Brightness preserving histogram equalization with maximum entropy (BPHEME) has proposed to maximize the entropy [128].

Adaptive histogram equalization (AHE) and intensity windowing have been compared using psychophysical observer studies to assess the probability that a clinical CT (computerized tomography) image of the chest contained the artificial lesion, and their

accuracy was evaluated [149]. Zhiming et. al has proposed a new method to solve the limitation like time-consuming and computationally expensive of the AHE method. In this proposed method three fast methods are combined to form a new fast AHE [147]. MRI of brain method helps to analyze, diagnose and treat various brain-related disease by using histogram equalization [106]. A statistical model has proposed to remove of intensity in homogeneities from the ultrasound B-scan images for the better analysis of breast and cardiac ultrasound images [133]. Exact histogram matching (EHM) is used to enhance and interpreted whole body scene images [45].

Comparative analysis for diagnosis in successive whole-body scans is discussed in [150]. The study shows that the procedures such as the diagnosis of osseous metastasis and evaluation of chemotherapy and radiation therapy for osseous tumor response can be improved using enhancement methods. For radiologists, the quantification of subtle interval changes between successive whole-body bone scans is a time-consuming process because of variations in intensity, geometry, and morphology. It is shown that using histogram-based enhancement, interpreting the successive whole-body bone scans becomes effective and easier for radiologists. Authors also presented the comparison between AHE, HM and EHM using performance parameters namely, peak signal-to-noise ratio, structural similarity, similarity measures, and histogram intersection. Soong-Der Chen et. al have proposed the brightness preserving method of contrast enhancement [110]. HE method based enhancement causes the annoying artifact and unnatural contrast modifications. They solve these problems and maintain the brightness of the image to a certain extent. However, it does not work under certain condition. Brightness preserving Bi-Histogram Equalization (BBHE) [54], Brightness Preserving Dynamic Histogram Equalization (BPDHE) [31], Dualistic Sub-Image Histogram Equalization (DSIHE) and Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) [20] are some popular extensions to

overcome the same problems. Brightness Preserving Dynamic Histogram Equalization (BPDHE) [31] is based on getting enhanced image such that the mean intensity is kept equal to the mean intensity of the input image so that the mean brightness can be maintained effectively. Preserving brightness in the histogram is a novel extension of BBHE referred to as minimum mean brightness error bi-histogram equalization (MMBEBHE) [111]. In BPDHE, the smoothed histogram obtained using a Gaussian filter is partitioned according to its local maxima. Each partition is then modified to the new dynamic range using histogram equalization independently. The resultant image gives mean brightness with respect to changes in dynamic range. Dualistic Sub-Image Histogram Equalization (DSIHE) is a method of contrast enhancement based on Shannon's entropy [25]. A dynamic histogram equalization technique is based on the advancement of conventional histogram equalization method. It enhanced the contrast of images without loss of any details [1, 7].

For consumer electronics products, an extension of HE method has proposed an algorithm to preserve the mean brightness of the given image and provides a natural enhancement [56]. Another method known as brightness preserving weighted dynamic range histogram equalization (BP-WDRHE) is also popular in brightness preserving for consumer electronic products [117]. The DRSHE method is also used to inhibit unnecessary changes in brightness and preserves naturalness of the original image [81, 82]. Some other methods like fuzzy image enhancement, the genetic algorithm, and neural network have become popular recently for image contrast enhancement [115, 123, 98, 86, 41]. There are many algorithms in literature for comparative best in image contrast enhancement as compare to HE based methods of image enhancement [47, 90]. For example, the genetic algorithm applied on image processing has shown the remarkable results as more brightness preserving and detailed information content [125]. A genetic algorithm acts as a popular and effective optimization tool that can produce optimized results [85, 99]. By using fitness

function individually it gives better results to convert gray levels into an overall better contrast-enhanced image [15]. A genetic method based resultant images are suitable for consumer electronics products. In this method combinations of simple and novel chromosome represent together [37, 85]. Applications of the cellular neural network are also used in the area of image processing. This is based on information processing systems [135, 136]. To improve the contrast of the very low light condition images and noise with the help of algorithm, which amplified the intensity of images [145]. It has been observed that the classical spatial methods such as Histogram Equalization based methods and its variants are still lead to over-enhancement and under-enhancement. So, the resultant image is not natural in visual clarity due to saturated with very bright or dark intensity levels. To overcome this drawback, the fuzzy set theory can be applied to handle both brightness preserving and contrast enhancement. As compared to the classical methods of image enhancement, the inexactness of gray levels is handled in a better way in the fuzzy domain [89]. Image contrast enhancement based on a weighted average of absolute color difference was proposed in [80] to get natural brightness in the input image. It is based on separation of a dynamic range of histogram into many parts. Each part then is redistributed into pixel intensities based on its area ratio. This approach has shown enhancement in image related to consumer electronic products where side-effects appear as false washed out and false contouring due to change in brightness. For this, it introduces an adaptive scale factor for scalable dynamic range preservation.

2.1.2 EDGE DETECTION

Edge detection is a set of mathematical methods in image processing, machine vision and computer vision [8, 49, 109, and 122]. Edge detection method detects the edges in a given image by emphasizing some characteristics by using filtering or masking so that the processed image includes quality with better visibility. Edges are significant local changes

of intensity in an image. There are many methods for edge detection. A standard edge detection Algorithm in five steps describing Smoothing, Finding gradients, Non-maximum suppression, Double thresholding, Edge tracking by hysteresis [14]. The genetic algorithm also used in the analysis of medical images on the basis of thin and continues detection of edges accurately [39]. A new edge-detection method is based on three procedures: image binarization, image contraction, and image subtraction [44]. Another edge detection algorithm is based on a scan line approximation technique, which is a novel method for range images [48].

A theory of edge detection is based on intensity changes, zero-crossing segments, a two-dimensional Gaussian distribution, and Laplacian [69]. The Gaussian function is used to smooth the image and Laplacian operator is used to constitute the location of edges by zero findings. Laplacian is merged with smoothing to find edges via zero-crossing [126]. Edge detection is also based on intensity changes by using appropriate filters [67]. FPGA based platform for edge detection has optimized for feature detection. It is mathematically simple and reliable with noisy images and low latency [84]. Another simple edge detection method has proposed a new method based on fuzzy reasoning. It is used to detect edges and to remove noise [95].

2.2 IMAGE ENHANCEMENT IN THE FUZZY DOMAIN

As discussed earlier, the fuzzy theory can handle the inexactness of gray levels in a better way. So, fuzzy image enhancement is very popular due to the speedy extension of fuzzy set based mathematical modeling. It acts as a utility method for dealing with uncertainty in an image [19, 28, 26, and 118]. It has been proven a powerful tool for presenting the image in a better way so that it can be used for a large number of applications in the area of image contrast enhancement [13, 23, and 46]. The fuzzy set theory was introduced by Zadeh in 1965, in which classical set-theoretic operation extended from ordinary set theory to fuzzy

sets [141]. Nowadays, image capturing devices are in many ranges from high resolutions to lower resolution in terms of pixels value. In this digital world, the technologies have been grown rapidly for many applications such as internet of thing (IoT) applications. Image enhancement techniques play an important role while processing the data from one device to another, an image enhancement technique could be used to forward the improved image data. In different qualities of an image, a device may fail to capture the better image quality and hence a good enhancement technique may be the need to achieve the required quality in the image [31]. It is quite reasonable to use some methods like smoothing to enhance images. Fuzzy sets provide a problem-solving tool between machines to real world [35, 79]. Hence we can say fuzzy rules are similar to human reasoning [71]. The use of the fuzzy rule-based procedure in image enhancement was primarily suggested by Tizhoosh et al [119]. Fuzzy rule-based systems are commonly used in computer vision for noise removal, smoothing and sharpening contrast to avoid uncertainty and vagueness of the features of images [50]. In another paper he has proposed, a fuzzy ordering is a generalization of the concept of ordering.

In this paper, various properties of similarity relations and fuzzy ordering are enquired [142]. The various evaluation operations are described in the fuzzy domain. Two fuzzy measuring tools are a Fuzzy expected value (FAV) and Fuzzy Expected Interval (FEI) to handle incomplete data [101]. Authors have shown many examples using these two measuring tools. Another enhancement method for reducing the impulse noise of all kinds using fuzzy impulse noise detection and reduction method (FIDRM) is proposed in [102]. It also used for an image having a mixture of impulse noise and other types of noise. For digital color images, Schulte et al. [103] have proposed a fuzzy two-step color filter. In this method, a fuzzy detection phase is applied and then an iterative fuzzy filtering technique

was used to reduce the impulse noise. Three separate membership functions are determined based on a calculation of fuzzy gradient values and on fuzzy reasoning.

2.2.1 FUZZY CONTRAST ENHANCEMENT

Contrast enhancement by using fuzzy is based on membership transformation in gray level mapping to know the degree of darkness or brightness in an image. Image enhancement by using fuzzy is based on contrast stretching method in such a way that light pixels appear much lighter and dark pixels appear much darker [17]. This way of representation shows, how's the human perception and fuzzy rules permit us to represent this knowledge in form of fuzzy sets. Fuzzy sets are effective to handle uncertain behavior in the images related to fuzziness [17, 138]. Fuzzy set concept based on partial membership value, while classical sets based on crisp value [96, 97]. A new thresholding technique is introduced which operate threshold as a Type-II fuzzy set [120]. This modified technique mentioned for brightness preserving knows as brightness preserving dynamic fuzzy histogram equalization (BPDFHE) [108]. This technique is based on various manipulation of the histogram for better enhancement of an image. Fuzzy models based nonlinear filters are also very efficient to save useful information of image data with noise removal.

As per reference [92], for noise removal, various filters like fuzzy filters are used. For noise reduction, various classical filters and fuzzy filters are used [87, 94, 72, and 73]. The fuzzy median filter is used for removing impulse noise [60]. Fuzzy filters are powerful enough to remove different types of noise as compared to classical filters [58]. In recent advances, neural fuzzy filters are very effective to remove noisy data from the images without destroying the useful information of the image [27]. Combinations of the three different filters with fuzzy rules are proposed for the enhancement [140]. Fuzzy impulse noise detection and reduction method have developed to reduce all kind of impulse noise for enhancement [113]. For color images, a new filter has presented for the reducing of additive

noise [112]. An adaptive fuzzy filter is contained in two more operators, fuzzy detector, and dynamic selector. In this method adaptively selected membership functions are defined instead of fixed membership functions [62]. By combining the smoothing filter, fuzzy enhancement method and gray transformation, Peng et al. [91] has proposed a generalized image enhancement algorithm with a combined scheme for image contrast enhancement.

Using a smoothing filter, noise or other small fluctuations in the input image are suppressed. It is similar to suppressing the high frequencies components in the Fourier transform domain. The average blur image edges are reduced by replacing the current point by the median of the brightness in its neighborhood. Using fuzzy enhancement method, the obtained image from the previous step is converted into fuzzy domain through fuzzification, iterative computation based on membership function, and de-fuzzification for reconverting in the spatial domain. After this step, the enhanced image is obtained. The final processed image is obtained by the gray transformation of the enhanced image. This method showed improvement in low-contrast and narrow-gray range images.

The fuzzy rule-based system applied different filters as per satisfaction of a different condition. Fuzzy enhancement used INT operator as a contrast intensifier to increase or decrease the degree of membership. It depends on the membership function to enhance input image [74]. In this, the concept of a fuzzy set is suggested to involve the primary enhancement, smoothing, and the enhancement of the input image. A contrast intensifier operator was used to extract the fuzzy properties corresponding to pixels [74]. Due to some limitation of INT operator NINT operator used as a new intensification operator which reduce computational time and utilized sigmoid function for enhancement [12, 78]. Various fuzzy patterns, fuzzy cluster analysis, fuzzy classifier design, and various fuzzy objective function algorithms are proposed by Bezdek et al. [10, 11]. These fuzzy models are used for a different kind of images enhancement like medical images etc. [12].

A novel Intuitionistic fuzzy-C means clustering algorithm proposed for the analysis of medical images. Breast ultrasound images also analyzed with enhancement algorithm based on fuzzy logic [130]. An adaptive fuzzy enhancement algorithm of the surface image has suggested the method of locally enhancing the image without additional optimization [64]. Fuzzy contrast technique is used for better enhancement of images without increasing the noise which is present in the input image [40]. It is also applicable to low contrast images [42]. This kind of fuzzy techniques consists of IF-THEN rules by using different membership functions [121, 52]. Enhancements of images are also effective and flexible by using fuzzy sets in fuzzy rule-based techniques [41]. On the basis of the fuzzy set theory, contrast factor parameter is used to enhance the degraded images [38, 47]. Image quality accessing model is also proposed for better enhancement [144]. It can be achieved with the concept of optimization of s-type membership functions [127].

Two types of fuzzy inference system (FIS) models are studied for image contrast enhancement of gray-scale image based on attributes such as the number of IF-THEN rules, different membership functions (MFs), fuzzy contrast factor [88, 116]. In Fuzzy Theory, there are two types of available fuzzy Rule-based models namely non-additive and additive rule model [32]. The non-additive rule-based model is also known as Mamdani fuzzy inference system (Mamdani FIS) while the additive rule-based model is known as a Takagi-Sugeno fuzzy inference system (Sugeno FIS) [68]. A fuzzy morphology is based on the Sugeno fuzzy integral [30]. In this thesis, fuzzy contrast enhancement is explored based on Mamdani fuzzy inference system. Due to the simplicity and better analysis of the problem on the basis of fuzzy rules, Fuzzy inference system is a better option in many application areas [70]. Utilization of fuzzy inference system for segmentation of low-contrast infrared ship images has proposed by Xiangzhi et al. [134]. For medical purposes, dualistic sub-image histogram equalization based enhancement and segmentation techniques were

proposed in [65] that applies the segmentation and then histogram equalization on each separated sub-images to get the enhanced image. For further analysis of medical images in the identification of defects, hole filling has been applied to replace the holes with pixel level as 1s. The steps include enhancement, segmentation, hole filling and then branch removal for the input image. For the ill-defined image, a minimization algorithm for compactness and fuzziness was proposed by Pal and Rosenfeld [76]. It extracts the fuzzy segmented version by minimizing the ambiguity in both intensity and spatial domain for the ill-defined image. The linear index of fuzziness and fuzzy geometry concepts were used to enhance the image.

2.2.2 FUZZY EDGE DETECTION

An Image segmentation splits an image into its sub-regions to collect the details which are found in a sub-region of the image. These details are helpful in analyzing images for the enhancement of images. The first category of image segmentation is describing a partition of images based on Sharpe changes in intensity known as edge and the second category is based on a set of predefined criteria known as thresholding, region growing and region splitting and merging [22]. With the help of thresholding edge, detection can be possible to overcome the criteria of the noisy condition. In this method, the first order derivative of the Gaussian filter is used for convolving the images. Edges found by canny can also create some false edges. The structure of the image can also be found with the help of a method known as USAN, which is helpful in edge detection [66]. Edges may also helpful for zero crossing [69].

For the measurement of the degree of fuzziness, entropy is used, which produces 1-pixel wide edges [36]. The intuitionistic fuzzy method is also popular in the concept of entropy in various clustering algorithm [18]. Fuzzy edge detection methods are Fuzzy Sobel edge detector [55], Entropy-Based Fuzzy Edge Detection [54], and Fuzzy template based edge

detector [53]. An improved Sobel edge detection method based on removal the effect of white Gaussian has shown the good results as compared to previous one [131]. Also, a fuzzy if-then-else rule-based method achieves good edges for enhancement of images [93]. Entropy optimization method has been used for edge detection in gray-level images [34]. It is based on global contrast intensification and local fuzzy edge detection.

Fuzzy sets are also used for X-ray images in edge detection [77]. An improved algorithm based on fuzzy set for edge detection was proposed by Pal and King [148]. In this algorithm, fuzzy properties were used and experimentally demonstrated the effectiveness of the algorithm for many applications of medical and pattern recognition. Based on this method, another fast edge detection algorithm has been proposed to show the improved efficiency of pal and kings algorithm in [129]. For the fast and accurate edge detection from the blurry images, the fast multilevel fuzzy edge detection (FMFED) algorithm has proposed to draw out thin edges and remove false edges [132]. It is based on the local characteristics of the images and the gradient value based on the edge detection operator. Another method, Fuzzy edge detection (FEDGE) was based on fuzzy categorization and classification, known as fuzzy Sobel method [51]. As compared to the Sobel method, the fuzzy Sobel method gives better-enhanced edges to get resultant images more clearly [57].

Liu et al. [63] have proposed a fast edge detection algorithm based on fuzzy theory. In this algorithm of edge detection, the threshold in the input image is determined using a threshold algorithm and then a new membership function is defined using it. Here, the fuzzy domain is obtained from the spatial domain of the input image. After these steps, a fuzzy enhancement operator is used to get the enhanced image. Finally, using max or min operators, edge detection has been done to get the resultant output image. This method has shown improved results for the multi-threshold image. Based on different detectors for edge detection in an image, statistical objective performance analysis, and detector parameter

selection was proposed in [139]. Although there is no any automatic parameter selection process for implementation of most edge detectors so that the authors have developed this method using the correspondence between the different detection results where an estimated best edge map is utilized as an estimated ground truth which is obtained using both a receiver operating characteristics analysis and a Chi-square test. Finally, a best edge detector parameter set would be determined using estimated ground truth from the similar statistical approach. It also considers the tradeoff between information and noisiness in the detection results. It helps in practical implementations of parametric edge detectors with the automatic parameter selection process.

CHAPTER III

Performance analysis of Contrast Enhancement Techniques in Spatial Domain

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CHAPTER III

PERFORMANCE ANALYSIS OF CONTRAST ENHANCEMENT TECHNIQUES IN SPATIAL DOMAIN

This chapter presents the quantitative analysis of contrast enhancement techniques that will allow us to find out the evolution, the impact, and the perspectives of image enhancement methods for computer vision and image analysis applications. We have carried out the analysis on different types of images based on quality attributes, studying trade-off in image contrast and brightness on used methods, and determining their advantages and disadvantages. First, the motivation about the chapter is described and then best histogram equalization (HE) based image contrast enhancement techniques are discussed in details. A comparative study using simulations results and analysis and concluding remarks are discussed at the end.

3.1 MOTIVATION

Image enhancement techniques facilitate the development of a new solution for computer imaging problem. It consists of point operations, mask operations and the global operations. The point operation is the technique of modifying pixel without depending on other pixel values using a particular formulation. Mask operation technique modifies the pixel values according to neighbor's pixel values. The global operation uses the techniques of modification of all the pixel values for an image or sub-image. Spatial domain processing methods include all the three types of operations whereas the frequency domain includes the global operations by the nature of frequency [25, 29]. The ultimate object of image enhancement methods is to make the images look better.

In the spatial domain, the image enhancement methods developed to explore the incremental on image contrast and image brightness for better visibility are based on direct manipulation of pixels of the image. For input images with poor quality, Histogram-based methods include the modifications on various pixel properties for sharpening image features for display and analysis. However, they have shown unsatisfied results due to uncertainties because of over-exposure, under-exposure, and over-smoothing problems. So, the enhanced images using most of the histogram-based methods are not appealing better look and feel invisibility [119, 123].

3.2 CONTRAST ENHANCEMENT TECHNIQUES

The various methods of image enhancement have been proposed in the scientific literature addressing the study on image contrast improvement. On performing a specific search in the databases of scientific literature (Scopus, Elsevier, Web of Science, IEEE), the number of references found largest for the following histogram based image enhancement methods. In histogram computation, the input image is transformed into the histogram and then into a specified histogram to achieve highlighted gray level. These methods have shown the effective enhancements based on its properties and features.

- i. Contrast Stretching [7,8]
- ii. Histogram Equalization (HE) [11, 41]
- iii. Contrast-limited Adaptive Histogram Equalization (CLAHE) [150]
- iv. Brightness preserving Bi-Histogram Equalization (BBHE) [54]
- v. Dualistic Sub-Image Histogram Equalization (DSIHE) [128]
- vi. Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) [20]
- vii. Brightness Preserving Dynamic Histogram Equalization (BPDHE) [31]

Above list of histogram-based image enhancement techniques is described next in details. The first classical technique is Contrast Stretching [7, 8] which uses the expansion of the full range of intensity of the input image in a proper way of stretching the contrast. So, the overall brightness of the image is improved for a given input image. The second widely used technique is Histogram Equalization [11, 41] from the histogram-based computation. In this method, equalization process is based on, allocation of more gray levels (i.e., it has most pixels) and allocation of fewer gray levels (i.e., it has fewer pixel). So the most heavily populated region of the histogram gets spread by equalization process. As a resultant, it shows an increment of contrast and often brings out hidden detail. It changes images from an impulse histogram to one with a flat histogram. The third best-suited technique is Contrast-limited adaptive histogram equalization (CLAHE) [150] which works on only parts of an image or can say on tiles of an image. Firstly, it divides the image into a number of tiles, then apply contrast enhancement on every tile individually and then it recombines results to give output image with enhancement. CLAHE works better as compare to histogram equalization in most cases for contrast enhancement of images.

3.2.1 CONTRAST STRETCHING

It is a method to expand the full range of intensity of an image so that the overall brightness of the image can increase. It is often called normalization. It can apply only a linear scaling function to the image pixel value. Before applying stretching method it is necessary to define upper and lower limit of image pixel value. For example for 8-bit image lower limit is 0 and the upper limit is 255. Transformation function used for contrast stretching [7, 8]:

$$g(x, y) = g1 + \left(\frac{g2 - g1}{f2 - f1} \right) [f(x, y) - f1] \quad (3.1)$$

Here mapping of gray levels [f1, f2] on new range [g1, g2]. Where f1 is minimum intensity and f2 is the maximum intensity of an image. Values below 0 are set to 0 and values more

or less 255 are set to 255. This function enhances the contrast of an image, which shows equal 1 distribution of intensity.

3.2.2 HISTOGRAM EQUALIZATION (HE)

It is a widely used technique in image processing because it is an automatic technique with no parameters to set. The expression of HE is given below from [11, 41]. Let $\{X(i, j)\}$ denote a given image composed of L discrete gray levels denoted as $\{X_0, X_1, \dots, X_{L-1}\}$, where $X(i, j)$ represents an intensity of the image at the spatial location (i, j) and $X(i, j)$. For a given image X , the Probability density function of Histogram equalization, $p(X_k)$ is defined as:

$$p(X_k) = \frac{n^k}{n} \quad \text{for } k = 0, 1, \dots, L-1 \quad (3.2)$$

Here $p(X_k)$ represent number of pixel of a specific intensity X_k for the histogram of input image. Based on the probability density function, the cumulative density function is defined as:

$$C(X) = \sum_{j=0}^k p(X_j) \quad (3.3)$$

Where $X_j = x$, for $j = 0, 1, \dots, L-1$.

Histogram equalization is based on mapping of the input image into the dynamic range, (X_0, X_{L-1}) , using the cumulative density function. The Histogram equalization formula is given as:

$$h(v) = \text{round} \left(\frac{cdf(v) - cdf_{min}}{(M \times N) - cdf_{min}} \right) \times (L - 1) \quad (3.4)$$

3.2.3 CONTRAST-LIMITED ADAPTIVE HISTOGRAM EQUALIZATION (CLAHE)

This contrast enhancement technique works on only parts of an image or can say on tiles of an image. First, this method divides the image into a number of tiles, then apply contrast enhancement on every tile individually and then it recombines results to give output image with enhancement [149]. This method works better as compare to histogram equalization in most cases for contrast enhancement of images. Overall enhancement in intensity is obtained using HE method. It can be seen using HE that the contrast in the background of the input image is improved significantly, but detailed information over the various regions of the image is lost due to over-brightness. So, CLAHE improves these drawbacks as compared to the HE.

3.2.4 BRIGHTNESS PRESERVING BI-HISTOGRAM EQUALIZATION (BBHE)

BBHE method has a basic idea of decomposing the input image into two sub-images. Then, each sub-image is applied histogram equalization separately [54]. It maintains the mean brightness of a given input image towards the enhancement of contrast in the process. The concept of BBHE is described below.

Let an image X is denoted by the mean of the image as X_m where $X_m \in \{0, L - 1\}$. The image X_m is divided into two sub-images as X_L and X_U such that $X = X_L \cup X_U$. This decomposition is expressed as:

$$X_L = \{X(i, j) | X(i, j) \leq X_m, \forall X(i, j) \in X\} \quad (3.5)$$

And

$$X_U = \{X(i, j) | X(i, j) > X_m, \forall X(i, j) \in X\} \quad (3.6)$$

Here, the sub-images are as $X_L \in \{X_0, X_1, X_2, \dots, X_m\}$ and $X_U \in \{X_{m+1}, X_{m+2}, X_{m+3}, \dots, X_{L-1}\}$. Next step is to calculate the PDF for both the images.

$$P_L(X_k) = \frac{n_L^k}{n_L} \quad (3.7)$$

Where $k = 0, 1, \dots, m$, and

$$P_U(X_k) = \frac{n_U^k}{n_U} \quad (3.8)$$

Where, $k = m + 1, m + 2, \dots, L - 1$.

The CDF for sub-histograms are given as:

$$C_L(X_k) = \sum_{j=0}^m P_L(X_j), \quad (3.9)$$

$$C_U(X_k) = \sum_{j=m+1}^{L-1} P_U(X_j), \quad (3.10)$$

Using above equations, the followings are the transform functions as:

$$T_L(X_k) = X_0 + (X_m - X_0)C_L(X_k) \quad (3.11)$$

And

$$T_U(X_k) = X_{m+1} + (X_{L-1} - X_{m+1})C_U(X_k) \quad (3.12)$$

Using the above functions, the sub-images are equalized independently and then output enhanced image is obtained by compositing these equalized sub-images. The obtained overall function is given as:

$$g(i, j) = T_L(X_k) \cup T_U(X_k) \quad (3.13)$$

3.2.5 DUALISTIC SUB-IMAGE HISTOGRAM EQUALIZATION (DSIHE)

It is claimed by the Wang et al [128] that there is no significant shift in the enhanced image using DSIHE method with respect to the brightness of the input image. However, it is shown that the obtained brightness using DSIHE method is the average value of input images' equal area level and middle value of gray level of the sub-image, $L/2$. In equal area Dualistic Sub-image HE (DSIHE) [128], different from the BBHE method, the input image is decomposed based on getting maximization of Shannon's entropy obtained in the output image. For this, two sub-images are obtained from the input image as one dark and one bright such that the equal area property is maintained (i.e., same pixel values in both).

3.2.6 MINIMUM MEAN BRIGHTNESS ERROR BI-HISTOGRAM EQUALIZATION (MMBEBHE)

As an extension of BBHE method, Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) method is proposed by Chen and Ramli [20]. Similar to the BBHE method [54], MMBEBHE method decomposes the input image into two sub-images having histogram separately. But, the difference in method is to set the separating point for sub-images by determining the minimum mean brightness error between the input image and the out image. MMBEBHE method is usually based on the following procedure: (i) calculation of absolute mean brightness error for threshold level; (ii) Determination of threshold level; (iii) Using threshold level from step 2, divide the input histogram into two and equalized them independently (similar to BBHE).

The comparison between BBHE and MMBEBHE are the followings.

- BBHE method is based on the decomposition of input image histogram only while the MMBEBHE decomposes the input image histogram using threshold level computation.

- BBHE method uses equalization on both the histogram separately while the MMBEBHE maintains the minimum brightness by comparing the input image and output image, and then equalized the both.

Based on the above observations, BBHE method generates the enhanced image with over-brightness of the brighter pixel. As an improved version, MMBEBHE checks the brightness difference and then equalized the histograms to achieve better enhancement as compared to BBHE.

3.2.7 BRIGHTNESS PRESERVING DYNAMIC HISTOGRAM EQUALIZATION (BPDHE)

The BPDHE is an extension of the Dynamic Histogram Equalization (DHE) method [1, 18] that is an extension towards the extraction of more detailed information from CLAHE and HE methods. Different from CLAHE method where HE is computed over the tiles, DHE method divides the input image histogram into the several numbers of sub-histograms in such a way that the new sub-histogram is computed until no dominating portion is present in this newly computed sub-histogram otherwise next sub-histogram is created for further checking dominating portion. Next step of DHE method is to allocate a dynamic gray level (GL) range for each computed sub-histogram in the previous step. This GL is used to map the traditional HE method. It is achieved through the distribution of a total dynamic range of gray levels among the sub-histograms according to their dynamic range in the input image and CDF of histogram values. This step does stretching range towards the contrast and hence the small features are avoided to be dominated and washed out. The complete steps of DHE include the three parts – histogram partitioning, GL range allocation for each sub-histogram and equalization as HE on each of them [18].

In BPDHE method, the partitioning the image histogram is taken into different parts where the point of partitioning could be according to local histogram min and max of image intensities. The number of histogram and equalization can be obtained dynamically based on local minima. However, BPDHE is similar to DHE [18], but, BPDHE uses an additional step of normalization [31]. The results of an image obtained using BPDHE are improved as compared to DHE but some false contouring under the connected regions are observed. It is due to wide intervals of intensities over the larger regions. However, the brightness preserving in the input image is achieved using BPDHE method.

3.3 RESULTS AND DISCUSSIONS

This section consists of comparative results analysis and discussions for above-discussed contrast enhancement techniques for different types of gray images. These techniques include contrasted stretching (CT), HE, CLAHE, BBHE, DSIHE, MMBEBHE, and BPDHE. The performance metrics used for results analysis are Entropy, PSNR, and SSIM. Figure 3.1 shows the input images used in the simulations.

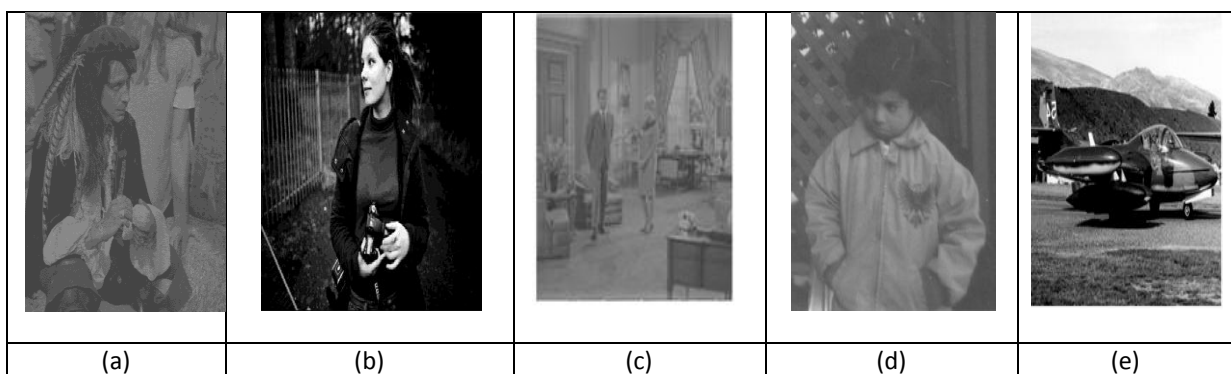


FIGURE 3.1 : INPUT IMAGES - (A) IMAGE - 1, (B) IMAGE - 2, (C) IMAGE - 3, (D) IMAGE - 4, (E) IMAGE - 5

For entropy calculations, Table 3.1 shows the results of given input images when the above-mentioned techniques are used.

TABLE 3.1: ENTROPY PERFORMANCE COMPARISON OF DIFFERENT METHODS FOR INPUT IMAGES

	CT	HE	CLAHE	BBHE	DSIHE	MMBEBHE	BPDHE
IMAGE 1	5.15	5.71	7.43	6.04	6.05	6.03	5.83
IMAGE 2	4.81	6.97	5.49	4.77	4.98	4.78	4.72
IMAGE 3	4.24	4.32	4.85	4.16	4.21	4.11	4.06
IMAGE 4	3.05	5.79	7.18	5.71	5.75	5.71	5.7
IMAGE 5	3.42	5.46	5.56	5.11	5.23	5.02	4.93
AVERAGE VALUE	4.134	5.65	6.102	5.158	5.244	5.13	5.048

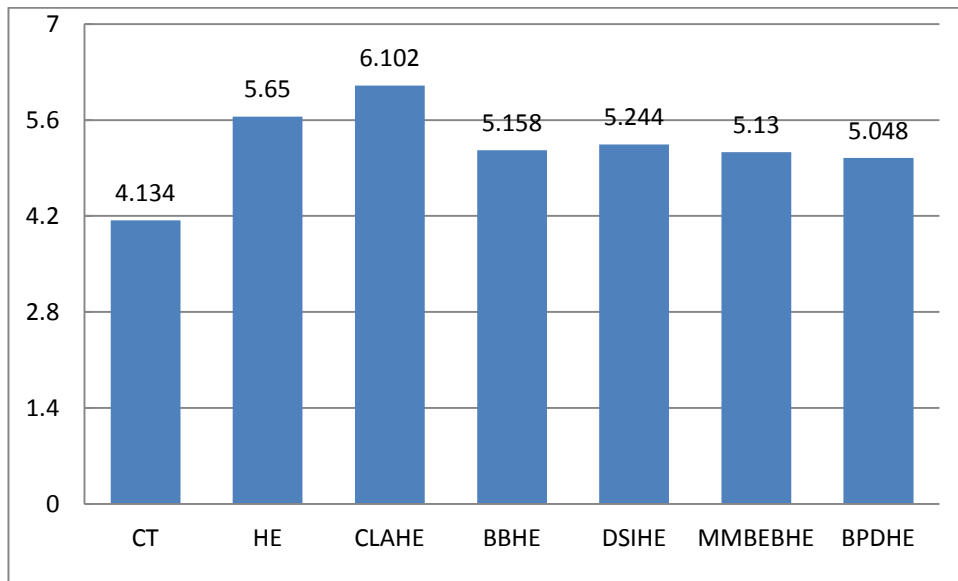


FIGURE 3.2: GRAPH FOR THE AVERAGED VALUE OF ENTROPY FOR DIFFERENT METHODS SHOWN IN TABLE 3.1.

The higher value of entropy measures the richness of the detail of images. Detailed information on the enhanced image is obtained for most of the techniques. To show the effective enhancement, the average calculations are carried out and mentioned in the last row of the table. The graph is also plotted in figure 3.2 for entropy measurement.

TABLE 3.2: PSNR PERFORMANCE COMPARISON OF METHODS FOR INPUT IMAGES

	CT	HE	CLAHE	BBHE	DSIHE	MMBEBHE	BPDHE
IMAGE 1	8.897	12.373	18.46	9.1	16.517	8.103	9.098
IMAGE 2	9.434	19.153	15.918	8.436	18.12	8.436	8.438
IMAGE 3	9.995	8.322	21.723	8.267	16.159	8.266	8.269
IMAGE 4	10.17	16.351	22.068	9.129	14.301	8.134	8.124
IMAGE 5	9.54	13.327	20.949	8.25	18.861	8.246	8.252
AVERAGE VALUE	8.8072	13.7052	19.8236	8.6364	16.7916	8.637	8.4362

For PSNR performance comparisons, Table 3.2 shows the comparative results of different methods for input images. A higher value of PSNR measures the better quality of the images. We can see from Table 3.2 that higher value of PSNR is observed in CLAHE, HE, DSIHE techniques. To get more insight, we calculate the averaged value of PSNR for all the input images. This is plotted in figure 3.3. It is observed from figure 3.3 that CLAHE shows the remarkably improved results.

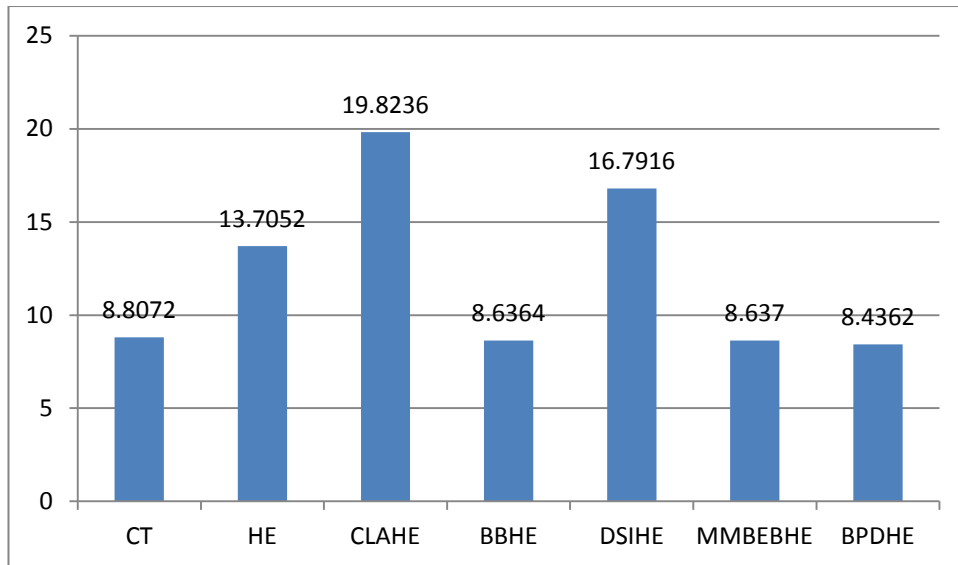


FIGURE 3.3: GRAPH FOR THE AVERAGED VALUE OF PSNR FOR DIFFERENT METHODS SHOWN IN TABLE 3.2

TABLE 3.3: SSIM PERFORMANCE COMPARISON OF METHODS FOR INPUT IMAGES

	CT	HE	CLAHE	BBHE	DSIHE	MMBEBHE	BPDHE
IMAGE 1	0.737	0.577	0.738	0.007	0.702	0.008	0.007
IMAGE 2	0.698	0.788	0.734	0.05	0.754	0.05	0.052
IMAGE 3	0.452	0.297	0.84	0.006	0.837	0.005	0.006
IMAGE 4	0.829	0.71	0.79	0.006	0.627	0.007	0.005
IMAGE 5	0.254	0.566	0.874	0.038	0.964	0.037	0.038
AVERAGE VALUE	0.594	0.5876	0.7952	0.0214	0.7768	0.0214	0.0216

For SSIM performance comparisons, Table 3.3 shows the results of different methods for input images. The higher value of SSIM measures the better quality of the images. It is observed from figure 3.4 based on average value calculations that CLAHE produces the much improved enhanced image.

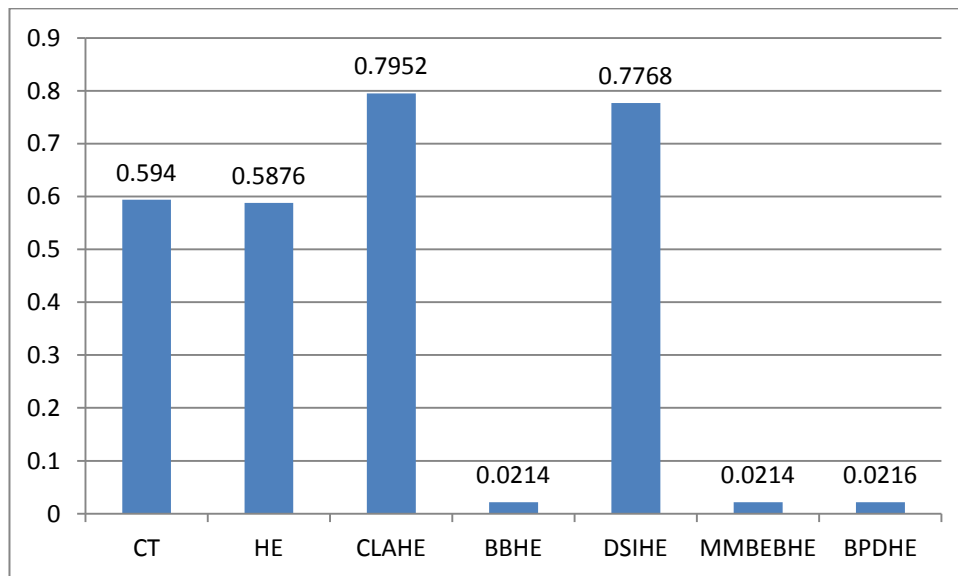


FIGURE 3.4: GRAPH FOR THE AVERAGED VALUE OF SSIM FOR DIFFERENT METHODS SHOWN IN TABLE 3.3

All the enhanced images for different enhancement techniques are shown in Figure 3.5 – Figure 3.9. We can observe the clarity in the visualization of the output image for all the five input images. Figure 3.5 includes the results of input image-1 for different enhancement techniques. The results of input image-2 are shown in Figure 3.6. For input image-3, enhanced output images are shown in Figure 3.7. For input image-4 and input image-5, output images using different enhancement techniques are shown in Figures 3.8 and 3.9 respectively.



FIGURE 3.5 : (a) ORIGINAL IMAGE-1, (b) CT, (c) HE, (d) CLAHE, (e) BBHE, (f) DSIHE, (g) MMBEBHE, (h) BPDHE



FIGURE 3.6 : (a) ORIGINAL IMAGE- 2, (b) CT, (c) HE, (d) CLAHE, (e) BBHE, (f) DSIHE, (g) MMBEBHE, (h) BPDHE

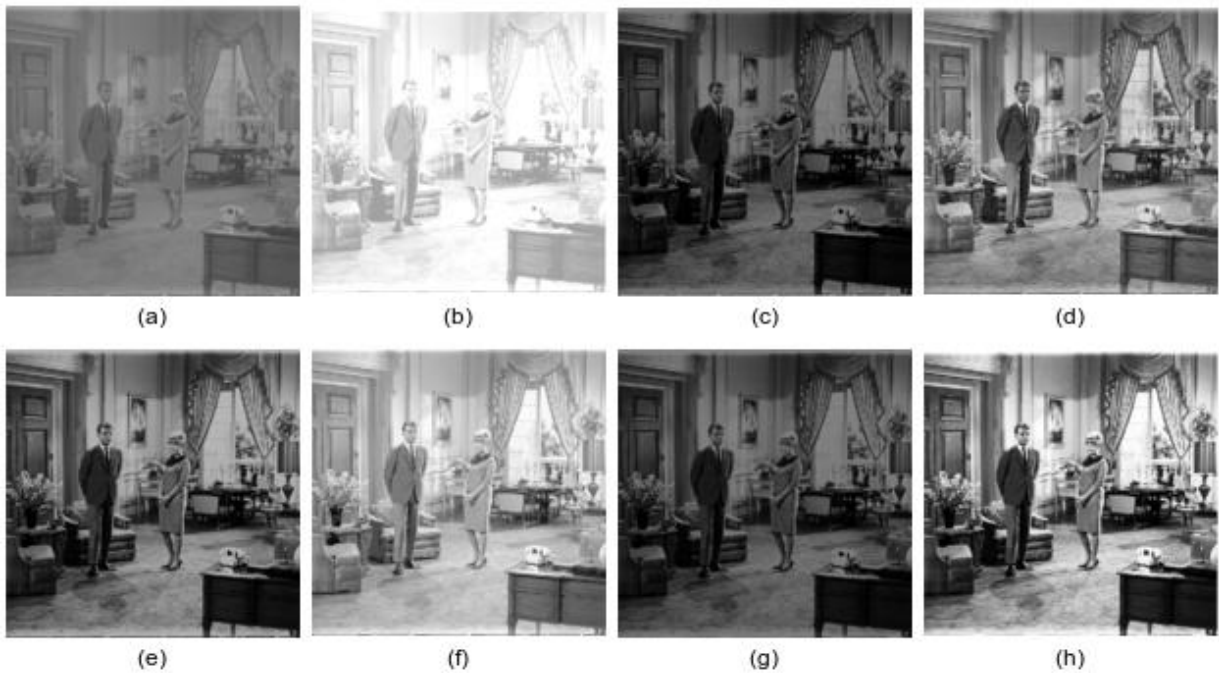


FIGURE 3.7 : (a) ORIGINAL IMAGE- 3, (b) CT, (c) HE, (d) CLAHE, (e) BBHE, (f) DSIHE, (g) MMBEBHE, (h) BPDHE

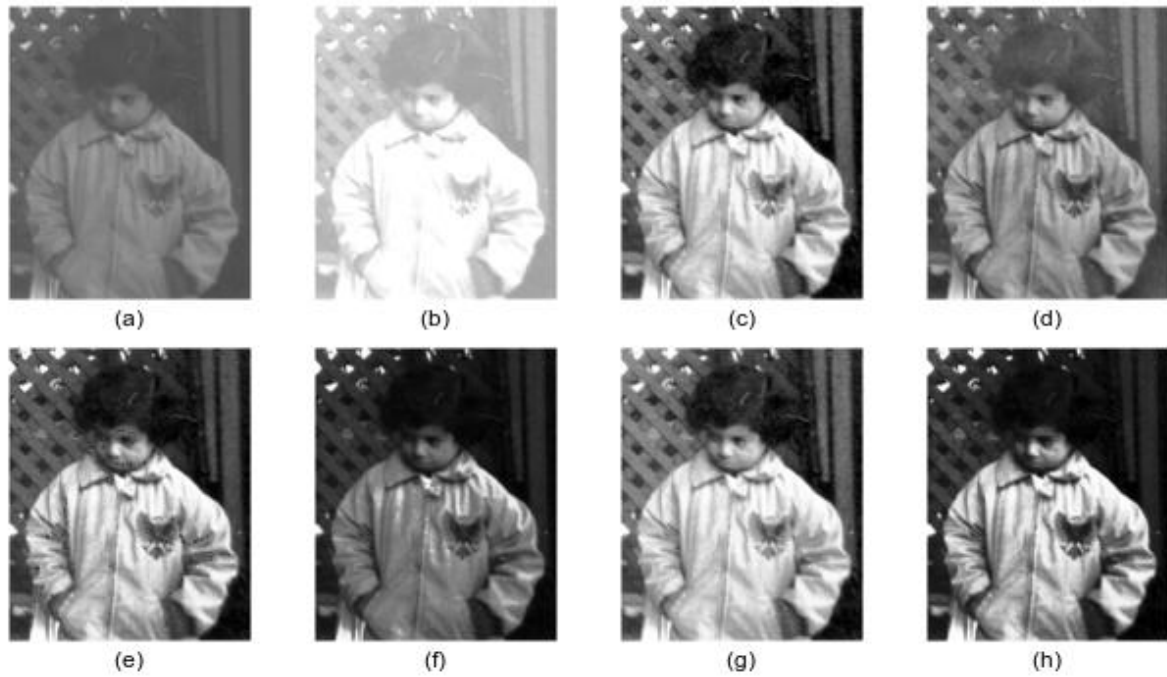


FIGURE 3.8 : (a) ORIGINAL IMAGE-4, (b) CT, (c) HE, (d) CLAHE, (e) BBHE, (f) DSIHE, (g) MMBEBHE, (h) BPDHE



FIGURE 3.9 : (a) ORIGINAL IMAGE-5, (b) CT, (c) HE, (d) CLAHE, (e) BBHE, (f) DSIHE, (g) MMBEBHE, (h) BPDHE

3.4 CONCLUSIONS

This chapter presents a comparative analysis of various contrast enhancement techniques such as Contrast Stretching (CT), HE, CLAHE, BBHE, DSIHE, MMBEBHE, BPDHE applied to different types of gray images. The experimental result shows that Contrast-limited adaptive histogram equalization gives a better result. Some degraded images that require the highest brightness, do not handle using HE, BBHE methods. These images can be enhanced well using CLAHE method. It can also be observed in our studies that all the enhancement methods work well for most of the images. The remarkable enhanced results are obtained using CLAHE, DSIHE methods. But, overall, it can be observed that some annoying side effects due to changes in gray level distribution are found using these methods.

CHAPTER IV

Fuzzy Contrast Enhancement Techniques

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CHAPTER IV

FUZZY CONTRAST ENHANCEMENT TECHNIQUES

In this chapter, contrast enhancement techniques using fuzzy theory are discussed and analyzed using performance parameters. As discussed in the previous chapter about image contrast enhancement using spatial domain processing where direct manipulation in image pixels is carried out. Using fuzzy theory, first image pixel values are converted into the fuzzy domain using some membership function and then the modifications are carried out in the fuzzy domain. After manipulation in the fuzzy domain, all the fuzzy values are reconverted back into spatial domain for getting output image. This applied step on image processing is known as fuzzy image processing. In literature, fuzzy contrast enhancement became attractive because of precise and human perception like enhancement using fuzzy logic approaches. Fuzzy logic approaches are able to handle vague and unclear difficulties by using expert knowledge based human perception. This knowledge acts as a powerful tool to mimic human reasoning.

4.1 BACKGROUND

In image processing, fuzzy techniques operate on fuzzy logic where the conversion from spatial domain method is required. In general, fuzzy enhancement technique considers the input image as metric of fuzzy values computed by some function or operation. The enhancement of the input image is then obtained using fuzzy operations based on fuzzy set theory. Fuzzy set theory is very popular due to its capability to deal with unclear and changeable information with uncertainty.

The enhancement of the input image is then obtained using fuzzy operations based on fuzzy set theory. The fuzzy set theory is very popular due to its capability to deal with unclear and changeable information with uncertainty [89, 90]. Fuzzy Techniques have mainly three rules to enhance images: (i) Fuzzification of the input image; (ii) modification of fuzzy value; (iii) Defuzzify. In these steps, the middle step is very powerful and effective step to enhance any fuzzy domain via modification of membership value. To get more insight into it, this chapter presents the detailed comparative analysis for both classical and fuzzy methods. Different types of images (normal and medical images) have been analyzed and the observations are made. In next section, fuzzy contrast enhancement techniques are discussed with their membership function modifications.

4.2 RELATED WORK

Fuzzy sets are effective to handle uncertain behavior in the images related with fuzziness. Fuzzy set logics are based on partial membership value, while classical sets are based on crisp value [90, 93]. It works efficiently to handle uncertainty for improvement of noisy images by using various fuzzy filters like a weighted fuzzy mean filter, FIRE-filter, iterative fuzzy control based filter [88, 55]. Fuzzy set values can be represented by linguistic variables, which imitate human perception. A system designed using fuzzy theory called the fuzzy system includes the fuzzy rules, inference mechanism and input-output variables. A complete system represents numerically an inferential mechanism of fuzzy sets [88]. It can be used in edge detection, smoothing, and noise reduction in images for enhancements [123, 119]. It presents the result of the individual filters for enhancement. The fuzzy rule-based system applied different filters as per satisfaction of a different condition. Fuzzy enhancement using an INT operator acts as a contrast intensifier for increasing or decreasing the degree of membership for image contrast improvement. Types and shapes of

membership functions play important role for conversion from spatial to fuzzy domain in fuzzy enhancement processing. Due to some limitation of INT operator, NINT operator was proposed as a new intensification operator which reduces computational time and utilized sigmoid function for enhancement [33, 44]. Fuzzy logic helps to implement human knowledge in terms of rules and different methods to give enhancement of images so analysis of images become easy and faster for any knowledge representation.

4.3 FUZZY IMAGE ENHANCEMENT

Enhancement of images by using fuzzy logic or using membership function and gray level mapping into the fuzzy plane is called fuzzy image enhancement. For image enhancement, the fuzzy system worked with the fuzzy set to get acceptable results. Fuzzy sets are the function which denotes an element of the problem domain in terms of number in the range of 0 to 1. These values are fuzzy not the crisp values. The membership functions are used for conversion from spatial domain. It is an ordered pair consisting of values of z and a corresponding membership function that assigns a grade of membership function to each z . That is [17]:

$$A = \{z, \mu_A(z) | z \in Z\} \quad (4.1)$$

Here A have an infinite number of elements when the variables are continuous. Thus ordinary sets are a special case of fuzzy sets. The structure of fuzzy image processing is given Figure 4.1. Fuzzification is the coding of the data while defuzzification is the decoding of data from normal plane to fuzzy plane and vice versa. Second step is to manipulate the features via modification of membership values. For modification of membership functions, appropriate fuzzy methods can be applied. For example, fuzzy rule-based approach, fuzzy integration approach and fuzzy segmentation. Membership values

modification in $\mu_A(z)$ has important role to know degree of darkness or lightness of the gray value in an image for contrast enhancement.

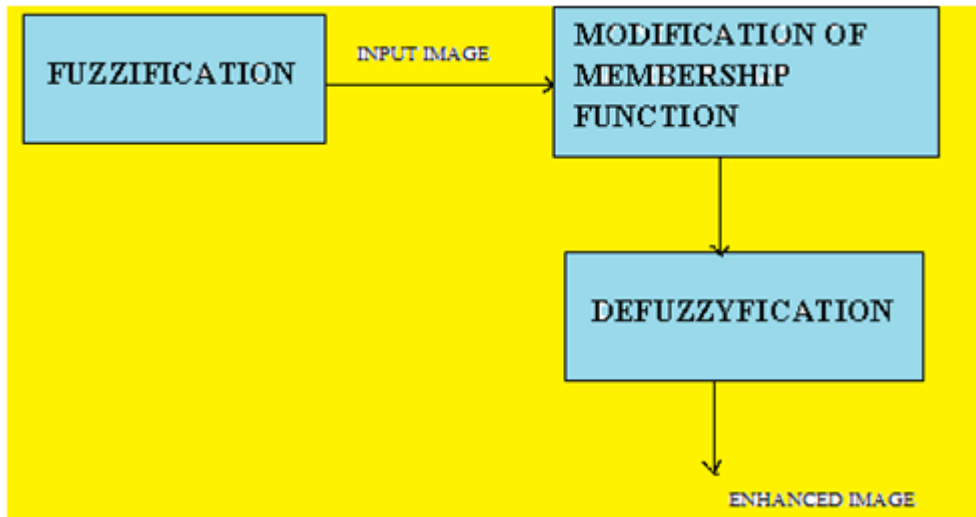


FIGURE 4.1: MODEL OF FUZZY IMAGE PROCESSING

4.3.1 MEMBERSHIP FUNCTIONS

The types of Membership functions are given below.

1. Piecewise linear functions:

- a) Triangular function.
- b) Trapezoidal function.
- c) Sigma function.

2. Smooth functions:

- a) S-shape function.
- b) Bell-shape function.

3. Gaussian function:

- a) Truncated Gaussian functions.

In the fuzzy set, the S-shaped function is used frequently in contrast enhancement method based on fuzzy image processing. Above membership functions can also be used for edge detection, smoothing, and contrast stretching for enhancement of images.

4.4 FUZZY CONTRAST ENHANCEMENT METHODS

There are four fuzzy contrast enhancement methods described for the contrast enhancement.

4.4.1 CONTRAST ENHANCEMENT BASED ON FUZZY RULE-BASED METHOD

Fuzzy IF-THEN rules are based on fuzzy set theory. It is a formulated form of human knowledge to represent a natural language expression [23, 122]. The formalized form of the rule is as follows:

IF A is B THEN C is D.

Here B is antecedent and D is consequent. That means conclusion can be derived easily if facts are known. In the application of the rule-based fuzzy system, the main steps are:

1. Fuzzify the input: By using membership functions, the fuzzy values are computed that should be between the interval [0, 1].
2. Perform the required fuzzy logical operations such as union, intersection, compliment etc.
3. Apply an implication method: we used AND for implication, which shows min operation.
4. Apply an aggregation method to the fuzzy sets from step 3: for aggregation OR is used, which shows max operation.
5. Defuzzify the final output fuzzy set: after this step, we find crisp scalar values as the output. Defuzzification achieved by computing the center of gravity of the aggregated fuzzy set.

The use of OR and AND is dependent on the problem in which rules are stated. The fuzzy rule-based approach is nonlinear in nature that incorporates human intuitions. Image quality evaluation is highly subjective. It can be enhanced by using human knowledge. Contrast enhancement of an image is based on a very simple membership function modification mechanism. An example is given below [119].

IF a pixel is dark, THEN make it darker.

IF a pixel is gray, THEN make it gray.

IF a pixel is bright, THEN make it brighter.

After it, defuzzification is done by using the inverse of the fuzzification to get resultant output images.

4.4.2 CONTRAST ENHANCEMENT BASED ON FUZZY INTENSIFICATION OPERATOR

Fuzzy Intensification operator is used to increasing the contrast of images and decreases the fuzziness [119]. A similar approach of fuzzy image enhancement, steps are conversion using membership function, the modification of membership values, and then reconversion back using inverse membership function. Step-1 is as follow. For an image I, the membership function is defined as:

$$\mu_{mn} = \left[1 + \frac{g_{\max} - g_{mn}}{F_d} \right]^{-F_e} \quad (4.2)$$

Here F_d is denominational fuzzifiers, F_e is exponential fuzzifiers. $\mu_{mn=1}$ represents maximum brightness and $\mu_{mn=0}$ represents complete darkness. Second step is as the intensity operation (INT) given below.

$$\mu'_{mn} = \begin{cases} 2 [\mu_{mn}]^2 & 0 \leq \mu_{mn} \leq 0.5 \\ 1 - 2[1 - \mu_{mn}]^2 & 0.5 \leq \mu_{mn} \leq 1 \end{cases} \quad (4.3)$$

Finally, the third step is the inverse of the modified membership function for getting resultant output in the spatial domain.

It is given as:

$$g'_{mn} = \begin{cases} G^{-1}(\mu'_{mn}) \\ g_{max} - F_d \left[(\mu'_{mn})^{\frac{1}{f_e}} - 1 \right] \end{cases} \quad (4.4)$$

The resultant output image produces the enhanced version of a given input image. It works on global intensity improvement principle. The overall contrast of the degraded image is shown with improved in contrast using this method.

4.4.3 CONTRAST ENHANCEMENT USING FUZZY HISTOGRAM

HYPERBOLIZATION

In this method, following steps are used to enhance the contrast of input images [120]:

- Selection of shape of membership function based on the user's demand.
- Setting the value of fuzzifier beta as the linguistic variable or linguistic hedges:
- Calculation and modification of the membership values and the generation of new gray level using linguistic hedges.

$$g'_{mn} = \left(\frac{L-1}{e^{-1}-1} \right) \cdot \left[e^{-\mu(g_{mn})^\beta} - 1 \right] \quad (4.6)$$

Here L is the maximum gray level.

4.4.4 CONTRAST ENHANCEMENT USING A FUZZY EXPECTED VALUE

In this method, following steps are used to enhance the contrast of input images [27, 28, 29]. Assume a fuzzy set A in a finite set $X = \{x_1, x_2, x_3, \dots, x_n\}$ which has μ_A . A subset value whose element above or equal to threshold value T is denoted by ξ_T , where fuzzy measure $M(\xi_T) = 1/N[\text{number of element } x: \mu_A(x) \geq T]$ for N number of elements.

- Determine fuzzy expected value (FEV) and compute the image histogram.

$$FEV = \sup_{0 \leq T \leq 1} \{ \min [T, M(\xi_T)] \} \quad (4.7a)$$

- Compute the distance of gray levels from FEV.

$$D_{mn} = \sqrt{|(FEV)^2 - (g_{mn})^2|} \quad (4.7b)$$

- Compute new gray levels:

$$g'_{mn} = \begin{cases} \max(0, FEV - D_{mn}) & \text{if } g_{mn} < FEV, \\ \min(L - 1, FEV + D_{mn}) & \text{if } g_{mn} > FEV, \\ FEV & \text{otherwise.} \end{cases} \quad (4.8)$$

4.5 EXPERIMENTAL RESULT

In this section, two studies are performed. One is based on a comparative analysis using normal images for different classical and fuzzy contrast enhancement method. Second study is on analysis of medical images using different classical and fuzzy contrast enhancement methods.

As discussed classical methods based on histograms in chapter 3, we present here a comparison between HE based and Fuzzy based contrast enhancement for more insight. The input images used for simulation results are shown in Figure below.



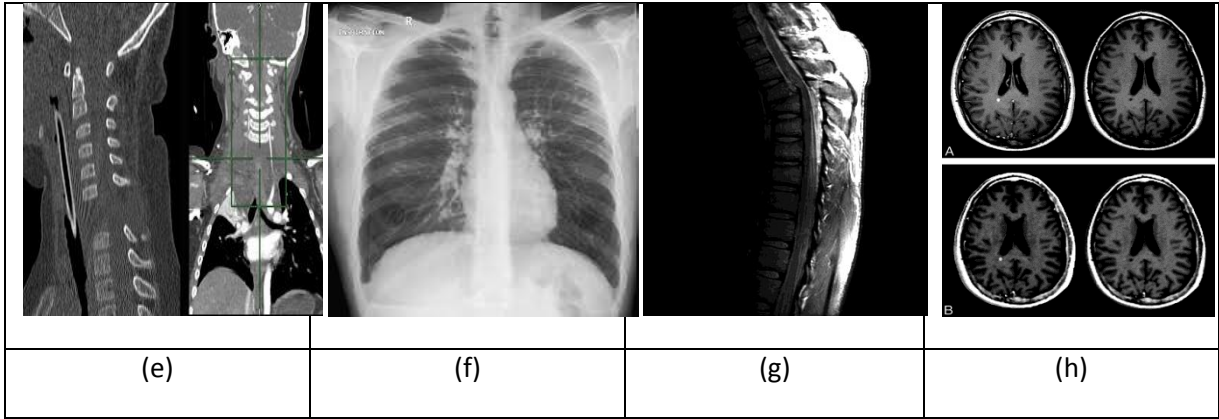


FIGURE 4.2 :INPUT IMAGES - (a) IMAGE – 1, (b) IMAGE – 2, (c) IMAGE – 3, (d) IMAGE – 4, (e) IMAGE – 5, (f) IMAGE – 6, (g) IMAGE – 7, (h) IMAGE – 8

4.5.1 ANALYSIS OF DIFFERENT NORMAL IMAGES USING CLASSICAL AND FUZZY TECHNIQUES

In the experiment, the different contrast enhancement techniques used to test on Matlab images. We have compared results of contrast stretching, histogram equalization and fuzzy logic [6] with the help of PSNR and MSE values and their graphical representation in Table 4.1. The results shown are satisfactory when the value of PSNR is higher and the value of MSE is found the minimum. The graph representation is shown in figure 4.3 for average values over all the images.

In Table 4.2, entropy performance parameter is measured for different methods using five input images. Over the all five images, average value is calculated for different methods to get more insight. It is plotted in bar graph as shown in figure 4.4.

TABLE 4.1: COMPARISON OF CLASSICAL AND FUZZY METHODS FOR NORMAL IMAGES BASED ON PSNR

	IMAGE 1	IMAGE 2	IMAGE 3	IMAGE 4	AVG
Fuzzy IF-THEN	30.7838	29.489	26.0458	25.7838	28.0256
FIO	33.3822	30.57	21.856	24.849	27.6643
FHH	27.7834	29.3059	26.917	23.264	26.81758
FEV	17.151	14.847	15.905	11.165	14.767
CT	8.897	9.434	9.995	10.17	9.624
HE	12.373	19.153	8.322	16.351	14.04975
CLAHE	18.46	15.918	21.723	22.068	19.54225

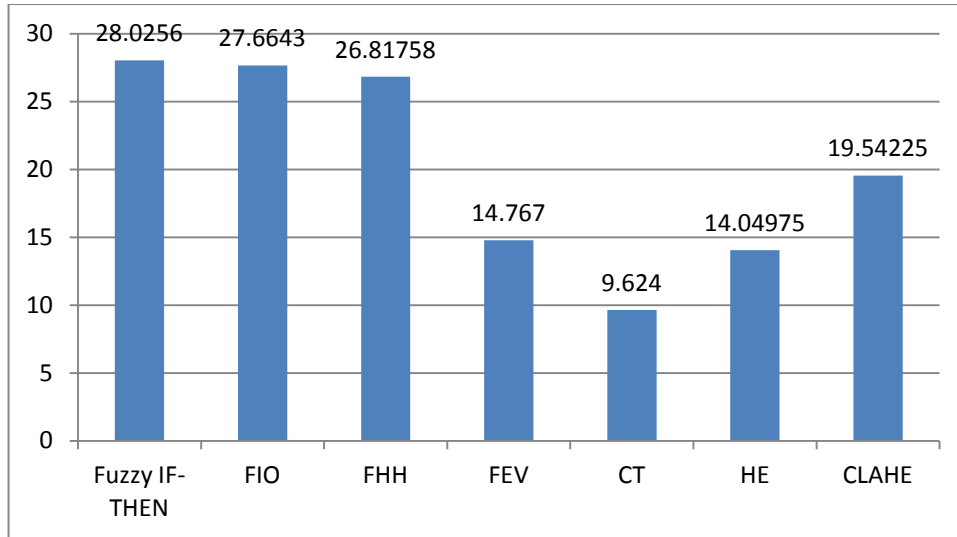


FIGURE 4.3: PSNR CHART FOR CLASSICAL AND FUZZY METHODS FOR NORMAL IMAGES

For higher value of entropy, the enhanced image contains more detailed information as compared to input image. It is shown that the fuzzy based methods such as FEV, FHM, FIO and fuzzy IF-THEN are found good than histogram based method for entropy.

Furthermore, structural similarity index (SSIM) is measured on enhanced images of different methods. It is shown in Table 4.3. This performance parameter reflects the qualitative visual appearance. Over the all five images, an average value is plotted in figure 4.5.

TABLE 4.2: COMPARISON OF CLASSICAL AND FUZZY METHODS FOR NORMAL IMAGES BASED ON ENTROPY

ENTROPY	IMAGE 1	IMAGE 2	IMAGE 3	IMAGE 4	AVG
Fuzzy IF-THEN	7.29	6.966	7.55	6.065	6.96775
FIO	6.091	7.34	6.069	7.113	6.65325
FHH	7.231	4.96	7.29	6.89	6.59275
FEV	7.97	4.88	4.17	6.87	5.9725
CT	5.15	4.81	4.24	3.05	4.3125
HE	5.71	6.97	4.32	5.79	5.6975
CLAHE	7.43	5.49	4.85	7.18	6.2375

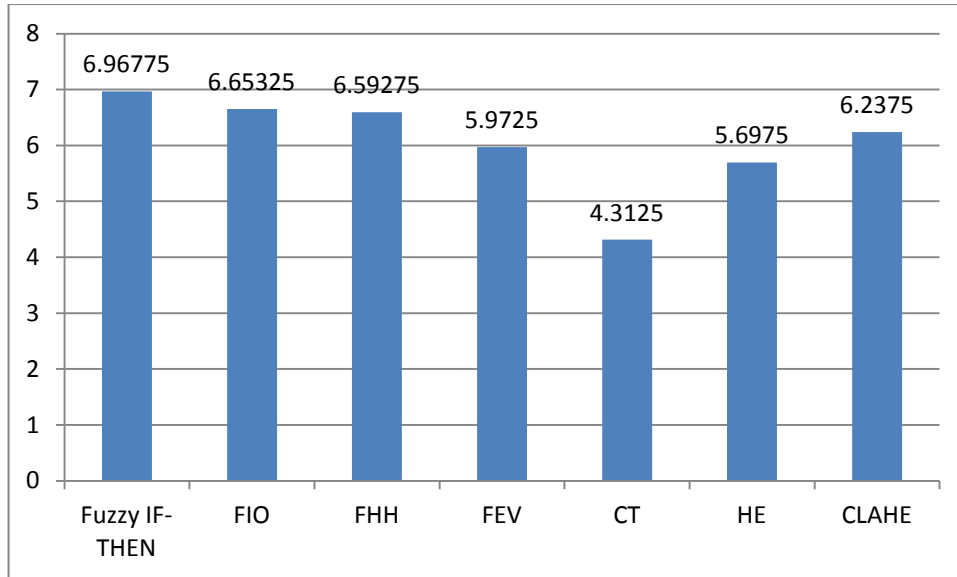


FIGURE 4.4: ENTROPY CHART FOR CLASSICAL AND FUZZY METHODS FOR NORMAL IMAGES

TABLE 4.3: COMPARISON OF CLASSICAL AND FUZZY METHODS FOR NORMAL IMAGES BASED ON SSIM

	IMAGE 1	IMAGE 2	IMAGE 3	IMAGE 4	AVG
Fuzzy IF-THEN	0.722	0.782	0.886	0.832	0.8055
FIO	0.946	0.117	0.851	0.636	0.6375
FHH	0.621	0.743	0.71	0.65	0.681
FEV	0.659	0.16	0.558	0.377	0.4385
CT	0.737	0.698	0.452	0.829	0.679
HE	0.577	0.788	0.297	0.71	0.593
CLAHE	0.738	0.734	0.84	0.79	0.7755

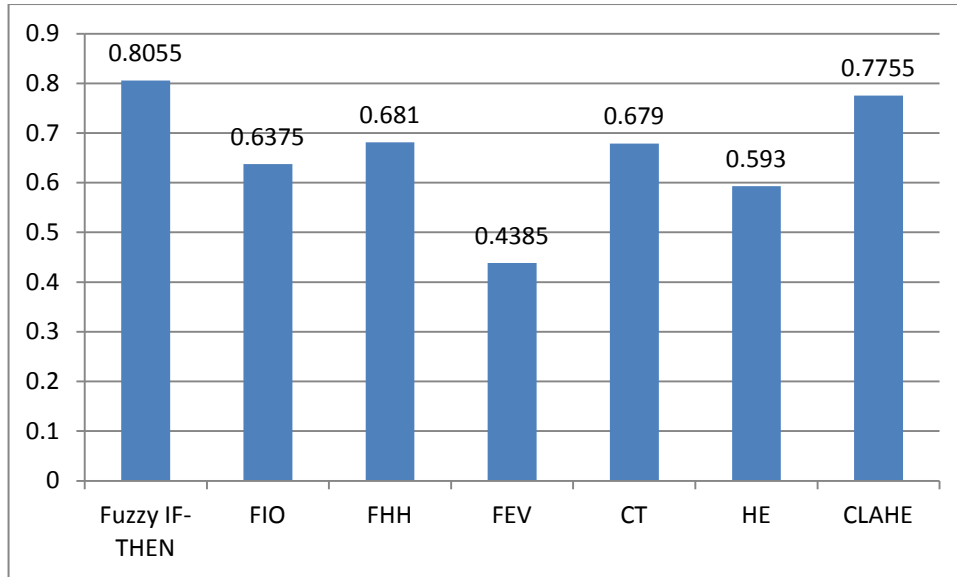


FIGURE 4.5: SSIM CHART FOR CLASSICAL AND FUZZY METHODS FOR NORMAL IMAGES

It can be seen from figure 4.5 and Table 4.3 that most of the methods have shown the good visual quality using SSIM values. It is also shown in figure 4.6, figure 4.7, figure 4.8 and figure 4.9.



FIGURE 4.6 : (a) ORIGINAL IMAGE - 1, (b) Fuzzy IF-THEN, (c) Fuzzy Intensify Operator (FIO), (d) Fuzzy Histogram Hyperbolization (FHH), (e) FEV, (f) Contrast stretching (CT), (g) HE, (h) CLAHE



FIGURE 4.7 : (a) ORIGINAL IMAGE - 2, (b) Fuzzy IF-THEN, (c) Fuzzy Intensify Operator, (d) Fuzzy Histogram Hyperbolization (FHH), (e) FEV, (f) Contrast stretching (CT), (g) HE, (h) CLAHE

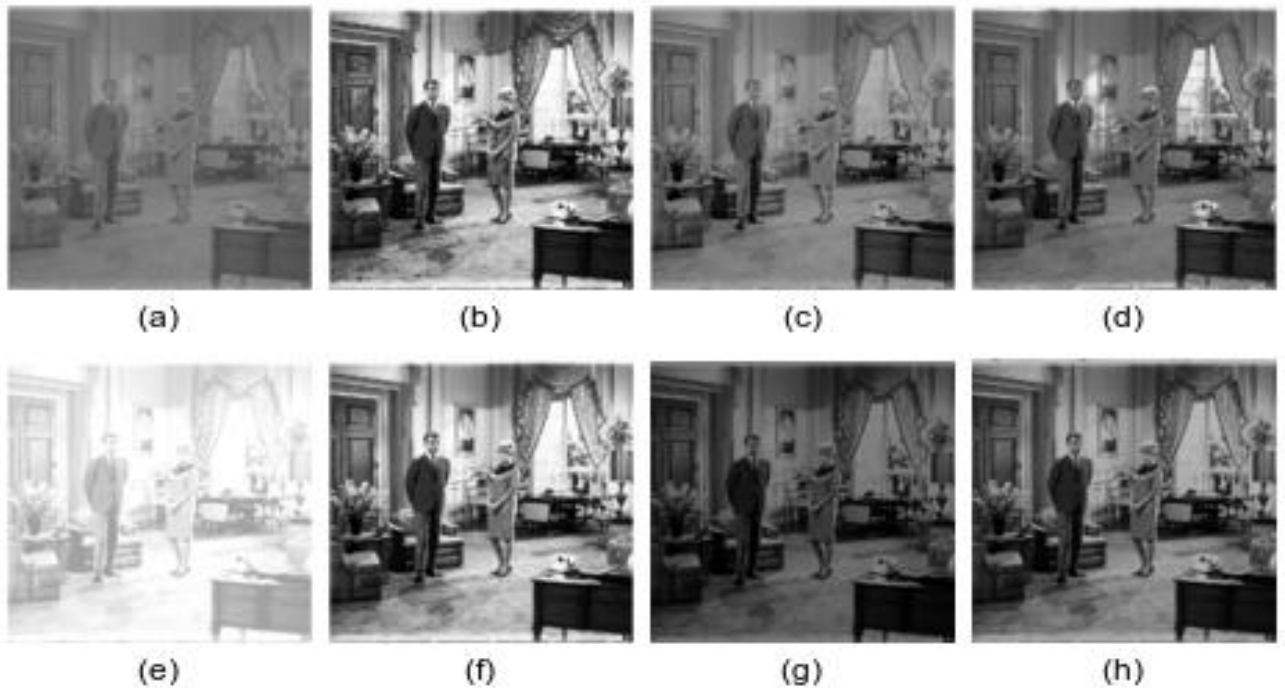


FIGURE 4.8 : (a) ORIGINAL IMAGE - 3, (b) Fuzzy IF-THEN, (c) Fuzzy Intensify Operator (FIO), (d) Fuzzy Histogram Hyperbolization (FHH), (e) FEV, (f) Contrast stretching (CT), (g) HE, (h) CLAHE

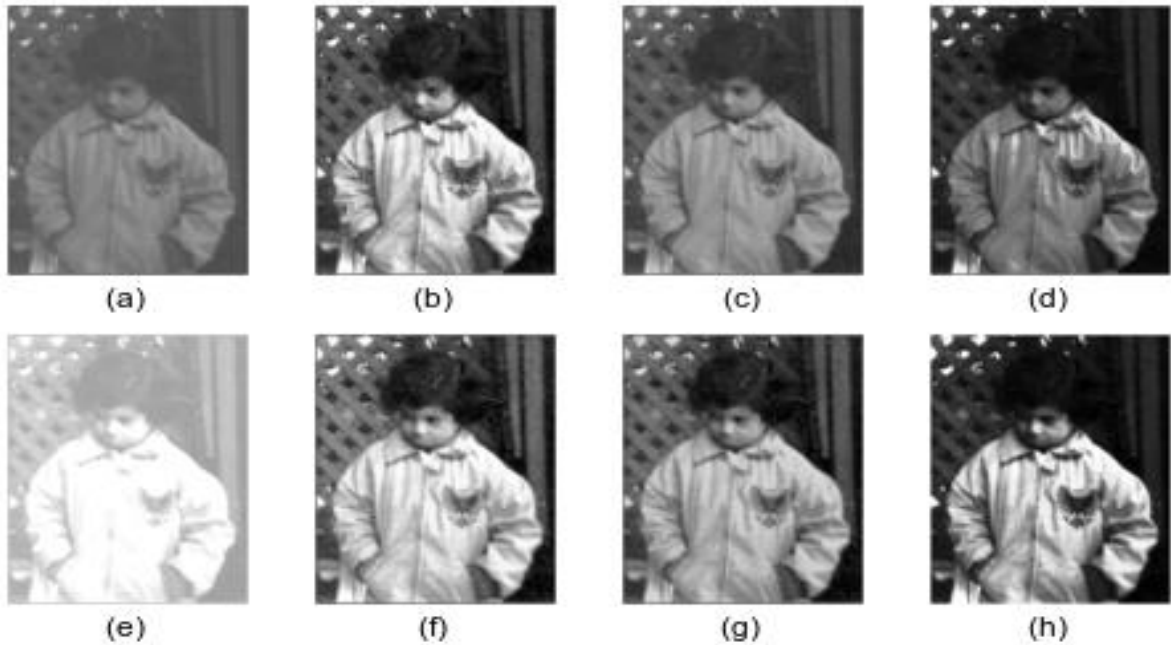


FIGURE 4.9 : (a) ORIGINAL IMAGE - 4, (b) Fuzzy IF-THEN, (c) Fuzzy Intensify Operator (FIO), (d) Fuzzy Histogram Hyperbolization (FHH), (e) FEV, (f) Contrast stretching (CT), (g) HE, (h) CLAHE

4.5.2 ANALYSIS OF DIFFERENT MEDICAL IMAGES USING CLASSICAL AND FUZZY TECHNIQUES

In the experiment, the result of different medical images is considered using classical HE based and Fuzzy based image contrast enhancement techniques. For medical images, PSNR measurements are shown in Table 4.4 for different enhancement techniques. An average value is calculated over the all five images is also shown in the table. Its graph is given in figure 4.10. Since medical images are utilized for diseases diagnosis, more contrast is enhanced using fuzzy techniques.

TABLE 4.4: PERFORMANCE PARAMETERS COMPARISON FOR MEDICAL IMAGES BASED ON PSNR

	IMAGE 1	IMAGE 2	IMAGE 3	IMAGE 4	AVG
Fuzzy IF-THEN	29.1393	25.21	25.02	28.6	26.99233
FIO	30.0727	24.5671	22.94	28.86	26.60995
FHH	25.5671	15.76	14.92	17.969	18.55403
FEV	11.296	14.148	12.545	12.324	12.57825
CT	17.897	22.301	24.039	23.182	21.85475
BPDHE	12.373	24.61	26.271	24.032	21.8215
CLAHE	18.34	15.67	20.33	31.08	22.36

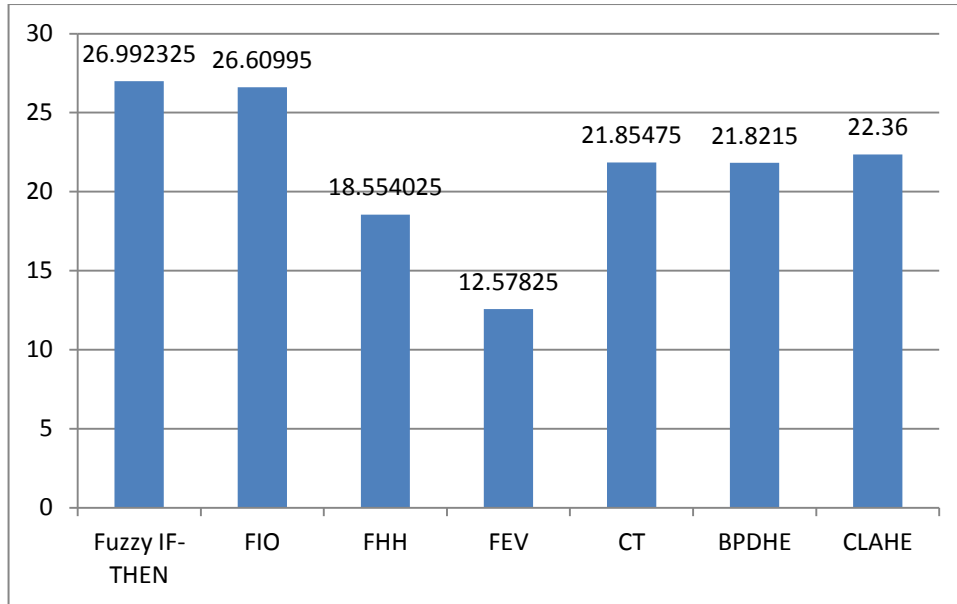


FIGURE 4.10: PSNR CHART FOR CLASSICAL AND FUZZY METHODS FOR MEDICAL IMAGES

TABLE 4.5: PERFORMANCE PARAMETERS COMPARISON FOR MEDICAL IMAGES BASED ON SSIM

	IMAGE 1	IMAGE 2	IMAGE 3	IMAGE 4	AVG
Fuzzy IF-THEN	0.412	0.775	0.739	0.495	0.60525
FIO	0.426	0.856	0.906	0.631	0.426
FHH	0.239	0.342	0.566	0.503	0.4125
FEV	0.263	0.62	0.541	0.438	0.4655
CT	0.213	0.536	0.506	0.404	0.41475
BPDHE	0.241	0.796	0.04	0.127	0.301
CLAHE	0.538	0.614	0.7	0.512	0.591

In Table 4.5, SSIM values are given for medical images. Average value is also calculated when all four images are taken for a particular method. It is plotted as the bar graph shown in figure 4.11. It can be seen that brightness is preserved using fuzzy techniques. It is also shown in enhanced images from different methods as given figure 4.12, figure 4.13, figure 4.14, figure 4.15.

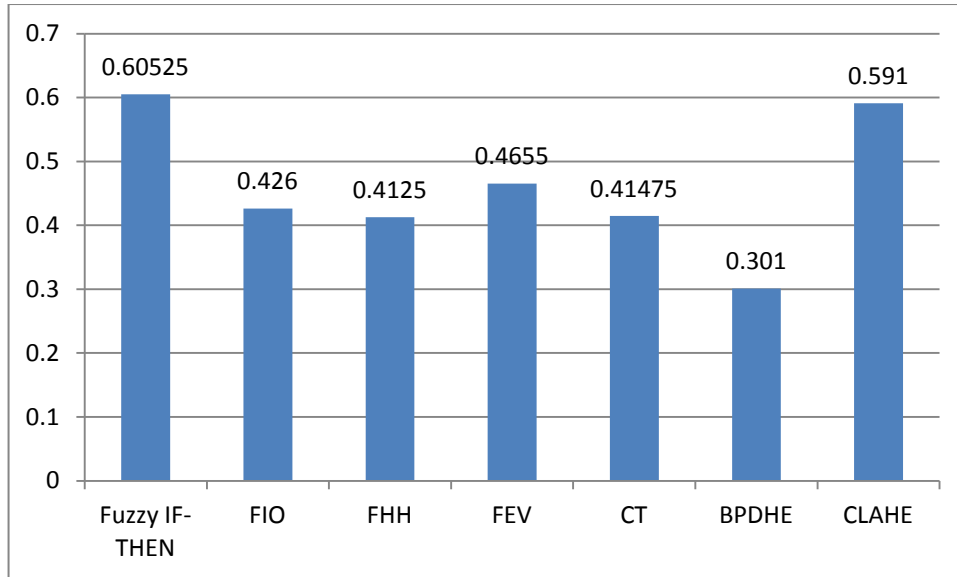


FIGURE 4.11: SSIM CHART FOR CLASSICAL AND FUZZY METHODS FOR MEDICAL IMAGES

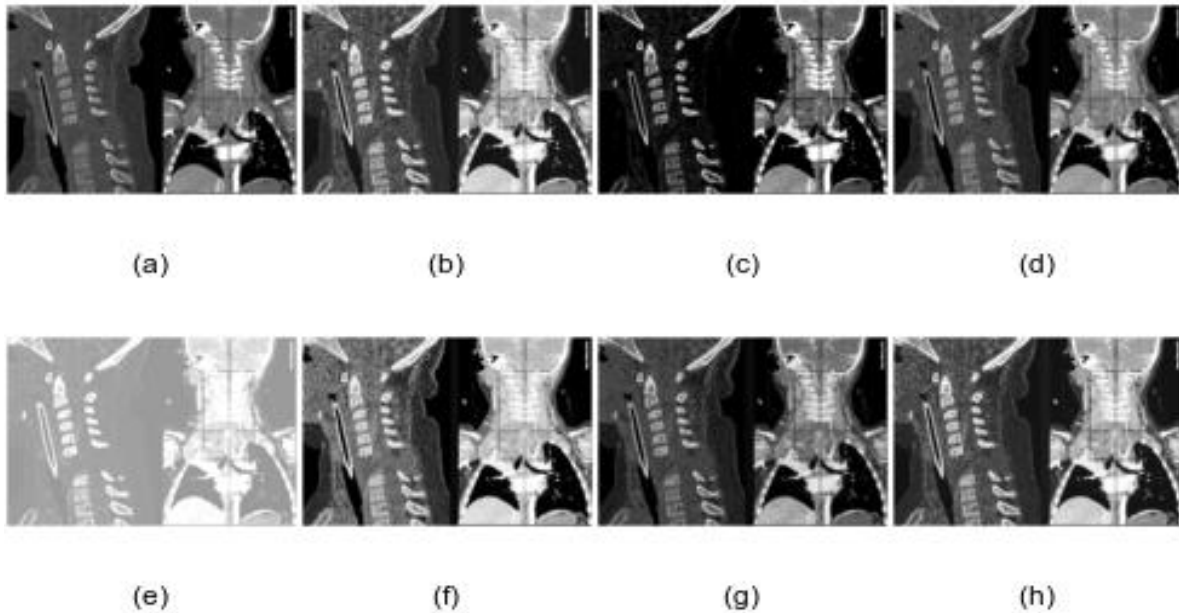


FIGURE 4.12 : (a) ORIGINAL IMAGE-5, (b) Fuzzy IF-THEN, (c) Fuzzy Intensify Operator Based, (d) Fuzzy Histogram Hyperbolization, (e) FEV based, (f) Contrast stretching (CT), (g) HE (h) CLAHE

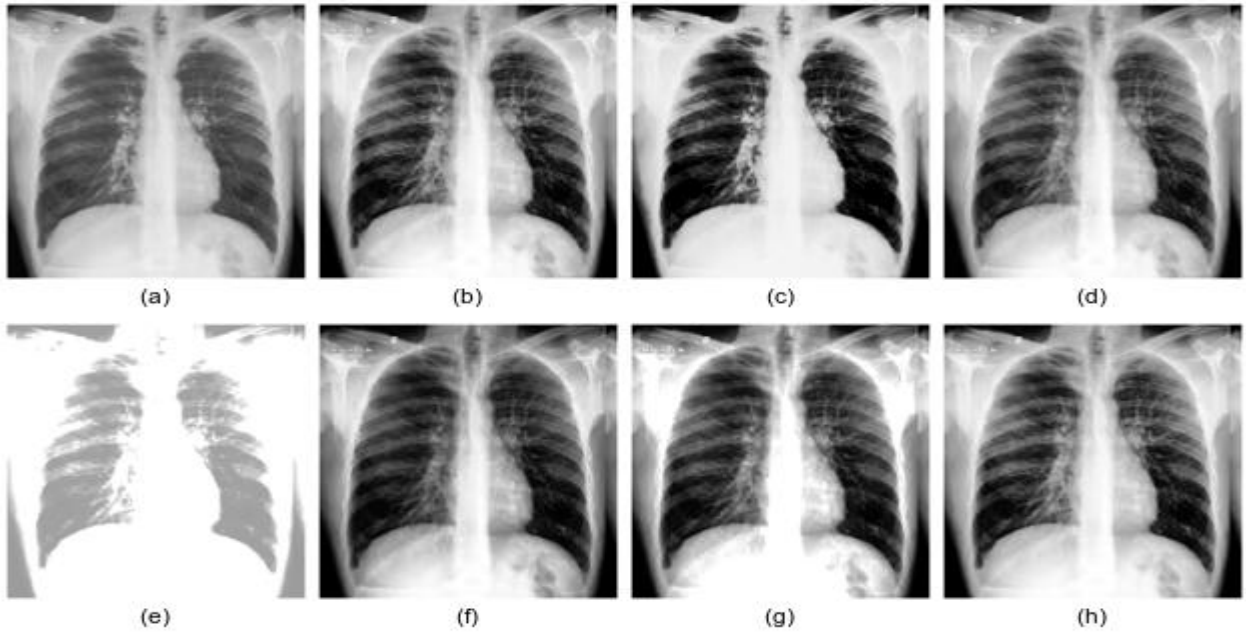


FIGURE 4.13 : (a) ORIGINAL IMAGE-6, (b) Fuzzy IF-THEN, (c) Fuzzy Intensify Operator Based, (d) Fuzzy Histogram Hyperbolization, (e) FEV based, (f) Contrast stretching (CT), (g) HE (h) CLAHE

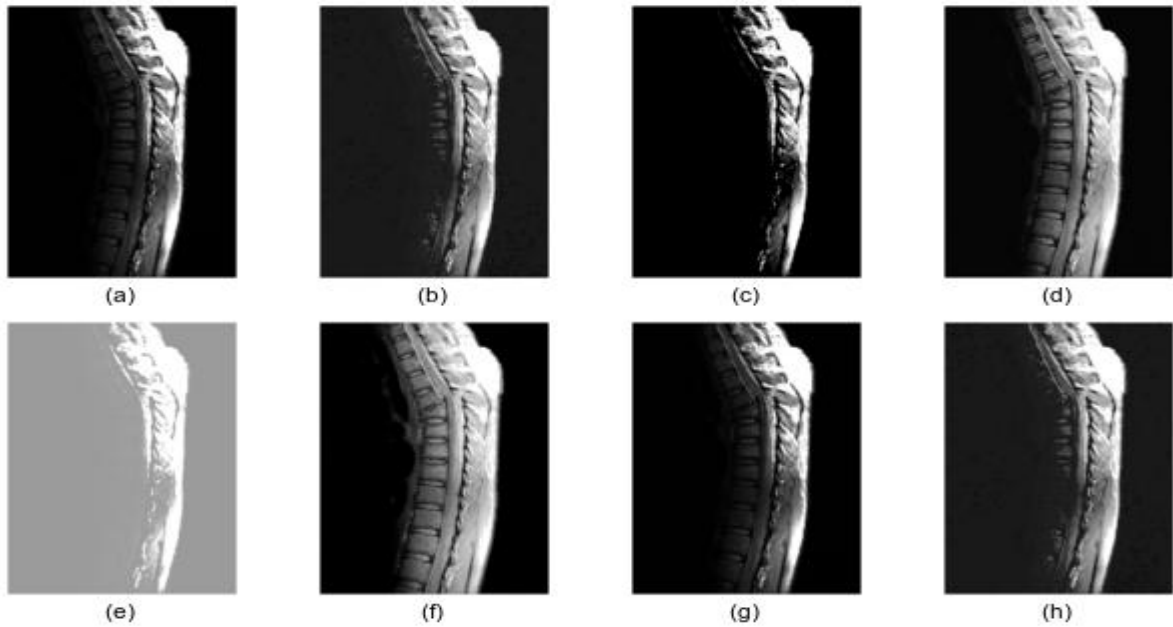


FIGURE 4.14 : (a) ORIGINAL IMAGE-7, (b) Fuzzy IF-THEN, (c) Fuzzy Intensify Operator Based, (d) Fuzzy Histogram Hyperbolization, (e) FEV based, (f) Contrast stretching (CT), (g) HE (h) CLAHE

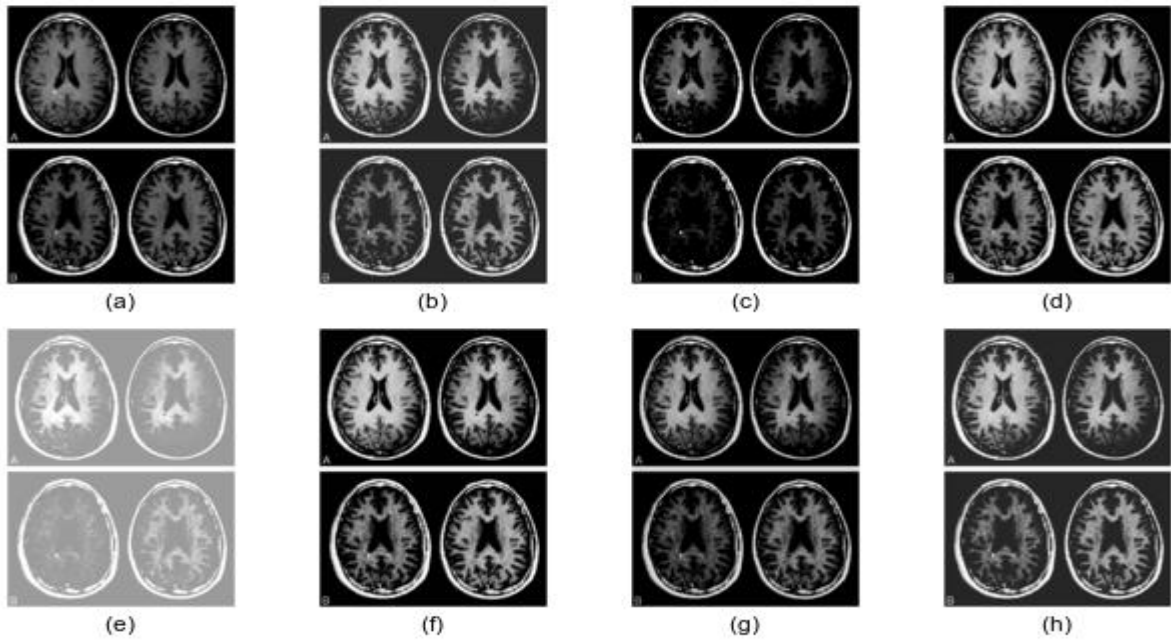


FIGURE 4.15 : (a) ORIGINAL IMAGE-8, (b) Fuzzy IF-THEN, (c) Fuzzy Intensify Operator Based, (d) Fuzzy Histogram Hyperbolization, (e) FEV based (f) Contrast stretching (CT), (g) HE (h) CLAHE

4.6 CONCLUSIONS

Fuzzy image enhancement techniques offer the proper way of producing the manipulations (based on fuzzy operations) due to its non-linear behaviors. These methods are knowledge-based based human perception and reasoning. There are several diversities of fuzzy logic, fuzzy set theory, and measure properties for modification of mapped pixel in the fuzzy plane. Resultant modified pixels are then obtained that are retransformed into the gray values for getting the enhanced image. It is main difference with other methodologies such as Histogram based or other methods in image processing. Our results and discussions show that fuzzy based image enhancement have higher PSNR and SSIM as compared to classical methods. It is due to effective use of membership function quality. To get reasonable enhancement, membership modification with respect to image quality should be taken into consideration. These observations are utilized in next chapters for gray-scale image enhancement.

CHAPTER V

Mamdani Fuzzy Inference System for Multiple Membership Functions

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CHAPTER V

MAMDANI FUZZY INFERENCE SYSTEM FOR MULTIPLE MEMBERSHIP FUNCTIONS

A concept is based on fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning known as fuzzy inference system (FIS). In Fuzzy Theory, there are three types of available fuzzy Rule-based models namely Mamdani fuzzy models, Sugeno fuzzy models, and Tsukamoto fuzzy models [46, 68, 116]. These fuzzy inference systems are different on the basis of their fuzzy rules, their aggregation, and defuzzification procedures. In this thesis, only Mamdani Fuzzy Inference System has been used for the imaging analysis.

5.1 BACKGROUND

Fuzzy Inference System is a popular and successful application found in various fields like the Expert system, decision analysis, automatic control, robotics, data classification and pattern recognition. Due to its multidisciplinary quality, It is also known as a fuzzy expert system, fuzzy-rule-based system, a fuzzy logic controller, and a fuzzy system. A fuzzy inference system takes input as crisp input or fuzzy inputs then it performs reasoning mechanism to derive a fair output to represents a fuzzy set with the help of the defuzzification method. Basically conventional fuzzy inference systems are based on knowledge domain which is used in automatic control, decision analysis, and expert system. After it, an expansion of the application of fuzzy inference system on the basis of optimization and adaptive techniques comes under the fields of adaptive control, nonlinear regression, and pattern recognition.

5.2 RELATED WORK

In spite of the spatial and frequency domain, fuzzy domain is known to be popular these days in various enhancement applications. In image enhancement methods, fuzzy domain is extracted from the spatial domain using some membership function. A fuzzy domain is based on fuzzy sets of fuzzy logic methods. Fuzzy sets are used to make rules to make machine just like as human perception [79, 71]. Fuzzy contrast technique is used for better enhancement of images without increasing the noise which is present in input image [40]. This method is also applicable to low contrast images [42]. This kind of fuzzy techniques based on fuzzy rule-based model also known as IF-THEN rules based fuzzy system. Using different membership functions, there are many techniques of conversion of image pixels into fuzzy pixels (i.e., fuzzy logic values) [121]. Enhancements of images are also effective and flexible by using fuzzy sets in fuzzy rule-based techniques [41].

5.3 FUZZY INFERENCE SYSTEM (FIS)

A general Fuzzy inference system (FIS) model is given below that can be presented to better determine the image contrast enhancement of gray-scale image based on feature schemes such as the number of IF-THEN rules, different membership functions (MFs), fuzzy contrast factor [116, 88, 138].

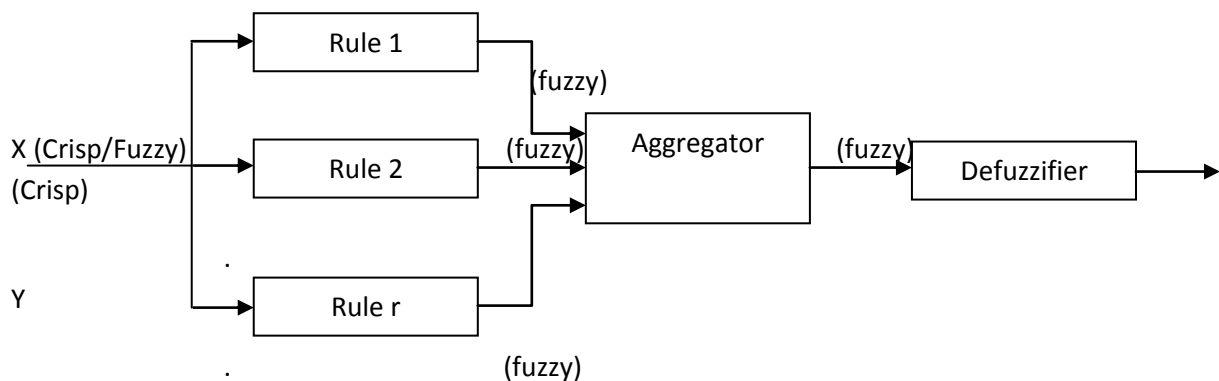


FIGURE 5.1: BLOCK DIAGRAM OF FUZZY INFERENCE SYSTEM

The block diagram of FIS is based on the crisp input, crisp output with fuzzification, decision-making unit, and defuzzification. Here fuzzification converts the crisp input into fuzzy input and then a collection of rules formed to map the fuzzy input to fuzzy output and then finally, defuzzification convert the fuzzy output into the crisp output. FIS are three types of available fuzzy Rule-based models namely Mamdani fuzzy models, Sugeno fuzzy models, and Tsukamoto fuzzy models [46, 68, 116]. These three models are different on the basis of different fuzzy rules and inference computations for a given input-output data set.

5.4 MAMDANI FUZZY INFERENCE SYSTEM

The first inference method, which is most common in literature and practice, is known as Mamdani inference system of fuzzy [68]. This method illustrates the fuzzy rule base with any number of inputs and outputs in the form of different cases. A fuzzy system with two crisp inputs x_1 and x_2 and single output y will describe rule based system in the Mamdani methods.

$$\text{IF } x_1 \text{ is } A_1^k \text{ and } x_2 \text{ is } A_2^k \text{ THEN } y^k \text{ is } B^k, \quad \text{for } k = 1, 2, \dots, r, \quad (5.1)$$

Here A_1^k and A_2^k are representing k^{th} input pairs and B^k representing output for the fuzzy set. In this representation two different case of Mamdani system are, case one based on max-min inference method and case two is based on max-product inference method.

5.4.1 CASE 1: GRAPHICAL MAMDANI (MAX-MIN) METHOD

The rule based system in equation 5.1, described membership for the input x_1 and x_2 are as

$$\mu(x_1) = \delta(x_1 - \text{input}(i)) = \begin{cases} 1, & x_1 = \text{input}(i); \\ 0, & \text{otherwise} \end{cases} \quad (5.2)$$

$$\mu(x_2) = \delta(x_2 - \text{input}(j)) = \begin{cases} 1, & x_2 = \text{input}(i); \\ 0, & \text{otherwise} \end{cases} \quad (5.3)$$

The aggregated output for the r rules will be given as

$$\mu_{B^k}(y) = \max_k [\min [\mu_{A_1^k}(\text{input (i)}), \mu_{A_2^k}(\text{input (j)})]], \quad k = 1, 2, \dots, r. \quad (5.4)$$

5.4.2 CASE 2: GRAPHICAL MAMDANI (MAX PRODUCT) METHOD

The phenomenon of the max-product implication is:

$$\mu_{B^k}(y) = \max_k [\mu_{A_1^k}(\text{input (i)}) \cdot \mu_{A_2^k}(\text{input (j)})], \quad k = 1, 2, \dots, r. \quad (5.5)$$

Mamdani fuzzy inference system also is known as a non-additive rule-based model.

5.5 MAMDANI FIS EVALUATION CRITERIA

Comparison of Mamdani methods has been given on the basis of image qualitative attributes of contrast enhancement of images and resultant images. Following contributions of this FIS are:

- (a) We propose FIS using different types of MFs for contrast enhancement and detailed analysis of Rule-base system is presented.
- (b) We perform an evaluation of different MFs based FIS against the state-of-the-art fuzzy enhancement techniques, based on different types of Rule-base design.
- (c) We describe the study of the interaction of input MFs and output MFs in the design of Rule-base for FIS.
- (d) We explore the potential of Rule-base design according to human perception in fuzzy based image enhancement algorithms.

5.6 PROPOSED FUZZY INFERENCE SYSTEM (FIS) EVALUATION CRITERIA

In this method, we have proposed a different number of combination of membership functions for better contrast enhancement of images. Here we have discussed four different cases of combination of multiple membership functions.

5.6.1 CASE 1: THREE MEMBERSHIP FUNCTIONS AND THEIR FUZZY RULES

This case is based on three combinations of Sigmoid shaped membership function and Gaussian membership function. Below figure 5.2 is showing input and output membership functions and their rules.

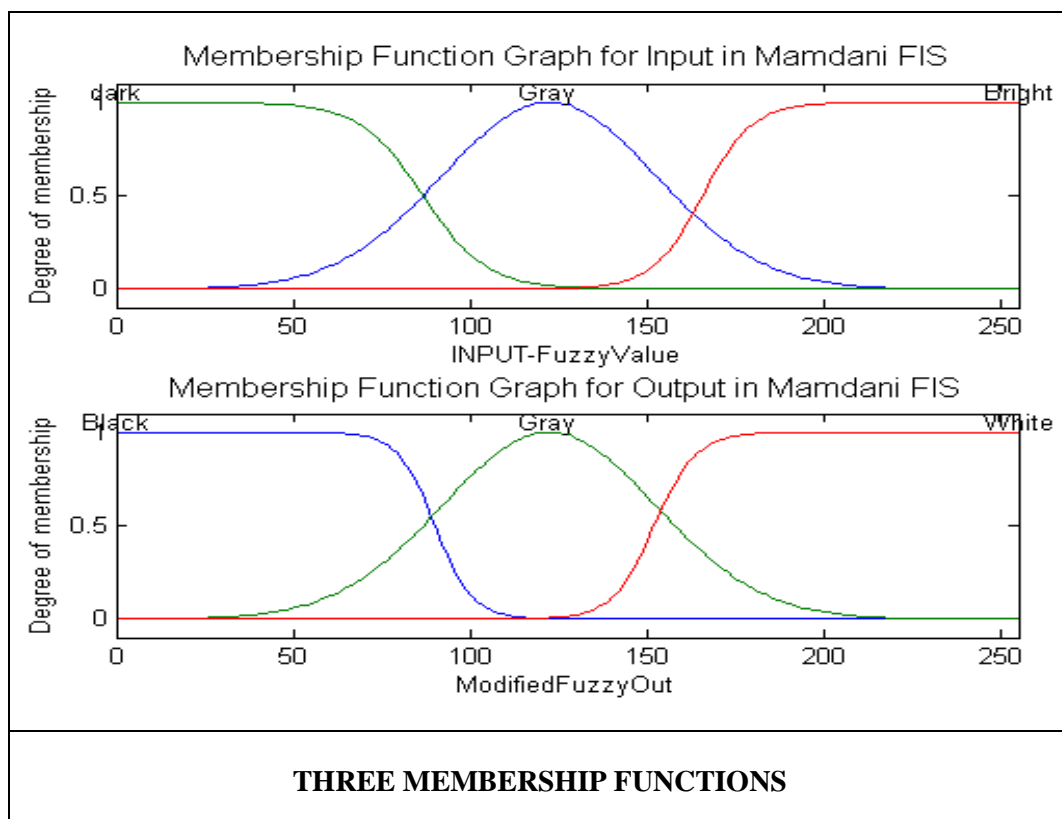


FIGURE 5.2: THREE MEMBERSHIP FUNCTION AND THEIR RULES

Number of membership functions taken in this case 1 is dark, Gray, and Bright for input and Black, Gray, and White are for output. The numbers of fuzzy rules are formed with the help of these inputs and output membership functions are as follows:

1. If (INPUT-MFs is dark) then (Output-MFs is Black)
2. If (INPUT-MFs is Gray) then (Output-MFs is Gray)
3. If (INPUT-MFs is Bright) then (Output-MFs is White)

5.6.2 CASE 2: FIFTEEN MEMBERSHIP FUNCTIONS AND THEIR FUZZY RULES

This case is based on fifteen combinations of Sigmoid shaped membership function and Gaussian membership function. Below figure 5.3 is showing input and output membership functions and their rules.

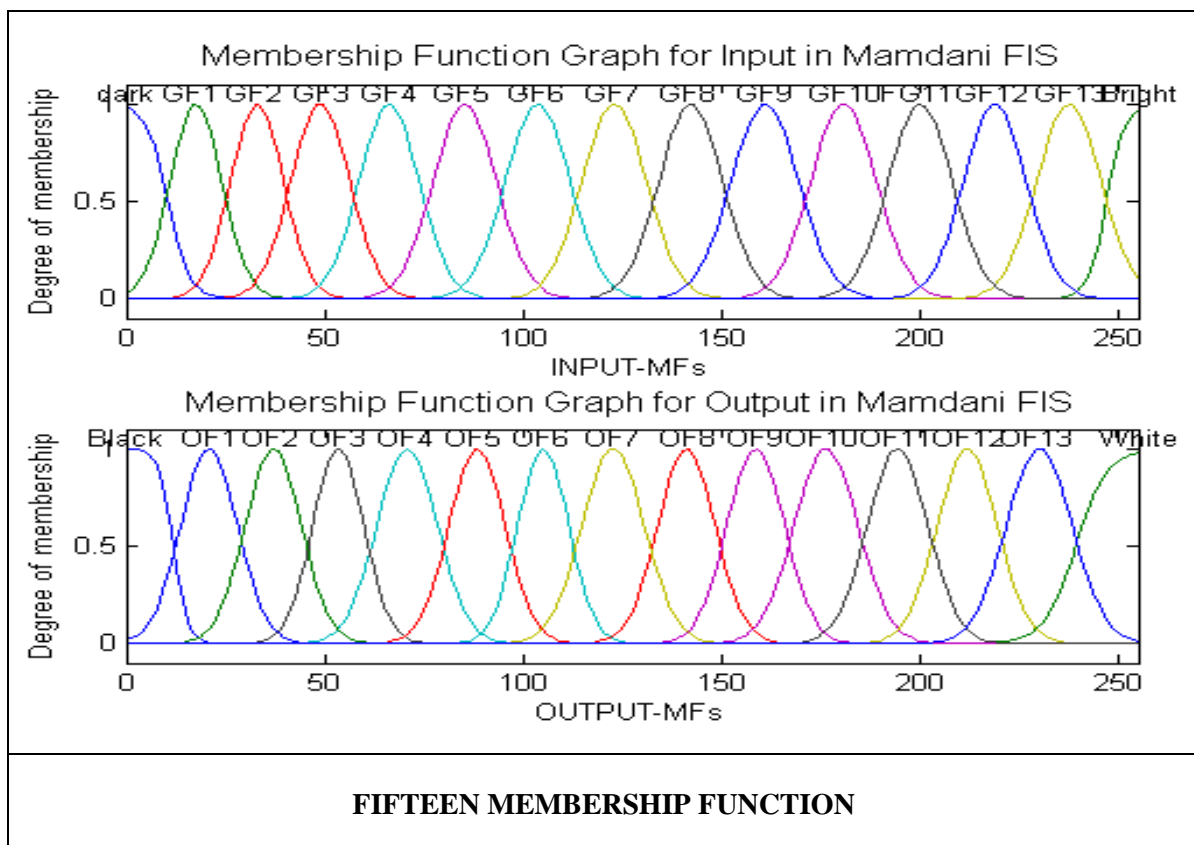


FIGURE 5.3: FIFTEEN MEMBERSHIP FUNCTIONS AND THEIR RULES

Number of membership functions taken in this case 2 are dark, Bright, GF1, GF2, GF3, GF4, GF5, GF6, GF7, GF8, GF9, GF10, GF11, GF12, GF13 for input and black, White, OF1, OF2, OF3, OF4, OF5, OF6, OF7, OF8, OF9, OF10, OF11, OF12, OF13 are for output. The numbers of fuzzy rules are formed with the help of these inputs and output membership functions are as follows:

1. If (INPUT-MFs is dark) then (Output-MFs is Black)
2. If (INPUT-MFs is GF1) then (Output-MFs is Black)
3. If (INPUT-MFs is GF2) then (Output-MFs is OF1)
4. If (INPUT-MFs is GF3) then (Output-MFs is OF2)
5. If (INPUT-MFs is GF4) then (Output-MFs is OF3)
6. If (INPUT-MFs is GF5) then (Output-MFs is OF4)
7. If (INPUT-MFs is GF6) then (Output-MFs is OF5)
8. If (INPUT-MFs is GF7) then (Output-MFs is OF8)
9. If (INPUT-MFs is GF8) then (Output-MFs is OF9)
10. If (INPUT-MFs is GF9) then (Output-MFs is OF10)
11. If (INPUT-MFs is GF10) then (Output-MFs is OF11)
12. If (INPUT-MFs is GF11) then (Output-MFs is OF12)
13. If (INPUT-MFs is GF12) then (Output-MFs is OF13)
14. If (INPUT-MFs is GF13) then (Output-MFs is White)
15. If (INPUT-MFs is Bright) then (Output-MFs is White)

5.6.3 CASE 3: NINETEEN MEMBERSHIP FUNCTIONS AND THEIR RULES

This case is based on nineteen combinations of sigmoid shaped membership function and Gaussian membership function. Below figure 5.4 is showing input and output membership functions and their rules.

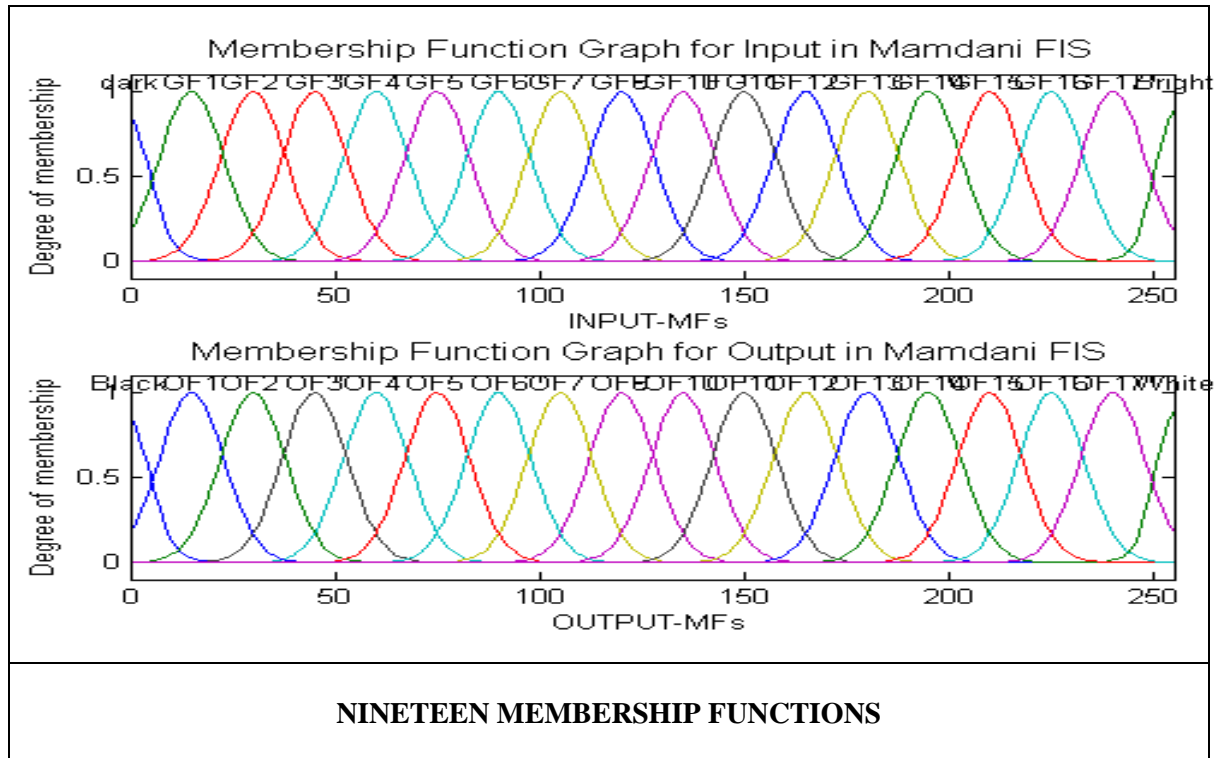


FIGURE 5.4: NINETEEN MEMBERSHIP FUNCTION AND THEIR RULES

Number of membership functions taken in this case 3 are dark, Bright, GF1, GF2, GF3, GF4, GF5, GF6, GF7, GF8, GF9, GF10, GF11, GF12, GF13, GF14, GF15, GF16, GF17 for input and black, White, OF1, OF2, OF3, OF4, OF5, OF6, OF7, OF8, OF9, OF10, OF11, OF12, OF13, OF14, OF15, OF16, OF17 are for output.

The numbers of fuzzy rules are formed with the help of these inputs and output membership functions are as follows:

1. If (INPUT-MFs is dark) then (Output-MFs is Black)
2. If (INPUT-MFs is GF1) then (Output-MFs is Black)
3. If (INPUT-MFs is GF2) then (Output-MFs is OF1)
4. If (INPUT-MFs is GF3) then (Output-MFs is OF2)
5. If (INPUT-MFs is GF4) then (Output-MFs is OF3)
6. If (INPUT-MFs is GF5) then (Output-MFs is OF4)
7. If (INPUT-MFs is GF6) then (Output-MFs is OF5)
8. If (INPUT-MFs is GF7) then (Output-MFs is OF6)
9. If (INPUT-MFs is GF8) then (Output-MFs is OF7)
10. If (INPUT-MFs is GF9) then (Output-MFs is OF10)
11. If (INPUT-MFs is GF10) then (Output-MFs is OF11)
12. If (INPUT-MFs is GF11) then (Output-MFs is OF12)
13. If (INPUT-MFs is GF12) then (Output-MFs is OF13)
14. If (INPUT-MFs is GF13) then (Output-MFs is OF14)
15. If (INPUT-MFs is GF14) then (Output-MFs is OF15)
16. If (INPUT-MFs is GF15) then (Output-MFs is OF16)
17. If (INPUT-MFs is GF16) then (Output-MFs is OF17)
18. If (INPUT-MFs is GF17) then (Output-MFs is White)
19. If (INPUT-MFs is Bright) then (Output-MFs is White)

5.6.4 CASE 4: TWENTY-SIX MEMBERSHIP FUNCTIONS AND THEIR FUZZY RULES

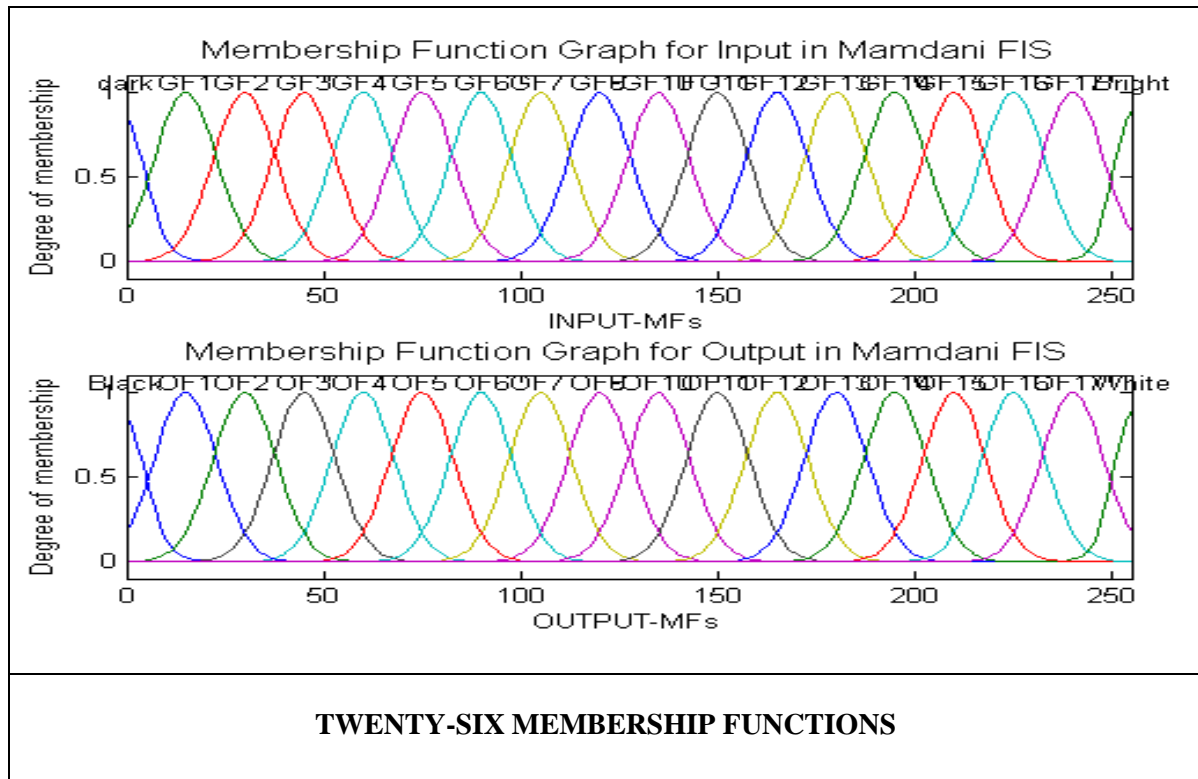


FIGURE 5.5: TWENTY-SIX MEMBERSHIP FUNCTIONS AND THEIR RULES

Number of membership functions taken in this case 3 are dark, Bright, GF1, GF2, GF3, GF4, GF5, GF6, GF7, GF8, GF9, GF10, GF11, GF12, GF13, GF14, GF15, GF16, GF17, GF18, GF19, GF20, GF21, GF22, GF23, GF24 for input and black, White, OF1, OF2, OF3, OF4, OF5, OF6, OF7, OF8, OF9, OF10, OF11, OF12, OF13, OF14, OF15, OF16, OF17, OF18, OF19, OF20, OF21, OF22, OF23, OF24 are for output. The numbers of fuzzy rules are formed with the help of these inputs and output membership functions are as follows:

1. If (INPUT-MFs is dark) then (Output-MFs is Black)
2. If (INPUT-MFs is GF1) then (Output-MFs is Black)
3. If (INPUT-MFs is GF2) then (Output-MFs is OF1)
4. If (INPUT-MFs is GF3) then (Output-MFs is OF2)

5. If (INPUT-MFs is GF4) then (Output-MFs is OF3)
6. If (INPUT-MFs is GF5) then (Output-MFs is OF4)
7. If (INPUT-MFs is GF6) then (Output-MFs is OF5)
8. If (INPUT-MFs is GF7) then (Output-MFs is OF6)
9. If (INPUT-MFs is GF8) then (Output-MFs is OF7)
10. If (INPUT-MFs is GF9) then (Output-MFs is OF8)
11. If (INPUT-MFs is GF10) then (Output-MFs is OF9)
12. If (INPUT-MFs is GF11) then (Output-MFs is OF10)
13. If (INPUT-MFs is GF12) then (Output-MFs is OF11)
14. If (INPUT-MFs is GF13) then (Output-MFs is OF14)
15. If (INPUT-MFs is GF14) then (Output-MFs is OF15)
16. If (INPUT-MFs is GF15) then (Output-MFs is OF16)
17. If (INPUT-MFs is GF16) then (Output-MFs is OF17)
18. If (INPUT-MFs is GF17) then (Output-MFs is OF18)
19. If (INPUT-MFs is GF18) then (Output-MFs is OF19)
20. If (INPUT-MFs is GF19) then (Output-MFs is OF20)
21. If (INPUT-MFs is GF20) then (Output-MFs is OF21)
22. If (INPUT-MFs is GF21) then (Output-MFs is OF22)
23. If (INPUT-MFs is GF22) then (Output-MFs is OF23)
24. If (INPUT-MFs is GF23) then (Output-MFs is OF24)
25. If (INPUT-MFs is GF24) then (Output-MFs is White)
26. If (INPUT-MFs is Bright) then (Output-MFs is White)

5.7 EXPERIMENTAL RESULTS AND ANALYSIS

On the basis of proposed fuzzy inference evaluation method, four cases are taken for multiple membership functions of FIS. These cases are based on sigmoid shaped membership function and Gaussian membership function taken as an input and output functions with their fuzzy rules. The input images used for simulation results are shown in figure 5.6.

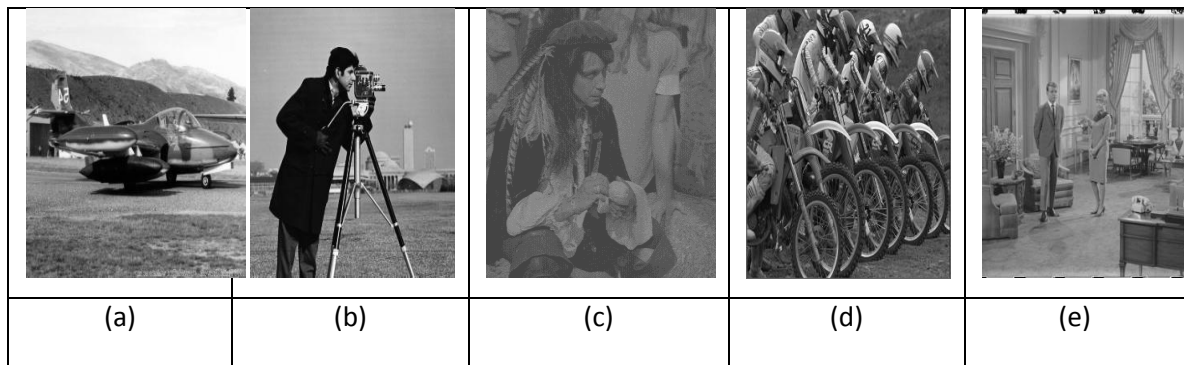


FIGURE 5.6: INPUT IMAGES USED FOR VARIOUS CASES

As above description of cases based on different combination of membership functions Table, 5.1 gives a comparison of cases based on MSE values.

TABLE 5.1: COMPARISON OF CASES BASED ON MSE VALUES

	CASE 1	CASE 2	CASE 3	CASE 4
IMAGE 1	21.914	11.8767	9.2052	15.6427
IMAGE 2	16.4304	12.691	8.9364	15.4997
IMAGE 3	18.8913	12.1918	9.1023	13.3168
IMAGE 4	11.6534	12.6703	10.1939	13.6592
IMAGE 5	11.1306	13.3171	9.4377	13.6356

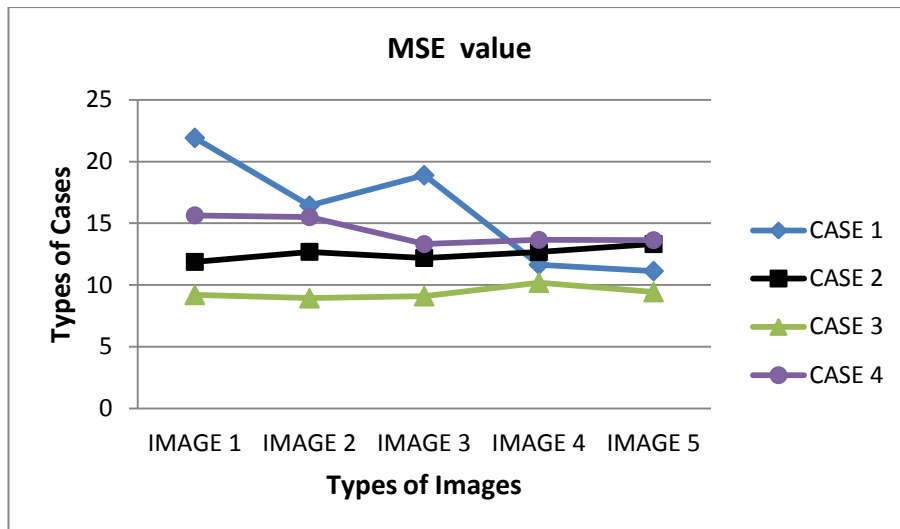


FIGURE 5.7: MSE VALUES WITH DIFFERENT CASES FOR DIFFERENT IMAGES

TABLE 5.2: COMPARISON OF CASES BASED ON PSNR VALUES

	CASE 1	CASE 2	CASE 3	CASE 4
IMAGE 1	34.7236	37.3839	38.4905	36.1877
IMAGE 2	35.9743	37.0959	38.6192	36.2276
IMAGE 3	35.3682	37.2701	38.5393	36.8868
IMAGE 4	37.4663	37.1029	38.0474	36.7766
IMAGE 5	37.6656	36.8867	38.3821	36.7841

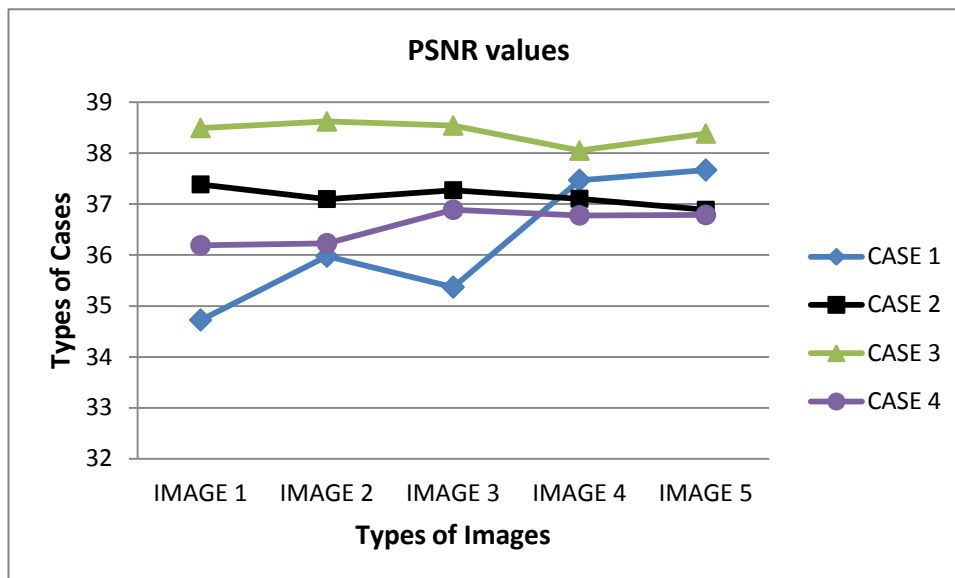


FIGURE 5.8: PSNR VALUES WITH DIFFERENT CASES FOR TYPES OF IMAGES

TABLE 5.3: COMPARISON OF CASES BASED ON INDEX OF FUZZINESS VALUES

	CASE 1	CASE 2	CASE 3	CASE 4
IMAGE 1	0.1621	0.38303	0.47048	0.36542
IMAGE 2	0.1182	0.19751	0.23403	0.17714
IMAGE 3	0.36661	0.68699	0.60318	0.57898
IMAGE 4	0.3683	0.68304	0.7282	0.63421
IMAGE 5	0.10024	0.19621	0.23225	0.1315

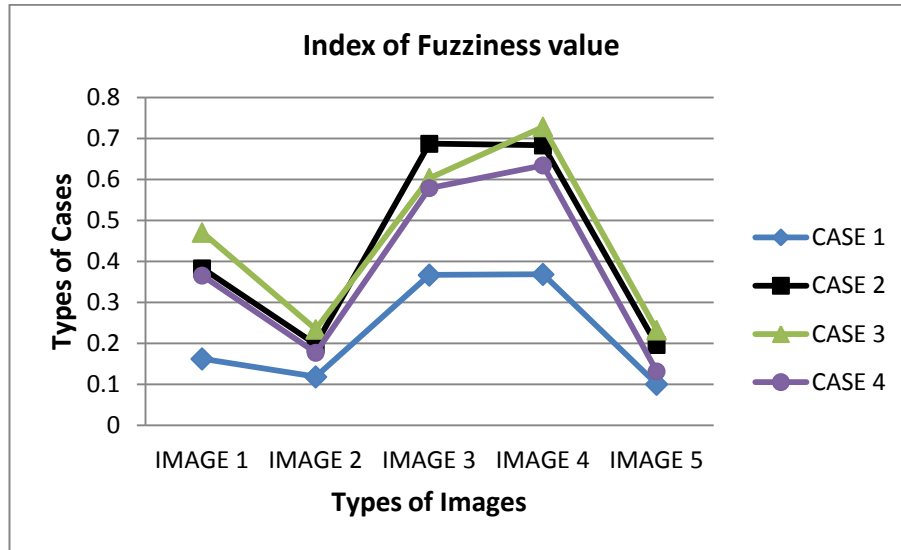


FIGURE 5.9: INDEX OF FUZZINESS WITH DIFFERENT CASES FOR DIFFERENT IMAGES

Figure 5.6, 5.7, and 5.8 show the results of case 1 using three combinations of membership functions can be improved by increasing the number of membership functions in case 2 and in case 3, but degradation of result in case 4 as compared to case 2 and case 3 shows after some increment of combination of membership function also goes down in terms of values.

On the basis of above rule-based and statistics, following observations of images and graph shows the comparison and clearly gives the visual aspect of images.




Input image	CASE 1	CASE 2	CASE 3	CASE 4
				
				
				
				
				

FIGURE 5.10: DIFFERENT CASES WITH ORIGINAL AND ENHANCED IMAGES

5.8 CONCLUSION

This chapter demonstrates a combination of multiple membership functions to optimize contrast enhancement of input image and produced an output image with better contrast as compared to the input image. Results and analysis show that Fuzzy Inference System FIS based design can capture more properties to handle the fuzziness for presenting the image in a better way. More combination of membership functions can produce the more properties and then fuzziness can be minimized to produce the better-enhanced image. It leads to the nonlinear property of membership in the fuzzy domain.

CHAPTER VI

A Novel Approach of Multiple Fuzzy Membership Functions for Contrast Enhancements

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CHAPTER VI

A NOVEL APPROACH OF MULTIPLE FUZZY MEMBERSHIP FUNCTIONS FOR CONTRAST ENHANCEMENTS

As discussed in the previous chapter, based on fuzzy set theory, the fuzzy method introduced two kinds of fuzzy inference model, in which the first kind of fuzzy inference model is introduced by Mamdani [32], and second fuzzy inference TSK model is introduced by Sugeno [24]. These models are used to handle the uncertainty in an image to improve the contrast of an image. To get more insight in the enhancement of images using fuzzy theory, this chapter includes the novel Mamdani FIS system for image contrast enhancement. Several case studies are carried out to determine the best type of membership functions for image contrast enhancement. An optimization algorithm has been used to apply to extract the useful information. Next section describes the motivation behind this work. Sections 6.2 and 6.3 include the related work and Mamdani FIS structure details. Our proposed work is described in Section 6.4 and 6.5 with detailed case studies and analysis. In Section 6.6, optimization criteria based on the Fuzzy Quality parameter is presented. The simulation results and its analysis are described in Section 6.7. Finally, the chapter is concluded in Section 6.8.

6.1 Motivation

In fuzzy inference system (FIS), input membership function (MFs) and output membership function (MFs) are mapped together by using rule- base design. This thesis considers the Mamdani FIS for image enhancement.

A given input image is then converted into fuzzy domain by using input MFs. In a fuzzy domain, rule-base is then applied to obtain a resultant modified fuzzy output (called output MFs). Finally, the output image would be generated using the centroid defuzzification method from output MFs that is simply to obtain the spatial domain. Idea is that how we can apply proper MFs used with Mamdani FIS for getting better image enhancement results. In this chapter, our proposal identifies the best MFs that can handle the almost all types of images. An optimization criterion is used to select the best MFs for a particular image. In MATLAB, Mamdani FIS is a GUI based fuzzy inference system where fuzzy-domain would be a conversion from MFs setting as both input and output side. FIS design consists of an input membership function rule base and output membership function blocks as shown in Fig. 6.1.

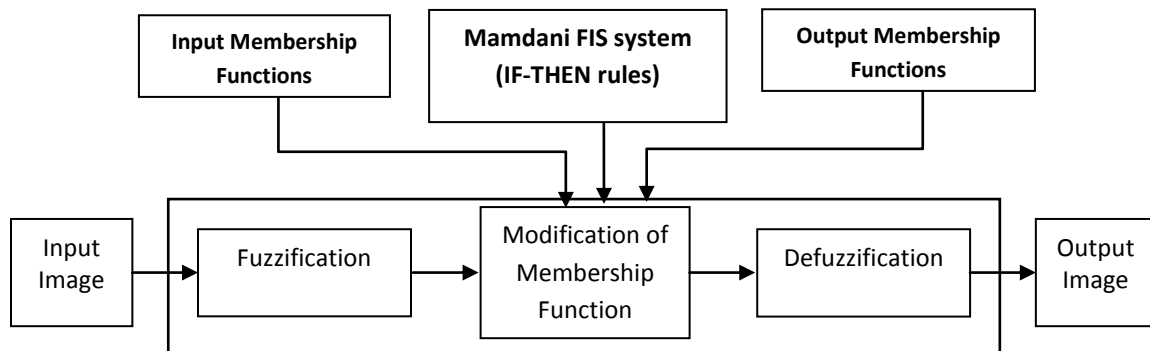


FIGURE 6.1: BLOCK REPRESENTATION OF MAMDANI FIS MODEL AND IMAGE ENHANCEMENT STEPS

6.2 RELATED WORK

Assume that an image is given with $M \times N$ pixels each with different intensities during the range $[0, L - 1]$. There are many works in literature employing fuzzy logics based image enhancement viz., edge detection, noise removal, etc. (see [29, 78, 121]). In present thesis, we restrict ourselves only works related to contrast stretching techniques or transformation functions in gray-level improvements. PAL and KING [78] was first to propose a contrast

enhancement technique using a Contrast Intensification (CI) operator. The CT operator reduces the fuzziness and thus improves the image contrast. Modified membership values are determined by CT operator. This operator stretches the contrast between the membership values. To obtain the good contrast, it transforms the MF values to much higher values for those MF values which are above 0.5. The MF values which are lower than 0.5 are transformed into much lower values in non-linear manner. Thus a good contrast is obtained using nonlinear ear stretching function. This CI operator (also known as INT operator) relies solely on membership function. In addition, this operator must be applied continuously on given image for attaining the proper enhancement. To overcome this limitation, NINT operator [33] is proposed which uses a Gaussian type fuzzification function containing a fuzzifier and a new intensification operator.

The concept of fuzzy histogram hyperbolization was proposed by Tizoosh [121]. The method modifies the input membership function into logarithmic function through nonlinear human brightness perception. Initially, MF and its shape are selected according to user's requirement. The MF values are calculated using this MF and a fuzzifier beta is set in order to modify the membership function for getting good contrast image. In this method, fuzzifier beta is a linguistic hedge which can be made a selection such that manner is very bright, very very bright, medium bright, very medium bright, low brightness, and so on. These selections can be made on the basis of image quality. If input image quality is low, then fuzzifier beta will produce a slightly bright image after the operation.

To the best of our knowledge, the use of the fuzzy rule-based procedure in image enhancement was primarily suggested by Tizhoosh et al [121]. Their works show the potential of membership function modification to improve the image brightness. However, the use of the different shape of membership function and their impact on fuzzy IF-THEN rule are not further explored. In this chapter, our objective is to extend the work of Tizhoosh

et al. [121] by considering the potential use of different shaped membership function to be used in fuzzy inference system for image contrast enhancement.

There is a lot of work published in the literature using a fuzzy inference system (FIS) design for image processing. But, in the field of image contrast enhancement, use of FIS design based on different membership functions (MFs) are not explored in details. Firstly, the idea of FIS was given by PAL and KING [78]. They have shown how working on pixels of an image can be useful for changing the internal features of the image when working on the fuzzy domain. An operator was proposed to reduce the fuzziness of the image, thus improve the overall image quality of the gray-scale image. NINT operator [33] was then proposed which uses a Gaussian type fuzzification function containing a fuzzifier and a new intensification operator. The concept of fuzzy histogram hyperbolization was proposed by Tizhoosh [121]. The method modifies the input membership function into logarithmic function through nonlinear human brightness perception. Initially, MF and its shape are selected according to user's requirement. The MF values are calculated using this MF and a fuzzifier beta is set in order to modify the membership function for getting good contrast image. In this method, fuzzifier beta is a linguistic hedge which can be made a selection such that manner is very bright, very very bright, medium bright, very medium bright, low brightness, and so on. These selections can be made on the basis of image quality. If input image quality is low, then fuzzifier beta will produce a slightly bright image after the operation.

Russo proposes rule-based operators based on human knowledge. Image quality can be improved by human observation and fuzzy rule-based are according to human intuitions which are nonlinear. The conditions for the fuzzy rule are designed on the basis of pixel gray level and neighborhood pixel values. The fuzzy rule-based systems based on soft decisions are proposed in and rule-based operators for image sharpening and smoothing are

suggested in [93, 94]. Fuzzy rule-based filters for image enhancement are proposed in [24]. A comparative study of mammogram images is given in [36] to explore the features of the image using different mechanisms such as contrast intensification, IF-THEN rules, and hyperbolization. The fashion is as follows: (i) If the image is dark then black, (ii) If the image is gray then gray, (iii) If the image is bright then white. The use of Fuzzy expected value (FEV) for image enhancement has been suggested by Schneider and Craig. In FEV, mean and median fuzzy set values are replaced to modify the more representative value in the grade of the membership function. A weighted FEV was also proposed by the same authors to improve more the image contrast [100].

Although various techniques of image enhancement can extract important features of the image in improving the image contrast several deficiencies in these techniques are still present. Thus, the optimization techniques have been proposed in [72, 79]. The enhanced images are produced by optimizing the gray-level information of the image. Other optimizations on the image are based on entropy, index of fuzziness or combination of both. However, the optimizations using the above measures need an iterative procedure which may be applied repeatedly to transform better image quality. To overcome these limitations, authors in [18, 127] have suggested the methods of locally enhancing the image without additional optimization.

6.3 MAMDANI FIS MODEL STRUCTURE

Based on fuzzy set theory, the fuzzy method introduced two kinds of fuzzy inference model, in which the first kind of fuzzy inference model is introduced by Mamdani [66], and second fuzzy inference TSK model is introduced by Sugeno [118]. These models are used to handle the uncertainty in an image to improve the contrast of an image. Improvements of contrast in the input image are also possible with the combination of fuzzy set theory and fuzzy entropy [86]. In MATLAB, Mamdani FIS is a GUI based fuzzy inference system where

fuzzy-domain would be a conversion from MFs setting as both input and output side. In fuzzy inference system (FIS), input membership function (MFs) and output membership function (MFs) are mapped together by using rule- base design. Fuzzy Inference System (FIS) is divided into three types, Mamdani FIS, Sugeno FIS and Tsukamoto FIS for various applications [62, 127]. The basic differences between these FIS model are that the procedures for their fuzzy rules, aggregation, and defuzzification differ mostly to each other. We restrict ourselves to consider the Mamdani FIS for image enhancement. A given input image is then converted into fuzzy domain by using input MFs. In a fuzzy domain, rule-base is then applied to obtain a resultant modified fuzzy output (called output MFs). Finally, the output image would be generated using the centroid defuzzification method from output MFs. A plot between input MFs and output MFs is referred to as transformation graph for given rule-base design. FIS design consists of an input membership function rule base and output membership function blocks as shown in Fig. 6.1. There are many approaches based on human reasoning applied to image enhancement. These also deal with ‘IF-THEN-ELSE’ fuzzy rule-based system [23]. The neighboring pixel values are antecedent part of the rule in these methods. The enhanced pixel values could be based on a decision by the consequent part of the rule base design. So, a soft decision based on human intuition plays important role in the enhancement of the image. But, they suffer from high cost in computations for generating fuzzy rule base. Image enhancement using fuzzy logic involves usually three stages that are also used by Mamdani FIS (see Fig. 6.1). These are image fuzzification, membership function modification, and image defuzzification.

This model takes input in the discrete form of the image as crisp input. It then feeds to a fuzzifier which uses membership function (MF) for converting into a fuzzy variable. MFs map the crisp variables to fuzzy variables and the degree of membership of these variables are calculated. The degree of membership is normalized in the range of 0 to 1. The fuzzy

variables converted using MFs are then fed into the IF-THEN rule base. Using the fuzzy IF-THEN rule base, fuzzy input variables are mapped to fuzzy output variables. This mapping of fuzzy variables can be partial or overlapped and according to output MFs taken at output side in Mamdani FIS. Finally, defuzzifier then converts the fuzzy output into the crisp output. In Mamdani FIS model, different defuzzification techniques can be used to get crisp output using output MFs. Their techniques can be centroid, the center of sums (COS) and mean of maximum defuzzification. In our method, the centroid method of defuzzification is utilized.

6.3.1 DIFFERENT TYPES OF MFs BASED PARTITION

There are 12 types of MFs according to fuzzy logic theory. Some of them are presented in the figures below. As shown in figures below, the x-axis range is defined from 0 to Z variable while the y-axis is set to 1. The variable Z varies for application to application. For 8-bit images, the range of x-axis could be between zero and 255 (it is known as pixel or gray level value). The range of the y-axis would be always from 0 to 1. It is called grade of membership. There are many membership functions used for fuzzy image enhancement.

6.3.2 THE ALGORITHM OF CALCULATING RULE-BASE

Fuzzy IF-Then rules are needed to map the input and output MFs for getting the resultant better fuzzy logic so that when input MFs may apply on a given image, it can convert into fuzzy logic according to input MFs. The IF-THEN rules could be able to take a decision based on human perception. A modified member function is obtained by applying IF-THEN rules that are equivalent to the output MFs. The obtained fuzzy logic is then reconverted back using centroid defuzzification into an enhanced version of the image. For the same IF-THEN rules, input MFs and output MFs selection in Mamdani FIS is important to get improved results. Because the modified membership functions would be different using the

same IF-THEN rule base. According to the literature, different fuzzy memberships play an important role to remove uncertainty in the image. Hence resultant image could preserve the contrast brightness than the input given image. Using the different combination of MFs using Mamdani FIS, contrast enhancement analysis has been done for understanding the role of fuzzy logic in fuzzy image enhancements. We show that how powerful is the fuzzy logic tool for contrast enhancement of gray-scale images. A comparison with classical methods such as histogram equalization and its variants has been done to show the improvements in terms of contrast preservation in histogram equalization.

Let us assume that the input and output fuzzy sets in FIS are defined by X and Y respectively. An input ($x \in X$) is given to Mamdani FIS. The corresponding output ($y \in Y$) is determined with the help of fuzzy If-Then rule base and logic operation. In Mamdani FIS, we use different MFs partitioning the X and Y fuzzy domains. Let us assume A_i and B_i are partitioning fuzzy sets of X and Y respectively. We have n number of IF-Then rules depending on selectiothe n of MFs in inference system. There are single-input, single-output fuzzy rules in the form of such that: $R_i : \text{if } \tilde{x} \text{ is } A_i \text{ then } \tilde{y} \text{ is } B_i$. Let us be given k number of MFs for X and Y, where $k = 1, 2, \dots, n$. Let $\tilde{x} \in X$ be the given input and $\tilde{y} \in Y$ be the appropriate output determine in the Mamdani FIS. Let A_k and B_k are input MFs partitioning X and output MFs portioning the Y respectively. The algorithm for calculating rule base in Mamdani FIS is shown inthe the Fig. 6.2.

```

INPUTS:  $n, \mathcal{A}_n, \mathcal{B}_n, \tilde{x} \in X, \tilde{y} \in Y, \mathcal{C} = n/2$ 
OUTPUT: A set of  $n$  Single – Input Single – Output fuzzy rule base
BEGIN
 $\mathcal{R}_1$  : If  $\tilde{x}$  is  $\mathcal{A}_1$  Then  $\tilde{y}$  is  $\mathcal{B}_1$ 
for  $k = 2$  to  $(n - 1)$  do
    if  $k \geq \mathcal{C}$  then
         $\mathcal{R}_k$  : If  $\tilde{x}$  is  $\mathcal{A}_k$  Then  $\tilde{y}$  is  $\mathcal{B}_{(k-1)}$ 
    else
        if  $k \leq \mathcal{C}$  then
             $\mathcal{R}_k$  : If  $\tilde{x}$  is  $\mathcal{A}_k$  Then  $\tilde{y}$  is  $\mathcal{B}_{(k+1)}$ 
        end if
    end if
end for
 $\mathcal{R}_n$  : If  $\tilde{x}$  is  $\mathcal{A}_n$  Then  $\tilde{y}$  is  $\mathcal{B}_n$ 
return RULES = Rules{ $\mathcal{R}_1, \mathcal{R}_2, \dots, \mathcal{R}_n$ }
END

```

FIGURE 6.2: ALGORITHM FOR CALCULATING FUZZY IF-THEN RULE BASE

6.4 NOVEL APPROACH USED WITH MAMDANI FIS

This section covers the proposed design used with Mamdani FIS for image contrast enhancement. First, the procedure for applying our model in Mamdani FIS is presented and then the terminology used for presenting the case studies is defined in next subsection.

6.4.1 A NOVEL MAMDANI FIS

Assume X be the given input image having intensities at pixels as x , where $x \in X$ and appropriate output be the Y having y intensities at pixels, where $y \in Y$. In Mamdani FIS, the followings are the procedure:

Step 1: Calculate the degree of input membership values $A_i \in [0,1]$ for $x \in X$ using given fuzzy membership functions (called input MFs), where $i = 1, 2, 3, \dots, n$.

Step 2: Calculate the degree of output membership values $B_i \in [0,1]$ for $y \in Y$ using given fuzzy membership functions (called output MFs), where $i = 1, 2, 3, \dots, n$.

Step 3: Obtain the set of n IF-THEN rules for given input and output fuzzy sets obtained in step-1 and step-2 above (see our algorithm).

Step 4: Obtain the overall modified output fuzzy set when n IF-THEN rules are applied.

Step 5: Defuzzify the resultant output fuzzy set using the centroid method of defuzzification given by

$$\tilde{Y} = \frac{\sum \tilde{y} \cdot \mu(\tilde{y})}{\sum \mu(\tilde{y})} \quad (6.1)$$

Where

\tilde{Y} - Represents the crisp output value

\tilde{y} - Represents the centroid of fuzzy values calculated from membership function

$\mu(\tilde{Y})$ - Represents the area from membership function bounded by degree of membership and abscissa.

6.4.2 DEFINITIONS AND TERMINOLOGIES USED

We first define the following terms and definition which are necessary to explain the proposed methods and procedure. Domain range of the grayscale image is from 0 to 255. This range is partitioned into equidistant and identically shaped membership functions (MFs). A major advantage of this partitioning is that the fuzzy rules obtained from the fixed MFs are always interpretable according to human perception. We used the same fashion in fuzzy rules for different numbers and different types of MFs. The types of MFs for input variables and output variables used in Mamdani FIS are considered using three membership functions (MFs) such as Triangular, Gaussian and Bell shaped membership function for image contrast enhancement. Their combinations for input variables and output variables used in Mamdani FIS are studied for evaluation of image contrast enhancement.

For example, Triangular MFs at input variables and Gaussian MFs at output variables for Mamdani FIS can be used for evaluation of image contrast enhancement. Studies include

their combinations and the selection number to partition the gray-scale range for the analysis of contrast image enhancement using Mamdani FIS. Followings are the terms and definitions used in this chapter.

- Symbol “T” denotes the use of Triangular membership function used with Mamdani FIS
- Symbol “G” denotes the use of Gaussian membership function used with Mamdani FIS
- Symbol “B” denotes the use of Bell-shaped membership function used with Mamdani FIS
- Symbol “T-T” denotes the use of Triangular MFs and Triangular MFs at input and output variables in Mamdani FIS respectively.
- Symbol “T-G” denotes the use of Triangular MFs and Gaussian MFs at input and output variables in Mamdani FIS respectively.
- Symbol “T-B” denotes the use of Triangular MFs and Bell MFs at input and output variable in Mamdani FIS respectively.
- Symbol “G-T” denotes the use of Gaussian MFs and Triangular MFs at input and output variable in Mamdani FIS respectively.
- Symbol “G-G” denotes the use of Gaussian MFs and Gaussian MFs at input and output variable in Mamdani FIS respectively.
- Symbol “G-B” denotes the use of Gaussian MFs and Bell MFs at input and output variable in Mamdani FIS respectively.
- Symbol “B-T” denotes the use of Gaussian MFs and Triangular MFs at input and output variable in Mamdani FIS respectively.
- Symbol “B-G” denotes the use of Bell MFs and Gaussian MFs at input and output variable in Mamdani FIS respectively.

- Symbol “B-B” denotes the use of Bell MFs and Bell MFs at input and output variable in Mamdani FIS respectively.

The number of MFs considered for input and output variables in Mamdani FIS are 15 20 25 and 30. For example, ‘15 G-G’ denotes the 15 partitioning the gray-scale range (0 to 255) using Gaussian MFs at both input and output variable in Mamdani FIS. Similarly, ‘20 B-T’ denotes the 20 partitioning the gray-scale range (0 to 255) using Bell MFs at the input and Triangular MFs at output variables in Mamdani FIS respectively. For simplicity, we restrict ourselves to study the combinations as ‘15 T-T’, ‘15 T-G’, ‘15 T-B’, ‘15 G-T’, ‘15 G-G’, ‘15 G-B’, ‘15 B-T’, ‘15 B-G’, ‘15 B-B’ for 15 partitions. Similarly, for 20 partitions, we have ‘20 T-T’, ‘20 T-G’, ‘20 T-B’, ‘20 G-T’, ‘20 G-G’, ‘20 G-B’, ‘20 B-T’, ‘20 B-G’, ‘20 B-B’. For 25 partitions, we get ‘25 T-T’, ‘25 T-G’, ‘25 T-B’, ‘25 G-T’, ‘25 G-G’, ‘25 G-B’, ‘25 B-T’, ‘25 B-G’, ‘25 B-B’. Finally, for 30 partitions, we have ‘30 T-T’, ‘30 T-G’, ‘30 T-B’, ‘30 G-T’, ‘30 G-G’, ‘30 G-B’, ‘30 B-T’, ‘30 B-G’, ‘30 B-B’.

By considering the above possible combinations, we divide evaluations into cases according to the same MFs selection and different MFs selection in Mamdani FIS. The same MFs selection includes ‘T-T’, ‘G-G’ and ‘B-B’ with 15, 20, 25, 30 numbers of MFs. Followings are the cases with combinations used with Mamdani FIS.

Case-1: Same MFs Selection in FIS

Case-1A: ‘15 T-T’, ‘15 G-G’, ‘15 B-B’ for 15 partitions.

Case-1B: ‘20 T-T’, ‘20 G-G’, ‘20 B-B’ for 20 partitions.

Case-1C: ‘25 T-T’, ‘25 G-G’, ‘25 B-B’ for 25 partitions.

Case-1D: ‘30 T-T’, ‘30 G-G’, and ‘30 B-B’ for 30 partitions.

Case-2: different MFs Selection in FIS

Case-2A: ‘15 T-G’, ‘15 T-B’, ‘15 G-T’, ‘15 G-B’, ‘15 B-T’, ‘15 B-G’ for 15 partitions.

Case-2B: ‘20 T-G’, ‘20 T-B’, ‘20 G-T’, ‘20 G-B’, ‘20 B-T’, ‘20 B-G’ for 20 partitions.

Case-2C: ‘25 T-G’, ‘25 T-B’, ‘25 G-T’, ‘25 G-B’, ‘25 B-T’, ‘25 B-G’ for 25 partitions.

Case-2D: ‘30 T-G’, ‘30 T-B’, ‘30 G-T’, ‘30 G-B’, ‘30 B-T’, ‘30 B-G’ for 30 partitions.

6.5 CHOICE OF MFS FOR MAMDANI FIS AND ANALYSIS CRITERIA

In this section, we present detail analysis for fuzzy image enhancement using Mamdani FIS through different cases on the basis of membership functions. Different cases are broadly divided into two parts. One is based on the classification of the same membership function and second is based on different membership functions.

6.5.1 SAME MF'S SELECTION IN FIS – CASE 1

This is based on the same MFs selection in FIS classified in four cases.

6.5.1.1 CASE-1A: SAME MF'S WITH 15 PARTITIONS

In this case, the same type of membership function has been used at both input and output in Mamdani FIS for 15 partitioning of the gray scale range which is from 0 to 255. Followings are the graphs of the membership functions and their combinations.

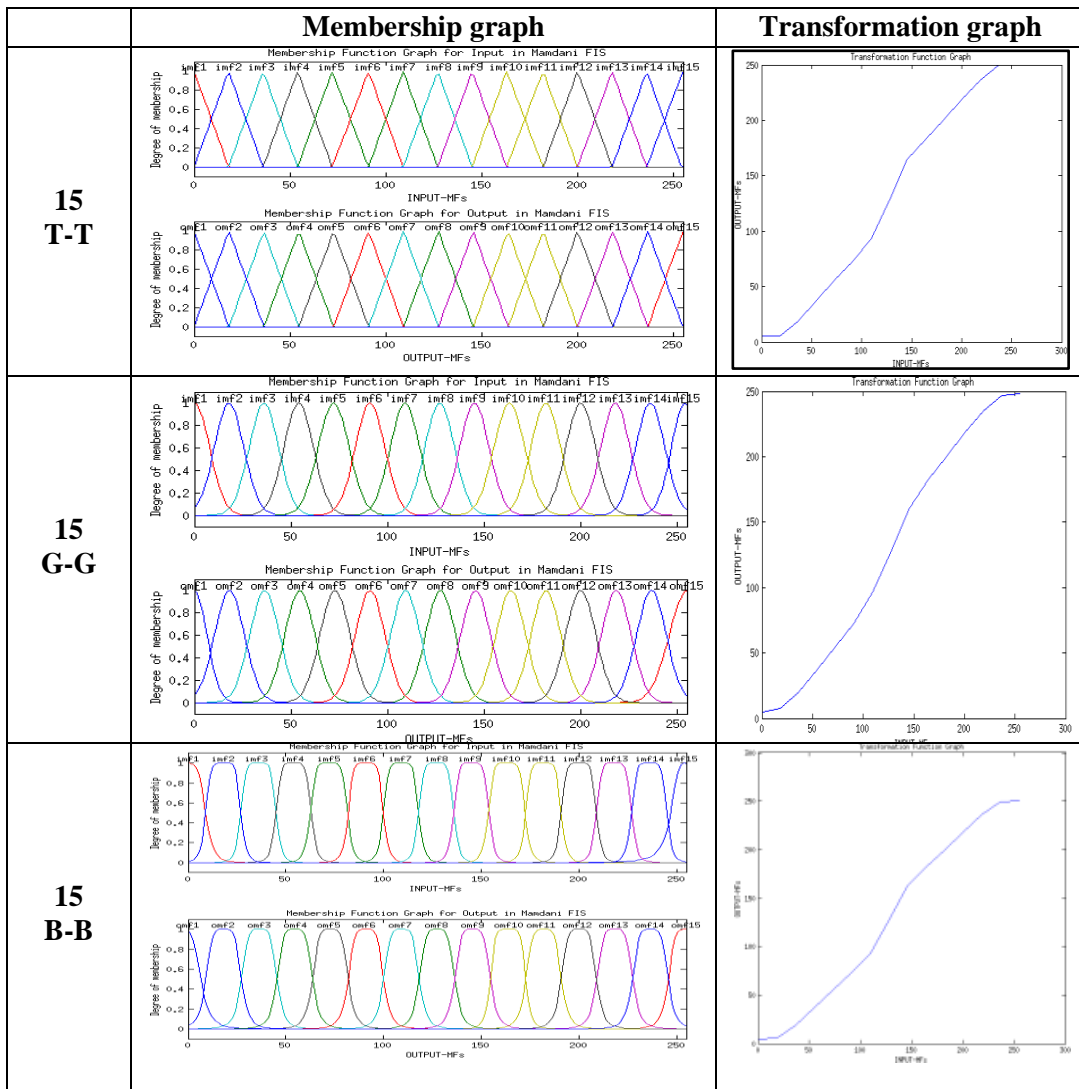


FIGURE 6.3: SAME MFS WITH 15 PARTITIONS

6.5.1.2 CASE-1B: SAME MF'S WITH 20 PARTITIONS

In this case, the same type of membership function has been used at both input and output in Mamdani FIS for 20 partitioning of the gray scale range which is from 0 to 255. Followings are the graphs of the membership functions and their combinations.

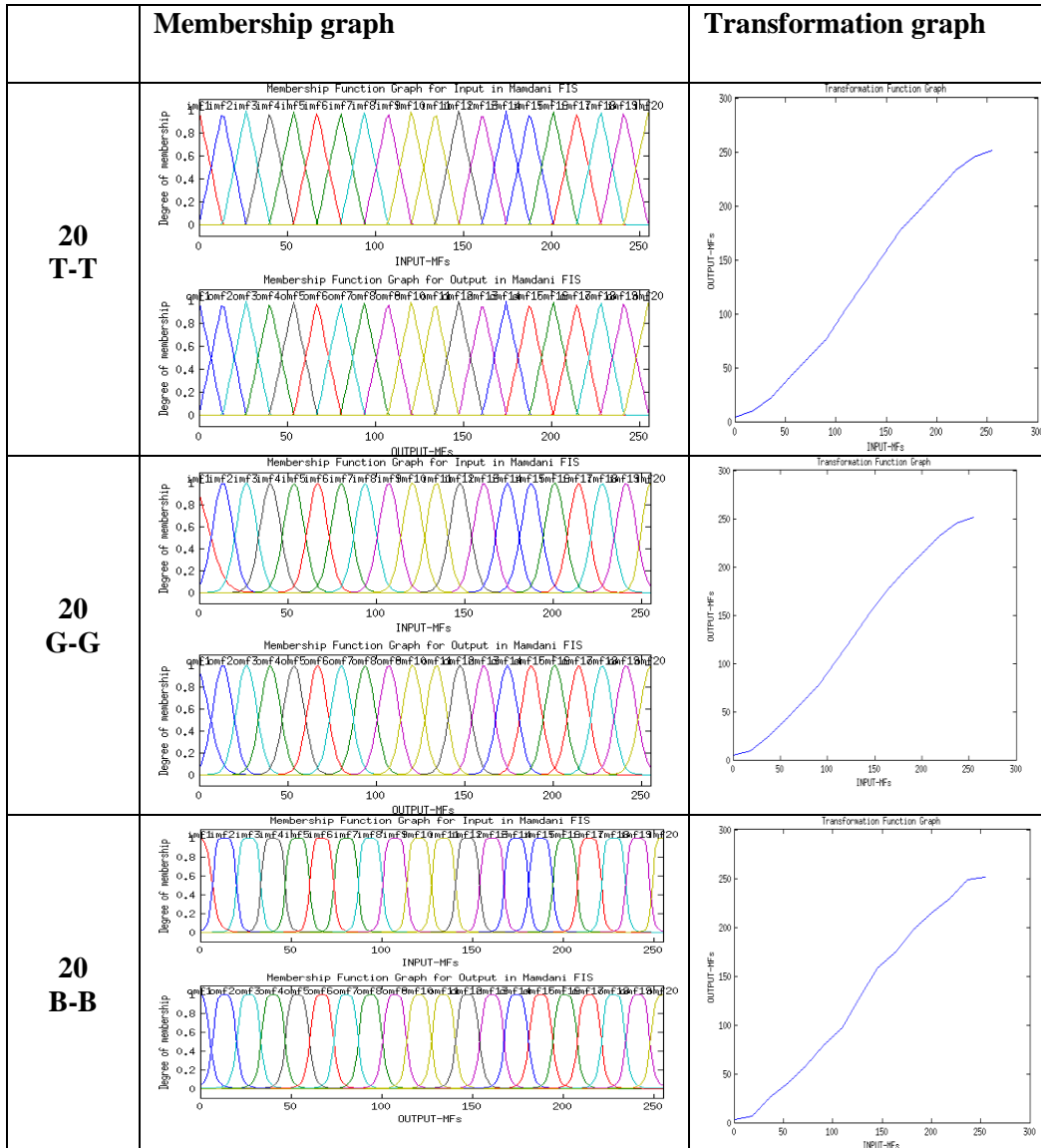


FIGURE 6.4: SAME MFS WITH 20 PARTITIONS

6.5.1.3 CASE-1C: SAME MF'S WITH 25 PARTITIONS

In this case, the same type of membership function has been used at both input and output in Mamdani FIS for 25 partitioning of the gray scale range which is from 0 to 255. Followings are the graphs of the membership functions and their combinations.

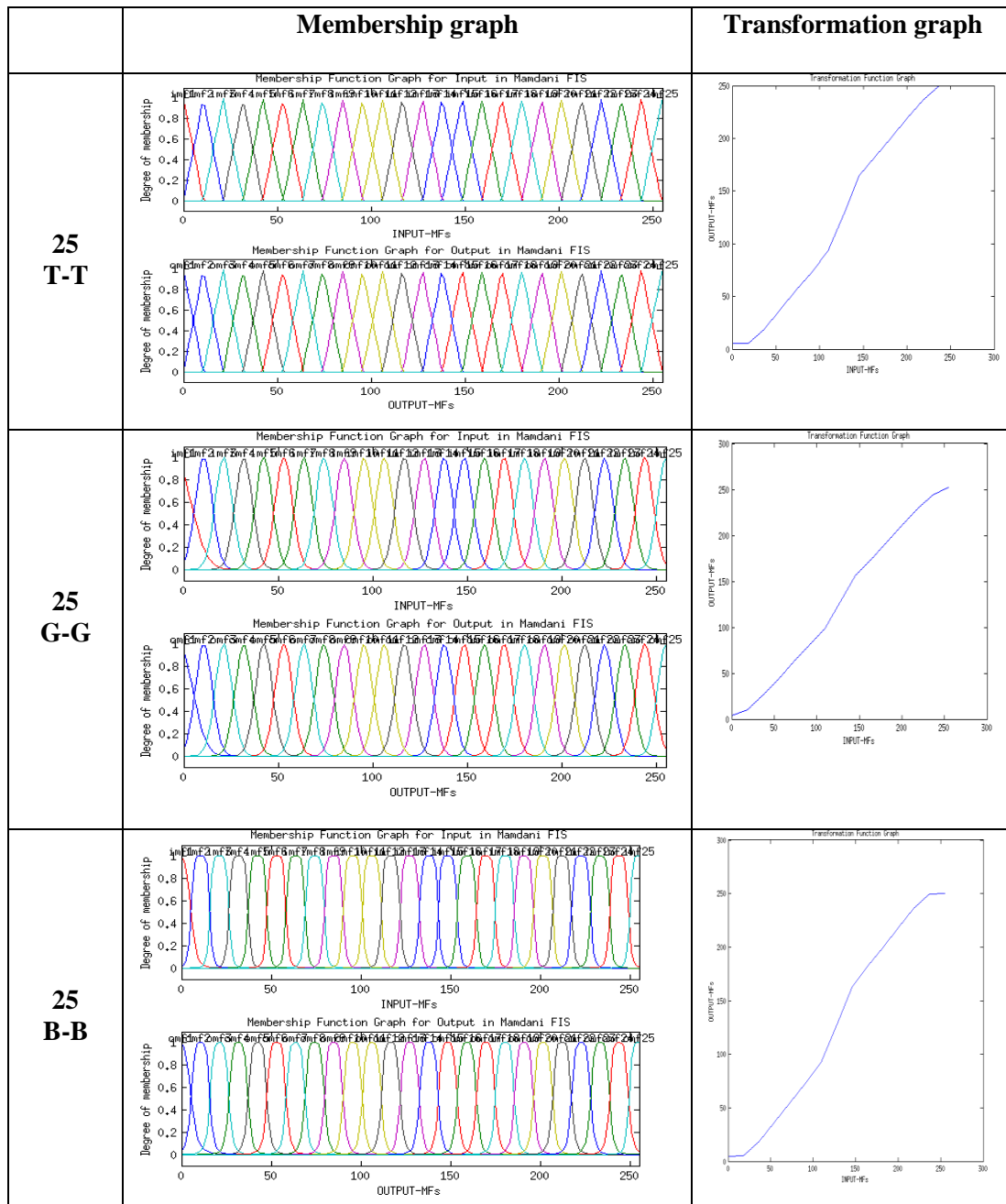


FIGURE 6.5: SAME MFS WITH 25 PARTITIONS

6.5.1.4 CASE-1D: SAME MF'S WITH 30 PARTITIONS

In this case, the same type of membership function has been used at both input and output in Mamdani FIS for 30 partitioning of the gray scale range which is from 0 to 255. Followings are the graphs of the membership functions and their combinations.

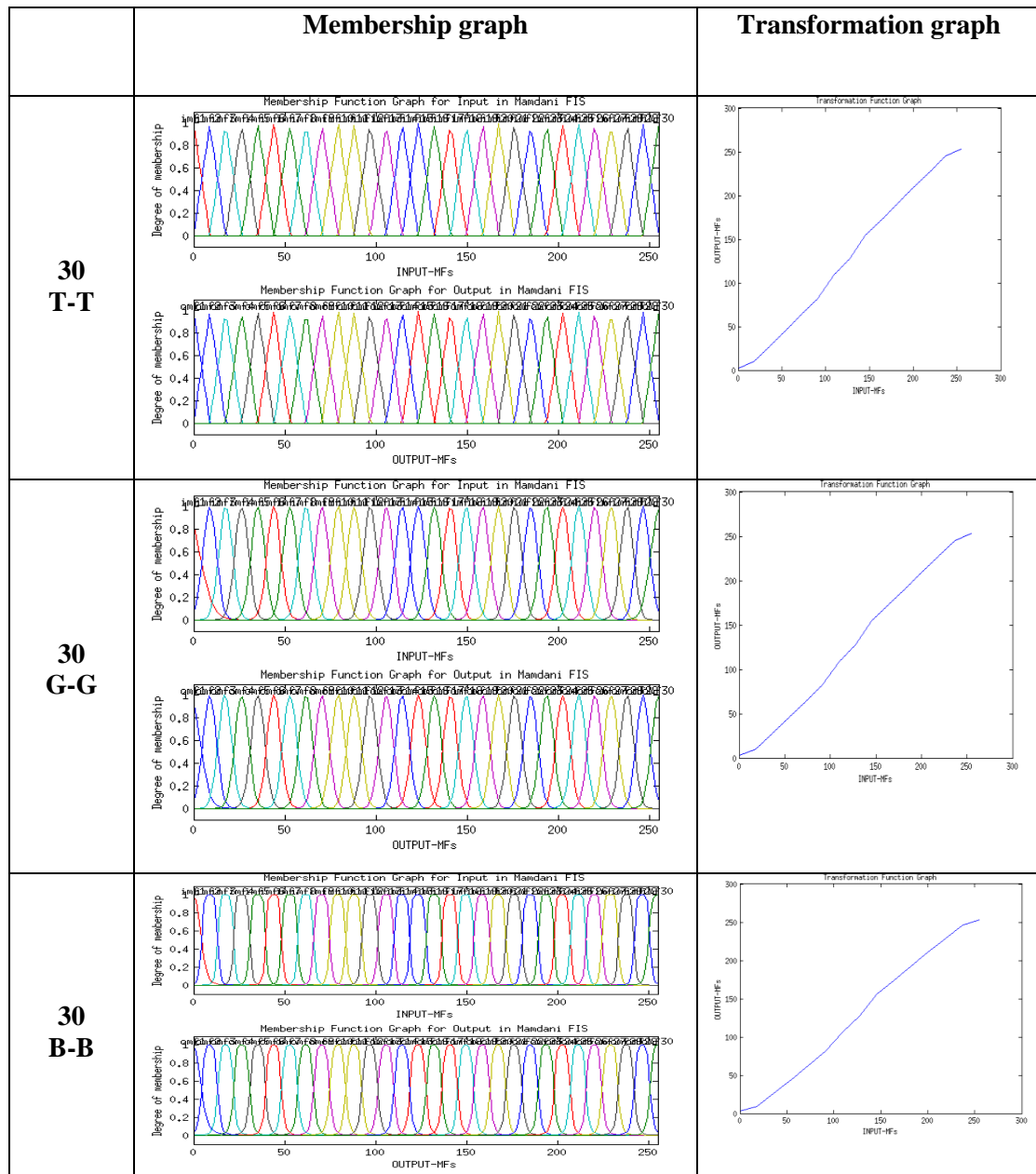


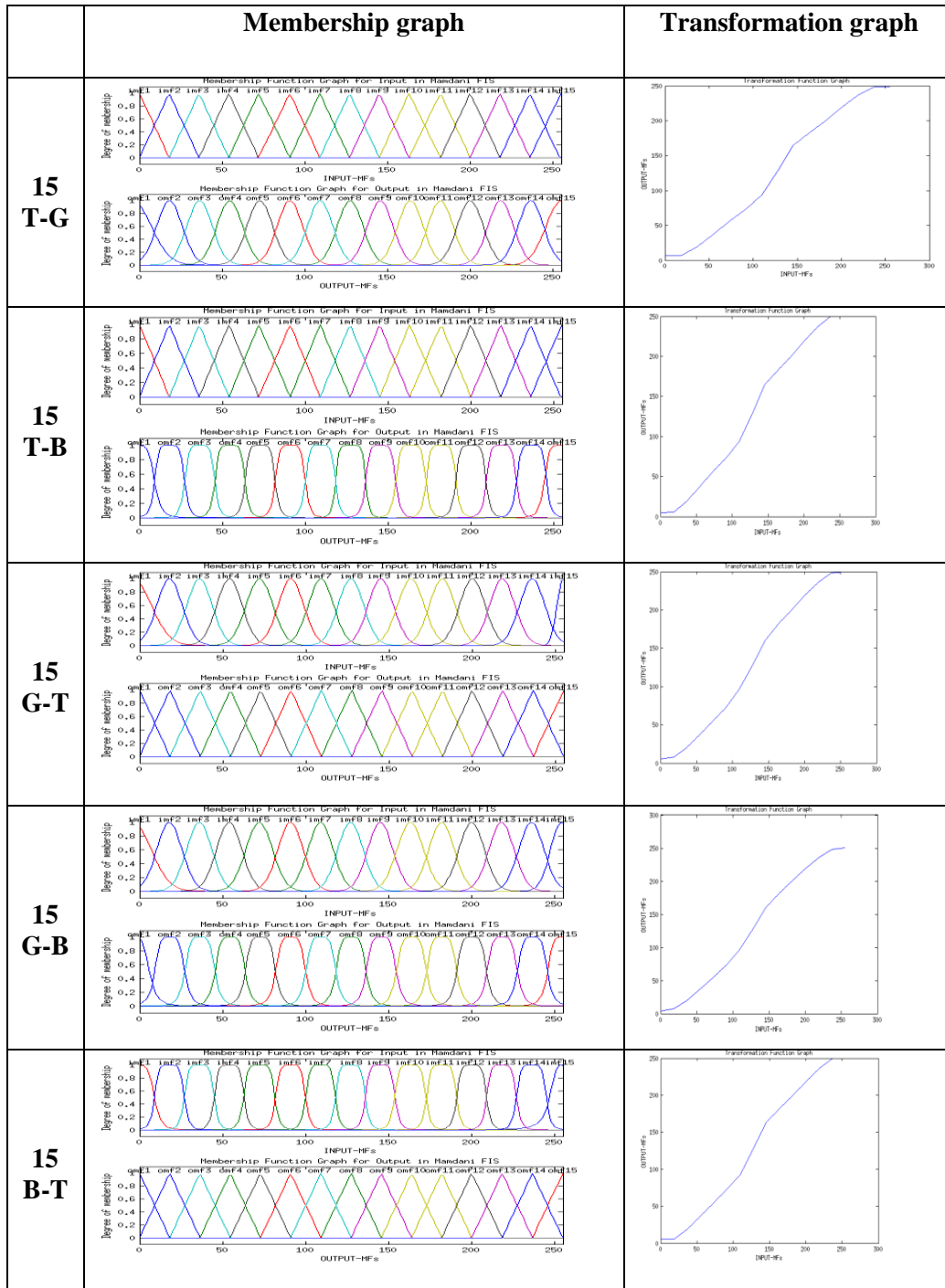
FIGURE 6.6: SAME MFS WITH 30 PARTITIONS

6.5.2 DIFFERENT MFs SELECTION IN FIS – CASE 2

This is based on the different MFs selection in FIS classified in four cases.

6.5.2.1 CASE-2A: DIFFERENT MFs WITH 15 PARTITIONS

In this case, a different type of membership function has been used in Mamdani FIS for 15 partitioning of the gray scale range which is from 0 to 255. Followings are the graphs of the membership functions and their combinations.



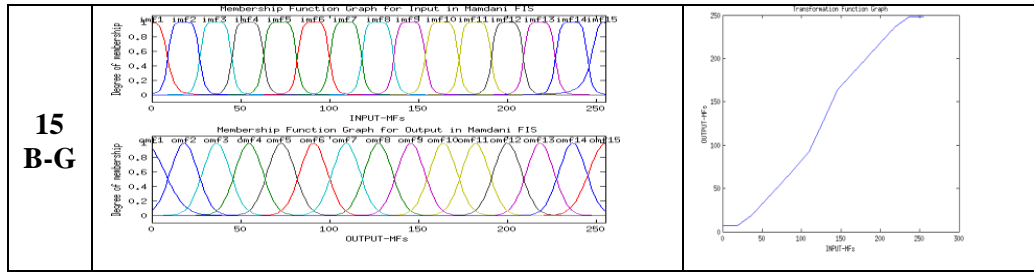
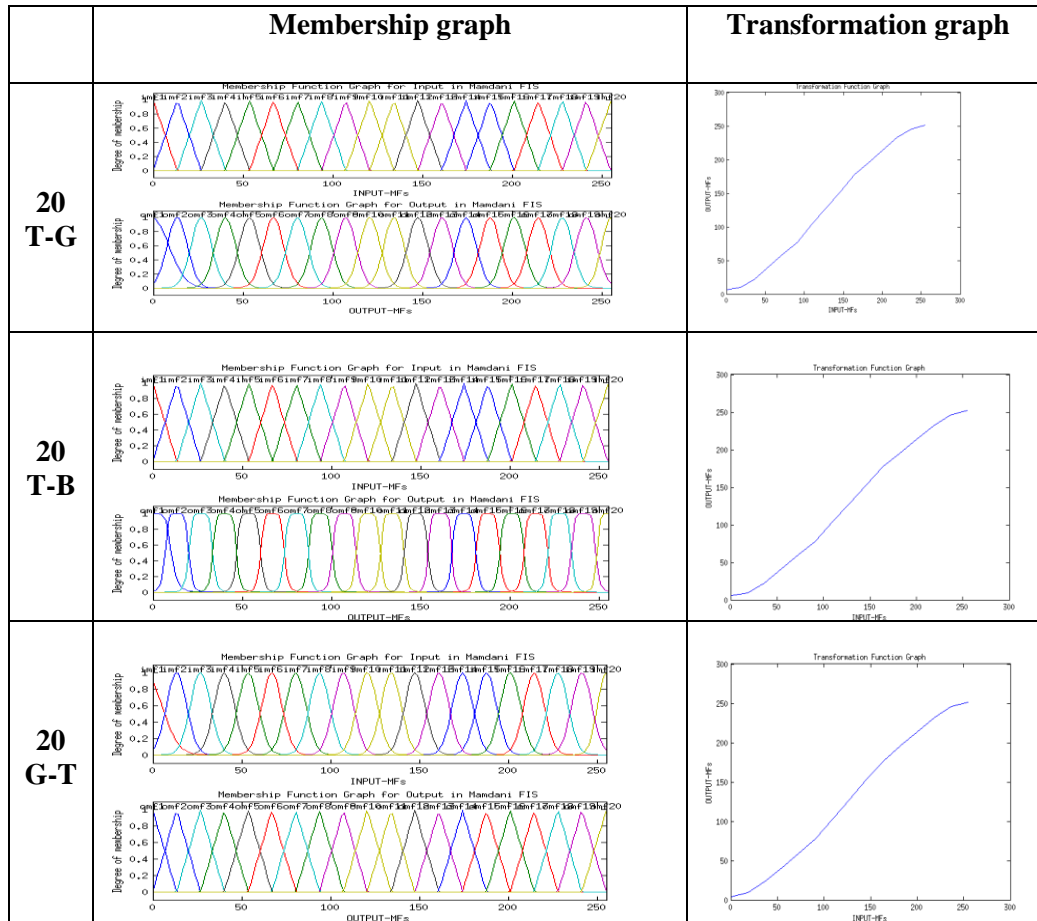


FIGURE 6.7: DIFFERENT MFS WITH 15 PARTITIONS

6.5.2.2 CASE-2B: DIFFERENT MFs WITH 20 PARTITIONS

In this case, a different type of membership function has been used in Mamdani FIS for 20 partitioning of the gray scale range which is from 0 to 255. Followings are the graphs of the membership functions and their combinations.



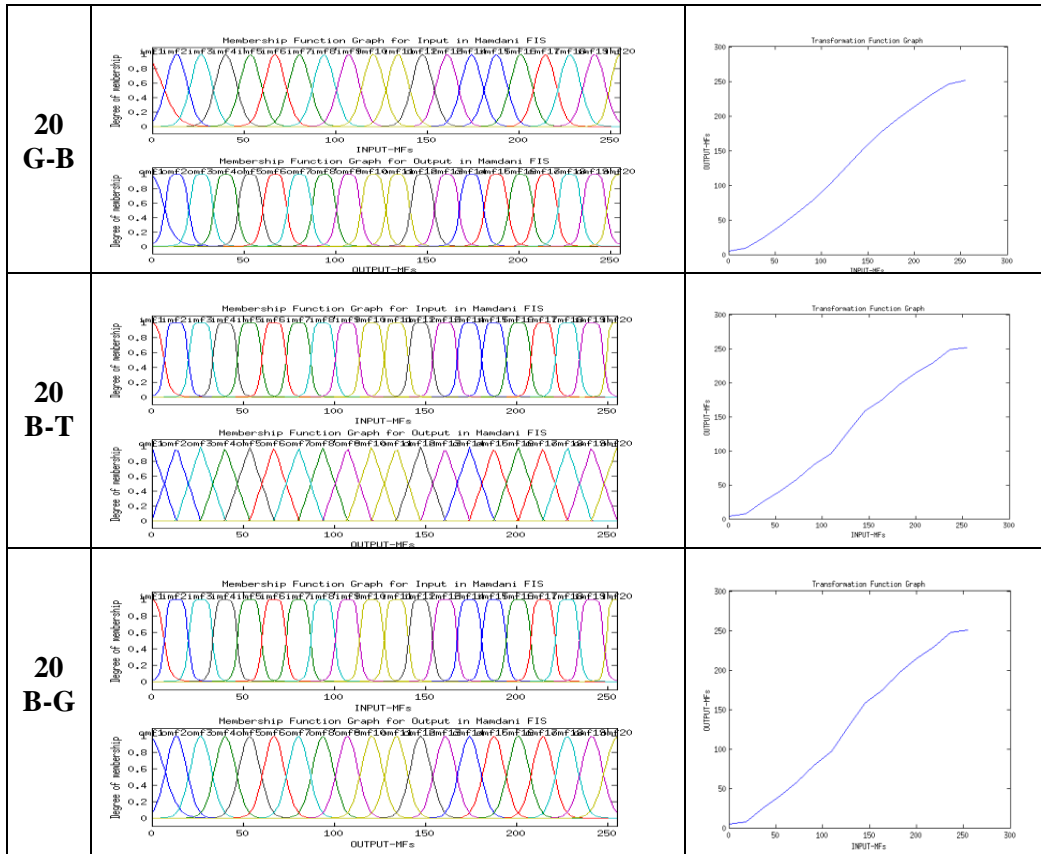
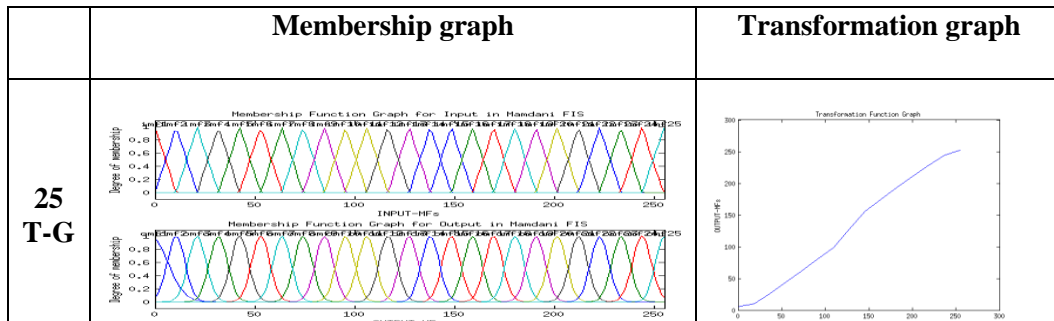


FIGURE 6.8: DIFFERENT MFS WITH 20 PARTITIONS

6.5.2.3 CASE-2C: DIFFERENT MF'S WITH 25 PARTITIONS

In this case, a different type of membership function has been used in Mamdani FIS for 25 partitioning of the gray scale range which is from 0 to 255. Followings are the graphs of the membership functions and their combinations.



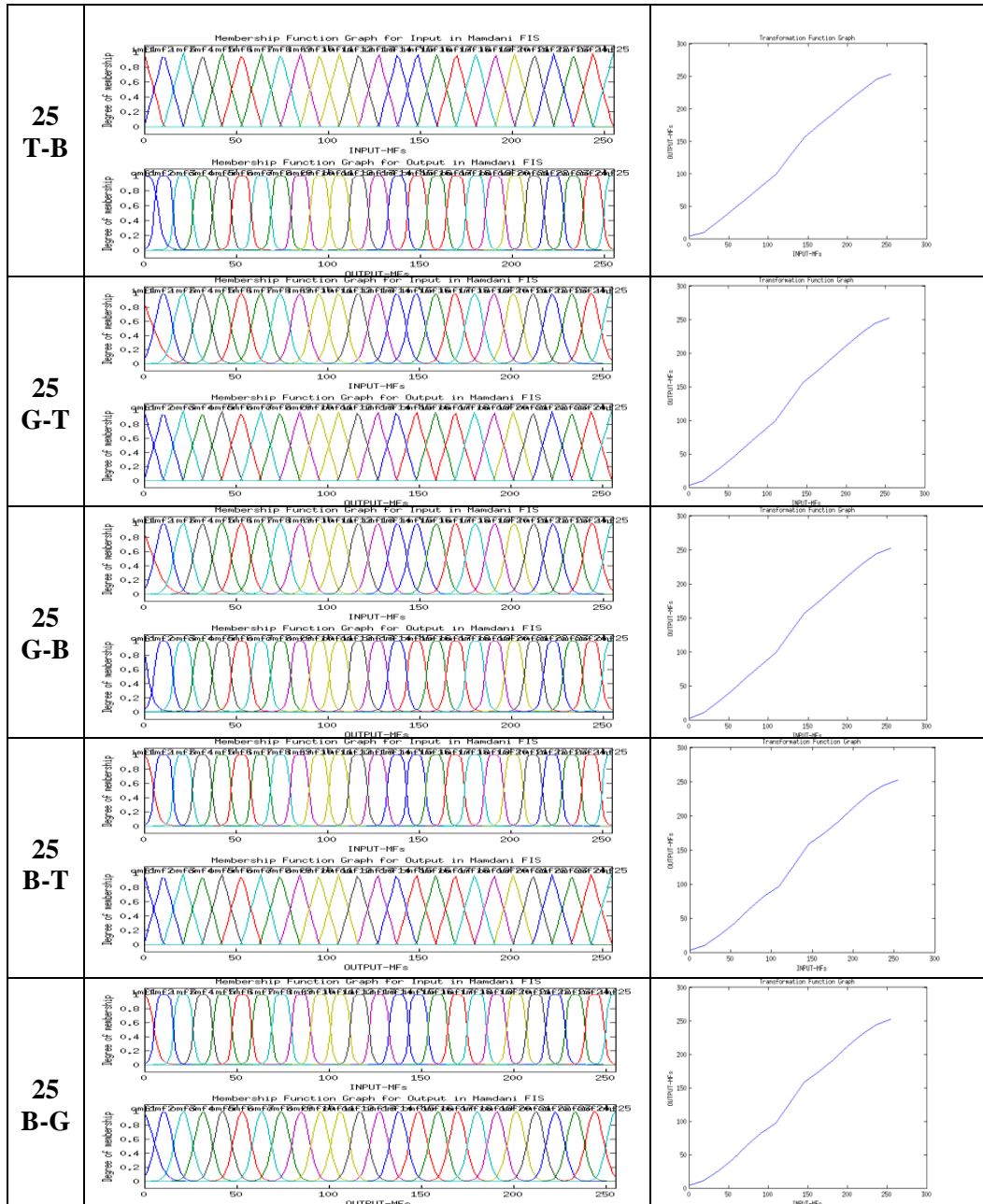


FIGURE 6.9: DIFFERENT MFS WITH 25 PARTITIONS

6.5.2.4 CASE-2D: DIFFERENT MFs WITH 30 PARTITIONS

In this case, a different type of membership function has been used in Mamdani FIS for 30 partitioning of the gray scale range which is from 0 to 255. Followings are the graphs of the membership functions and their combinations.

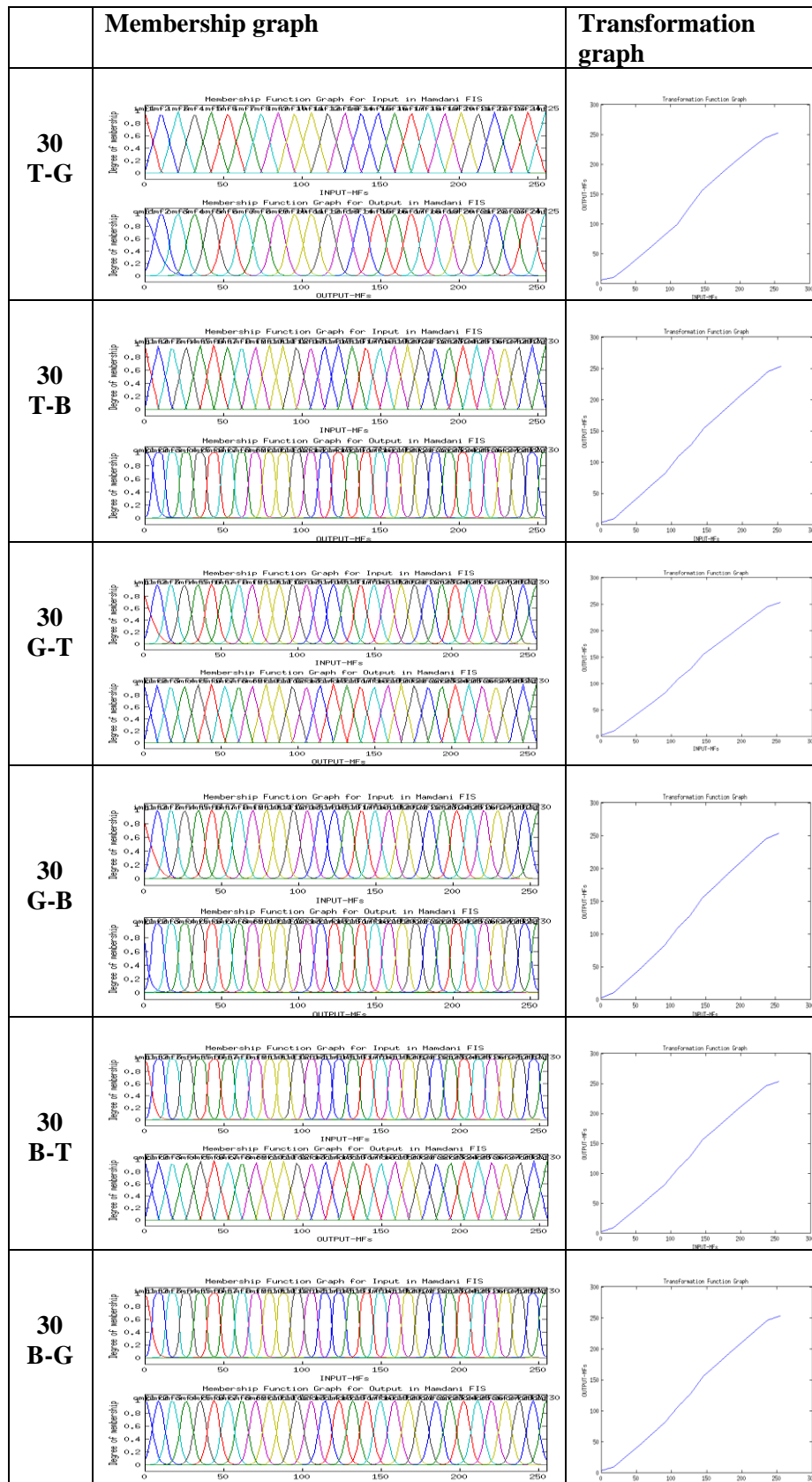


FIGURE 6.10: DIFFERENT MFS WITH 30 PARTITIONS

6.6 FUZZY OPTIMIZATION USING FUZZY IMAGE QUALITY FUNCTION

The fuzzy contrast of an image depends on how far an operator would stretch the membership function with respect to the reference point [98]. In this work, the multiple numbers and different membership functions are used. Thus, fuzzy optimization using fuzzy quality proposed in [98] can be applied for getting best membership function combinations from a set of MFs as described in section 3.1. The average value of fuzzy contrast gives the overall intensity of image while the only fuzzy contrast value indicates the spread of the gradient with respect to the reference point. The ratio of fuzzy average contrast to fuzzy contrast is the quality of the image in the fuzzy domain. Following is the algorithm of optimization using fuzzy quality.

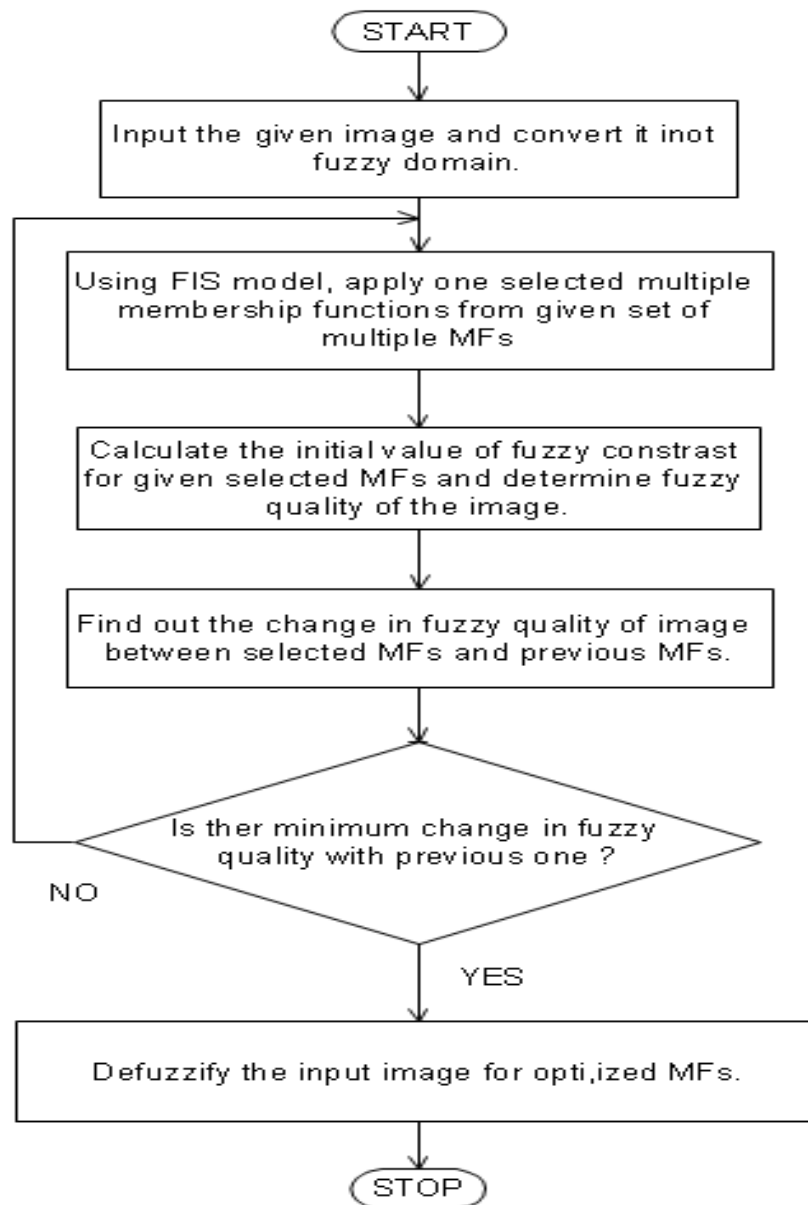


FIGURE 6.11: FLOW CHART FOR OPTIMIZATION ALGORITHM

Step 1: Input the given image and convert it into the fuzzy domain.

Step 2: In a fuzzy domain, apply one selected multiple membership functions from a given set of multiple MFs in section 3.1.

Step 3: Calculate the initial value of fuzzy contrast for given selected MFs and determine the fuzzy quality of the image.

Step 4: Find out the change in the fuzzy quality of image between selected MFs and previous MFs

Step 5: Repeat the step 2, 3 and 4, until the minimum change in fuzzy quality is obtained.

Step 6: Defuzzify the input image for optimized MFs.

6.7 EXPERIMENTAL STUDY

In the above figures on the basis of a transformation function, we can see the contrast enhancement of images. These transformation functions show better contrast enhancement of images visually. But person to person perception may be different to measure the contrast of images. To measure the better contrast of images some qualitative attributes are used like PSNR, Index of fuzziness (IOF). A higher value of these attributes shows better enhancement of contrast. In MATLAB, we have simulated the Mamdani FIS by considering the cases according to same types of MFs and different types of MFs as explained in the last section. In this section, simulation results by taking the all the cases in Mamdani FIS are presented in tabular form using IMAGE-1, IMAGE-2, IMAGE-3, and IMAGE-4.

TABLE 6.1: FROM CASE-1A, PSNR VALUES FOR 15 SAME MFS

Cases	Image 1	Image 2	Image 3	Image 4
T-T	36.4067	35.8818	37.3227	36.1043
G-G	36.5157	35.9416	37.5282	36.1805
B-B	36.296	35.7825	36.8351	35.9819

TABLE 6.2: FROM CASE-1B, PSNR VALUE FOR 20 SAME MFS

Cases	Image 1	Image 2	Image 3	Image 4
T-T	37.6673	37.162	39.1187	37.2796
G-G	37.8332	37.2124	39.3009	37.3338
B-B	37.6821	37.1169	38.7348	37.1798

TABLE 6.3: FROM CASE-1C, PSNR VALUE FOR 25 SAME MFS

Cases	Image 1	Image 2	Image 3	Image 4
T-T	38.5106	38.0118	38.8412	38.0853
G-G	38.5398	38.0414	39.0012	38.1178
B-B	38.4487	37.9750	38.6382	38.016

TABLE 6.4: FROM CASE-1D, PSNR VALUE FOR 30 SAME MFS

Cases	Image 1	Image 2	Image 3	Image 4
T-T	39.0890	38.8681	39.3676	38.9674
G-G	39.2085	38.8989	39.4493	38.9758
B-B	39.1347	38.8297	39.2441	38.8872

**TABLE 6.5: FROM CASE-1A, INDEX OF FUZZINESS (IOF)
FOR 15 SAME MFS**

Cases	Image 1	Image 2	Image 3	Image
T-T	0.3075	0.0349	0.3464	0.1096
G-G	0.3503	0.0372	0.3221	0.1061
B-B	0.2001	0.0387	0.1382	0.1318

**TABLE 6.6: FROM CASE-1B, INDEX OF FUZZINESS (IOF)
FOR 20 SAME MFS**

Cases	Image 1	Image 2	Image 3	Image 4
T-T	0.1856	0.0318	0.3976	0.0883
G-G	0.3566	0.0505	0.3166	0.0913
B-B	0.2043	0.0801	0.2175	0.1082

**TABLE 6.7: FROM CASE-1C, INDEX OF FUZZINESS (IOF)
FOR 25 SAME MFS**

Cases	Image 1	Image 2	Image 3	Image 4
T-T	0.4118	0.0678	0.3007	0.1037
G-G	0.4552	0.0513	0.3342	0.1
B-B	0.3015	0.0423	0.2105	0.1235

**TABLE 6.8: FROM CASE-1D, INDEX OF FUZZINESS (IOF)
FOR 30 SAME MFS**

Cases	Image 1	Image 2	Image 3	Image 4
T-T	0.0851	0.0485	0.3515	0.0762
G-G	0.2529	0.0946	0.3735	0.075
B-B	0.162	0.0504	0.2295	0.111

**TABLE 6.9: FROM CASE-2A, PSNR VALUES
FOR 15 DIFFERENT MFS**

Cases	Image 1	Image 2	Image 3	Image 4
T-G	36.4208	35.8924	37.3307	36.124
T-B	36.3884	35.8619	37.3156	36.0784
G-T	36.4933	35.9225	37.5135	36.1615
G-B	36.5123	35.9329	37.5122	36.1706
B-T	36.2942	35.7737	36.8521	35.9733
B-G	36.3159	35.7968	36.8656	36.0056

**TABLE 6.10: FROM CASE-2B, PSNR VALUE
FOR 20 DIFFERENT MFS**

Cases	Image 1	Image 2	Image 3	Image 4
T-G	37.6809	37.1701	39.1311	37.2949
T-B	37.6626	37.1573	39.1004	37.2702

G-T	37.8052	37.1984	39.2752	37.3164
G-B	37.8475	37.212	39.2922	37.3293
B-T	37.6653	37.1033	38.7221	37.1726
B-G	37.6873	37.1171	38.7477	37.1937

TABLE 6.11: FROM CASE-2C, PSNR VALUE FOR 25 DIFFERENT MFS

Cases	Image 1	Image 2	Image 3	Image 4
T-G	38.5273	38.0226	38.8585	38.0985
T-B	38.5094	38.0171	38.8541	38.0844
G-T	38.5163	38.0287	38.9814	38.104
G-B	38.5329	38.0406	38.9954	38.1161
B-T	38.4304	37.9615	38.6298	38.0062
B-G	38.4534	37.9744	38.6475	38.0206

TABLE 6.12: FROM CASE-2D, PSNR VALUE FOR 30 DIFFERENT MFS

Cases	Image 1	Image 2	Image 3	Image 4
T-G	38.5273	38.0226	38.8585	38.0985
T-B	39.0854	38.8745	39.3585	38.9611
G-T	39.2076	38.8924	39.4546	38.9871
G-B	39.2124	38.8962	39.4459	38.9895
B-T	39.1289	38.823	39.2486	38.8827
B-G	39.1311	38.8308	39.2489	38.8894

TABLE 6.13: FROM CASE-2A, INDEX OF FUZZINESS (IOF) FOR 15 DIFFERENT MFS

Cases	Image 1	Image 2	Image 3	Image 4
T-G	0.3137	0.037	0.3579	0.1063
T-B	0.3527	0.0464	0.3654	0.1047
G-T	0.1797	1.6277	1.5273	0.1053
G-B	0.3086	0.0349	0.3229	0.1058
B-T	0.1951	0.0262	0.1322	0.1305
B-G	0.2006	0.0302	0.1391	0.1306

**TABLE 6.14: FROM CASE-2B, INDEX OF FUZZINESS (IOF)
FOR 20 DIFFERENT MFS**

Cases	Image 1	Image 2	Image 3	Image 4
T-G	0.1856	0.0237	0.3848	0.0889
T-B	0.1401	0.0156	0.3652	0.0954
G-T	0.3597	0.0537	0.3304	0.088
G-B	0.3464	0.0561	0.3193	0.0947
B-1	0.1923	0.0958	0.2574	0.1014
B-G	0.183	0.0898	0.2313	0.1048

**TABLE 6.15: FROM CASE-2C, INDEX OF FUZZINESS (IOF)
FOR 25 DIFFERENT MFS**

Cases	Image 1	Image 2	Image 3	Image 4
T-G	0.4177	0.0668	0.3043	0.1023
T-B	0.4237	0.0595	0.3158	0.1022
G-T	0.4456	0.0532	0.3504	0.0984
G-B	0.4552	0.041	0.3088	0.1033
B-T	0.3188	0.0553	0.2192	0.1205
B-G	0.3203	0.0543	0.2116	0.1206

**TABLE 6.16: FROM CASE-2D, INDEX OF FUZZINESS (IOF)
FOR 30 DIFFERENT MFS**

Cases	Image 1	Image 2	Image 3	Image 4
T-G	0.4177	0.0668	0.3043	0.1023
T-B	0.0766	0.0541	0.3323	0.0800
G-T	0.2551	0.0905	0.3713	38.9871
G-B	0.2411	0.0954	0.3463	0.0797
B-T	0.1493	0.0444	0.2142	0.1152
B-G	0.1606	0.0484	0.2295	0.112

6.8 RESULTS AND DISCUSSIONS

Obtained enhanced images using these input images in the case of same and different membership functions are shown in figures in this section. Case 1A, 1B, 1C, 1D are showing the same membership functions results and Case 2A, 2B, 2C, 2D are showing different membership function results.

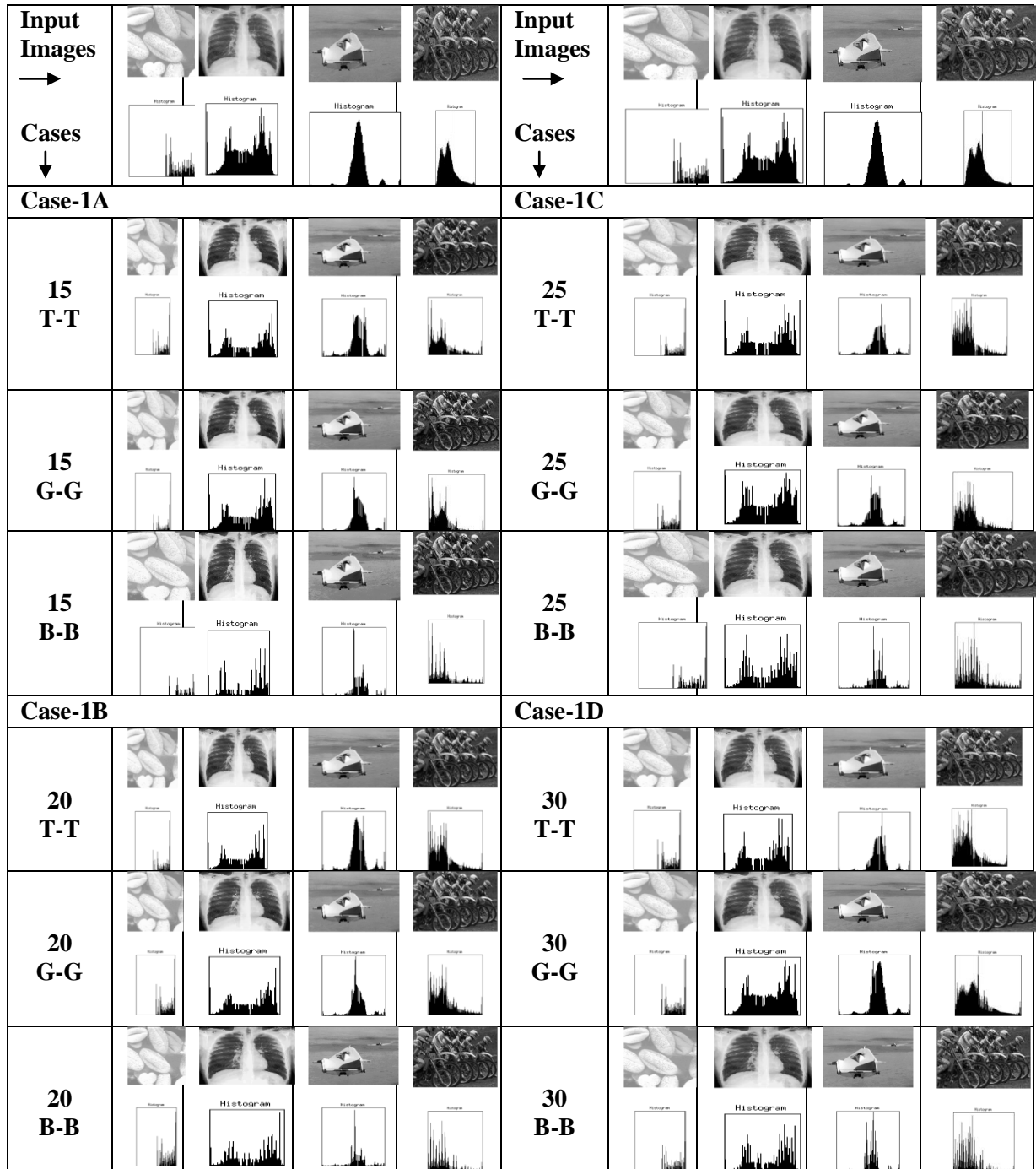


FIGURE 6.12: RESULTS FOR 15, 20, 25, 30 SAME MEMBERSHIP FUNCTIONS

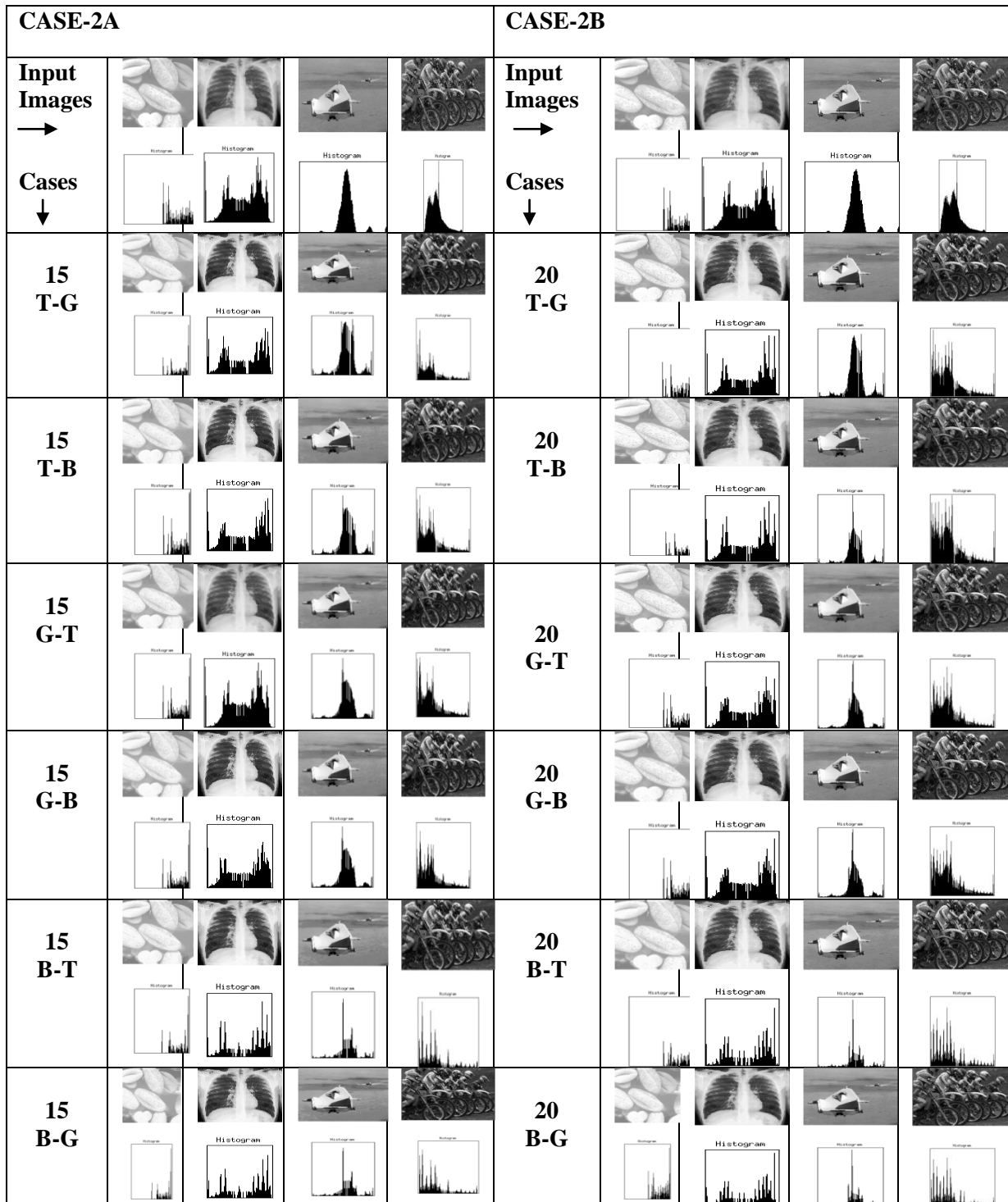


FIGURE 6.13: RESULTS FOR 15, 20 DIFFERENT MEMBERSHIP FUNTIONS

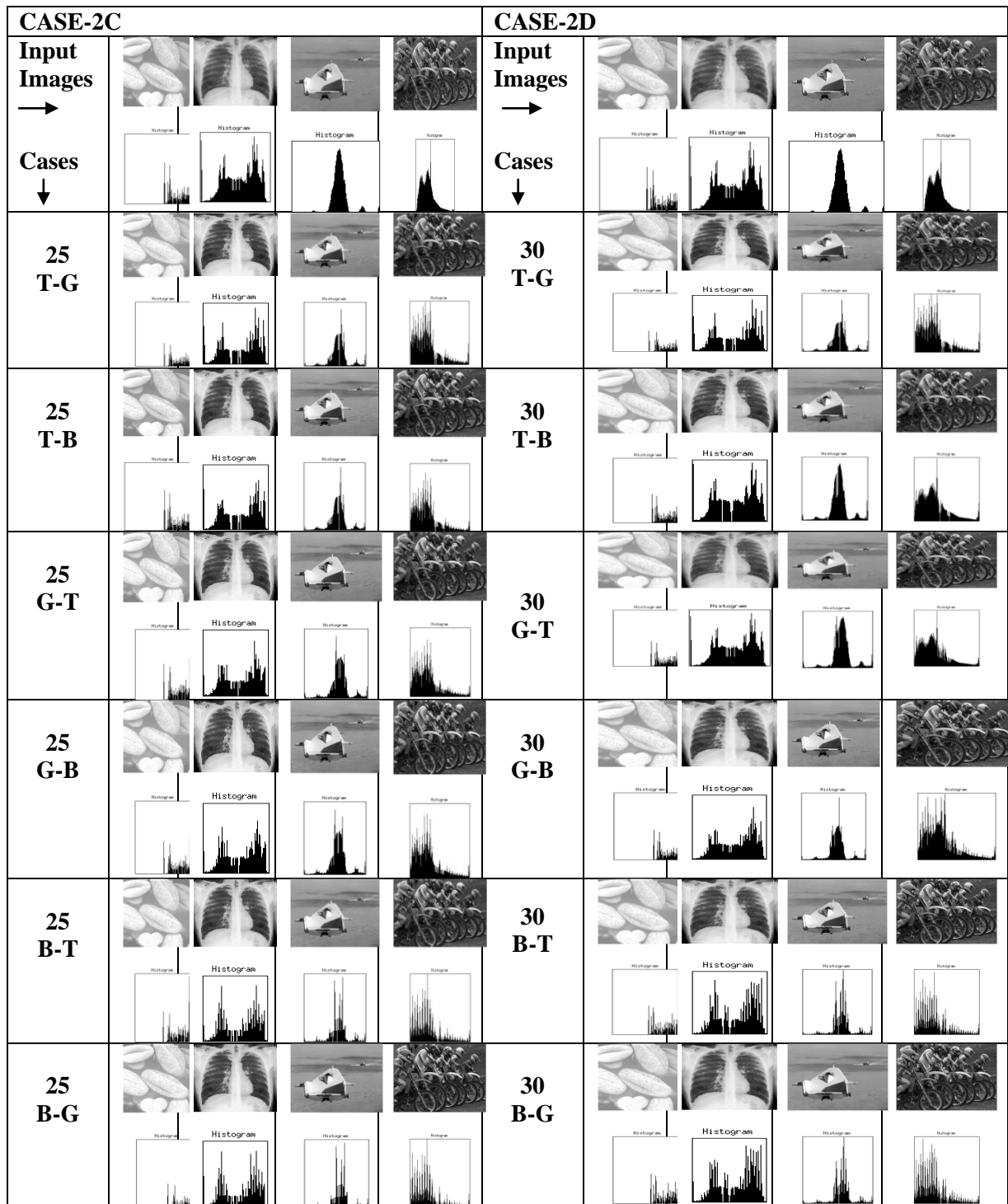


FIGURE 6.14: RESULTS FOR 25, 30 DIFFERENT MEMBERSHIP FUNCTIONS

6.9 RESULT ANALYSIS USING FUZZY OPTIMIZATION

In this subsection, simulation results by taking the best case using fuzzy optimization in Mamdani FIS are presented using four different types of input (IMAGE-1, IMAGE-2, IMAGE-3 and IMAGE-4) are as show in Fig. 6. These results are produced based on the selection of best MFs combinations obtained for the fuzzy quality parameter in the optimization algorithm. It indicates that the cases 1D, 2A and 2C are found to be best MFs in Mamdani FIS for image contrast enhancement. The cases are shown with incremental enhanced of contrast enhancement. It is observed using different cases that as per application requirement, the best-optimized MFs can be selected using our fuzzy optimization algorithm. Tables 1 and 2 show the PSNR and IOF parameters for obtained results using cases 1D, 2A, and 2C.

TABLE 6.17: RESULTS FOR PSNR CALCULATIONS IN INCREASE ORDER FOR DIFFERENT CASES BY OPTIMIZATION ALGORITHM

Input Image types	Gaussian -Gaussian MFs (1D Case: 25G-G)	Gaussian – Triangular (2A Case: 15G-T)	Gaussian - Bell Shape (2C Case: 25G-T)
IMAGE 1	37.371	36.4933	36.884
IMAGE 2	36.972	35.9225	35.982
IMAGE 3	36.154	37.5135	37.572
IMAGE 4	37.103	36.1615	36.186


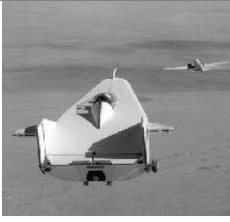

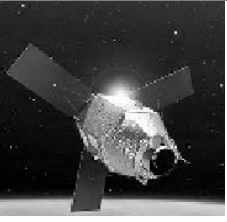



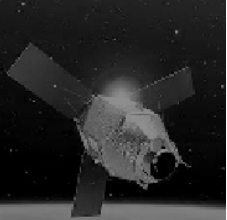



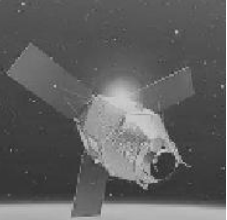

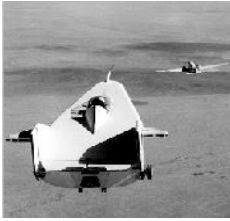

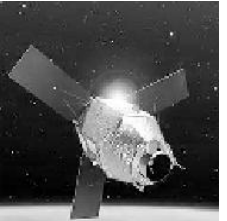
	(a) IMAGE-1	(b) IMAGE-2	(c) IMAGE-3	(d) IMAGE-4
Input images				
CASE –ID (25 G-G) Gaussian - Gaussian MFs				
	PSNR = 37.371 IOF = 0.01470	PSNR = 36.972 IOF = 0.01523	PSNR = 36.154 IOF = 0.1986	PSNR = 37.103 IOF = 0.1721
CASE–2A (15 G-T) Guassian - Triangular MFs				
	PSNR = 36.4933 IOF = 0.01509	PSNR = 35.9225 IOF = 0.01526	PSNR = 37.5135 IOF = 0.2185	PSNR = 36.1615 IOF = 0.1538
CASE–2C (25 G-T) Gaussian- Bell Shape MFs				
	PSNR = 36.884 IOF = 0.01797	PSNR = 35.982 IOF = 0.01263	PSNR = 37.572 IOF = 0.2176	PSNR = 36.186 IOF = 0.1483

FIGURE 6.15 : RESULTS USING DIFFERENT MEMBERSHIP FUNCTIONS(MFS) FOR (A) IMAGE-1,(B) IMAGE-2, (C) MAGE-3, (D) IMAGE-4.

**TABLE 6.18: RESULTS FOR IOF CALCULATIONS IN INCREASE ORDER FOR
DIFFERENT CASES BY OPTIMIZATION ALGORITHM**

Input Image types	Gaussian -Gaussian MFs(1D Case: 25G-G)	Gaussian – Triangular (2A Case: 15G-T)	Gaussian -Bell Shape (2C Case: 25G-T)
IMAGE 1	0.01470	0.01509	0.01797
IMAGE 2	0.01523	0.01526	0.01263
IMAGE 3	0.1986	0.2185	0.2176
IMAGE 4	0.1721	0.1538	0.1483

6.10 RESULT ANALYSIS WITH EXISTING TECHNIQUES

In this subsection, based on results obtained using fuzzy quality-based optimization in the selection of best membership function in the fuzzy domain, case 2C- 25G-T is identified as best possible MFs in Mamdani FIS as shown in the previous section. Here, a comparative analysis is presented with existing fuzzy based techniques for image contrast enhancement. Followings are the algorithms used for comparisons:

- (i) Simple If-Then Fuzzy Rule-based [23],
- (ii) Fuzzy Distribution based [78],
- (iii) Fuzzy Hyperbolization based [121],
- (iv) Brightness Preserving and Non-parametric modified Bi-histogram Equalization (BPNMBHE) [151], and
- (v) Our approach using optimization of MFs.






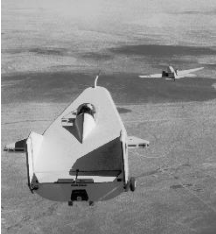

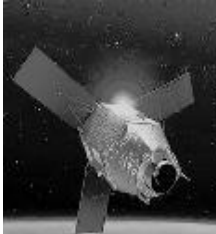
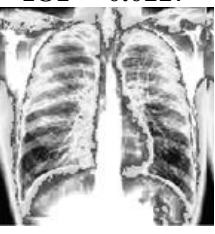










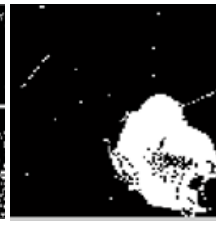
	(a) IMAGE-1	(b) IMAGE-2	(c) IMAGE-3	(d) IMAGE-4
Proposed method	 PSNR = 36.884 IOF = 0.01797	 PSNR = 35.982 IOF = 0.01263	 PSNR = 37.572 IOF = 0.2176	 PSNR = 36.186 IOF = 0.1483
BPNMBHE [18]	 PSNR = 38.3051 IOF = 0.0117	 PSNR = 33.996 IOF = 0.0089	 PSNR = 35.052 IOF = 0.0963	 PSNR = 34.248 IOF = 0.0483
Fuzzy IF-THEN Rule-based [4]	 PSNR = 31.9351 IOF = 0.12293	 PSNR = 30.7308 IOF = 0.184505	 PSNR = 30.8043 IOF = 0.14138	 PSNR = 30.8043 IOF = 0.14138
Fuzzy Distribution based [7]	 PSNR = 29.2057 IOF = 0.13184	 PSNR = 27.0389 IOF = 0.0961	 PSNR = 29.4361 IOF = 0.031084	 PSNR = 27.5133 IOF = 0.188
Fuzzy Hyperbolization based [8]	 PSNR = 28.0798 IOF = 0.21201	 PSNR = 24.1215 IOF = 0.21201	 PSNR = 27.2927 IOF = 0.21201	 PSNR = 25.5671 IOF = 0.21061

FIGURE 6.16: RESULTS ANALYSIS WITH PROPOSED METHOD AND EXISTING TECHNIQUES FOR GIVEN IMAGES

**TABLE 6.19: RESULTS FOR PSNR CALCULATIONS WITH EXISTING FUZZY
BASED TECHNIQUES**

Input Image types	Our approach	BPNMBHE [18]	Fuzzy IF-THEN rule-based [4]	Fuzzy Distribution based [7]	Fuzzy Hyperbolization based [8]
IMAGE 1	36.884	38.3051	31.9351	29.2057	28.0798
IMAGE 2	35.982	33.996	30.7308	27.0389	24.1215
IMAGE 3	37.572	35.052	30.8043	29.4361	27.2927
IMAGE 4	36.186	34.248	30.8043	27.5133	25.5671

**TABLE 6.20: RESULTS FOR IOF CALCULATIONS WITH EXISTING FUZZY
BASED TECHNIQUES**

Input Image types	Our approach	BPNMBHE [151]	Fuzzy IF-THEN rule-based [23]	Fuzzy Distribution based [78]	Fuzzy Hyperbolization based [121]
IMAGE 1	0.01797	0.0117	0.12293	0.13184	0.21201
IMAGE 2	0.01263	0.0089	0.184505	0.0961	0.21201
IMAGE 3	0.2176	0.0963	0.14138	0.031084	0.21201
IMAGE 4	0.1483	0.0483	0.14138	0.188	0.21061

6.11 CONCLUSION

This chapter proposes Mamdani FIS for multiple membership functions such as 15, 20, 25, and 30. As per value of PSNR and IOF, it is observed that increment of membership function in FIS gives better contrast enhancement, it also is shown by histogram of output images versus input images also with the help of experimental values in the case when we are taking some kind of membership functions, Gaussian and Gaussian combination giving better results and when we are taking different membership functions, in this case, Gaussian and bell functions giving better results. But these increments of membership function has some limitation, like in case of 25 MFs and 30 MFs PSNR values are near about means after some increment of membership function there is study state of membership functions.

After that increment of membership function doesn't enhance results or slight changes in results.

After analysis with cases, a new optimization method using multiple membership functions such as 15, 20, 25, and 30 in Mamdani FIS system is proposed. It is found that the selection of membership functions in the fuzzy domain while converting and modifying the intensity levels in the image is important as per types of the input image. In this chapter, a fuzzy quality parameter is used to obtain the best-fitted MFs that give best-enhanced results of the input images. As per value of PSNR and IOF, it is observed that increment of membership function in FIS gives better contrast enhancement as calculated using fuzzy quality optimization. It is also shown that the Gaussian and Gaussian combination indicates better results. Based on a comparative study of existing fuzzy based techniques, results obtained are more improved and shown to be best visual enhanced images in terms of contrast and clarity. The PSNR and IOF results using our MFs in FIS show the out of performance than that of existing algorithms such as Simple If-then fuzzy Rule-based [23], Fuzzy Distribution based [78], Fuzzy Hyperbolization based [121], Brightness Preserving and Non-parametric modified Bi-histogram Equalization (BPNMBHE) [151]. As a resultant, the motivation is to design a weight based fuzzy neural model, which can take into account all the combinations of various MFs to capture the best-optimized MFs for Mamdani FIS system.

CHAPTER VII

Comparative Study on Edge Detection in Classical and Fuzzy Domains

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CHAPTER VII

COMPARATIVE STUDY ON EDGE DETECTION IN CLASSICAL AND FUZZY DOMAIN

This chapter is based on various spatial edge detection methods and fuzzy based edge detection methods. An edge detection based comparative analysis is presented using the spatial edge detection methods and fuzzy if-then-else methods for determining the advantage and disadvantage in terms of more suitability in edges. A change of intensity is an important issue of the edge detection. In the spatial edge detection method, various masks are used to detect edges and in the fuzzy domain, masks are used with the fuzzy if-then-else method. It is helpful to analyze an image in various applications. An image segmentation is an area in which image is subdivided into sub-regions for extracting characteristics of images which will help to analysis in various applications. Forgetting accuracy sharp changes of intensity is an important issue which is known as edge detection. Various spatial edge detection method and fuzzy based edge detection method are included.

7.1 RELATED WORK

The first category is describing a partition of images based on Sharpe changes in intensity known as edge and the second category is based on a set of predefined criteria known as thresholding, region growing and region splitting and merging [1] [2]. With the help of thresholding edge, detection can be possible to overcome the criteria of the noisy condition. In this method first order derivative of a Gaussian filter used for convolving the images [3]. Edges found by canny can also create some false edges.

The structure of the image can also find with the help of a method known as USAN, which is helpful in edge detection [4]. Edges may also find Edges may also find with the help of zero crossing [5]. For the measurement of the degree of fuzziness, entropy has used, which produced 1-pixel wide edges [6]. Image segmentation is a difficult task to make images meaningful. By using a canny method image segmentation may give many false edges to increase the complexity of image characteristics. Instead of the Canny method, two steps Chan These method is helpful to detect best edges [7]. All the classical spatial methods like Canny edge detector, Sobel method, Prewitt edge detection, and Laplacian of Gaussian are not been able to detect correct and smooth edges in images. Latterly a new method intuitionistic fuzzy set (IFS) theory was proposed to detect correct and smooth edges. The intuitionistic fuzzy method used the concept of entropy in various clustering algorithm [9].

7.2 EDGE DETECTION METHODS

Following are the two domains of edge detection methods; one is spatial domain edge detection methods and second is fuzzy domain edge detection methods.

7.2.1 SPATIAL DOMAIN EDGE DETECTION TECHNIQUES

Spatial filtering is used in the Edge detection to used break off between gray levels. For the edge detection in images, first-order derivative and second order derivatives are used. First order derivative is worked out by using gradient and second order derivative are found by the Laplacian.

7.2.2 GRADIENT OPERATOR

The gradient of an image $f(x, y)$ at a location (x, y) is defined as the vector:

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} \begin{bmatrix} \frac{\partial t}{\partial x} \\ \frac{\partial t}{\partial y} \end{bmatrix} \quad (7.1)$$

The magnitude of the above vector:

$$\nabla f = \text{mag}(\nabla f) \sqrt{G_x^2 + G_y^2}$$

The direction of the gradient vector:

$$\alpha(x, y) = \tan^{-1} \left(\frac{G_x}{G_y} \right) \quad (7.2)$$

7.2.2.1 SOBEL MASK

Mask used by this method is:

-1	-2	-1
0	0	0
1	2	1

-1	0	-1
-2	0	-2
-1	0	1

FIGURE 7.1: SOBEL MASK

Using the below equations Sobel mask is used for edge detection.

$$G_x = (Z_7 + 2Z_8 + Z_9) - (Z_1 + 2Z_2 + Z_3) \quad (7.3)$$

$$G_y = (Z_3 + 2Z_6 + Z_9) - (Z_1 + 2Z_4 + Z_7) \quad (7.4)$$

7.2.2.2 PREWITT MASK

Mask used by this method is:

-1	0	1
-1	0	1
-1	0	1

-1	-1	-1
0	0	0
1	1	1

FIGURE 7.2: PREWITT MASK

Using the below equations Prewitt mask is used for edge detection.

$$G_x = (Z_7 + Z_8 + Z_9) - (Z_1 + Z_2 + Z_3) \quad (7.4)$$

$$G_y = (Z_3 + Z_6 + Z_9) - (Z_1 + Z_4 + Z_7) \quad (7.5)$$

7.2.2.3 ROBERT MASK

Mask used by this method is:

-1	0
0	1

0	-1
1	0

FIGURE 7.3: ROBERT MASK

Using the below equations Robert mask is used for edge detection.

$$G_x = (Z_9 - Z_5) \quad (7.6)$$

$$G_y = (Z_8 - Z_6) \quad (7.7)$$

7.2.2.4 CANNY EDGE DETECTION

- It uses smoothing as a process to remove noise.
- Finding the gradient of images which has a large magnitude.
- By using double thresholding.

7.2.2.5 LAPLACIAN

The Laplacian of a 2-D function $f(x, y)$ is a second-order derivative. The Laplacian is merged with smoothing to find edges via zero-crossing.

0	-1	0
-1	4	-1
0	-1	0

-1	-1	-1
-1	8	-1
-1	-1	-1

FIGURE 7.4: LAPLACIAN MASK

In Laplacian filtering, enhanced image can be found by:

$$F'(x, y) = F(x, y) + C\nabla F(x, y) \quad (7.8)$$

7.2.2.6 LAPLACIAN OF A GAUSSIAN

Laplacian of a Gaussian sometimes is called the Mexican hat function. The Gaussian function is used to smooth the image and Laplacian operator is used to constitute the location of edges by zero findings. Here, Figure-5 is a 5×5 mask to approximate the shape of Mexican hat function.

0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	16	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

FIGURE 7.5: LAPLACIAN OF GAUSSIAN FILTER

7.2.3 FUZZY EDGE DETECTION METHODS

In many applications, edge detection becomes very important due to the criticality of the use of images like in medical images diagnosis of disease is very crucial. Due to this reason, images must be free of poor contrast, vagueness, blurred or broken edges. That's why because of the above reasons fuzzy method is suitable to take into account the unclearness and equivocalness present in the image [17]. Several Fuzzy edge detection methods are the following:

7.2.3.1 FUZZY SOBEL EDGE DETECTION

In this method the image is divided into two regions:

i. Fuzzy edge region

In this method, if pixels have a high difference in the gray level with their neighborhood region then the pixels are separated by the fuzzy edge region.

ii. Fuzzy smooth region

In this method, if pixels have less difference of gray level with their neighborhood region then the pixels are separated by the fuzzy smooth region.

By using fuzzy reasoning the modified fuzzy edge detector is generalized by using the following fuzzy rules:

$$R(x, y) = \begin{cases} 255, & \text{if } G(x, y) \geq HT \\ 0, & \text{if } G(x, y) \leq LT \\ G(x, y) \cdot \max(\mu_{SFR}(x, y), \mu_{EFR}(x, y)) & \text{Otherwise} \end{cases} \quad (7.6)$$

Where μ_{SER} and μ_{EFR} are the membership functions of the image smooth and edge regions.

$G(x, y)$ is the gradient value using a Sobel operator. $R(x, y)$ is the resultant pixel at location (x, y) .

7.2.3.2 ENTROPY-BASED FUZZY EDGE DETECTION

As per information theory, the defined formula of entropy is given as:

$$H(t_1, t_2) = -P_{smooth} \log_2(P_{smooth}) - P_{edge} \log_2(P_{edge}) \quad (7.12)$$

Where P_{edge} and P_{smooth} are Probability distributions.

$$P_{edge} = \sum_k h g_k \cdot \mu_{edge}(k) \quad (7.13)$$

$$P_{smooth} = \sum_k h g_k \cdot \mu_{smooth}(k) \quad (7.14)$$

Here P_{smooth} and P_{edge} are weight area on the gradient histogram and when membership function μ_{smooth} and μ_{edge} are weights.

In edge detection, the best parameter values are compact edge representation of images that's why minimum entropy $H(t_1, t_2)$ parameters are selected. The necessary assumptions for minimum and maximum entropy are:

$$\partial H(t_1, t_2) / \partial t_1 = 0 = -(\partial P_{smooth} / \partial t_1 \times \log(P_{smooth} / P_{smooth})) \quad (7.15)$$

$$\partial H(t_1, t_2) / \partial t_2 = 0 = -(\partial P_{smooth} / \partial t_2 \times \log(P_{smooth} / 1 - P_{smooth})) \quad (7.16)$$

The entropy will be minimized, When

$$P_{smooth} = P_{edge} = 1/2 \quad (7.17)$$

The best set of parameter $(\tilde{t}_1, \tilde{t}_2)$ will satisfy the following condition:

$$H(\tilde{t}_1, \tilde{t}_2) = \min_{r=0,1,2\dots R}(H(t_1(r), t_2(r))) \quad (7.18)$$

The edge image is calculated as

$$\text{Edge - image}(x, y) = 1 \quad (7.19)$$

7.2.3.3 FUZZY TEMPLATE BASED EDGE DETECTION

Two types of fuzzy template based edge detector method are available. In the first method, fuzzy edge templates are designed and these templates are convolved with the image [12].

For finding the existence of edge:

$$H(x, y) = \max_{T=1, \text{to } n} (H_T(x, y)) \quad (7.20)$$

Where n=number of templates.

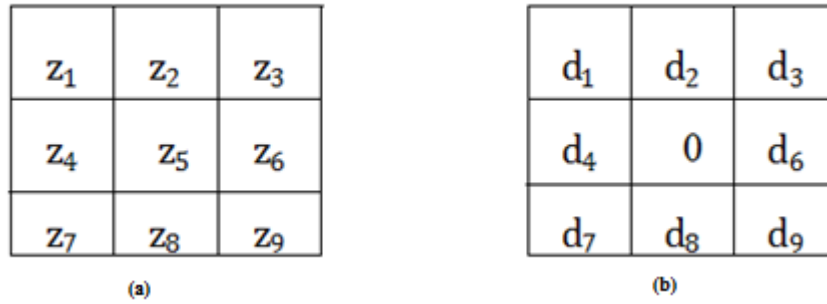
The new images are found with the support of threshold, the value which is below the threshold is set to 0 and above the threshold is set as 1. In the second method fuzzy divergence used in between image window and a set of 16 fuzzy templates [8].

7.2.3.4 FUZZY IF-THEN RULES BASED EDGE DETECTION

The fuzzy rule-based concept has been taken from Fuzzy set theory [14] [15] because of its simplicity and effectiveness. It is an inference form of uncertain knowledge to handle and analyze information in an effective manner. It could be combined different filters along with fuzzy if-then rules to detect edges for enhancement of images [16]. For edge detection fuzzy logic algorithm using the following rules:

(1) If a pixel belongs to the same region, then make it brighter; else make it darker, where values related to brighter and darker are fuzzy sets.

(2) A 3x3 pixel neighborhood and corresponding intensity differences between the center pixels and its neighbors are shown below.



**FIGURE 7.6: 3X3 NEIGHBORHOOD : (A) PIXEL NEIGHBORHOOD
(B) INTENSITY DIFFERENCE**

Here, $d_i = z_i - z_5$, for $i = 1, 2, \dots, n$. The d_i denotes the intensity difference between the i th neighbor and the center point.

The followings are the if-then-else rules based on fuzzy values.

IF d_2 is zero AND d_6 is zero THEN z_5 is white

IF d_6 is zero AND d_8 is zero THEN z_5 is white

IF d_8 is zero AND d_4 is zero THEN z_5 is white

IF d_4 is zero AND d_2 is zero THEN z_5 is white

ELSE z_5 is black

Membership functions zero, black, and white are used for the fuzzy sets zero, black, and white respectively. These are shown in Figure 7.7.

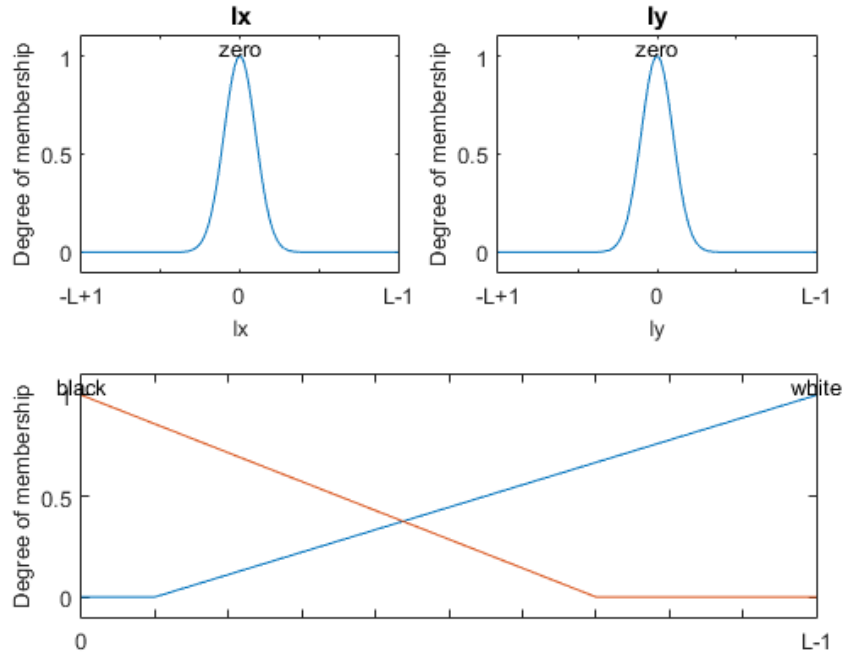


FIGURE 7.7: MEMBERSHIP FUNCTIONS (ZERO, BLACK AND WHITE)

7.2.3.5 FUZZY AND PSO BASED EDGE DETECTION

Edge detection method using particle swarm optimization (PSO) is one of the fuzzy-based identification of edge-strength for various imaging applications [78]. It detects the edge via edge-strength estimation using fuzzy reasoning and optimization using PSO. In this method, the intensity change in gray value is measured by edge-strength value. To estimate the edge-strength, fuzzy rules have been developed. After this, edges in the image are identified based on threshold value obtained using fuzzy reasoning from rules. Further, the possibility of false edge-detection is minimized by particle swarm optimization approach. Followings are the steps involved in this method.

Step-1: Estimation of edge-strength based on gradient G_x and G_y along the horizontal and vertical direction. After this, fuzzy rules are applied. The gradient value is calculated [78] as

$$G(x, y) = |G_x| + |G_y| \quad (7.21)$$

The rules are given by authors as follows.

IF G_x is Low AND G_y is Low THEN edge – strengt H is Low

IF G_x is Low AND G_y is High THEN edge – strengt H is Medium

IF G_x is High AND G_y is Low THEN edge – strengt H is Medium

IF G_x is High AND G_y is High THEN edge – strengt H is High

Step-02: Edge-strength threshold selection for differentiating edge pixels from non-edge pixels in the image. For this, trapezoidal membership functions are used to represent the conditional probabilities for a pixel to be “edge” or “no edge” in given edge-strength of the pixel.

Step-03: Optimization using PSO is used to minimize the error for detecting the false edges.

7.3 SIMULATIONS AND RESULT ANALYSIS

This chapter compares various classical method of edge detection and various fuzzy edge detection methods. Based on performance evaluation parameters, we can compare all these methods. For experimental analysis of edge detection, eight different gray images have been used to evaluate the performance as shown in figure 7.8. To detection of efficient edge pixels, the statistical mean and variance model has been used in our simulations for effectiveness quantitatively. For the general case based on statistical analysis, measured higher mean and lower variance value using any method are able to show better edges. Classical methods and fuzzy methods of edge detection using different input images are evaluated as shown in Figure 7.9 and Figure 7.10. Further, a quantitative analysis with classical and fuzzy edge detection methods is presented where mean values, variance values, MSE values, and PSNR values are used as performance attributes.

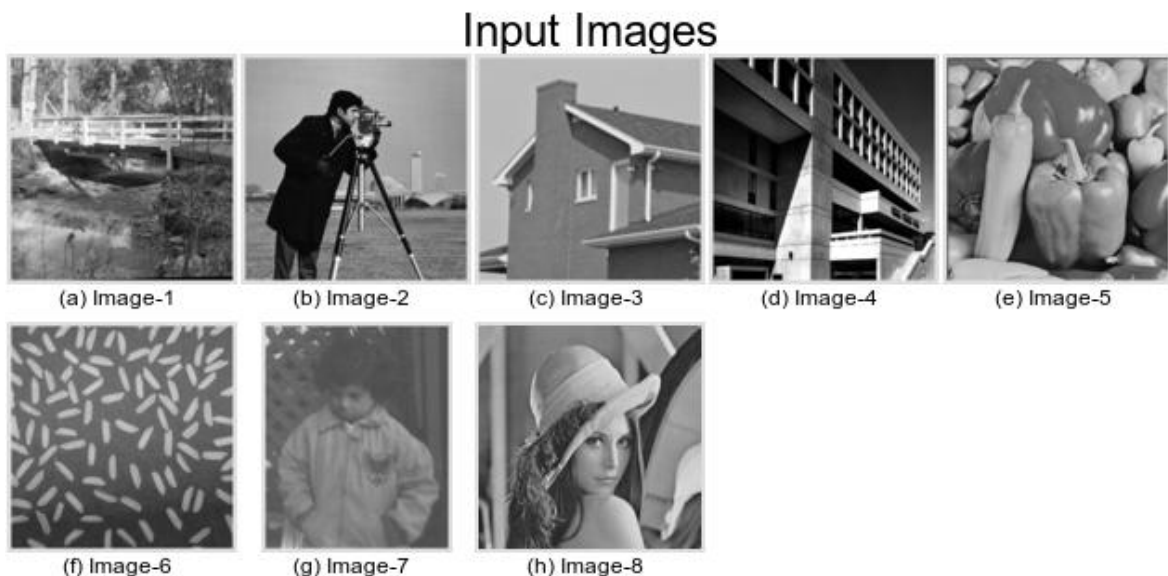


FIGURE 7.8 : INPUT IMAGES (a) ORIGINAL IMAGE – 1 (b) ORIGINAL IMAGE – 2 (c) ORIGINAL IMAGE – 3 (d) ORIGINAL IMAGE – 4 (e) ORIGINAL IMAGE – 5

7.3.1 EXPERIMENTAL STUDY-1 OF CLASSICAL EDGE DETECTION METHODS

Results of classical edge detection methods are shown in figure 7.9. As per visualization and clarity of edges canny edge detection method are giving more edges as compared to other methods.

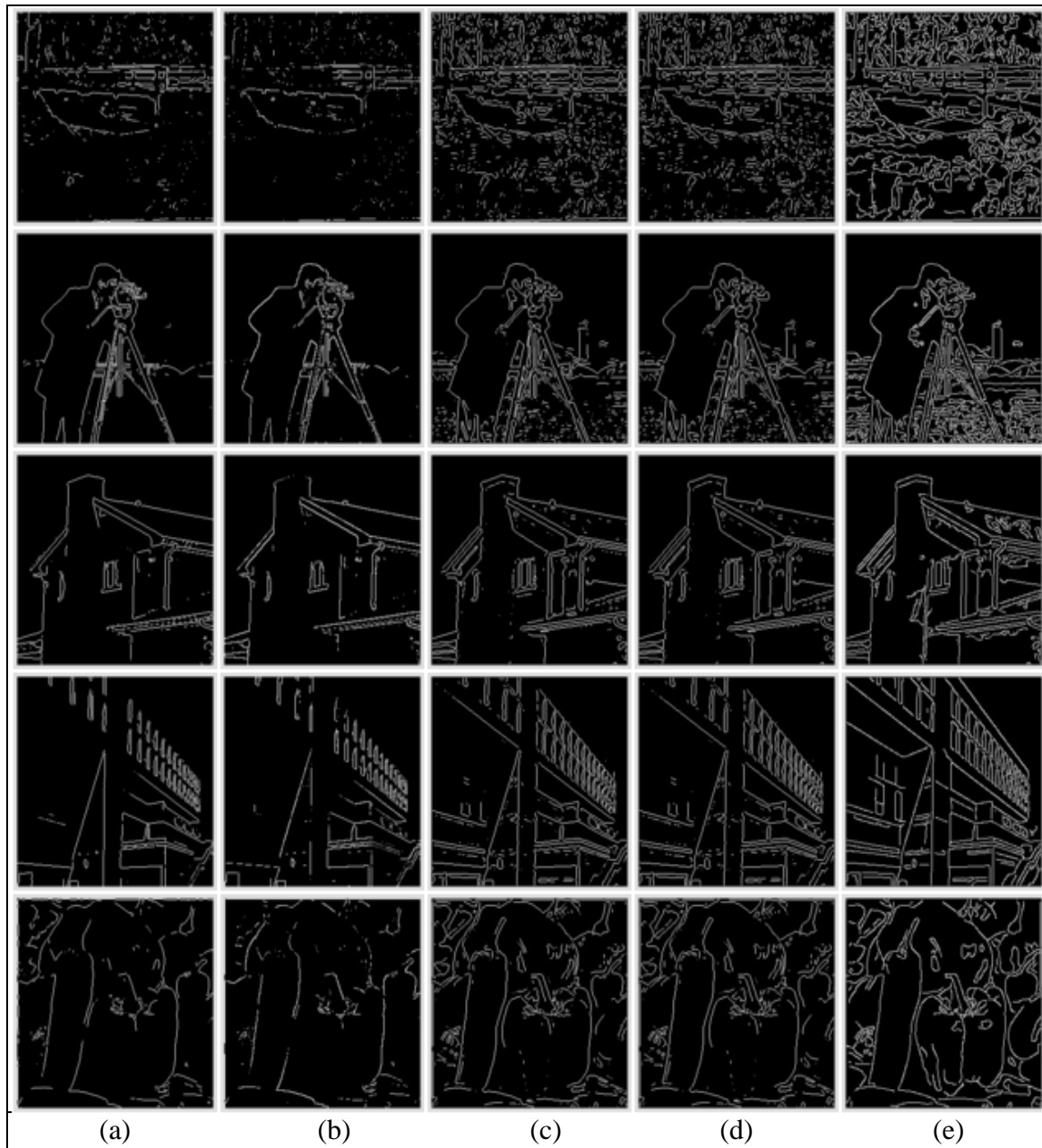


FIGURE 7.9 : CLASSICAL EDGE DETECTION (ED) METHODS – (a) SOBEL EDGE DETECTION (ED) (b) PREWITT ED (c) ROBERTS ED (d) LAPLACE ED (e) CANNY ED

7.3.2 EXPERIMENTAL STUDY-2 OF FUZZY EDGE DETECTION METHODS

In this subsection, the analysis of fuzzy edge detection methods is presented.

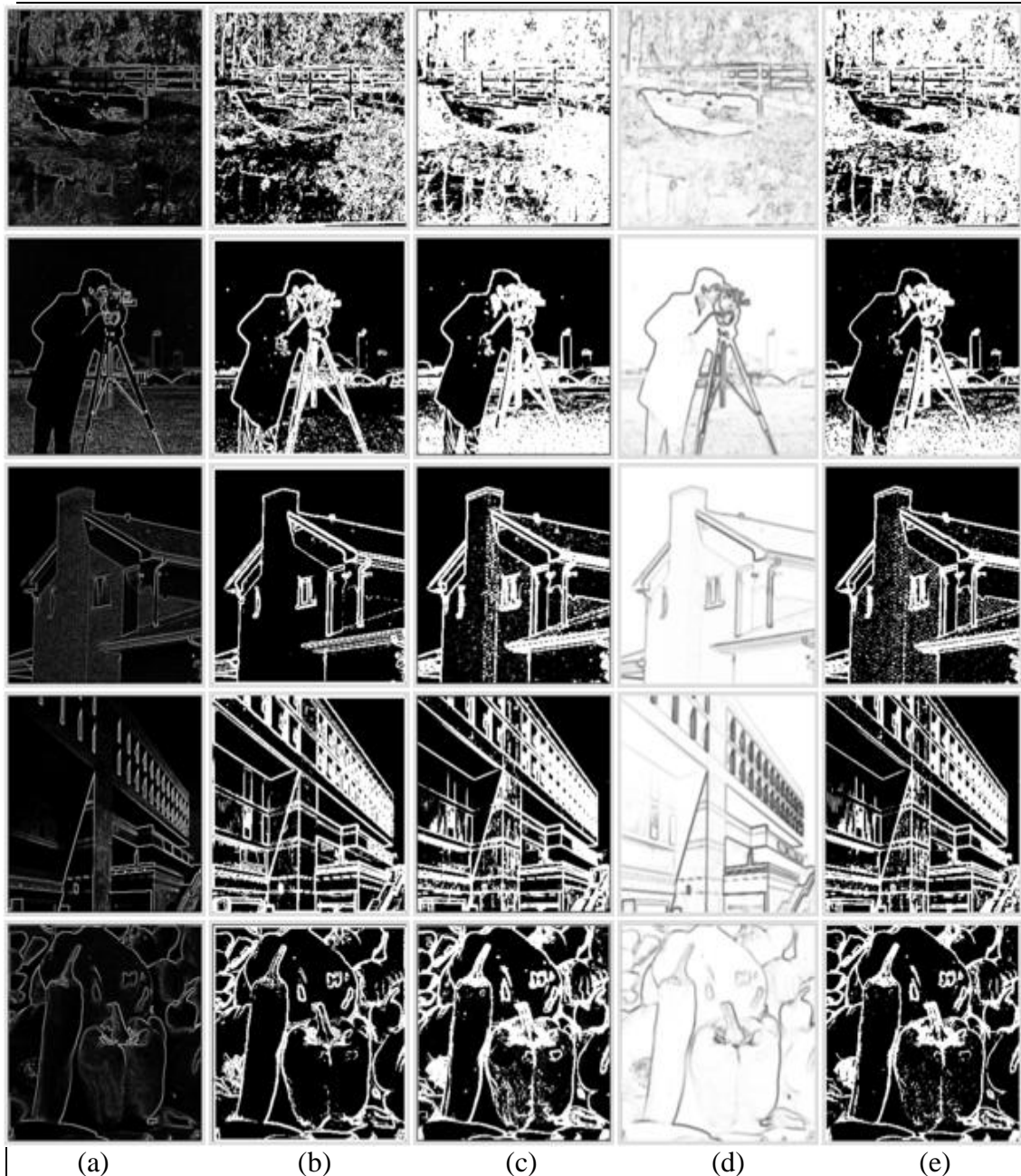


FIGURE 7.10: FUZZY EDGE DETECTION (ED) - (a) FUZZY SOBEL EDGE DETECTION (ED) (b) ENTROPY-BASED ED (c) TEMPLATE-BASED ED (d) FUZZY IF-THEN BASED ED (e) FUZZY-PSO BASED ED

Results of fuzzy edge detection methods are shown in figure 7.10. As per visualization and clarity of edges, fuzzy methods are giving better clarity of edges as compared to classical edge

detection methods. As shown in figures above, the Fuzzy-PSO based ED is shown most improved as compared to others fuzzy ED methods. Also, fuzzy IF-THEN method works better for better edge identification in an image.

7.3.3 EXPERIMENTAL STUDY-3 COMPARISONS OF CLASSICAL AND FUZZY EDGE DETECTION METHODS

In this subsection, we have compared various methods of spatial domain edge detection with one of the fuzzy edge detection method known as fuzzy if-then rules. Here I_x is a x direction gradient and I_y is a y direction gradient used to evaluate the FIS. ZE, WH, and BL membership functions are shown in Figure 7.7.

Followings are the procedure of edge detection using fuzzy If-then rules and flowchart is shown in Figure 7.11.

Step-1: Apply the simple filters (convolution) to obtain the image gradients.

Step-2: Define image gradients of the input image with respect to the x-axis and the y-axis direction.

Step-3: Design a Fuzzy Inference System (FIS) with 2 inputs and 1 output.

Step-4: Set the Fuzzy-If Then Rules into FIS:

- i) If (I_x is ZE) and (I_y is ZE) then I_{out} is WH
- ii) If (I_x is not ZE) and (I_y is not ZE) then I_{out} is BL

Step-5: Obtain the membership function of image gradients as I_x and I_y .

Step-6: Apply the I_x and I_y to above FIS for Evaluation.

Step-7: Store the result obtained from the output of FIS. This resultant would produce the edge of the image.

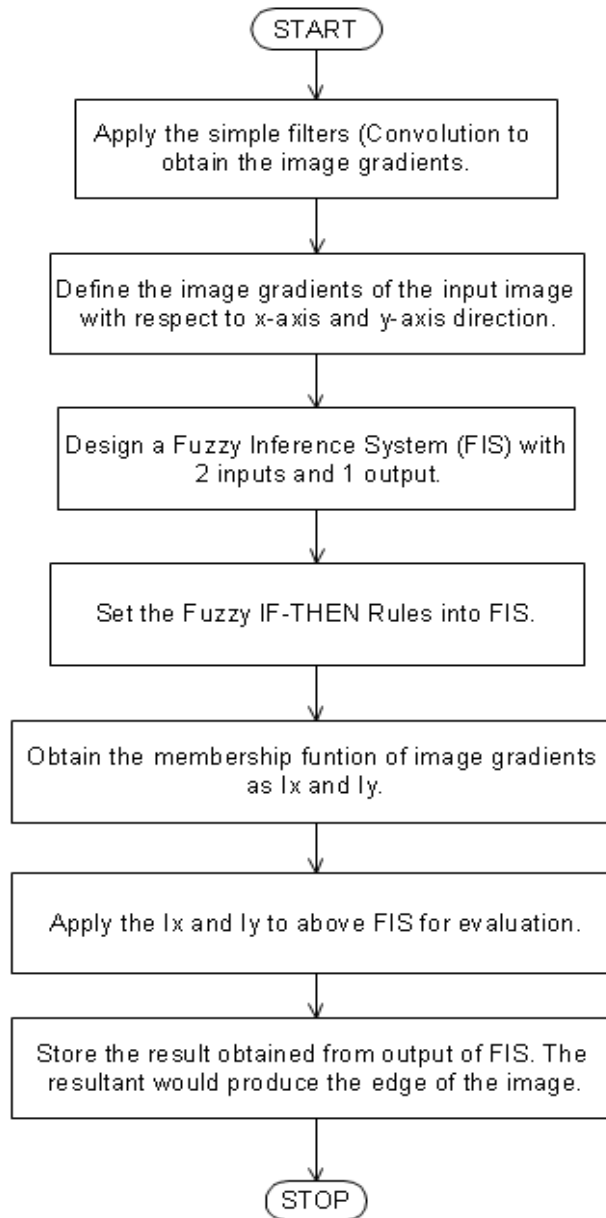


FIGURE 7.11: FLOW CHART OF EDGE DETECTION USING FUZZY IF-THEN RULES

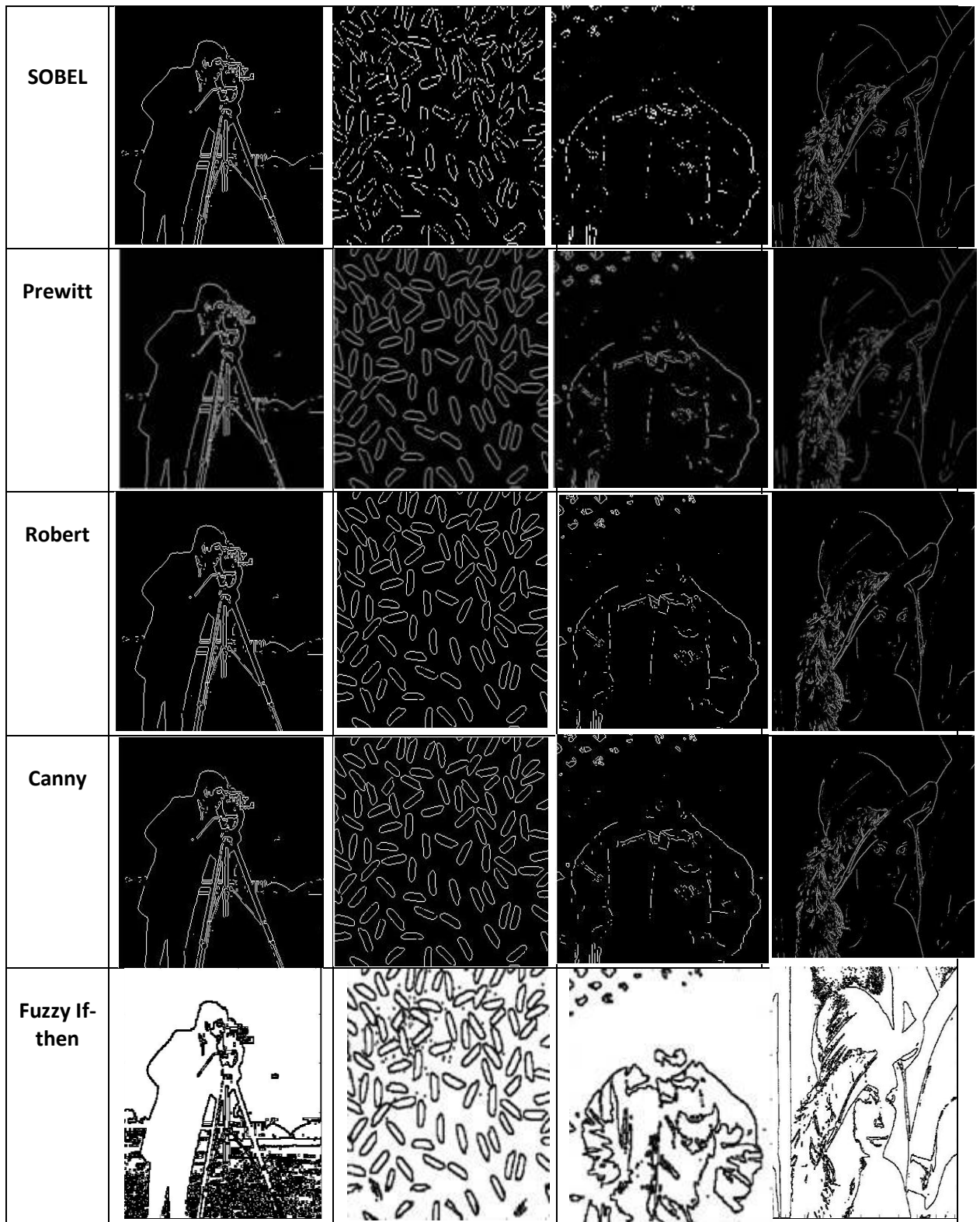


FIGURE 7.12: RESULTS OF VARIOUS CLASSICAL AND FUZZY EDGE DETECTION METHODS

The output results using classical and fuzzy based ED methods are shown in Figure 7.12. So on the basis of the above resultant images, it is concluded that as compare to classical edge detection methods fuzzy edge detection methods gives remarkable results. It is also evident from the results given in Figure 7.10 that the optimization based on fuzzy reasoning or other techniques has shown a higher probability of finding the edge pixels in the gray images.

7.4 CONCLUSIONS

In this chapter, edge detection based on spatial domain and fuzzy domain are discussed and compared with the results and discussions. To the best of our knowledge, we have discussed more relevant methods of edge detection. These are Sobel ED, Prewitt ED, Roberts ED, Laplace ED, and Canny ED as the classical methods while fuzzy based methods include Fuzzy Sobel ED, Entropy-based ED, Template-Based ED, Fuzzy IF-THEN based ED, and Fuzzy-PSO based ED. Both the types are analyzed with different input images and quantitative results. It has been observed that fuzzy reasoning based rules get the improved results. Further, a comparison between classical and Fuzzy based ED methods has been done where it has been observed that the fuzzy-based ED methods have shown remarkable results as compared classical based ED methods such as Sobel, Prewitt, Robert, and Canny.

CHAPTER VIII

Conclusions and Future Scope

CHAPTER VII

CONCLUSIONS AND FUTURE SCOPE

Image enhancement is an emerging method for analyzing the images clearer for interpretation and analysis in the spatial domain. Image enhancement based applications are simple to understand and analyze images. It can be observed that for finding any anomalies in a specific image or for the purpose of diagnosing, images must be clearly visible, enhanced and sharpened. Otherwise, uses of low contrast, blurred or noisy images are risky and failed to analyze. Present work is for contrast enhancement and edge detection of gray images using classical and fuzzy methods in the spatial domain. The experimental results presented are analyzed on the basis of various performance parameters, shall be very helpful for further research. Major findings are drawn with the help of quantitative and qualitative observations.

In this dissertation, it has been observed that the classical spatial methods produce the enhanced image which is not natural in visual clarity due to saturated with very bright or dark intensity levels. To overcome this drawback, the fuzzy set theory is used to handle both brightness preserving and contrast enhancement. In a fuzzy domain, the inexactness of gray levels is handled in a better way as compared with classical spatial domain methods. For this, a fuzzy inference system consisting of input membership function, inference system using if-then rules and output membership function. Using this Mamdani fuzzy inference system (FIS), better membership functions based on the observations and findings are identified from comparative results and analysis. It is also based on combinations of multiple membership functions for improved clear visual images.

A novel fuzzy Mamdani FIS is then proposed utilizing the optimization of fuzzy image quality in order to preserve the brightness and contrast of the image between the combinations of membership functions. Our proposed optimization algorithm solves the problem of under-exposed or over-exposed and unnatural enhancement. Our criterion is to determine the optimum results through the selection of best cases of membership function combinations that are based on the fuzzy quality parameter. The algorithm calculates and compares the fuzzy quality for the different cases and it stops only when minimum fuzzy quality is achieved for given membership functions. Next study is on edge detection techniques using classical and fuzzy logic approaches for various types of images such as medical images and normal images.

From the present research work, the following important points are concluded:

- The research challenges in the domain of image enhancement and edge detection are discussed. A brief overview of all the domains in image processing such as spatial, fuzzy and frequency domain has been included before describing the problem domain of thesis. The performance metrics used for evaluation are defined with expressions are also included in this chapter. These performance metrics are used throughout the thesis for analysis of proposed image enhancement techniques. The detailed literature on image contrast enhancement techniques and edge detection techniques are presented. According to obtained findings, it is observed that a very little information about the image enhancement using fuzzy inference system (FIS) is available. A FIS consists of input membership function, inference system with fuzzy rules and output membership function based on fuzzy set theory. The various FIS based methods for image enhancement designed in the present research work are efficient, effective and simple in design for various applications.

- The quantitative analysis of contrast enhancement techniques that will allow us to find out the evolution, the impact, and the perspectives of image enhancement methods for computer vision and image analysis applications. We carry out the analysis on different types of images based on quality attributes, studying trade-off in image contrast and brightness on used methods, and determining their advantages and disadvantages. Contrast enhancement based on classical approach is a technique of image processing for the enhancement of contrast in the spatial domain where the image pixel values are manipulated based on global information obtained from a histogram of the input image. Studies are on comparative analysis of various contrast enhancement techniques such as Contrast Stretching, HE, CLAHE, BBHE, DSIHE, MMBEBHE, DHE, BPDHE applied to different types of gray images. The experimental result shows that Contrast-limited adaptive histogram equalization gives a better result, and for some images contrast stretching gives a better result. Some degraded images that require the highest brightness, do not handle using HE, BBHE, DSIHE methods. These images can be enhanced using MMBEBHE method. It can also be observed in our studies that all the enhancement methods work well for most of the images. But, overall, it can be observed that some annoying side effects due to changes in gray level distribution are found using these methods.
- Image enhancement technique based on fuzzy logic as motivated by the results and discussions of the previous chapter 3. The fuzzy set theory is very popular due to its capability to deal with unclear and changeable information with uncertainty. Fuzzy image enhancement techniques offer the proper way of producing the manipulations (based on fuzzy operations) due to its non-linear behaviors. These methods are knowledge-based based human perception. For modification of mapped pixel in the fuzzy plane, there is a diversity of fuzzy logic, fuzzy set theory, and

fuzzy measure theory. Then, new fuzzy levels are retransformed into the gray values for getting the enhanced image. This is the main difference with other methodologies such as Histogram based or other methods of image processing. To get more insight into it, the different existing methods of classical contrast enhancement techniques have been compared with the fuzzy-based image enhancement method. A detailed results analysis of images has been done using different qualitative attributes of the image in the simulation.

- Mamdani fuzzy inference system (Mamdani FIS) for fuzzy image enhancement is found a potential tool for better enhancement. The various case studies have been considered to get more insight into fuzzy enhancement for Mamdani fuzzy inference system (Mamdani FIS) using different shaped membership functions (MFs). Results and analysis presented in chapter 5 show that the images with good steps of grays between black and white are commonly the best images for the aim of human perception.
- A novel approach is proposed using a Mamdani fuzzy inference system (FIS) for contrast image enhancement through different and multiple shaped membership functions combinations and optimization for achieving best-satisfied enhancement. It has been observed that different types of MFs, their shapes, and combinations are important to get better fuzzy logic levels as per image pixel when it is used with Mamdani FIS. According to intuitions based on local image quality, an algorithm for generating fuzzy IF-THEN base for Mamdani FIS is also proposed in order to modify the membership functions for achieving overall resultant enhanced image quality. Analysis of this chapter shows that the use of multiple shaped membership functions in the different set of combinations for Mamdani FIS shows the best handling of non-linear pixel modification intensities when optimization is done

based on fuzzy quality. Thus, the overall contrast of input image is shown to be improved after applying optimization in the fuzzy domain. The fuzzy quality is determined by the ratio of average fuzzy contrast and fuzzy contrast. The overall intensity is handled by the average value of fuzzy contrast while fuzzy contrast value indicates the spread of the gradient. The resultant obtained images using our scheme have been measured with the help of statistical matrix parameters so that accuracy of the different combination of contrast enhancement methods can be observed distinctly.

- As another contribution, a comparative study on edge detection techniques both spatial and fuzzy domain based is discussed.

In future, the present work can also be extended as a future scope given below:

- For finding better enhancement techniques of the images, classical methods and fuzzy methods can be compared and analyzed with other present enhancement methods like genetic algorithms, neural network methods, and neuro-fuzzy system.
- This work can also be extended for color images in the spatial domain as well as in the frequency domain.
- Mamdani FIS method will be very helpful in the field of defense, satellite images, robotics, and in medical applications because of a set of image quality using different sized membership functions and rule base.
- Optimization criteria used in this thesis can be extended further to tune using the fuzzy histogram or contrast-tone mapping.
- Fuzzy edge detection technique can be extended by applying the high boost filtering techniques.



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APPENDIX

Reprints of the Published Papers

An Optimized Multiple Fuzzy Membership Functions based Image Contrast Enhancement Technique

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Abstract

Image enhancement is an emerging method for analyzing the images clearer for interpretation and analysis in the spatial domain. The goal of image enhancement is to serve an input image so that the resultant image is more suited to the particular application. In this paper, a novel method is proposed based on Mamdani fuzzy inference system (FIS) using multiple fuzzy membership functions. It is observed that the shape of membership function while converting the input image into the fuzzy domain is the essential important selection. Then, a set of fuzzy If-Then rule base in fuzzy domain gives the best result in image contrast enhancement. Based on a different combination of membership function shapes, a best predictive solution can be determined which can be suitable for different types of the input image as per application requirements. Our result analysis shows that the quality attributes such as PSNR, Index of Fuzziness (IOF) parameters give different performances with a selection of numbers and different sized membership function in the fuzzy domain. To get more insight, an optimization algorithm is proposed to identify the best combination of the fuzzy membership function for best image contrast enhancement.

Keywords: Image enhancement, fuzzy logic, fuzzy optimization, fuzzy inference system, membership function.

1. Introduction

Fuzzy enhancement techniques have proven a powerful tool for presenting the image in a better way so that it can be used for a large number of applications in the area of contrast enhancement [1]-[4]. Nowadays, image-capturing devices are in many ranges from high resolutions to lower resolution in terms of pixels value. In this digital world, the technologies have been grown rapidly for many applications such as internet of thing (IoT) applications; Image enhancement techniques play an important role while processing the data from one device to another, an image enhancement technique could be used to forward the improved image data. Various methods of enhancement are available as first derivation technique like Sobel mask, a second derivative technique like Laplace mask and much more [1]. Different devices could require different qualities of improved images for processing the data or applications. In different qualities of an image, a device may fail to capture the better image quality and hence a good enhancement technique may be the need to achieve the required quality in the image. Qualities of images are affected due to the availability of various kinds of noises in the images like salt and pepper noise, Gaussian noise, and impulse noise.

In this paper, it is shown that how can we get a range of better quality enhanced image outputs for given image. Different fuzzy membership functions and their combinations are utilized with rule-base in fuzzy inference system for getting a range of improved contrast images. To the best of our knowledge, the use of the fuzzy rule-based procedure in image enhancement was primarily suggested by Tizhoosh et al. [8]. Based on same fuzzy inference system, recently, paper in [11] show the potential of membership function modification to improve the image brightness. Hasikin et al. [11] have used the two membership functions as the triangular and the sigmoid function to get conversion between spatial and fuzzy domain. An algorithm for optimization was used to determine the best attribute using a mathematical model for image enhancement. In this scheme, adaptive fuzzy contrast factor enhancement technique was proposed that uses the single membership function as a sigmoid function at both input and inverse of sigmoid membership function at the step of defuzzification for low contrast-uniform illumination images. In a fuzzy domain, there are various parameters such as intensification, fuzzifier, and crossover point. These are important for the desired appearance of images [12]. Similarly, a Gaussian membership function used along with histogram equalization for fuzzy image enhancement in a recent paper by Devi and Rabbani [10]. Gopalan and Arathy [12] have proposed an optimal fuzzy system where they have shown that the membership function separation from some reference point or crossover point is directly related to the fuzzy image quality.

As per observations from recent works on fuzzy image enhancement, the use of the different shape of membership functions and their impacts on fuzzy IF-THEN rules are not explored further. In this paper, we extend the work of Tizhoosh et al. [8] and Hasikin et al. [11] by considering the potential use of the different shaped membership function to be used in fuzzy inference system for image contrast enhancement. This paper proposes a new algorithm for generating the fuzzy IF-THEN rules automatically when many memberships functions are combined together for a resultant membership function. The rule base is according to intuitions drawn based on location information and human observations. A set of different membership functions and their modified membership

functions by the Mamdani FIS is the basis for the transformation of the input image into an enhanced image with good quality. First, we design different combinations of membership functions for Mamdani FIS. In our study, triangular, Gaussian, and bell-shaped membership functions are utilized and their impact on image enhancement are studied. We show based on results analysis that by using optimization in the fuzzy domain, the best membership function can be selected to produce the better-enhanced image after defuzzification. With the motivation on image quality on different membership functions, the algorithm of fuzzy optimization using fuzzy quality is also proposed to determine the best membership function and its combinations. Simulation results that show the effectiveness of optimization is given in details.

The rest of the paper is organized as follows. Section 2 presents the highlights of related literature of the work. The basic structure of Mamdani FIS used in our work is explained in the Section 3 with terminology and definitions used throughout the paper. How our model would use If-then rule base and different membership function (MFs), is also explained this section. The working of proposed design is described in Section 4 along with fuzzy optimization technique. The results and discussions using the proposed and the existing techniques are given in the section 5. Finally, the paper conclusion and future work can be found in the Section 6.

2. Related Work

Assume that an image is given with $M \times N$ pixels each with different intensities having fuzzy membership grade values in the range of 0 to 1. There are many works in literature employing fuzzy logics based image enhancement viz., edge detection, noise removal, etc. (see [1, 7, 8]). In this paper, we restrict ourselves only works related to contrast stretching techniques or transformation functions in gray-level improvements. PAL and KING [7] was first to propose a contrast enhancement technique using a Contrast Intensification (CI) operator. The CT operator reduces the fuzziness and thus improves the image contrast. CT operator determines modified membership values. This operator stretches the contrast between the membership values. To obtain the good contrast, it transforms the MF values to much higher values for those MF values, which are above 0.5. The MF values which are lower than 0.5 are transformed into much lower values in non-linear manner. Thus, a good contrast is obtained using nonlinear stretching function. This CI operator (also known as INT operator) relies solely on membership function. In addition, this operator must be applied continuously on given image for attaining the proper enhancement. To overcome this limitation, NINT operator [9] is proposed which uses a Gaussian type fuzzification function containing a fuzzifier and a new intensification operator. Tizoosh [8] proposed the concept of fuzzy histogram hyperbolization. The method modifies the input membership function into logarithmic function through nonlinear human brightness perception. Initially, MF and its shape are selected according to user's requirement. The MF values are calculated using this MF and a fuzzifier beta is set in order to modify the membership function for getting good contrast image. In this method, fuzzifier beta is a linguistic hedge which can be made selection such that manner is very bright, very very bright, medium bright, very medium bright, low bright, and so on. These selections can be made on the basis image quality. If input image quality is low, then fuzzifier beta will produce slightly bright image after operation. Russo [13, 15] proposes rule-based operators based on human knowledge. Image quality can be improved by human

observation and fuzzy rule-based are according to human intuitions, which are nonlinear. The conditions for fuzzy rule are designed based on pixel gray level and neighborhood pixel values. The fuzzy rule-based systems based on soft decisions are proposed in [13] and rule-based operators for image sharpening and smoothing are suggested in [15]. Fuzzy rule-based filters for image enhancement are proposed in [16]. A comparative study on mammogram images is given in [17] to explore the features of the image using different mechanisms such as contrast intensification, IF-THEN rules, and hyperbolization. The fashion is as follows: (i) If image is dark then black, (ii) If image is gray then gray, (iii) If image is bright then white. Schneider and Craig [20, 21] have suggested the use of Fuzzy expected value (FEV) for image enhancement. In FEV, mean and median fuzzy set values are replaced to modify the more representative value in the grade of membership function. A weighted FEV was also proposed by the same authors to improve more the image contrast [21]. Although various techniques of image enhancement can extract important features of image in improving the image contrast several deficiencies in these techniques are still present. Thus, the optimization techniques have been proposed in [22, 23, 24, 25]. The enhanced images are produced by optimizing the gray-level information of the image. Other optimizations on image are based on entropy, index of fuzziness or combination of [24, 25, 26]. However, the optimizations using above measures need iterative procedure, which may be applied repeatedly to transform better image quality. To overcome these limitations, authors in [26, 27, 28, 29] have suggested the methods of locally enhancing the image without additional optimization.

Based on the selection of membership function in order to modify the membership function or convert during the fuzzy process, Hasikin et al. [11] utilized two-membership functions such as the triangular and the sigmoid function to get conversion between spatial and fuzzy domain. Recently, Devi and Rabbani [10] used a Gaussian membership function used along with histogram equalization for fuzzy image enhancement. Gopalan and Arathy [12] have shown that how the membership function separation from some reference point or crossover point is directly related to the fuzzy image quality in the design of the optimal fuzzy system. Deng et al. [14] used intuitionistic fuzzy sets for image enhancement where the restricted membership function and hyperbolisation function are used during fuzzy enhancement process. Based on classical histogram equalization (HE), Brightness Preserving and Non-parametric modified Bi-histogram Equalization (BPNMBHE) is proposed by Yao et al. [18]. In this approach, the input image is divided into two sub-images using the average intensity value and then both the sub-images are enhanced by HE. The final output image can be obtained by merging both the enhanced sub-images. HE based optimization problem is formulated by Shin and Hong [19] to the contrast enhancement for preserving localities of the histogram as an improvement in HE.

3. Mamdani FIS Model Structure

Based on fuzzy set theory, the fuzzy method introduced two kinds of fuzzy inference model, in which the first kind of fuzzy inference model is introduced by Mamdani [27], and second fuzzy inference TSK model is introduced by Sugeno [28]. These models are useful to handle the uncertainty in an image to improve the contrast of an image. Improvements of contrast in the input image are also possible with the combination of fuzzy set theory and fuzzy entropy [29]. In MATLAB, Mamdani FIS is a GUI based fuzzy

inference system where fuzzy-domain would be a conversion from MFs setting as both input and output side. In fuzzy inference system (FIS), input membership function (MFs) and output membership function (MFs) are mapped together by using rule- base design. Fuzzy Inference System (FISs) is divided into three types, Mamdani FIS, Sugeno FIS and Tsukamoto FIS for various applications [27, 28]. The basic differences between these FIS model are that the procedures for their fuzzy rules, aggregation, and defuzzification differ mostly to each other. We restrict ourselves to consider the Mamdani FIS for image enhancement. A given input image is then converted into fuzzy domain by using input MFs. In a fuzzy domain, rule-base is then applied to obtain a resultant modified fuzzy output (called output MFs). Finally, output image would be generated using centroid defuzzification method from output MFs. A plot between input MFs and output MFs is referred as transformation graph for given rule-base design. FIS design consists of input membership function rule base and output membership function blocks as shown in Fig. 1. There are many approaches based on human reasoning applied on image enhancement. These also deal with 'IF-THEN-ELSE' fuzzy rule-based system [3-6]. The neighboring pixel values are antecedent part of the rule in these methods. The enhanced pixel values could be based on a decision by the consequent part of the rule base design. So, a soft decision based on human intuition plays important role in enhancement of the image. But, they suffer from high cost in computations for generating fuzzy rule base. Image enhancement using fuzzy logics involves usually three stages that are also used by Mamdani FIS (see Fig. 1). These are image fuzzification, membership function modification, and image defuzzification. This model takes input in discrete form of the image as crisp input. If then feeds to fuzzifier which uses membership function (MF) for converting into fuzzy variable. MFs maps the crisp variables to fuzzy variables and the degree of membership of these variables are calculated. The degree of membership is normalized in the range of 0 to 1. These are image fuzzification, membership function modification and image defuzzification. This model takes input in discrete form of the image as crisp input. If then feeds to fuzzifier which uses membership function (MF) for converting into fuzzy variable. MFs maps the crisp variables to fuzzy variables and the degree of membership of these variables are calculated. The degree of membership is normalized in the range of 0 to 1. The fuzzy variables converted using MFs are then fed into the IF-THEN rule base. Using the fuzzy IF-THEN rule base, fuzzy input variables are mapped to fuzzy output variables. This mapping of fuzzy variables can be partial or overlapped and according to output MFs taken at output side in Mamdani FIS.

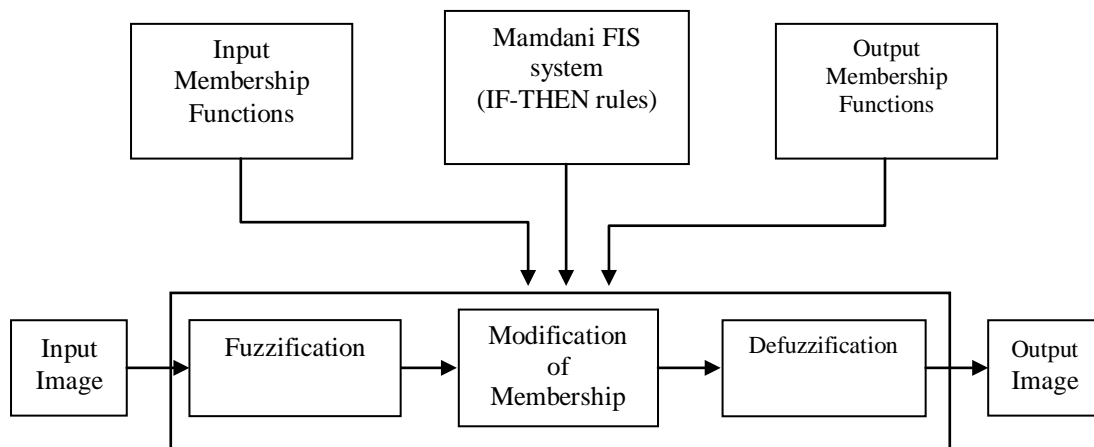


Fig. 1. Block Representation of Mamdani FIS model and Image Enhancement steps

Finally, defuzzifier then converts the fuzzy output into the crisp output. In Mamdani FIS model, different defuzzification techniques can be used to get crisp output using output MFs. Their techniques can be centroid, the centre of sums (COS) and mean of maximum defuzzification. In this paper, we used centroid method of defuzzification.

There are 12 types of MFs according to fuzzy logic theory. Fig 2 shows the triangular (T), Gaussian (G), bell-shaped (B) and sigmoid (S) membership function. As shown in figures, the x-axis range is defined from 0 to Z variable while the y-axis is set to 1. The variable Z varies from application to application. For 8-bit images, the range of x-axis could be between zero and 255 (it is known as pixel or gray level value). The range of y-axis would be always from 0 to 1. It is called grade of membership. There are many membership functions used for fuzzy image enhancement.

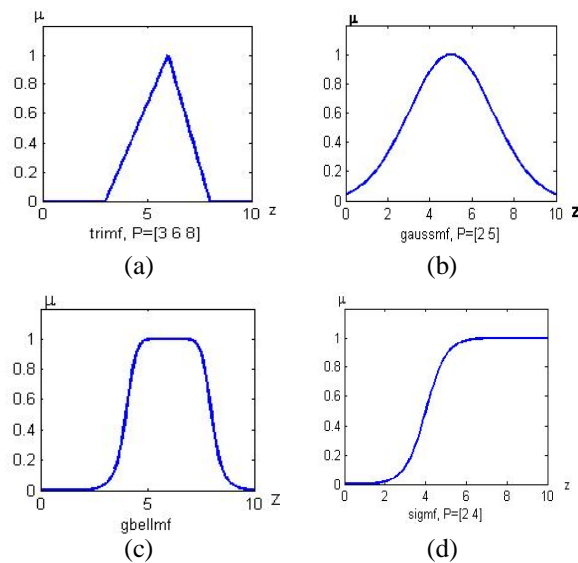


Fig. 2. Types of Membership Functions (MFs)
(a) Triangular (b) Gaussian (c) Bell-shaped (d) Sigmoid

3.1 Definitions and terminology used

We firstly define the following terms and definition, which is necessary to explain the proposed methods and procedure. Domain range of gray scale image is from 0 to 255. This range is partitioned into equidistant and identically shaped membership functions (MFs). A major advantage of this partitioning is that the fuzzy rules obtained from the fixed MFs are always interpretable according to human perception. In this paper, we used same fashion in fuzzy rules for different numbers and different types of MFs. The types of MFs for input variables and output variables used in Mamdani FIS are considered using three membership functions (MFs) such as Triangular, Gaussian and Bell shaped membership function for image contrast enhancement. Their combinations of input variables and output variables used in Mamdani FIS are studied for evaluation of image contrast enhancement. For example, Triangular MFs at input variables and Gaussian MFs at output variables for Mamdani FIS can be used for evaluation of image contrast enhancement. Studies include their combinations and the selection number to partition the gray-scale range for the analysis of contrast image enhancement using Mamdani FIS. Followings are the terms and definitions used in this paper. Assume symbol 'T' denotes

the use of Triangular MF, symbol 'G' denotes Gaussian MF and 'B' denotes Bell-shaped MF. We can make following combinations with Mamdani FIS.

- 'T-T' denotes the use of Triangular MFs and Triangular MFs at input and output variables.
- 'T-G' denotes the use of Triangular MFs and Gaussian MFs at input and output variables.
- 'T-B' denotes the use of Triangular MFs and Bell MFs at input and output variables.
- 'G-T' denotes the use of Gaussian MFs and Triangular MFs at input and output variables.
- 'G-G' denotes the use of Gaussian MFs and Gaussian MFs at input and output variables.
- 'G-B' denotes the use of Gaussian MFs and Bell MFs at input and output variables.
- 'B-T' denotes the use of Gaussian MFs and Triangular MFs at input and output variables.
- 'B-G' denotes the use of Bell MFs and Gaussian MFs at input and output variables.
- 'B-B' denotes the use of Bell MFs and Bell MFs at input and output variables.

The number of MFs considered for input and output variables in Mamdani FIS are 15, 20, 25 and 30. For example, '15 G-G' denotes the 15 partitioning the gray-scale range (0 to 255) using Gaussian MFs at the both input and output variable in Mamdani FIS. Similarly, '20 B-T' denotes the 20 partitioning the gray-scale range (0 to 255) using Bell MFs at the input and Triangular MFs at output variables in Mamdani FIS respectively. For simplicity, we restrict ourselves to study the combinations as '15 T-T', '15 T-G', '15 T-B', '15 G-T', '15 G-G', '15 G-B', '15 B-T', '15 B-G', '15 B-B' for 15 partitions. Similarly, for 20 partitions, we have '20 T-T', '20 T-G', '20 T-B', '20 G-T', '20 G-G', '20 G-B', '20 B-T', '20 B-G', '20 B-B'. For 25 partitions, we get '25 T-T', '25 T-G', '25 T-B', '25 G-T', '25 G-G', '25 G-B', '25 B-T', '25 B-G', '25 B-B'. Finally, for 30 partitions, we have '30 T-T', '30 T-G', '30 T-B', '30 G-T', '30 G-G', '30 G-B', '30 B-T', '30 B-G', '30 B-B'. By considering above possible combinations, the evaluations have been done into cases according to the same MFs selection and different MFs selection in Mamdani FIS. The same MFs selection includes 'T-T', 'G-G' and 'B-B' with 15, 20, 25, 30 numbers of MFs. Followings are the cases with combinations used with Mamdani FIS.

Case-1: Same MFs Selection in FIS

Case-1A: '15 T-T', '15 G-G', '15 B-B' for 15 partitions.

Case-1B: '20 T-T', '20 G-G', '20 B-B' for 20 partitions.

Case-1C: '25 T-T', '25 G-G', '25 B-B' for 25 partitions.

Case-1D: '30 T-T', '30 G-G', and '30 B-B' for 30 partitions.

Case-2: different MFs Selection in FIS

Case-2A: ‘15 T-G’, ‘15 T-B’, ‘15 G-T’, ‘15 G-B’, ‘15 B-T’, ‘15 B-G’ for 1 partitions.

Case-2B: ‘20 T-G’, ‘20 T-B’, ‘20 G-T’, ‘20 G-B’, ‘20 B-T’, ‘20 B-G’ for 20 partitions.

Case-2C: ‘25 T-G’, ‘25 T-B’, ‘25 G-T’, ‘25 G-B’, ‘25 B-T’, ‘25 B-G’ for 25 partitions..

Case-2D: ‘30 T-G’, ‘30 T-B’, ‘30 G-T’, ‘30 G-B’, ‘30 B-T’, ‘30 B-G’ for 30 partitions.

The graphical representation of combinations for same MFs and different MFs is derived from graphical of ‘15 T-T’, ‘15 G-G’, ‘15 B-B’ as shown in Fig. 3. As shown in Fig. 4 that Triangular, Gaussian, and Bell shaped MFs are partitioned over the range of 0 to 255 for an 8-bit image. Similarly, Case 1B, 1C, and Case 1D can be designed by increasing number of corresponding MFs. Using different MFs on same pixel range (0 to 255), we can have designed for Case-2 in a similar way as shown in Fig. 4.

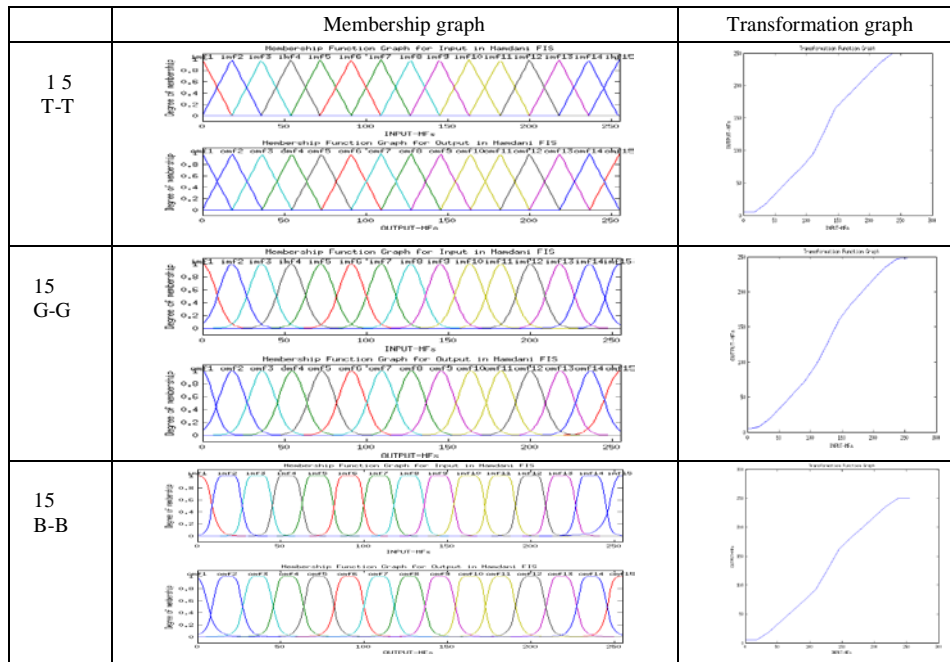


Fig. 3. Same MFs with 15 partitions

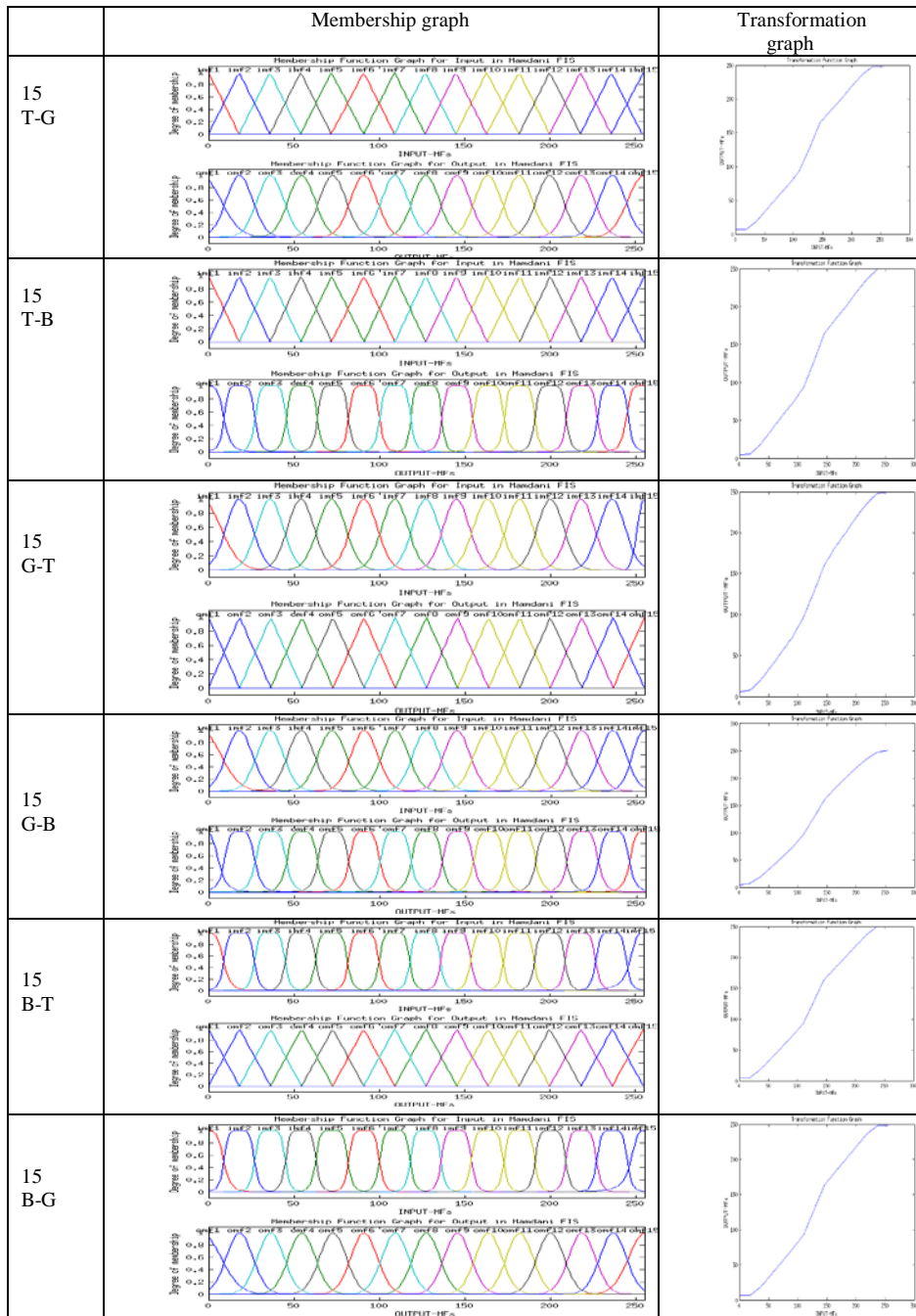


Fig. 4. Different MFs with 15 partitions

3.2 Rules base design for Mamdani FIS

Fuzzy IF-Then rules are needed to map the input and output MFs for getting the resultant better fuzzy logic so that when input MFs may apply on a given image, it can convert into fuzzy logic according to input MFs. The IF-THEN rules could be able to take

a decision based on human perception. A modified member function is obtained by applying IF-THEN rules that are equivalent to the output MFs. The obtained fuzzy logic is then reconverted back using centroid defuzzification into an enhanced version of the image. For same IF-THEN rules, input MFs and output MFs selection in Mamdani FIS is important to get improved results. Because the modified membership function would be different using same IF-THEN rule base. According to literature, different fuzzy memberships play an important role to remove uncertainty in the image. Hence, the resultant image could preserve the contrast brightness than the input given image. Using the different combination of MFs using Mamdani FIS, contrast enhancement analysis has been done in this paper for understanding the role of fuzzy logics in fuzzy image enhancements. We show that how powerful is the fuzzy logic tool for contrast enhancement of gray-scale images. A comparison with a classical methods such as histogram equalization and its variants has been done to show the improvements in terms of contrast preservation histogram equalization.

Let us assume that input and output fuzzy sets in FIS are defined by $A(X)$ and $A(Y)$ respectively. An input ($x \in X$) is given to Mamdani FIS. The corresponding output ($y \in Y$) is determined with the help of fuzzy If-Then rule base and logic operation. In Mamdani FIS, we use different MFs partitioning the $A(X)$ and $A(Y)$ fuzzy domains. Let us assume $F_i(x)$ and $F_i(y)$ are partitioning fuzzy sets of $A(X)$ and $A(Y)$ respectively. We have n number of IF-Then rules depending on the selection of MFs in inference system. There are single-input, single-output fuzzy rules in the form of such that: R_i : if x is $F_i(x)$ then y is $F_i(y)$.

Let us be given the k number of MFs for $A(X)$ and $A(Y)$, where $k = 1, 2, 3, \dots, n$. Let $F_k(x)$ and $F_k(y)$ are input MFs partitioning $A(X)$ and output MFs portioning the $A(Y)$ respectively. The algorithm for calculating rule base in Mamdani FIS is shown in [Fig. 5](#).

```

INPUT:  $F_n(x), F_n(y), x, y, n, C = n/2$ 
OUTPUT: A set of  $n$  Single – Input Single – Output fuzzy rule base
BEGIN
   $R_1$ : if  $x$  is  $F_1(x)$ , then  $y$  is  $F_1(y)$ 
  FOR  $k = 2$  to  $(n - 1)$  do
    IF  $k \geq C$  then
       $R_k$ : if  $x$  is  $F_k(x)$ , then  $y$  is  $F_{(k-1)}(y)$ 
    ELSE
      IF  $k \leq C$  then
         $R_k$ : if  $x$  is  $F_k(x)$ , then  $y$  is  $F_{(k+1)}(y)$ 
      ENDIF
    ENDIF
  ENDFOR
   $R_n$ : if  $x$  is  $F_n(x)$ , then  $y$  is  $F_n(y)$ 
RETURN: RULES =  $\{R_1, R_2, R_3, \dots, R_n\}$ 
END

```

Fig. 5. Algorithm for calculating Fuzzy IF-THEN Rule base

4. PROPOSED APPROACH OF CONTRAST ENHANCEMENT

4.1. A Novel Mamdani FIS

Assume X be the given input image having intensities at pixels as x , where $x \in X$ and appropriate output be the Y having y intensities at pixels, where $y \in Y$. In Mamdani FIS, the followings are the procedure:

- Step 1:** Calculate the degree of input membership values $F_i(x)$ using given fuzzy membership functions (called input MFs), where $i = 1, 2, 3, \dots, n$.
- Step 2:** Calculate the degree of output membership values $F_i(y)$ using given fuzzy membership functions (called output MFs), where $i = 1, 2, 3, \dots, n$.
- Step 3:** Obtain the set of n IF-THEN rules for given input and output fuzzy sets obtained in step-1 and step-2 above (see our algorithm).
- Step 4:** Obtain the overall modified output fuzzy set when n IF-THEN rules are applied.
- Step 5:** Defuzzify the resultant output fuzzy set using centroid method of defuzzification given by

$$Y = \frac{\sum y \cdot F(y)}{\sum F(y)} \quad (1)$$

Where

Y – Represents the crisp output value

y – Represents the centroid of fuzzy values calculated from membership function.

$F(y)$ – Represents the area from membership function bounded by degree of membership and abscissa

4.2 Fuzzy Optimization using fuzzy image quality function

The fuzzy contrast of an image depends on how far an operator would stretch the membership function with respect to the reference point [12]. In this work, the multiple numbers and different membership functions are used. Thus, fuzzy optimization using fuzzy quality proposed in [12] can be applied for getting best membership function combinations from a set of MFs as described in section 3.1. The average value of fuzzy contrast gives the overall intensity of image while the only fuzzy contrast value indicates the spread of the gradient with respect to the reference point. The ratio of fuzzy average contrast to fuzzy contrast is the quality of the image in the fuzzy domain. Following is the algorithm of optimization using fuzzy quality.

- Step 1:** Input the given image and convert it into the fuzzy domain.
- Step 2:** In a fuzzy domain, apply one selected multiple membership functions from given set of multiple MFs in section 3.1.
- Step 3:** Calculate the initial value of fuzzy contrast for given selected MFs and determine fuzzy quality of the image.
- Step 4:** Find out the change in fuzzy quality of image between selected MFs and previous MFs
- Step 5:** Repeat the step 2, 3 and 4, until the minimum change in fuzzy quality is obtained.
- Step 6:** Defuzzify the input image for optimized MFs.

5. Results and Discussions

In this section, the detailed result analysis is presented with our proposed scheme and the existing technique. All the algorithms proposed in this paper are implemented and simulated in MATLAB 7.14 installed in window 7 PC. Followings are the qualitative attributes used for results and analysis.

(i) Peak Signal-To-Noise Ratio (PSNR) [30]:

It is a ratio of the maximum power of a signal and the power of distorting noise.

$$\text{PSNR} = 10\text{Log}_{10}\left(\frac{255}{\sqrt{\text{MSE}}}\right) \quad (2)$$

$$\text{Where, } \text{MSE} = \frac{1}{mn} \sum_{i=0}^{(m-1)} \sum_{j=0}^{(n-1)} [f(i,j) - g(i,j)]^2 \quad (3)$$

Here, f represents the original or input image and g represents the enhanced image.

(ii) Index of fuzziness (IOF) [31]

It represents equivocalness present in the image by evaluating the space between its fuzzy attribute levels to nearest ordinary level. Index of fuzziness (IOF) defined as:

$$I(A) = (2/n^k). d(A, \tilde{A}) \quad (4)$$

Where the distance, $d(A, \tilde{A})$ denotes between fuzzy set A and its nearest ordinary set \tilde{A} .

5.1 Result analysis using fuzzy optimization

In this subsection, simulation results by taking the best case using fuzzy optimization in Mamdani FIS are presented using four different types of input (IMAGE-1, IMAGE-2, IMAGE-3 and IMAGE-4) are as show in Fig. 6. These results are produced based on the selection of best MFs combinations obtained for the fuzzy quality parameter in the optimization algorithm. It indicates that the cases 1D, 2A and 2C are found to be best MFs

in Mamdani FIS for image contrast enhancement. The cases are shown with incremental enhanced of contrast enhancement. It is observed using different cases that as per application requirement, the best-optimized MFs can be selected using our fuzzy optimization algorithm. **Tables 1** and **2** show the PSNR and IOF parameters for obtained results using cases 1D, 2A, and 2C.




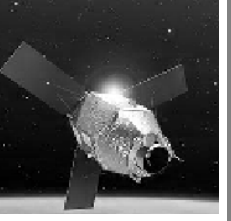



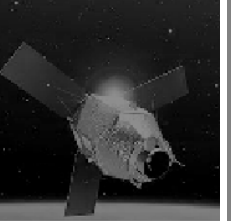



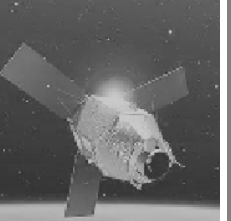

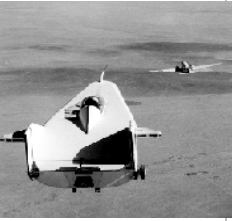

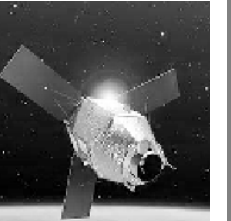
	(a) <i>IMAGE-1</i>	(b) <i>IMAGE-2</i>	(c) <i>IMAGE-3</i>	(d) <i>IMAGE-4</i>
Input images				
CASE –1D (25 G-G) Guassain -Guassain MFs				
	PSNR = 37.371 IOF = 0.01470	PSNR = 36.972 IOF = 0.01523	PSNR = 36.154 IOF = 0.1986	PSNR = 37.103 IOF = 0.1721
CASE–2A (15 G-T) Guassain -Trangular MFs				
	PSNR = 36.4933 IOF = 0.01509	PSNR = 35.9225 IOF = 0.01526	PSNR = 37.5135 IOF = 0.2185	PSNR = 36.1615 IOF = 0.1538
CASE–2C (25 G-T) Guassain-B ell Shape MFs				
	PSNR = 36.884 IOF = 0.01797	PSNR = 35.982 IOF = 0.01263	PSNR = 37.572 IOF = 0.2176	PSNR = 36.186 IOF = 0.1483

Fig. 6. Results using Different Membership Functions(MFs) for (a) IMAGE-1,(b) IMAGE-2, (c) MAGE-3, (d) IMAGE-4.

Table 1. Results for PSNR calculations in increase order for different Cases by optimization algorithm

Input Image types	Gaussian -Gaussian MFs (1D Case: 25G-G)	Gaussian -Triangular (2A Case: 15G-T)	Gaussian -Bell Shape (2C Case: 25G-T)
IMAGE 1	37.371	36.4933	36.884
IMAGE 2	36.972	35.9225	35.982
IMAGE 3	36.154	37.5135	37.572
IMAGE 4	37.103	36.1615	36.186

Table 2. Results for IOF calculations in increase order for different Cases by optimization algorithm

Input Image types	Gaussian -Gaussian MFs (1D Case: 25G-G)	Gaussian -Triangular (2A Case: 15G-T)	Gaussian -Bell Shape (2C Case: 25G-T)
IMAGE 1	0.01470	0.01509	0.01797
IMAGE 2	0.01523	0.01526	0.01263
IMAGE 3	0.1986	0.2185	0.2176
IMAGE 4	0.1721	0.1538	0.1483

5.2 Result analysis with existing techniques

In this subsection, based on results obtained using fuzzy quality-based optimization in the selection of best membership function in the fuzzy domain, case 2C- 25G-T is identified as best possible MFs in Mamdani FIS as shown in the previous section. Here, a comparative analysis is presented with existing fuzzy based techniques for image contrast enhancement. Followings are the algorithms used for comparisons: (i) Simple If-Then Fuzzy Rule-based [4], (ii) Fuzzy Distribution based [7], (iii) Fuzzy Hyperbolization based [8], (iv) Brightness Preserving and Non-parametric modified Bi-histogram Equalization (BPNMBHE) [18], and (v) our approach using optimization of MFs.


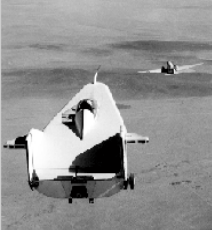

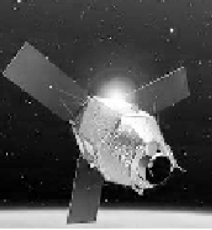

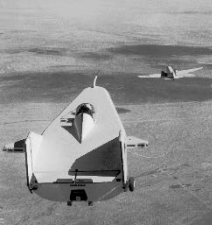

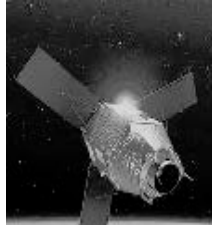
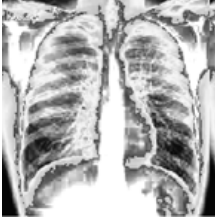


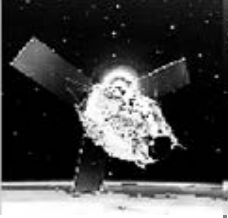



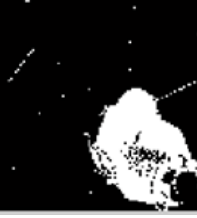



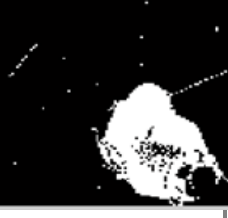
	<i>(a)IMAGE-1</i>	<i>(b)IMAGE-2</i>	<i>(c) IMAGE-3</i>	<i>(d) IMAGE-4</i>
Proposed method	 PSNR = 36.884 IOF = 0.01797	 PSNR = 35.982 IOF = 0.01263	 PSNR = 37.572 IOF = 0.2176	 PSNR = 36.186 IOF = 0.1483
BPMBHE [18]	 PSNR = 38.3051 IOF = 0.0117	 PSNR = 33.996 IOF = 0.0089	 PSNR = 35.052 IOF = 0.0963	 PSNR = 34.248 IOF = 0.0483
Fuzzy IF-THEN Rule-based [4]	 PSNR = 31.9351 IOF = 0.12293	 PSNR = 30.7308 IOF = 0.184505	 PSNR = 30.8043 IOF = 0.14138	 PSNR = 30.8043 IOF = 0.14138
Fuzzy Distribution based [7]	 PSNR = 29.2057 IOF = 0.13184	 PSNR = 27.0389 IOF = 0.0961	 PSNR = 29.4361 IOF = 0.031084	 PSNR = 27.5133 IOF = 0.188
Fuzzy Hyperbolization based [8]	 PSNR = 28.0798 IOF = 0.21201	 PSNR = 24.1215 IOF = 0.21201	 PSNR = 27.2927 IOF = 0.21201	 PSNR = 25.5671 IOF = 0.21061

Fig. 7. Results analysis with proposed method and existing techniques for given images

Table 3. Results for PSNR calculations with Existing Fuzzy based Techniques

Input Image types	Our approach	BPNMBHE [18]	Fuzzy IF-THEN rule-based [4]	Fuzzy Distribution based [7]	Fuzzy Hyperbolization based [8]
IMAGE 1	36.884	38.3051	31.9351	29.2057	28.0798
IMAGE 2	35.982	33.996	30.7308	27.0389	24.1215
IMAGE 3	37.572	35.052	30.8043	29.4361	27.2927
IMAGE 4	36.186	34.248	30.8043	27.5133	25.5671

Table 4. Results for IOF calculations with Existing Fuzzy based Techniques

Input Image types	Our approach	BPNMBHE [18]	Fuzzy IF-THEN rule-based [4]	Fuzzy Distribution based [7]	Fuzzy Hyperbolization based [8]
IMAGE 1	0.01797	0.0117	0.12293	0.13184	0.21201
IMAGE 2	0.01263	0.0089	0.184505	0.0961	0.21201
IMAGE 3	0.2176	0.0963	0.14138	0.031084	0.21201
IMAGE 4	0.1483	0.0483	0.14138	0.188	0.21061

6 Conclusion

This paper proposes new optimization method using multiple membership functions such as 15, 20, 25, and 30 in Mamdani FIS system. It is found that the selection of membership functions in the fuzzy domain while converting and modifying the intensity levels in the image is important as per types of the input image. In this paper, a fuzzy quality parameter is used to obtain the best-fitted MFs that give best-enhanced results of the input images. As per value of PSNR and IOF, it is observed that increment of membership function in FIS gives better contrast enhancement as calculated using fuzzy quality optimization. It is also shown that the Gaussian and Gaussian combination indicates better results. Based on a comparative study of existing fuzzy based techniques, results obtained are more improved and shown to be best visual enhanced images in terms of contrast and clarity. The PSNR and IOF results using our MFs in FIS show the out of performance than that of existing algorithms such as Simple If-then fuzzy Rule-based [4], Fuzzy Distribution based [7], Fuzzy Hyperbolization based [8], Brightness Preserving and Non-parametric modified Bi-histogram Equalization (BPNMBHE) [18]. As a resultant, the motivation is to design a weight based fuzzy neural model, which can take into account of all the combinations of various MFs to capture the best-optimized MFs for Mamdani FIS system.

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Comparison of Mamdani Fuzzy Inference System for Multiple Membership Functions

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Abstract—Contrast enhancement is an emerging method for image enhancement of specific application to analyze the images clearer for interpretation and analysis in the spatial domain. The goal of Contrast enhancement is to serve an input image so that resultant image is more suited to the particular application. Images with good steps of grays between black and white are commonly the best images for the aim of human perception, a novel approach is proposed in this paper based on fuzzy logic. Mamdani fuzzy inference system models are developed to enhance the contrast of images based on different membership functions (MFs).

Index Terms—Contrast enhancement; fuzzy logic; fuzzy inference system; spatial domain; membership function.

I. INTRODUCTION

Image enhancement technique is a process that gives an output image which is more suitable for analysis of a specific application like Medical, Satellite images, Military, Print Media. It is broadly classified in two categories, spatial domain and frequency domain. In Frequency domain, image enhancement is mainly based on Fourier transform and the Spatial domain is based on pixels manipulation of an image. Due to fast computation, efficiency, and less processing resources, spatial domain technique is more suitable as equivalence to other methods. Image enhancement has classified in the spatial domain as brightness control, contrast enhancement, noise reduction and edge enhancement. Apart from other methods, contrast enhancement method is used to remove noise and contrast improvement from given image to enhance the image for faster interpretation and analysis.

Image enhancement methods are also known as Contrast enhancement methods, which is mainly used three basic types of functions negative and identity transformation, log and inverse-log transformation, and nth power and nth root transformations. These functions are used to remove noise, improve visibility and increase contrast to enhance the image for proper analysis and interpretation [5, 6].

In spite of these two domains, one more domain has been described recently to enhance images in various enhancement applications which are known a fuzzy domain. A fuzzy domain is based on fuzzy sets of fuzzy logic methods. Fuzzy logic methods able to handle vague and unclear difficulties by using expert knowledge and represent knowledge as a powerful tool to mimic human reasoning. Fuzzy sets are used to make rules to make machine just like as human perception [7, 8]. Fuzzy contrast technique is used for better enhancement of images without increasing the noise which is present in input image [9]. This method is also applicable to low contrast images [10]. This kind of fuzzy techniques based on fuzzy rule-based model also known as IF-THEN rules by using different membership functions [11]. Enhancements of images are also effective and flexible by using fuzzy sets in fuzzy rule-based techniques [12].

Two types of fuzzy inference system (FIS) models are presented to better determine the image contrast enhancement of gray-scale image based on attributes such as the number of IF-THEN rules, different membership functions (MFs), fuzzy contrast factor [13, 14, 15].

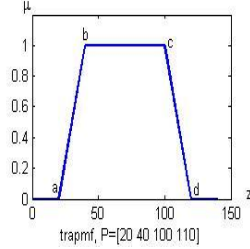
In Fuzzy Theory, there are two types of available fuzzy Rule-based models namely non-additive and additive rule model. The non-additive rule based model is also known as Mamdani fuzzy inference system (Mamdani FIS) while additive rule based model is known as Takagi-Sugeno fuzzy inference system (Sugeno FIS) [2, 3, 4]. The main differences between these two FIS are as follows. (i) Sugeno FIS requires less number of rules as compared to Mamdani FIS, (ii) the computation required for defuzzification would be less in Sugeno FIS than Mamdani FIS because output membership function is not used in Sugeno FIS during defuzzification and the resultant output would be weighted average.

Sugeno FIS uses simple IF-THEN rules and incorporates these rules based on human reasoning rather than a complex mathematical model. Thus, Mamdani FIS is widely used due to intuitive nature of rule base. Sugeno FIS is computationally efficient and well suited to work with optimization and linear techniques. Crisp

input values are obtained from given input image and it is then converted into fuzzy values using the input MFs [1]. Followings are the generalized MFs used in this paper.

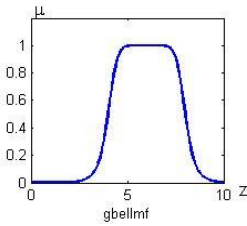
1. Trapezoidal Membership function ($\mu(z)$) =

$$\begin{cases} 1 - \frac{a-z}{c} & a-c \leq z < a \\ 1 & a \leq z < b \\ 1 - \frac{z-b}{d} & b \leq z \leq b+d \\ 0 & \text{Otherwise} \end{cases}$$

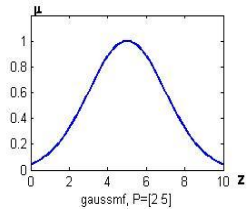


2. Bell Membership function ($\mu(z)$) =

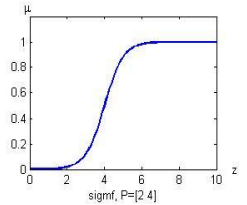
$$\begin{cases} S(z; c-b, c - \frac{b}{2}, c) & z \leq c \\ 1 - S(z; c, c + \frac{b}{2}, c+b) & z > c \end{cases}$$



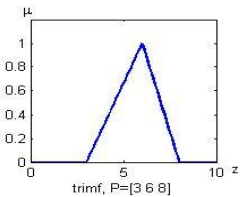
3. Gaussian Membership function ($Gaussian(x; m, \sigma)$) = $exp\left\{-\frac{(x-m)^2}{\sigma^2}\right\}$



4. Sigmoid Membership function ($Sigmoid(x, a, c)$) = $\frac{1}{1 + e^{-a(x-c)}}$



5. Triangular Membership Function $\mu(z) = \begin{cases} 1 - \frac{a-z}{b} & a-b \leq z < a \\ 1 - \frac{z-a}{c} & a \leq z \leq a+c \\ 0 & \text{otherwise} \end{cases}$



II. FUZZY RULE BASE FIS DESIGN

The fuzzy contrast factor plays an important role in the enhancement of contrast for low contrast images. Here challenges are the use of the potential of fuzzy rule-based approach and different MFs for the analysis of the image using Mamdani FISs.

Fuzzy rule base will be a fuzzy partitioning for input and output domains. These rules base would be generated automatically utilizing the available local image-specific information.

In this paper, Comparison of Mamdani methods has been given on the basis of image qualitative attributes of contrast enhancement of images and resultant images. Following contributions of this paper are:

- We propose FIS using different types of MFs for contrast enhancement and detailed analysis of Rule-base system is presented.
- We perform an evaluation of different MFs based FIS against the state-of-the-art fuzzy enhancement techniques, based on different types of Rule-base design.
- We describe the study of the interaction of input MFs and output MFs in the design of Rule-base for FIS.
- We explore the potential of Rule-base design according to human perception in fuzzy based image enhancement algorithms.

Major headings should be typeset in boldface with the first letter of important words capitalized.

III. EVOLUTION AND PERFORMANCE ATTRIBUTES

In Contrast enhancement technique quality of images can be different as per human perception. Here a description of different quality attributes has been given. On the basis of these quality attributes we can compare the better appearance of images.

Various performance attributes are following:

A. Mean Square Error (MSE)

$$MSE = \frac{1}{mn} \sum_0^{m-1} \sum_0^{n-1} |f(i, j) - g(I, j)|^2 \quad (1)$$

B. Peak Signal-To-Noise Ratio (PSNR)

$$PSNR = 10 \log_{10} \left(\frac{255}{\sqrt{MSE}} \right) \quad (2)$$

C. Index of Fuzziness (IOF)

$$I(A) = (2/n^k). d(A, \tilde{A}) \quad (3)$$

Where $d(A, \tilde{A})$ denotes between fuzzy set A and its nearest ordinary set \tilde{A} .

Here we have taken four different cases in which different combinations of membership functions are selected. On the basis of different quality values shown in all tables, image quality will be better for the higher value of PSNR and a smaller value of MSE. For evaluations, given input images are shown in figure (1) and their results are given in tables 1, 2, 3, and 4.

IV. EXPERIMENTAL STUDIES

Here four cases are taken on the basis of multiple membership functions of FIS. Following input images are taken for evaluation of result:



Fig.1. input images

A. CASE 1

This case is based on three combinations of Sigmoid shaped membership function and Gaussian membership function. Below figure (2) is showing input and output membership functions and their rules.

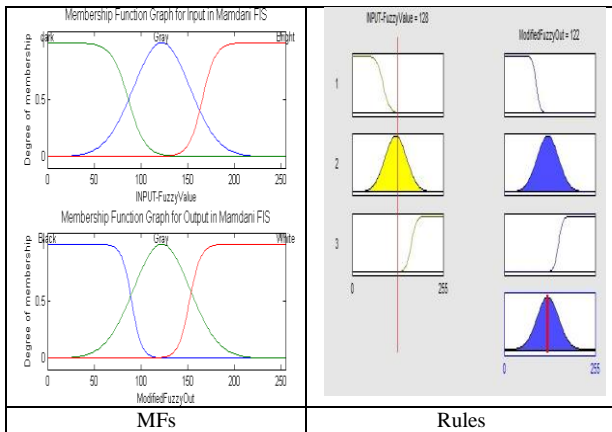


Fig.2. Three Membership functions and their rules.

Table 1. Three combinations of MFs

Input Image	MSE	PSNR	INDEX OF FUZZINESS(IOF)
IMAGE 1	21.914	34.7236	-0.095621
IMAGE 2	16.4304	35.9743	-0.23182
IMAGE 3	18.8913	35.3682	-0.086661
IMAGE 4	11.6534	37.4663	0.013683
IMAGE 5	11.1306	37.6656	-0.24024

B. CASE 2

This case is based on fifteen combinations of Sigmoid shaped membership function and Gaussian membership function. Below figure (3) is showing input and output membership functions and their rules.

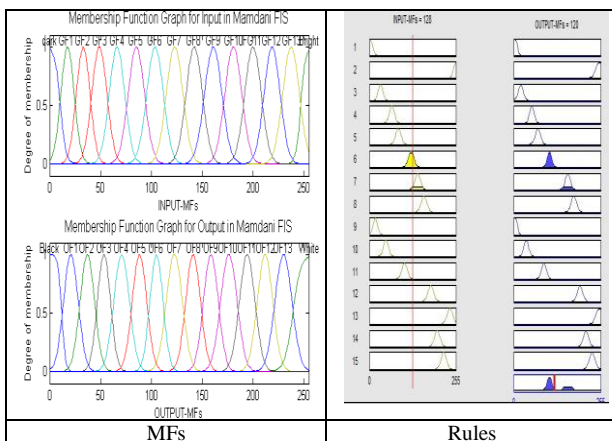


Fig.3. Fifteen Membership functions and their rules.

Table 2. Fifteen combinations of MFs.

	MSE	PSNR	INDEX OF FUZZINESS(IOF)
IMAGE 1	11.8767	37.3839	-0.018303
IMAGE 2	12.691	37.0959	-0.19751
IMAGE 3	12.1918	37.2701	-0.028699
IMAGE 4	12.6703	37.1029	0.088304
IMAGE 5	13.3171	36.8867	-0.19621

C. CASE 3

This case is based on nineteen combinations of Sigmoid shaped membership function and Gaussian membership function. Below figure (4) is showing input and output membership functions and their rules.

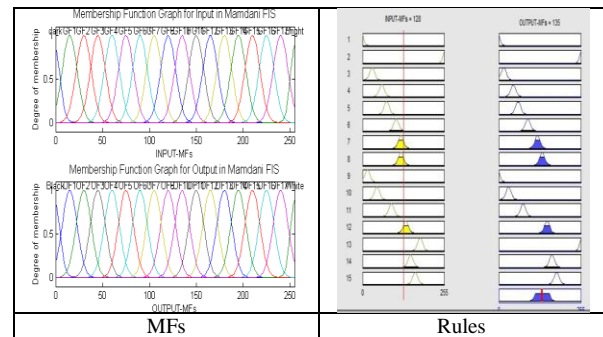


Fig.4. Nineteen Membership functions and their rules.

Table 3. Nineteen combinations of MFs.

	MSE	PSNR	INDEX OF FUZZINESS(IOF)
IMAGE 1	15.6427	36.1877	-0.046542
IMAGE 2	15.4997	36.2276	-0.17714
IMAGE 3	13.3168	36.8868	-0.057898
IMAGE 4	13.6592	36.7766	0.063421
IMAGE 5	13.6356	36.7841	-0.2315

D. CASE 4

This case is based on Twenty-six combinations of Sigmoid shaped membership function and Gaussian membership function. Below figure (5) is showing input and output membership functions and their rules.

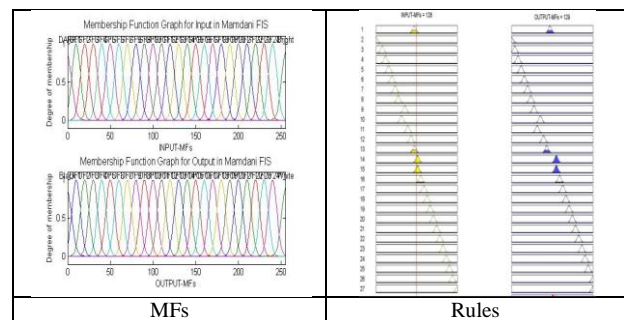


Fig.5. Twenty-six Membership functions and their rules.

Table 4. Twenty-six combinations of MFs.

	MSE	PSNR	INDEX OF FUZZINESS(IOF)
IMAGE 1	9.2052	38.4905	-0.047048
IMAGE 2	8.9364	38.6192	-0.23403
IMAGE 3	9.1023	38.5393	-0.050318
IMAGE 4	10.1939	38.0474	0.07282
IMAGE 5	9.4377	38.3821	-0.23225

On the basis of above statistics, we can compare quality and contrast of images. Higher the PSNR and lower the MSE value shows the better contrast of images. Index of fuzziness (IOF) gives indistinctness present in an image. The lower value of the index of fuzziness will proceed for better enhancement.

V. RESULTS AND DISCUSSIONS

On the basis of images and graph, following observations show the comparison and clearly gives the visual aspect of images.

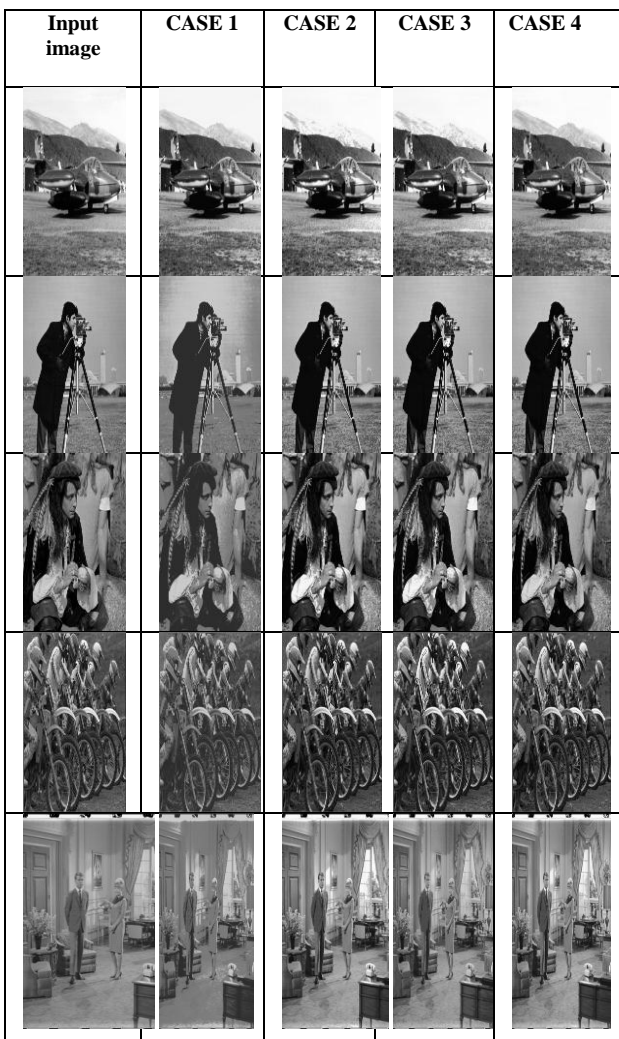


Fig.6. Different cases for Original and Enhanced Images.

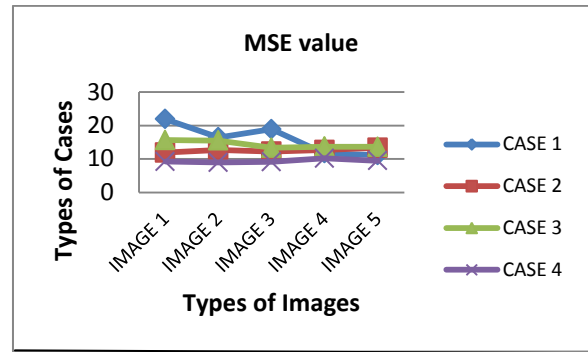


Fig.7. MSE values of different images.

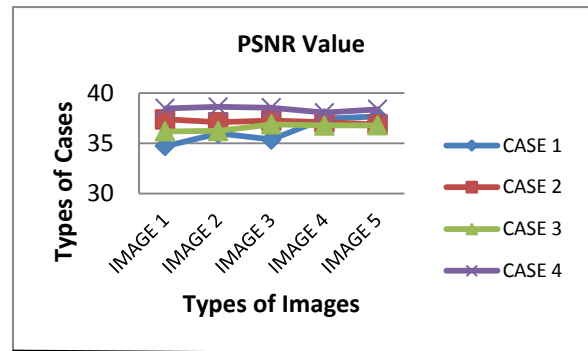


Fig.8. PSNR values of different images.

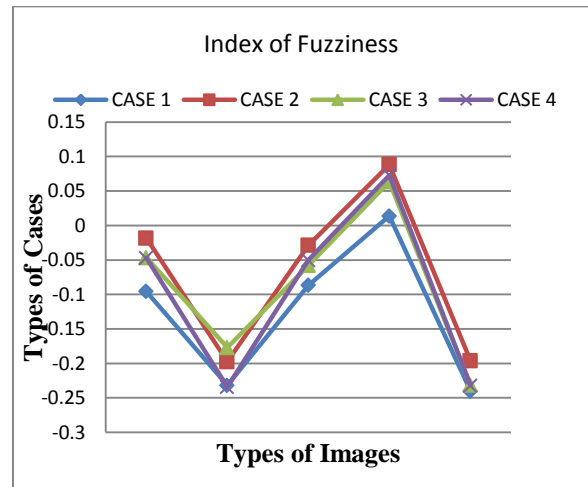


Fig.9. Index of Fuzziness values of different images.

VI. CONCLUSIONS AND FUTURE WORK

This paper demonstrates a combination of multiple membership functions to optimize contrast enhancement of input image and produced an output image with better contrast as compared to the input image. Results and analysis show that FIS is a power tool for presenting the image in a better way. As a future scope more combination of membership functions introduced for better analysis and enhanced image.

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An Analysis of Fuzzy and Spatial Methods for Edge Detection

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Abstract—An image segmentation is an area in which image is subdivided into sub-regions for extracting characteristics of images which will help to analysis in various applications. For getting accuracy sharp changes of intensity is an important issue which is known as edge detection. In this paper various spatial edge detection methods and fuzzy based edge detection method has described and spatial edge detection methods and fuzzy if-then-else are compared to know which method will be more suitable to find edges for the enhancement of images.

Index Terms—Image segmentation, Edge, Threshold, Fuzzy method.

I. INTRODUCTION

A method in which various input image properties is obtained as an output known as transition. Transition state of the input image to output image lay in the segmentation.

An Image segmentation splits an image into its sub-regions to collect the details which are found in a sub-region of the image. These details are helpful to analyzing images for the enhancement of images. The accuracy of enhancement is based on accurate segmentation method. For this reason, more care should be taken to improve images with the help of accurate segmentation. It is helpful to control the environment in many applications like in military to detect objects, industrial inspection applications etc. An image segmentation method has two types of categories to achieve accuracy. The first category is describing a partition of images based on Sharpe changes in intensity known as edge and the second category is based on a set of predefined criteria known as Thresholding, region growing and region splitting and merging [1] [2]. With the help of thresholding edge, detection can be possible to overcome the criteria of the noisy condition. In this method first order derivative of Gaussian filter used for convolving the images [3]. Edges found by canny can also create some false edges. The structure of image can also find with the help of method known as USAN, which is helpful in edge detection [4]. Edges may also

find with the help of zero crossing [5]. For measurement of the degree of fuzziness, entropy has used, which produced 1-pixel wide edges [6]. Image segmentation is a difficult task to make images meaningful. By using canny method image segmentation may give many false edges to increase the complexity of image characteristics. Instead of Canny method, a two steps Chan These method is helpful to detect best edges [7]. All the classical spatial methods like Canny edge detector, Sobel method, Prewitt edge detection, and Laplacian of Gaussian are not been able to detect correct and smooth edges in images. Latterly a new method intuitionistic fuzzy set (IFS) theory was proposed to detect correct and smooth edges. The intuitionistic fuzzy method used the concept of entropy in various clustering algorithm [9].

The remaining paper is divided as follows. Section II is describing various classical edge detection techniques available in the literature. Section III is describing fuzzy domain edge detection techniques. Section IV is based on experimental study and results. And in the last section V conclusions are drawn.

II. SPATIAL DOMAIN EDGE DETECTION TECHNIQUES

Spatial filtering is used in the Edge detection to used break off between gray levels. For the edge detection in images first order derivative and second order derivatives are used. First order derivative are worked out by using gradient and second order derivative are found by the Laplacian.

A. Gradient operator

The gradient of an image $f(x, y)$ at a location (x, y) is defined as the vector:

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \quad (1)$$

Magnitude of above vector:

$$\nabla f = \text{mag}(\nabla f) = \sqrt{G_x^2 + G_y^2} \quad (2)$$

The direction of the gradient vector:

$$\alpha(x, y) = \tan^{-1} \left(\frac{G_x}{G_y} \right) \quad (3)$$

Different types of edge detection methods are based on three categorizations:

B. Classical edge detection methods:

i. Sobel Mask

Mask used by this method is:

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

Fig.1. Sobel Mask

Using the below equations Sobel mask is used for edge detection.

$$G_x = (Z_7 + 2Z_8 + Z_9) - (Z_1 + 2Z_2 + Z_3) \quad (4)$$

$$G_y = (Z_3 + 2Z_6 + Z_9) - (Z_1 + 2Z_4 + Z_7) \quad (5)$$

ii. Prewitt Mask

Mask used by this method is:

-1	-1	-1
0	0	0
1	1	1

-1	0	1
-1	0	1
-1	0	1

Fig.2. Prewitt Mask

Using the below equations Prewitt mask is used for edge detection.

$$G_x = (Z_7 + Z_8 + Z_9) - (Z_1 + Z_2 + Z_3) \quad (6)$$

$$G_y = (Z_3 + Z_6 + Z_9) - (Z_1 + Z_4 + Z_7) \quad (7)$$

iii. Robert Mask

Mask used by this method is:

-1	0
0	1

-1	0
0	1

Fig.3. Robert mask

Using the below equations Robert mask is used for edge detection.

$$G_x = (Z_9 - Z_5) \quad (8)$$

$$G_y = (Z_8 - Z_6) \quad (9)$$

C. First order edge detection method

i. Canny edge detection

- It uses smoothing as a process to remove noise.
- Finding the gradient of images which has a large magnitude.
- By using double thresholding.

D. Second, order edge detection method

i. Laplacian

The Laplacian of a 2-D function f(x,y) is a second-order derivative. The Laplacian is merged with smoothing to find edges via zero-crossing.

0	-1	0
-1	4	-1
0	-1	0

-1	-1	-1
-1	8	-1
-1	-1	-1

Fig.4. Laplacian mask

In Laplacian filtering enhanced image can be found by:

$$F'(x, y) = F(x, y) + CVF(x, y) \quad (10)$$

ii. Laplacian of a Gaussian (LOG)

Laplacian of a Gaussian sometimes is called the Mexican hat function. Gaussian function is used to smooth the image and Laplacian operator is used to constitute the location of edges by zero findings. Here, Figure-5 is a 5×5 mask to approximate the shape of Maxican hat function.

0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	16	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

Fig.5. Laplacian of Gaussian Filter

III. FUZZY DOMAIN EDGE DETECTION TECHNIQUES

In many applications, edge detection becomes very important due to the criticality of use of images like in medical images diagnosis of disease is very crucial. Due to this reason, images must be free of poor contrast, vagueness, blurred or broken edges. That's why because of the above reasons fuzzy method is suitable to take into account the unclearness and equivocalness present in the image [17]. Several Fuzzy edge detection methods are following:

A. Fuzzy Sobel edge detector [13]

In this method the image is divided into two regions:

i. Fuzzy edge region

In this method, if pixels have a high difference in the gray level with their neighborhood region then the pixels are separated by the fuzzy edge region.

ii. Fuzzy smooth region

In this method, if pixels have less difference of gray level with their neighborhood region then the pixels are separated by the fuzzy smooth region.

By using fuzzy reasoning the modified fuzzy edge detector is generalized by using following fuzzy rules:

$$\begin{aligned} R(x, y) &= 255, \text{ if } G(x, y) \geq HT \\ &= 0, \text{ if } G(x, y) \leq LT \\ &= G(x, y) \cdot \max(\mu_{SFR}(x, y), \mu_{EFR}(x, y)) \\ &\quad \text{Otherwise} \end{aligned} \quad (11)$$

Where μ_{SER} and μ_{EFR} are the membership functions of the image smooth and edge regions.

$G(x, y)$ is the gradient value using Sobel operator.

$R(x, y)$ is the resultant pixel at location (x, y) .

B. Entropy-Based Fuzzy Edge Detection [11]

As per information theory, defined formula of entropy is given as:

$$H(t_1, t_2) = -P_{smooth} \log_2(P_{smooth}) - P_{edge} \log_2(P_{edge}) \quad (12)$$

Where P_{edge} and P_{smooth} are Probability distributions.

$$P_{edge} = \sum_k h g_k \cdot \mu_{edge}(k) \quad (13)$$

$$P_{smooth} = \sum_k h g_k \cdot \mu_{smooth}(k) \quad (14)$$

Here P_{smooth} and P_{edge} are weight area on the gradient histogram and when membership function μ_{smooth} and μ_{edge} are weights.

In edge detection, the best parameter values are compact edge representation of images that's why minimum entropy $H(t_1, t_2)$ parameters are selected.

The necessary assumptions for minimum and maximum entropy are:

$$\frac{\partial H(t_1, t_2)}{\partial t_1} = 0 = -(\frac{\partial P_{smooth}}{\partial t_1} \times \log(P_{smooth} / (1 - P_{smooth}))) \quad (15)$$

$$\frac{\partial H(t_1, t_2)}{\partial t_2} = 0 = -(\frac{\partial P_{smooth}}{\partial t_2} \times \log(P_{smooth} / (1 - P_{smooth}))) \quad (16)$$

The entropy will be minimum,

$$\text{When } P_{smooth} = P_{edge} = 1/2 \quad (17)$$

The best set of parameter $(\tilde{t}_1, \tilde{t}_2)$ will satisfy the following condition:

$$H(\tilde{t}_1, \tilde{t}_2) = \min_{r=0,1,2\dots R}(H(t_1(r), t_2(r))) \quad (18)$$

The edge image is calculated as

$$\text{Edge-image}(x, y) = 1 \quad (19)$$

C. Fuzzy template based edge detector

Two types of fuzzy template based edge detector method are available.

In first method, fuzzy edge templates are designed and these templates are convolved with the image [12].

For finding the existence of edge:

$$H(x, y) = \max_{T=1, \dots, n}(H_T(x, y)) \quad (20)$$

Where n =number of templates.

The new images are found with the support of threshold, the value which is below the threshold are set as 0 and above the threshold are set as 1.

In second method fuzzy divergence used in between image window and a set of 16 fuzzy templates [8].

D. Fuzzy If-then Rules based Edge Detection

This fuzzy technique is based on rule-based fuzzy logic. The fuzzy rule-based concept has been taken from Fuzzy set theory [14] [15] because of its simplicity and effectiveness. It is an inference form of uncertain knowledge to handle and analyze information in an effective manner. It could be combined different filters along with fuzzy if-then rules to detect edges for enhancement of images [16]. For edge detection fuzzy logic algorithm using following rules [1]:

(1) If a pixel belongs to the same region, then make it brighter; else make it darker, where values related to brighter and darker are fuzzy sets.

(2) A 3x3 pixel neighborhood and corresponding intensity differences between the center pixels and its neighbors are shown below.

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

d_1	d_2	d_3
d_5	0	d_6
d_7	d_8	d_9

Fig.6. 3x3 mask

The followings are the if-then-else rules based on fuzzy values.

IF d_2 is zero AND d_6 is zero THEN z_5 is white
 IF d_6 is zero AND d_8 is zero THEN z_5 is white
 IF d_8 is zero AND d_4 is zero THEN z_5 is white
 IF d_4 is zero AND d_2 is zero THEN z_5 is white
 ELSE z_5 is black

Membership functions ZE, BL, and WH is used for the fuzzy sets zero, black, and white.

IV. EXPERIMENTAL STUDY AND RESULTS

In this study, several images have taken from internet and Matlab for the experiment of edge detection. Followings are the procedure of edge detection using fuzzy If-then rules:

- Step-1:** Apply the simple filters (convolution) to obtain the image gradients.
- Step-2:** Define the image gradients of input image with respect to x-axis and y-axis direction.
- Step-3:** Design a Fuzzy Inference System (FIS) with 2 inputs and 1 output.
- Step-4:** Set the Fuzzy-If Then Rules into FIS.
- Step-5:** Obtain the membership function of image gradients as Ix and Iy.
- Step-6:** Apply the Ix and Iy to above FIS for Evaluation.
- Step-7:** Store the result obtained from output of FIS. This resultant would produce the edge of the image.

In this, we are comparing various classical method of edge detection with fuzzy if-then-else rule-based edge detection method. Based on performance evaluation parameters, we can compare various methods.

In the experiments, we have compared various methods of edge detection on the basis of two performance analysis parameters. One is PSNR and another is MSE, below every output image these values are written and we can compare on the basis of these values, which method is giving better results.

The mathematical formula of the PSNR is as follows:

$$PSNR = 20Log_{10}(\frac{255}{\sqrt{MSE}}) \quad (21)$$

Where, MSE (Mean square error) is as follows:

$$MSE = \frac{1}{mn} \sum_0^{m-1} \sum_0^{n-1} ||f(i,j) - g(l,j) ||^2 \quad (22)$$

Where f = matrix data of the original image, g = matrix data of the degraded image, m = no of rows of pixels of an image, l = index of that row, n = no of columns of pixels of an image, j = index of that column.

Higher the values of PSNR will show better results because only on the basis of visualization strongly we cannot reach the conclusion, which method is better.

Table 1. MSE values of different images

	Image 1	Image 2	Image 3	Image 4
SOBEL	12698.83	14161.36	17974.31	17702.02
PREWITT	12698.91	14161.36	17974.38	17702.12
ROBERT	12699.58	14163.92	17974.16	17702.16
CANNY	12683.91	14161.25	17962.88	17693.80
FUZZY IF-THEN ELSE	0.34	0.34	0.24	0.27

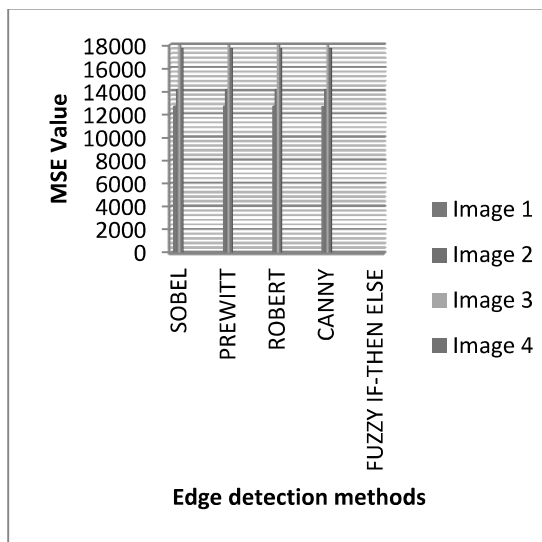
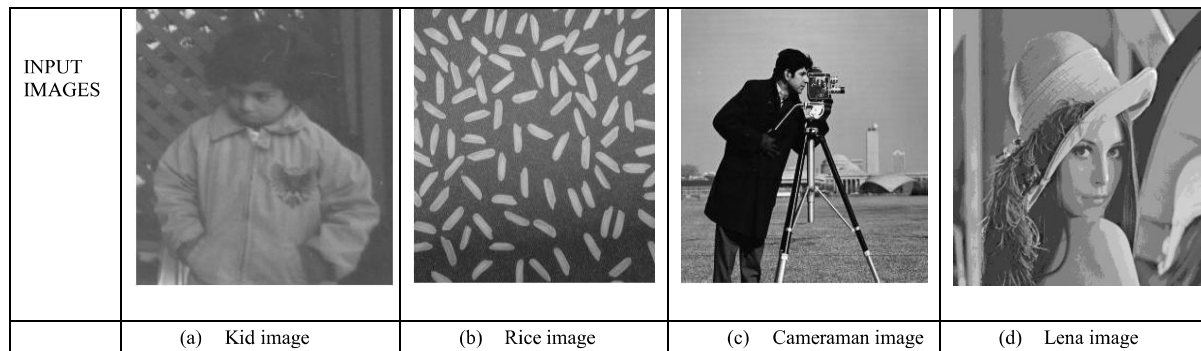


Fig.7. PSNR values of different images



SOBEL				
Prewitt				
Robert				
Canny				
Fuzzy If-then				

Fig.8. Results of various edge detection methods

Table 2. PSNR values of different images.

	Image 1	Image 2	Image 3	Image 4
SOBEL	7.40	6.65	5.62	11.71
PREWITT	7.40	6.65	5.62	11.71
ROBERT	7.40	6.65	5.62	11.71
CANNY	7.40	6.65	5.62	11.71
FUZZY IF-THEN ELSE	53.14	52.79	54.34	59.87

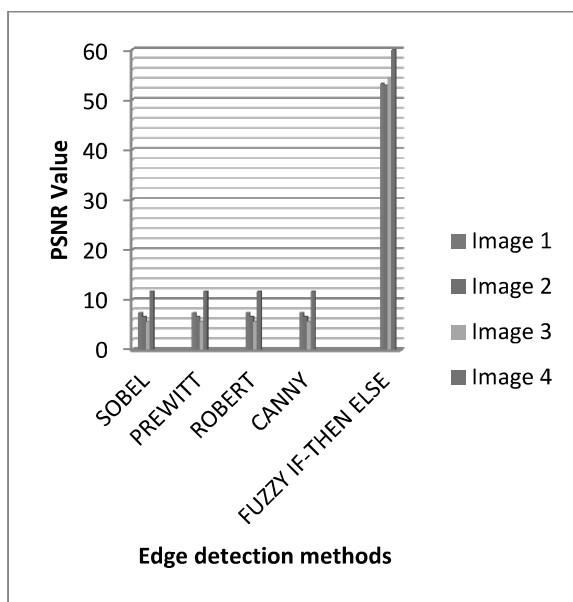


Fig.9. PSNR values of different images

V. CONCLUSION

In this paper, edge detection based on image segmentation of various spatial methods and fuzzy methods are discussed and compared the result of various spatial edge detection technique and fuzzy if-then method. The experimental study is performed on various images collected from internet and Matlab. As per experimental results fuzzy method is giving better results as compared to spatial fuzzy methods like Sobel, Prewitt, Robert and Canny on the basis of visualization and with the help of quantitative values of performance parameters like PSNR, and MSE. The values of PSNR of the fuzzy method are higher as compared to other methods. Graphs of MSE values and PSNR values clearly showing better result of fuzzy if-then else method on the basis of their higher values of PSNR. However, fuzzy edge detection method is giving better results.

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Image Enhancement Techniques in the Spatial Domain: An Overview

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ABSTRACT: Enhancement is the process of manipulating an image so that the resultant is more suitable than the original for a specific application. Usually, the images taken by different cameras or devices are not suitable due to dull and less contrast, then using the digital image processing one can enhance or sharpen the image. Lots of techniques are available as first derivation technique like Sobel mask, second derivative technique like Laplace mask and many more. This paper highlights the different techniques of image enhancement and its importance in the spatial domain. Many papers has searched and found that lots of new techniques are also on working for better enhancement. This paper gives an overview of various techniques for image enhancement in spatial domain for the grey scale image.

KEYWORDS: *Image Enhancement, Survey, Spatial Domain, Digital Image Processing Applications.*

1. INTRODUCTION

Image enhancement is a process on image that emphasizes the image features by extracting the some characteristics while restraining the others in the image. It can be the one of the methods to improve the quality of the original image which can easily be applied for computer imaging problems. There are many objectives in image enhancement such as contrast enhancement, noise reduction, feature enhancement etc. Usually, image enhancement techniques make the selective operations on some features in image without increasing or decreasing the image information.

In other words, Image enhancement is a technique to convert original image in a form which is more suitable for computer vision applications and human use. Image enhancement methods are generally edge detection methods and image contrast enhancement. Edge detection method detects the edges in given image by emphasizing some characteristics by using filtering or masking, so that the processed image includes quality with better visibility. This is an important stage in medical images analysis to improve the quality (clarity) of images for humans or further processing for medical purposes. The examples of enhancement operations include removing blurring and noise, increasing contrast, and revealing details. The enhancement techniques differ from one application to another according to their objectives.

In general, the image enhancement techniques are classified into two domains namely spatial domain and Frequency domain methods. Spatial domain methods directly deal with the image pixels by manipulated them using some operations in order to achieve the desired enhancement in terms of quality or visibility. In this domain, logarithmic transformation, power law transformations are used as a tool for processing on image pixels. Histogram equalization and its variants are also common methods of enhancement in spatial domain [Alamri et. al (2010)]. Frequency domain methods are based on the nature of the frequency (and sequence) transformation. The principle behind on the methods of frequency domain consists of computation using Fourier transform, manipulation of transform coefficients in frequency domain, then inverse transformation to get resultant enhanced image.

2. LITERATURE REVIEW

Several mathematical tools have been used in edge detection for example feature synthesis uses for the fine-to-coarse integration of information. Alamri et. al (2010) explained Segmentation using edge detection techniques in his paper. Canny (1986) has proposed a standard edge detection Algorithm in five steps describing Smoothing, Finding gradients, Non-maximum suppression, Double thresholding, Edge tracking by hysteresis. For contrast image enhancement, Histogram Equalization (HE) is popular method in which cumulative density function used for mapping the gray levels of the input image according to uniform probability distribution. HE improves the contrast by stretching the dynamics range of the image's histogram. But, the brightness of input image may change using this method that causes undesirable artefacts appeared in the resultant image. So that it cannot be used in some applications. Mean preserving Bi-histogram Equalization (BBHE) [Kim (1997)] has been proposed to solve this problem. It preserves the mean brightness with improved contrast of given input image. Zhiming and Jianhua (2006) propose extension of Histogram Equalization by combining three accelerative techniques namely local histogram, cumulative histogram functions and use of block size W^2 . This technique is complex in terms of computation and processing time. Yeganeh et al (2008) proposes another technique of contrast enhancement based on Histogram Equalization. Authors proved to be more efficient by equalizing the histogram of input image while increasing the dynamic range.

Apart from the techniques based on Histogram Equalization, one can use artificial intelligence schemes for processing the input image, so that a satisfactory resultant image can be obtained which fulfils the major requirement of image processing applications. The artificial intelligence schemes include Pollination based Optimization, Intelligent Waterdrop, Neural Networks, Biogeography based Optimization, Bacterial foraging optimization, genetic algorithm, and membrane computing, etc [Pal and King (1980), Hammadou and Bouzerdoum (2001), Zhang et.al (2013), Nikolova and Steidl (2014)]. Cellular Neural Networks (CNNs) [Chua et. al (1988), Chua et. al (1988)] have shown to be very efficient tool in image processing tasks. These are nonlinear dynamic systems designed from connected a large array of processing units (cells) with each others in a neighbourhood. For example, 2-dimensional discrete time (DT) CNNs proposed by Chua et. al (1988) have been shown to be more powerful in image processing and pattern recognition applications such as edge detection, feature extraction, noise reduction, shadow detection, hole filling, etc.

It is shown by Caponetti et. al (1994) that a genetic algorithm acts as a popular and effective optimization tool to improve the contrast of a given image. By using fitness function individually it gives better results to convert gray image into better contrast enhanced image. Genetic algorithm is used to get best gray level by using simple chromosome structure [verma et. al (2012), kim (1997)].

One can apply an optimization technique like genetic algorithm used for optimal edge configuration. For each edge configuration fitness value assigns, which represents survive and reproduce of an individual [Canny (1986)]. Genetic algorithm also used in analysis of medical images on the basis of thin and continues detection of edges accurately [Hashemi et. al. (2009)]. This approach used in different modalities like MRI, CT, Ultrasound. In this technique cost functions used in optimization.

3. ENHANCEMENT METHOD

There is different method for better enhancement of an image. All are listed below.

3.1. Intensity transformation method

3.1.1. Image negative

- 3.1.2. Log transformation
- 3.1.3. Power-law transformation
- 3.2. Piecewise Linear transformations
 - 3.2.1. Contrast Stretching
 - 3.2.2. Intensity-level slicing
 - 3.2.3. Bit Plane slicing
- 3.3. Histogram processing
 - 3.3.1. Histogram Equalization
 - 3.3.2. Histogram Matching
- 3.4. Spatial filtering
- 3.5. Frequency Domain

We discussed here the complete description of enhancement of an image in spatial filtering.

4. SPATIAL FILTERING METHOD

Spatial filtering is one of the principal tools used to enhance the image by accepting or rejecting certain frequency components. Spatial filtering is also called spatial mask, kernels templates and windows consists of neighbourhood and predefined operation that is performed on the image pixel. The most important neighbourhood operator is convolution. To convolve something means roll together. Correlation is the process of moving a filter mask over the image and computing the sum of product at each location. The methods of convolution are the same, except that the filter is first rotated by 180°. Filtering creates a new pixel with coordinates equal to the coordinates of the centre of the neighbourhood, and whose value is the result of filtering operation. Let 3×3 be a filtering mask at any point (x, y) in the image, the response, $g(x, y)$ of the filter is the sum of product of the filter coefficients and the image pixel encompassed by the filter. It can be expressed as

$$G(x, y) = w(-1, -1)(f(x - 1, y - 1) + w(-1, 0)(f(x - 1, y) + w(-1, -1)(f(x - 1, y + 1) + w(0, -1)(f(x, y - 1) + w(0, 0)(f(x, y) + w(0, 1)(f(x, y + 1) + w(1, -1)(f(x + 1, y - 1) + w(1, 0)(f(x + 1, y) + w(1, 1)(f(x + 1, y + 1)). \quad (1)$$

Let us take a filter of size $m \times n$ then before convolution or correlation padding is very important, means add $(m - 1)$ row of 0 at the bottom and add $(m - 1)$ row of 0 at the Top. And add $(n - 1)$ row of 0 at left and $(n - 1)$ row of 0 at the right side of the image function $f(x, y)$.

4.1. Smoothing Filter

Smoothing filter is used for blurring and for noise reduction. Blurring is used in pre-processing task, such as removal of small detail from an image like reduction of noise from an image. Average filtering is used for removal of noise also called the low pass filter. Median Filter is used for smooth the image which suffers from salt and paper noise because of its appearances white and black dots superimposed on an image.

4.2. Using Derivative

Sharpening of the image is done by spatial differentiation which enhances edges and other discontinuities and deemphasizes areas with slowly varying intensities. The first derivative of digital function is defined in terms of differences. It is zero in areas of constant intensities nonzero at the onset of an intensity step or ramp and nonzero along ramp. Spatial filtering is used in the Edge detection to used break off between gray levels. For the edge detection in images first order derivative and second order derivatives are used. First order derivative are worked out by using gradient and second order derivative are found by the Laplacian.

4.2.1. Gradient operator

The gradient of an image $f(x, y)$ at a location (x, y) is defined as the vector:

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \partial t / \partial x \\ \partial t / \partial y \end{bmatrix} \quad (2)$$

Magnitude of above vector:

$$\nabla f = \text{mag}(\nabla f) = \sqrt{G_x^2 + G_y^2} \quad (3)$$

The direction of the gradient vector:

$$\alpha(x, y) = \tan^{-1} \left(\frac{G_x}{G_y} \right) \quad (4)$$

4.2.2. Edge detection techniques



Z_1	Z_2	Z_3
Z_4	Z_5	Z_6
Z_7	Z_8	Z_9

Fig.1 Original images and 3×3 region of an image

Let a 3×3 region of an image (the z 's are gray-level values)

Here calculation of gradient of an image based on partial derivatives $\frac{\partial f}{\partial x}$ and $\frac{\partial f}{\partial y}$ at every pixel location. Here different methods used filters or mask as a sub image, and these filter mask moves point to point in an image to calculate that point using a predefined relationship.

Sobel Method

$$G_x = (z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3) \quad (5)$$

$$G_y = (z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7) \quad (6)$$

Using the above two Equations, Fig. 2 shows the Sobel mask used for image enhancement in edge detection applications.

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

Fig. 2 Sobel Mask

As shown in Fig 3, the effect of Sobel filtering is drawn using given images. Here, we can see that varying shades of gray levels are eliminated, thus the edges are identified quite visible.



Fig.3 Enhancement of images using Sobel method

Prewitt Method

$$G_x = (z_7 + z_8 + z_9) - (z_1 + z_2 + z_3) \quad (7)$$

$$G_y = (z_3 + z_6 + z_9) - (z_1 + z_4 + z_7) \quad (8)$$

Here Fig-4 is called Prewitt masks, are used to implement these two equations. By applying convolution Prewitt mask are easier to implement as compared to Sobel mask, but result may differ.

-1	-1	-1
0	0	0
1	1	1

-1	0	1
-1	0	1
-1	0	1

Fig-4 Prewitt Masks

The effect of prewitt masks in image enhancement is shown in Fig. 5. Here, it is shown that the image is much more smoothing than the Sobel method. Because, the Prewitt mask takes more emphasis on pixels near to the centre of the mask.



Fig. 5 Enhancement of images using Prewitt method

Roberts Method

$$G_x = (z_9 - z_5) \quad (9)$$

$$G_y = (z_8 - z_6) \quad (10)$$

Here Fig. 6 is called Roberts masks, are used to implement these two equations

-1	0
0	1

0	-1
1	0

Fig-6 Roberts Masks

Fig. 7 shows the effect of Roberts masks in image enhancement. The resultant image highlights the regions with high spatial frequency corresponding to the edges. Thus, visibility in edges would be estimated value of gradient over the neighbourhood of the image.

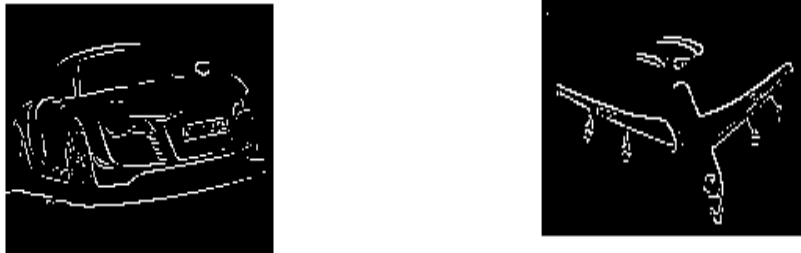


Fig-7 Enhancement of an image by Roberts Method

Laplacian

The Laplacian of a 2-D function $f(x,y)$ is a second-order derivative defined

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \quad (11)$$

$$\nabla^2 f = 4z_5 - (z_2 + z_4 + z_6 + z_8) \quad (12)$$

The Laplacian is merged with smoothing to find edges via zero-crossing.

Here Fig-8 is called Laplacian mask, are used to implement these two equations

0	-1	0
-1	4	-1
0	-1	0

-1	-1	-1
-1	8	-1
-1	-1	-1

Fig. 8 Laplacian Mask

In Laplacian filtering enhance image can be found by

$$F'(x, y) = F(x, y) + C\nabla F(x, y) \quad (13)$$



Fig-9: Enhancement of an images by Zero-Crossing method

Laplacian of a Gaussian (LOG)

Laplacian of a Gaussian sometimes is called the Mexican hat function. Gaussian function is used to smooth the image and Laplacian operator is used to constitute the location of edges by zero findings. Here Fig-10 is a 5×5 mask to approximate the shape of Maxican hat function.

0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	16	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

Fig-10: Laplacian of Gaussian Filter

Figure 11 shows the effect of this filtering and shows the sharpen image with smoothing.



Fig-11: Enhancement of an image by LOG method

Canny Method

The Canny edge detection algorithm has following steps:

- (i) It used smoothing as a process to remove noise from the image to blurring of the image.
- (ii) Finding the Gradient of the image which has large magnitude.
- (iii) By using Double thresholding, Non-Maximum suppression and edge tracking by hysteresis



Fig-12: Enhancement of an image by Canny method

Fig. 12 shows the output of given images using Canny edge detector method. It shows that this method detects the large scale edges by good detection and localization.

5. GENETIC ALGORITHM(GA)

Genetic Method used as a optimization techniques, to search survival and reproduction of individual by using fitness function. A GA need less information to solve any problem as compare to conventional optimization methods. In Enhancement of image genetic method take a very important role to find the best enhanced image by taking chromosome as a image matrix of n population and edge detection technique as fitness function to find best offspring. In this method chromosomes are used as a child who is caring all best qualities of mother and father both with their own qualities. For this GA has four stapes Selection, Crossover, Mutation, Fitness function. Following algorithm shows working of GA.

6. NEURAL NETWORK (NN) METHOD

Neural network is used as image enhancement technique by using BP neural network to determine the best image transform function. In this method original image is normalized and then using non-linear function image is transformed by using some parameter in BP neural network. Final image is again determined by reverse normalization. Neural Network is also used to remove noise from the images by using three layers with low pass spatial smoothing filters to enhance images.

In contrast enhancement of the images using Neural Network technique, normalization of an image can be determined by the function given below:

$$N(x,y) = f(x,y) - \text{Min}(\text{intensity}) / (\text{max}(\text{intensity}) - \text{Min}(\text{Intensity}))$$

Where $N(x,y)$ is normalized image, $\text{Min}(\text{intensity})$ is minimum intensity used in the image, $\text{max}(\text{intensity})$ is maximum intensity in the image. After normalization Neural Network technique is used for getting required output using forward propagation and back propagation by adjusting weights for training a sample and also to reduce the error between expected output and actual output.

Applying transformation function on the normalized image, Transformed image can be found by

$$Tf(x,y) = T'(N(x,y))$$

$Tf(x,y)$ is transformed image and $T'(x,y)$ is nonlinear transformed function. The final enhanced image found by reverse normalization by using formula

$$\text{Final image } (x,y) = 255Tf(x,y).$$

7. FUZZY METHOD

Fuzzy set theory is a utilitarian tool for Image Processing with the help of classical mathematics and integral imprecision of real world. Basically human perception is deferent as compare to machine understanding, that's why fuzzy sets are used to make understating of machine as like human perception[]. Fuzzy sets are able to handle fuzziness in image to enhance contrast of the images and to remove unclearness in edges, boundaries, regions, features of image. Fuzzy sets are used to remove noise from images by using fuzzy filters to enhance the images. Fuzzy set theory is also apply to enhance contrast of images as well as used smoothing method to enhance images [13].In which Fuzzy entropy and membership function used for contrast enhancement of images.

8. CONCLUSION

After surveying various papers, one of the simpler methods of image enhancement has been proposed by Canny. Later, the extensions of this method have been proposed by considering additional functions such as local, mean brightness preserving and cumulative functions. Apart from these techniques, best optimized results for enhancing the image can be obtained using artificial intelligent system. For example, fuzzy method and neural network techniques are usually used for contrast enhancement and smoothing the images by using various filters.

Now a day's new technique like optimization technique as a genetic algorithm and neural network are very effective tools to give magnificent results in this field. MATLAB is used to implement in easy way to implement all the image processing application.

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Comparative analysis of Contrast Enhancement Techniques with Fuzzy Logic

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Abstract— Image enhancement is one of the techniques of Digital Image processing to convert original image into an enhanced image form which is more suitable for a specific application. Many techniques are available to enhance the images as per requirements, in which some of the methods are used to enhance contrast of the images. In this paper different existing methods of Contrast enhancement technique like Contrast Stretching and Histogram Equalization are being compared with the fuzzy based image enhancement method. The performance analysis of different methods of contrast enhancement has been given for comparative evaluation.

Keywords—image enhancement, contrast stretching, histogram, fuzzy logic, Digital Image Processing.

I. INTRODUCTION

Image Enhancement is a method in which output of image is an improved form of input image. Different Enhancement techniques are there, like removal of noise, contrast enhancement, edge detection, and restoration etc. For removal of noise from the images, different types of filters are there like Median filters, Average filters, Gaussian filters etc. If some noise present in the images then after removing noise the image looks as an enhanced image. In a case of dimmed image contrast enhancement method is applied over the image to increase the contrast of the image. In case of contrast of edge enhancement method, number of methods are there to contrast edges of the images, and after that image can be sharpened and look as an enhanced image. Number of work has been done for enhancing the images. Contrast enhancement is a one of the spatial domain method to improve the contrast of images without using segmentation. Due to simplicity and effectiveness of contrast enhancement functions, they used in variety of fields like medical image processing, consumer electronics, satellite images, geological applications etc. One well known function of contrast enhancement is histogram equalization, which is used in various applications for contrast enhancement of images. Histogram equalization is used in useful applications like medical image processing, radar image processing for object tracking [2]. In spite of great functioning of contrast enhancement it may create some annoying artifacts may result of lack of preserving the mean brightness. After histogram

equalization, another method of contrast enhancement is Contrast stretching. Contrast stretching is used to expand the chain of intensity levels of an image [3]. Due to uncertainty like over smoothing, blurring and deformation of edges. So because of lot of uncertainties and vague information in above methods, another method known as fuzzy image enhancement method used to recover heavily noisy images. Fuzzy image enhancement is very popular due to speedy extension of fuzzy set based mathematical modeling. Fuzzy set theory is a very useful method for dealing the uncertainty in an image [4]. It is quite reasonable to use some methods like smoothing with fuzzy sets to enhance images. Fuzzy sets provide a problem-solving tool between machines to real world [5, 7]. Or can say fuzzy rules are similar to human reasoning [11]. Fuzzy statistics of digital images handled the inaccurate of gray level values in a better way [6, 8]. Henceforth this modified technique mentioned for brightness preserving know as brightness preserving dynamic fuzzy histogram equalization(BPDFHE).The BPDFHE technique consist of fuzzy histogram computation, partitioning of the histogram, dynamic histogram equalization of the partition, and normalization of the image brightness. Fuzzy models based non linear filters are also very efficient to save useful information of image data with noise removal. As per reference [9], for noise removal neural fuzzy filters are used. Also for noise reduction a classical spatial filter, neural network (NN), cellular neural network (CNN) and fuzzy filters are used [10]. Several well known FIRE-filters, the weighted fuzzy mean filter, and the iterative fuzzy control based filter. For image noise reduction fuzzy techniques mainly deal with impulse noise.

II. CONTRAST ENHANCEMENT TECHNIQUES

A. Contrast Stretching:

Contrast stretching is an easy piecewise linear transformation technique. This is used to expand full range of intensity of an image, so that the overall brightness of image can increase.

Transformation function used for contrast stretching:

$$g(x, y) = g_1 + \left(\frac{g_2 - g_1}{f_2 - f_1}\right)[f(x, y) - f_1] \quad (1)$$

Here mapping of gray levels [f1, f2] on new range [g1, g2]. Where f1 is minimum intensity and f2 is maximum intensity of an image.

B. Histogram Equalization:

Histogram Equalization is one of simplest and widely used technique of image processing. It is known an automatic technique with no parameter to set.

Probability density function of Histogram equalization, $p(X_k)$ is defined as:

$$P(X_k) = \frac{n^k}{n} \quad \text{for } k = 0, 1, \dots, L-1 \quad (2)$$

Here $P(X_k)$ represent number of pixel of a specific intensity X_k for the histogram of input image.

Based on the probability density function, the cumulative density function is defined as:

$$C(X) = \sum_{j=0}^k p(X_j) \quad (3)$$

Where $X_j = x$, for $j = 0, 1, \dots, L-1$

Histogram equalization, maps the input image into the entire dynamic range, (X_0, X_{L-1}) , by using the cumulative density function, transform function of output image of

$$T(x_i, y_i) = f_0 + (f_1 - f_0) \sum_{j=0}^i p(X_j) \quad (4)$$

Histogram Equalization is also used for flattens a histogram.

C. FUZZY LOGIC:

Fuzzy logic provides solution of a problem just like as human can do as per availability of all possible input. As per Dr Lotfi Zadeh, Fuzzy logic handles the concept of partial truth values between “completely truth” and “completely false”. Fuzzy techniques which operate on fuzzy set just like spatial domain method operate on pixels. So fuzzy enhancement technique consider image as fuzzy set and performed various operations of fuzzy set theory then it produced enhancement of input image. Fuzzy set theory is very popular and useful due to its capability to deal with unclear and changeable information, flexible, based on Natural language, conceptually easy to use and understand. It used to remove noise from images by using fuzzy filters and Smoothing method to enhance the images. Fuzzy Techniques has mainly three rules to enhance images: (i) Fuzzification of the input image (ii) modification of fuzzy value (iii) Defuzzify.

The principle of fuzzy enhancement technique is:

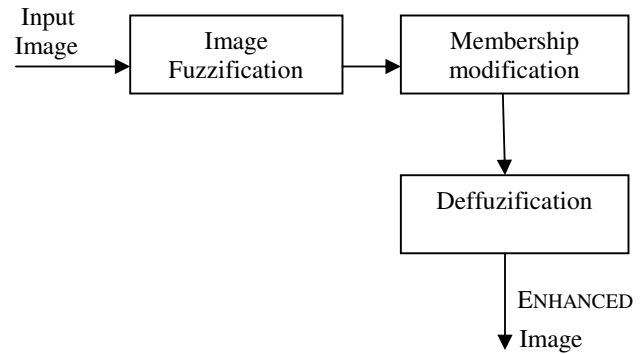


Fig 1: Principle of fuzzy enhancement techniques.

III. QUALITATIVE ATTRIBUTE OF AN IMAGE

In image enhancement technique quality of an image can be subjective. It can be different for person to person, so because of this reason it is compulsory to establish some parameters to compare the quality of an image. PSNR and MSE are the parameters to show quality of image.

A. Peak signal-to noise ratio (PSNR):

It is a ratio between the maximum power of a signal and power of corrupting noise. Here signal is the original data, and the noise is the error. The mathematical formula of the PSNR is as follows:

$$PSNR = 20 \log_{10} \left(\frac{255}{\sqrt{MSE}} \right) \quad (5)$$

B. Mean square error (MSE):

It is the cumulative squared error between the compressed and the original image.

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left| f(i, j) - g(i, j) \right|^2 \quad (6)$$

Where f = matrix data of original image,
 g = matrix data of degraded image,
 m = no of rows of pixels of an image,
 i = index of that row,
 n = no of columns of pixels of an image,
 j = index of that column.

So, quality of image will be better when value of PSNR is higher and value of MSE is minimum.

IV. EXPERIMENTAL RESULTS

In the experiment, the different contrast enhancement techniques used to test on Matlab images. In this paper we have compared results of contrast stretching, histogram equalization and fuzzy logic [6] with the help of PSNR and MSE values and their graphical representation in table 1. The result will be better when value of PSNR is higher and value of MSE is minimum.

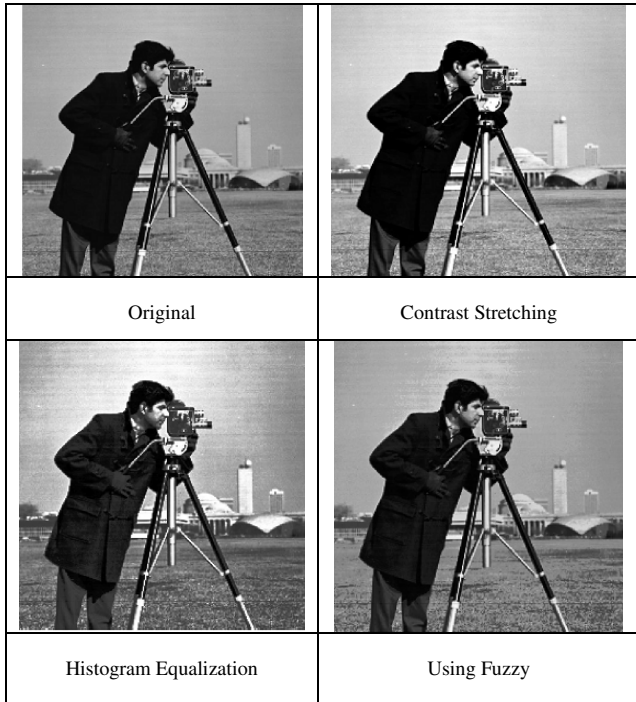


Fig 2: Results for the image 1.

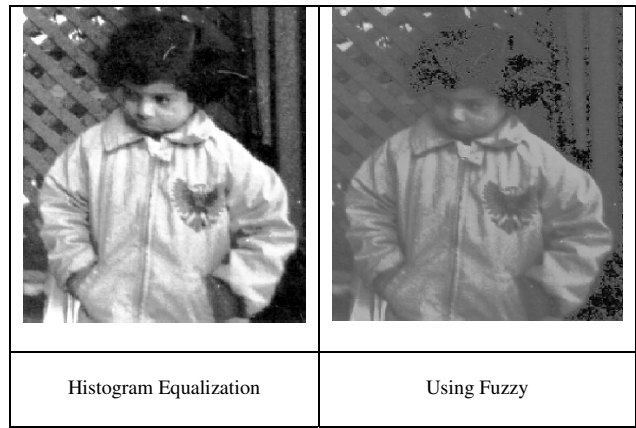
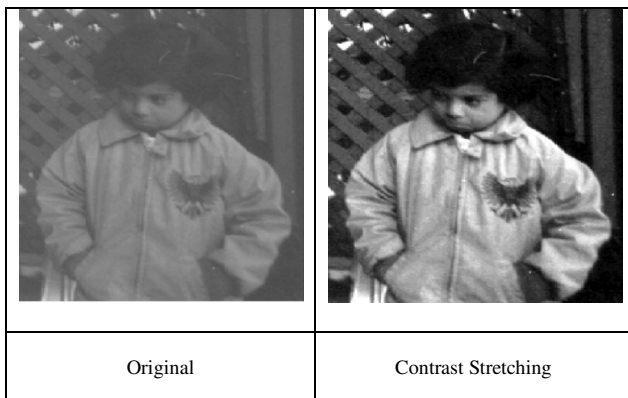


Fig 3: Results for the image 2.

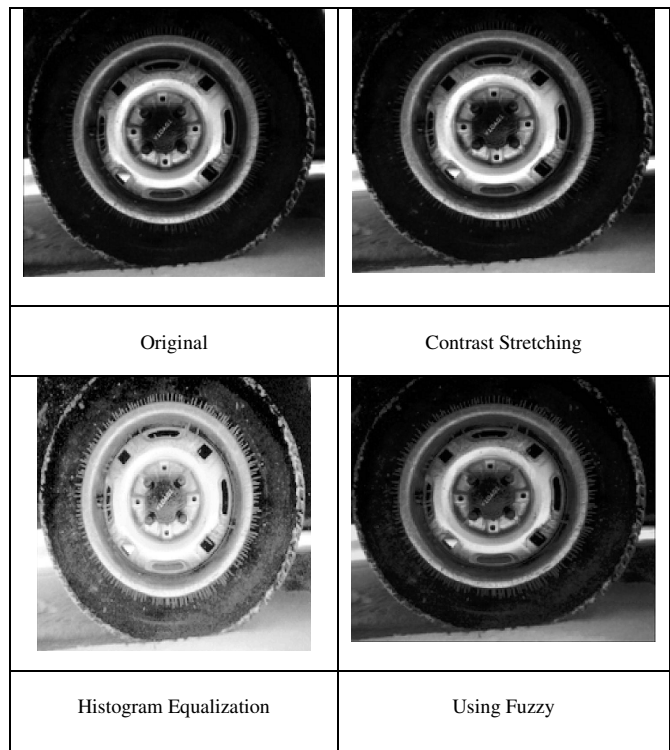


Fig 4: Results for the image 3.

Table 1: MSE and PSNR value of different types of images

Contrast Enhancement Techniques	Image 1		Image 2		Image 3	
	PSNR	MSE	PSNR	MSE	PSNR	MSE
Contrast Stretching	18.59	907.48	14.83	2298.04	42.78	2.51
Histogram Equalization	19.13	800.54	13.64	3022.84	8.51	6707.76
Using Fuzzy	30.84	53.99	25.45	199.25	27.32	88.09

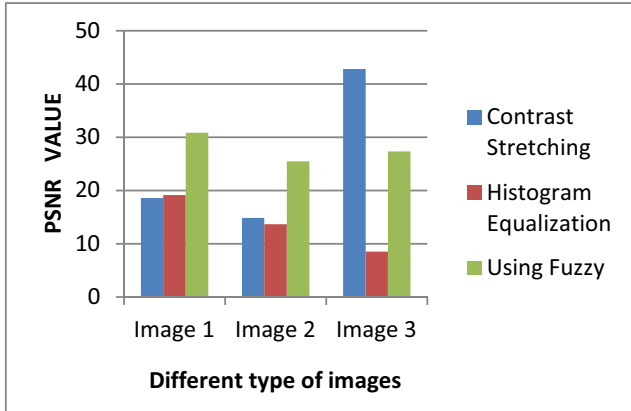


Fig 5: PSNR Value of different images by using contrast enhancement techniques.

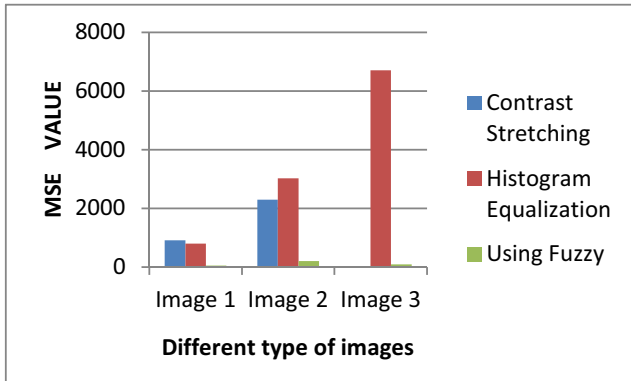


Fig 6: MSE Value of different images by using contrast enhancement techniques.

V. CONCLUSION

This paper proposed a comparative analysis of contrast enhancement techniques such as contrast stretching, histogram equalization and fuzzy logic applied on different gray images given in matlab. The result shows that in many cases fuzzy logic gives better result for enhancement of images.

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Comparative analysis of Contrast Enhancement Techniques on different Images

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Abstract- Contrast enhancement is an important technique of image processing for the enhancement of contrast of an image in the spatial domain. Numbers of contrast enhancement techniques are available. This paper proposes comparative analysis of various contrast enhancement techniques applied on different types of images. PSNR, MSE value and graphical forms are used to analyze the best enhancement technique on corresponding images.

Keywords- Contrast Enhancement, Spatial Domain, Digital Image Processing Applications.

I. INTRODUCTION

Enhancement is a method in which output of image is an improved form of input image for a specific application.. Different Enhancement techniques are there, like removal of noise, contrast enhancement, edge detection, and restoration etc. For removal of noise from the images, different types of filters are there like Median filters, Average filters, Gaussian filters etc. If some noise present in the images then after removing noise the image look as a enhance image. In a case of dimed image contrast enhancement method is applied over the image to increase the contrast of the image. In case of contrast of edge enhancement method, number of methods are there to contrast edges of the images, and after that image can be sharpened and look as an enhanced image. Number of work has been done for enhancing the images. Contrast enhancement is a one of the spatial domain method to improve the contrast of images without using segmentation. It is a visually appealing area of image enhancement method, because viewer can judge about which method is working well and giving good results. Some of the intensity transformations functions are used for image enhancement like linear, logarithmic and power-law (Gamma) transformation functions. Identity function and image negative functions are part of linear function; in this negative image is a result of using negative transformation function, in which black or gray color converted in white and vice versa. Log and inverse-log transformations are part of logarithmic function. Log function used to expand dark pixel in an image and compression is used for higher-level values and vice versa for inverse-log transformation function. Power-Law (Gamma) transformation is also used for contrast enhancement. A simple and effective

function of contrast enhancement is histogram equalization, which is used in many contrast enhancement applications, like medical image processing etc. Due to its simplicity and easy approach, this is a good enhancement method [3]. An image after using histogram equalization gives brighter image as compared to input image, because it shows uniform distribution. So we can say, for automatic enhancement this method is more suitable. But this method also has limitation of not taking mean brightness of an image, so for generating a specific histogram, Histogram Matching or Histogram Specification is used. One of the newly contrast enhancement method of brightness preserving bi-histogram equalization (BBHE) is proposed by Yeong-Taeg Kim [7, 8]. This algorithm is used to preserved mean brightness for enhancing images. These methods produced unnatural brightness for image contrast enhancement. Some other methods like fuzzy image enhancement, Genetic algorithm are also used for image contrast enhancement [1, 9, 4, 5]. As compare to histogram equalization and similar methods, genetic algorithm produced more bright and effective image for contrast enhanced. Genetic algorithm is based on method of optimization, which is based on natural genetics. It is more suitable for global search space to find optimal solution. It used parameters like population size, selection, crossover, type, crossover rate and mutation rate. It is used fitness function for evaluating intensity of edges of input images. Due to this algorithm, dynamically relationship between input images to output images can be changed [10]. Other enhancement method is known as Fuzzy technique [1, 2, 6], which operate on fuzzy sets just like spatial domain method operate on pixels. So fuzzy enhancement technique consider image as fuzzy set and performed various operations of fuzzy set theory it produced enhancement image. Fuzzy set theory is very popular and useful due to its capability to deal with unclear and changeable information, flexible, based on Natural language, conceptually easy to use and understand. It used to remove noise from images by using fuzzy filters and Smoothing method to enhance the images. Fuzzy Techniques has mainly three rules to enhance image :(i) Fuzzification of the input image(ii) modification of fuzzy value (iii) Defuzzify. This paper explains three contrast enhancement techniques, applies on different types of images and analyzed the quality after enhancement, by measuring its PSNR and MSE value.

II. CONTRAST ENHANCEMENT TECHNIQUES

Several methods are available for Contrast Enhancement:

A. Contrast Stretching [7, 8]

It is a method to expand full range of intensity of an image, so that the overall brightness of image can increase.

Transformation function used for contrast stretching:

$$g(x, y) = g1 + \left(\frac{g2 - g1}{f2 - f1} \right) [f(x, y) - f1] \quad (1)$$

Here Mapping of gray levels [f1, f2] on new range [g1, g2]. Where f1 is minimum intensity and f2 is maximum intensity of an image.

This function enhances contrast of an image, which shows equal distribution of intensity.

B. Histogram Equalization [11]

It is widely used technique in image processing because it is automatic technique with no parameters to set. This process is based on, allocation of more gray levels, where there are most pixels, and allocation of fewer gray levels, where there are fewer pixel. So according to this most heavily populated region of the histogram, shows increment of contrast, and often bring out previously hidden detail. It changes images from an impulse histogram to one with a flat histogram.

Probability density function of Histogram equalization, $p(X_k)$ is defined as:

$$P(X_k) = \frac{n^k}{n} \quad \text{for } k = 0, 1, \dots, L-1 \quad (2)$$

Here $P(X_k)$ represent number of pixel of a specific intensity X_k for the histogram of input image.

Based on the probability density function, the cumulative density function is defined as:

$$C(X) = \sum_{j=0}^k p(X_j) \quad (3)$$

Where $X_j = x$, for $j = 0, 1, \dots, L-1$

Histogram equalization, maps the input image into the entire dynamic range, (X_0, X_{L-1}) , by using the cumulative density function, transform function of output image of

$$T(x_i, y_i) = f0 + (f1 - f0) \sum_{j=0}^i p(X_j) \quad (4)$$

Histogram Equalization is also used for flattens a histogram.

C. Contrast-limited adaptive histogram equalization (CLAHE) [12]

This contrast enhancement technique works on only parts of an image or can say on tiles of an image. First this method, divide image into number of tiles, then apply contrast enhancement on every tile individually and then it recombines results to give output image with enhancement. This method works better as compare to histogram equalization in most cases for contrast enhancement of images.

III. QUALITATIVE ATTRIBUTE OF AN IMAGE

In image enhancement technique quality of an image can be subjective. It can be different for person to person, so because of this reason it is compulsory to establish some parameters to compare the quality of an image. Following are the matrix used to inquire the quality of images:

A. Peak signal-to noise ratio (PSNR)

It is a ratio between the maximum power of a signal and power of corrupting noise. Here signal is the original data, and the noise is the error. The mathematical representation of the PSNR is as follows:

$$PSNR = 20 \text{Log}_{10} \left(\frac{255}{\sqrt{MSE}} \right) \quad (5)$$

B. Mean square error (MSE)

It is the cumulative squared error between the compressed and the original image.

$$MSE = \frac{1}{mn} \sum_0^{m-1} \sum_0^{n-1} |f(i, j) - g(i, j)|^2 \quad (6)$$

Where f = matrix data of original image,
 g = matrix data of degraded image,
 m = no of rows of pixels of an image,
 i = index of that row,
 n = no of columns of pixels of an image,
 j = index of that column.

So, quality of image will be better when value of PSNR is higher and value of MSE is minimum.

IV. EXPERIMENTAL STUDY

Experimental study is applied by taking different types of contrast enhancement technique on different types of images. We performed analysis using statistical analyzer like PSNR and MSE. Fig (1) (a) shows the original image and fig(1)(b) shows the enhanced image by using contrast stretching, fig(1)(c) shows the enhanced image by using histogram equalization, fig(1)(d) shows the enhanced image

by using Contrast-limited adaptive histogram equalization. PSNR and MSE values of 5 images by using above three techniques are given in tables and graphs.

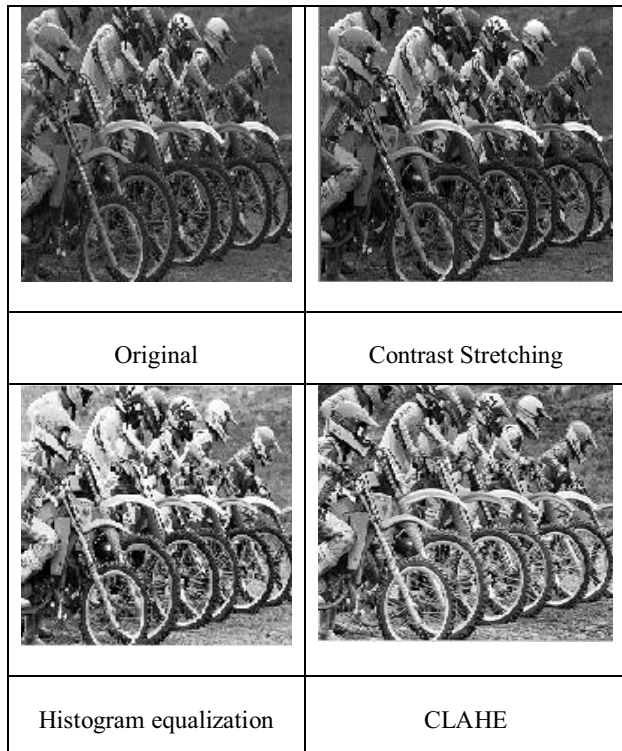


Fig 1: Results for the Image 1.

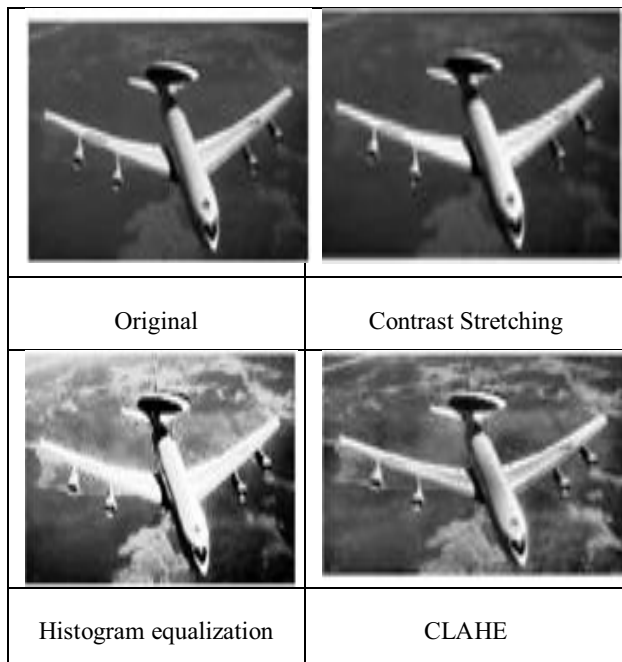


Fig 2: Results for the Image 2

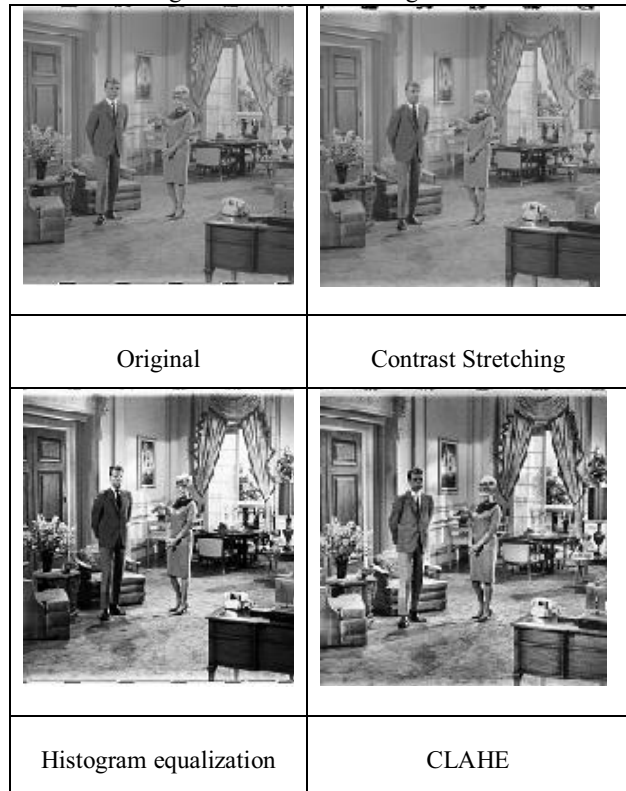


Fig 3: Results for the Image 3.

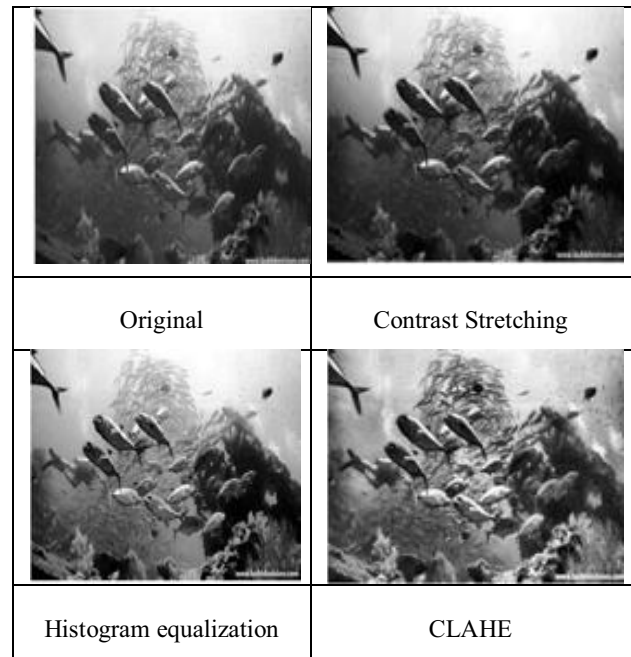


Fig 4: Results for the Image 4.

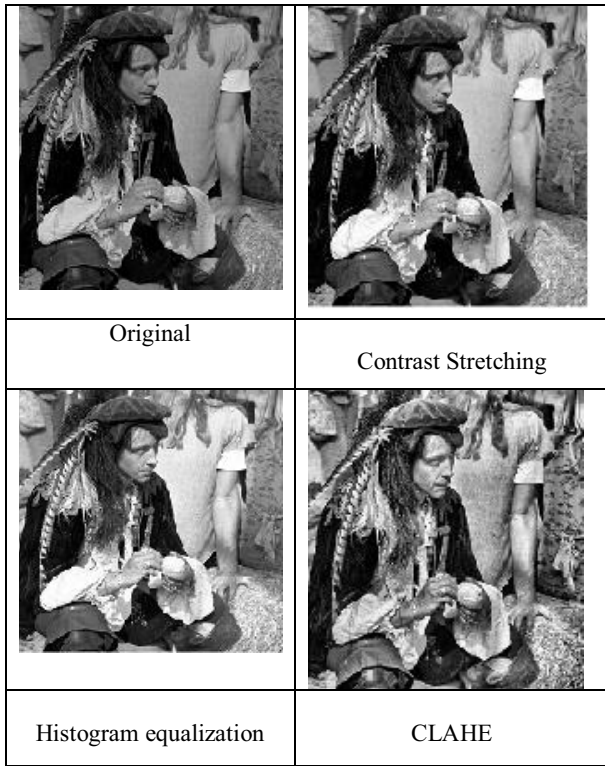


Fig 5: results for the image 5

Table 1: MSE values of different images

	Image 1	Image 2	Image 3	Image 4	Image 5
Contrast enhancement Techniques	MSE	MSE	MSE	MSE	MSE
Contrast Stretching	35.91	58.41	39.56	166.60	598.22
Histogram Equalization	3202.79	4566.03	22.27	499.78	1818.22
CLAHE	2690.93	1284.51	23.79	1495.86	1705.13

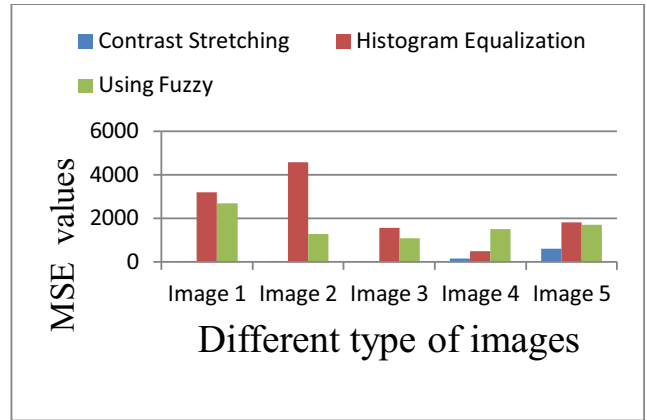


Fig 6: MSE values of different images.

Table 2: PSNR values of different images.

	Image 1	Image 2	Image 3	Image 4	Image 5
Contrast enhancement Techniques	PSNR	PSNR	PSNR	PSNR	PSNR
Contrast Stretching	40.39	24.38	39.56	27.47	32.44
Histogram Equalization	20.89	5.45	22.27	22.70	27.61
CLAHE	21.65	10.95	23.79	17.94	27.89

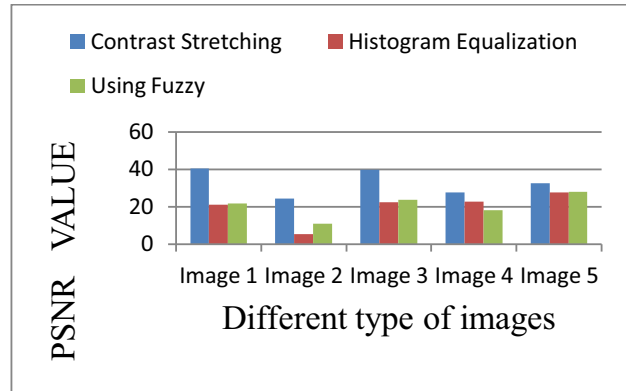


Fig 7: PSNR values of different images

V. CONCLUSION

This paper proposed a comparative analysis of contrast enhancement techniques such as contrast stretching,

histogram equalization and Contrast-limited adaptive histogram equalization applied on different types of gray images. Experimental result shows that Contrast-limited adaptive histogram equalization gives better result, and for some images contrast stretching gives better result. So according to above experiment Contrast-limited adaptive histogram equalization gives better image quality as compare to other above methods.

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A COMPARATIVE STUDY OF CLASSICAL CONTRAST ENHANCEMENT TECHNIQUE AND FUZZY LOGIC ON MEDICAL IMAGES

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ABSTRACT—Image enhancement for medical applications is important task for the purpose of diagnosis of various diseases using image analysis. Better selection of Image enhancement techniques helps the doctors in diagnosing. Use of low contrast and noisy medical images are risky and failed in diagnosing any anomalies in an X-ray or CT scan. For correct diagnosis, analysis of images must be faster, clear and enhanced. Contrast enhancement is one of the techniques of image processing which increase contrast of an original image and removes noise that makes the images clearer for interpretation and analysis. In this paper various medical images are enhanced by using different existing methods of contrast enhancement technique and fuzzy based image enhancement techniques. The performance analysis of different methods of contrast enhancement has been given for comparative evaluation on the basis of different qualitative attributes like PSNR and MSE of images.

An Analysis of Images using Fuzzy Contrast Enhancement Techniques

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Abstract – This paper presents an Image enhancement technique based on fuzzy logic that addresses different membership values and fuzzy techniques for contrast enhancement of images. A fuzzy technique has been designed based on human perception for better improvement of contrast in the given image. As per literature, contrast enhancement techniques have shown improved image quality using the method of adjustment of parametric value for different membership functions. The membership values are used in the paper to show the degree of darkness or brightness of an image. A detailed image analysis has been done using different qualitative attributes of the image in the simulation. The results show that the better enhancement in image contrast. It can be obtained by taking different membership function for transformation of membership values in the fuzzy domain.

Keywords—Image enhancement; Contrast enhancement; Digital Image Processing; Fuzzy logic; Membership function

I. INTRODUCTION

Image enhancement is an important method to increase the quality of image to improve appearance and visibility of the image. A different image enhancement technique to be used depends on particular application as per human perception. It is categorized in two parts: spatial domain and frequency domain. Frequency domain is based on transformation of images by using frequency transform. It is a fast but time consuming method. Spatial domain is based on pixel modification for image enhancement. Contrast enhancement is a one of the important technique of image enhancement in spatial domain. Contrast enhancements with all details of images are need as an expert knowledge to overcome the difficulties of many areas like traffic control analysis, bio medical image analysis, remote sensing etc. Contrast enhancement is the gray level transformations suchlike in this method light pixels appear brighter while dark pixel appear darker. By using histogram equalization and contrast stretching, contrast enhancement is possible. In histogram equalization normalized cumulative histogram used as the gray scale mapping function. Due to simplicity and effectiveness histogram equalization is widely used in contrast enhancement [2]. Histogram equalization is used for local as well as global contrast enhancement of gray scale images [3]. Contrast enhancement by using fuzzy is based on membership transformation in gray level mapping to know

the degree of darkness or brightness in an image. Image enhancement by using fuzzy is based on contrast stretching method in such a way that light pixels appear much lighter and dark pixels appear much darker. This way of representation shows, how's the human perception and fuzzy rules permit us to represent this knowledge in form of fuzzy sets. Fuzzy sets are effective to handle uncertain behavior in the images related with fuzziness [4]. Fuzzy set concept based on partial membership value, while classical sets based on crisp value [5]. Fuzzy sets are very efficient to handle uncertainty for improvement of noisy images by using various fuzzy filters like weighted fuzzy mean filter, FIRE-filter, iterative fuzzy control based filter [6][7]. Fuzzy sets are represented by in terms of linguistic, which imitate human perception for enhancement. Fuzzy system works on fuzzy rules that numerically represent inferential mechanism of fuzzy sets [8]. A fuzzy rule based system is able to remove noise, edge detection, and smoothing for enhancement of input images [9] [11]. It presents result of the individual filters for enhancement. Fuzzy rule based system applied different filters as per satisfaction of different condition. Fuzzy enhancement used INT operator as a contrast intensifier to increase or decrease degree of membership. It depends on membership function to enhance input image. Due to some limitation of INT operator NINT operator used as a new intensification operator which reduce computational time and utilized sigmoid function for enhancement [10] [12]. Fuzzy logic helps to implement human knowledge in terms of rules and different methods to give better enhancement of images so analysis of images become easy and faster for any knowledge representation.

II. FUZZY IMAGE ENHANCEMENT TECHNIQUES

Enhancement of images by using fuzzy plane is known as Fuzzy image enhancement or using membership function and gray level mapping into fuzzy plane is known as fuzzy image enhancement. For image enhancement, fuzzy system worked with fuzzy set to get acceptable results. Fuzzy sets are the function which denote element of problem domain in terms of number in the range of 0 to 1. These values are fuzzy not the crisp values. Fuzzy sets and membership functions are two similar or interchangeable terms used in fuzzy system. a fuzzy

set is an ordered pair consisting of values of z and a corresponding membership function that assigns a grade of membership function to each z . That is:

$$A = \{z, \mu_A(z) | z \in Z\} \quad (1)$$

Here A have infinite number of elements, when the variables are continuous. Thus ordinary sets are a special case of fuzzy sets. The structure of fuzzy image processing model:

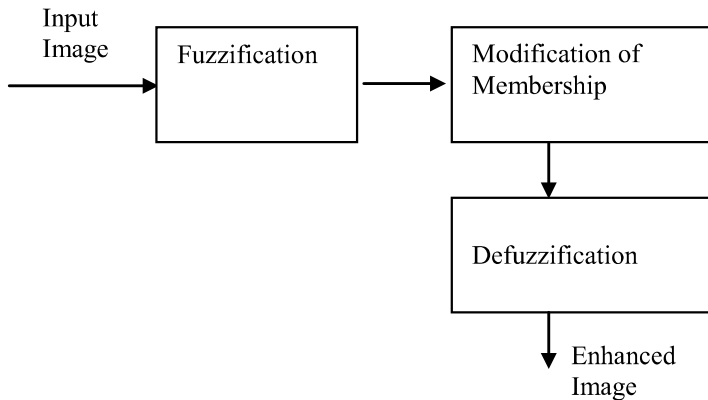


Fig 1: Model of Fuzzy Image processing

Fuzzy enhancement method has three parts 1. Fuzzification 2. Membership transformation 3. Defuzzification. Here Fuzzification is the coding of the data while defuzzification is the decoding of data from normal plane to fuzzy plane and vice versa. Middle step is the very powerful and main step to enhance any fuzzy system via modification of membership value. For modification of membership functions appropriate fuzzy methods are used, like fuzzy rule based approach, fuzzy integration approach and fuzzy segmentation. Membership values $\mu_A(z)$ has important role to know degree of darkness or lightness of the gray value in an image for contrast enhancement. Classification of Membership functions are:

1. Piecewise linear functions:
 - a) Triangular function.
 - b) Trapezoidal function.
 - c) Sigma function.
2. Smooth functions:
 - a) S-shape function.
 - b) Bell-shape function.
3. Gaussian function:
 - a) Truncated Gaussian function.

In fuzzy set, S shaped function is used frequently to get contrast enhancement of input image. These membership functions are also used for edge detection, smoothing, contrast stretching etc for enhancement of images.

A. Contrast Enhancement Based On Fuzzy Rule Based System

Fuzzy IF-THEN rules are based on fuzzy set theory [5]. It is a formulated form of human knowledge to represent a natural language expression. The formalized form of the rule is as follows:

IF A is B THEN C is D . Here B is antecedent and D is consequent. That means conclusion can be derived easily if facts are known.

In the application of rule-based fuzzy logic, Principal steps are:

1. Fuzzyfy the input: By using membership functions fuzzy values are calculated between the interval $[0, 1]$.
2. Perform any required fuzzy logical operations:
3. Apply an implication method: we used AND for implication, which shows min operation.
4. Apply an aggregation method to the fuzzy sets from step 3: for aggregation OR is used, which shows max operation.
5. Defuzzify the final output fuzzy set: This is a final step, after this step we find crisp scalar output. Defuzzification achieved by computing the centre of gravity of the aggregated fuzzy set.

The use of OR and AND is depend on the problem in which rules are stated. Fuzzy rule-based approach is nonlinear in nature that incorporates human intuitions. Image quality evaluation is highly subjective. It can be enhanced by using human knowledge. Contrast enhancement of a image is based on a very simple membership function modification mechanism, which is used as follows:

- IF a pixel is dark, THEN make it darker.
- IF a pixel is gray, THEN make it gray.
- IF a pixel is bright, THEN make it brighter.

After it defuzzification is done by using the inverse of the fuzzification and gives enhanced output image.

B. Contrast Enhancement Based On Fuzzy Intensification Operator

Fuzzy Intensification operator is used to increase the contrast of images and decrease the fuzziness. For an image I , the membership uncton is defined as

$$\mu_{mn} = \left[1 + \frac{g_{\max} - g_{mn}}{F_d} \right]^{-F_e} \quad (2)$$

Here F_d is denominational fuzzifiers, F_e is exponential fuzzifiers. $\mu_{mn=1}$ represents maximum brightness and $\mu_{mn}=0$ represents complete darkness.

III. IMAGE QUALITY ATTRIBUTES

Image quality attributes are used to prove enhancement of images on the basis of numerical values. Here three attributes like PSNR, MSE, and Image Contrast are:

A. Peak Signal-To Noise Ratio (PSNR)

$$PSNR = 10 \log_{10} \left(\frac{255}{\sqrt{MSE}} \right) \quad (3)$$

B. Mean Square Error (MSE)

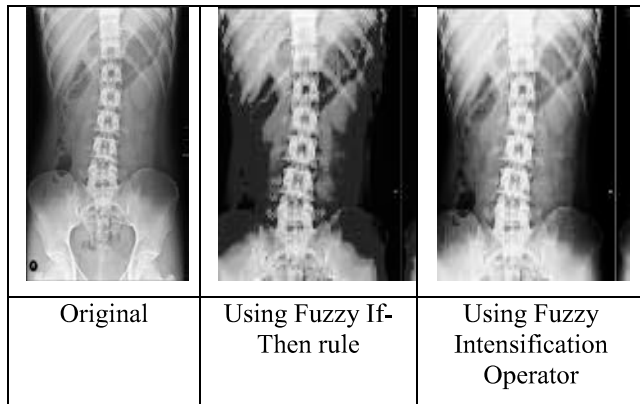


Fig 2: Image 1

$$MSE = \frac{1}{mn} \sum_0^{m-1} \sum_0^{n-1} ||f(i,j) - g(i,j)||^2 \quad (4)$$

C. Image Contrast(C)

$$C = \sqrt{\sum_{m=0}^{L-1} (m - m_{avg})^2 p(m)} \quad (5)$$

Where L = No of Gray levels of image,
 p (m) = histogram value,
 m = gray level value.

IV. EXPERIMENTAL RESULTS

In the experiment result different Fuzzy contrast enhancement techniques have taken to test different images. Better contrast of image is based on the minimum MSE value and maximum PSNR value. Table I and Table II shows quality attributes values.

TABLE I. QUALITY ATTRIBUTES OF DIFFERENT IMAGES USING FUZZY IF- THEN RULE

Fuzzy If-Then rule	MSE	PSNR	C(I/P)	C(O/P)
Image 1	28.6932	33.553	6305.6621	6300
Image 2	34.1395	32.7982	6300.6249	6300
Image 3	39.1244	32.2063	6300	6300

TABLE II. QUALITY ATTRIBUTES OF DIFFERENT IMAGES USING FUZZY INTENSIFICATION OPERATOR

Fuzzy Intensification operator	MSE	PSNR	C(I/P)	C(O/P)
Image 1	22.3251	34.6429	6305.6621	6309.6386
Image 2	21.7416	34.7579	6300.6249	6307.3877
Image 3	32.2639	33.0436	6300	6300.0557

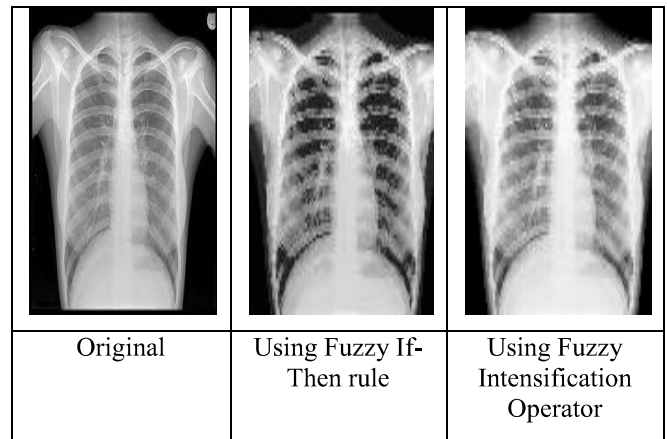


Fig 4: Image 3

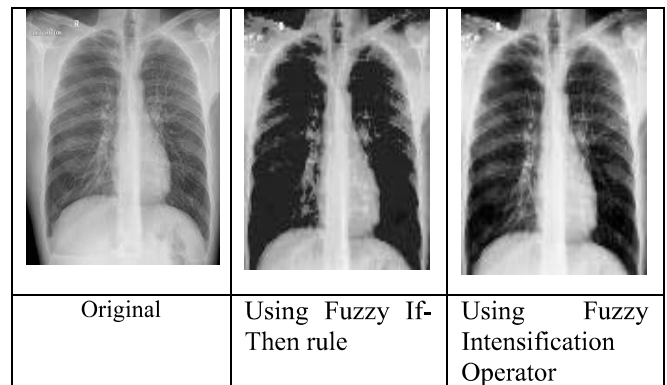


Fig 3: Image 2

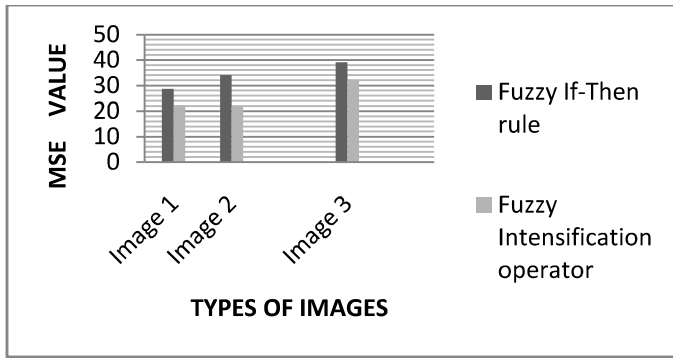


Fig 5: MSE values by using Fuzzy If-Then rule and Fuzzy Intensification operator

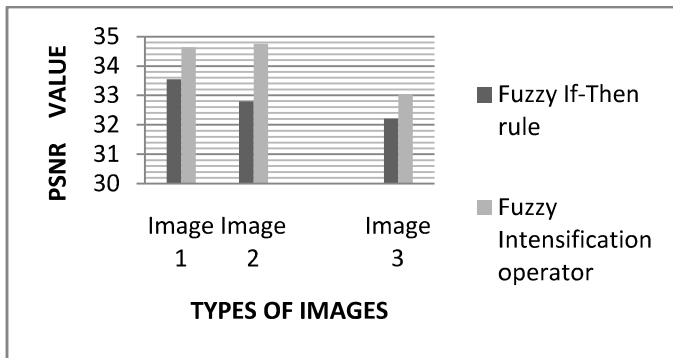


Fig 6: PSNR values by using Fuzzy If-Then rule and Fuzzy Intensification operator



Fig 7: Image Contrast (I/P) values by using Fuzzy If-Then rule and Fuzzy Intensification operator

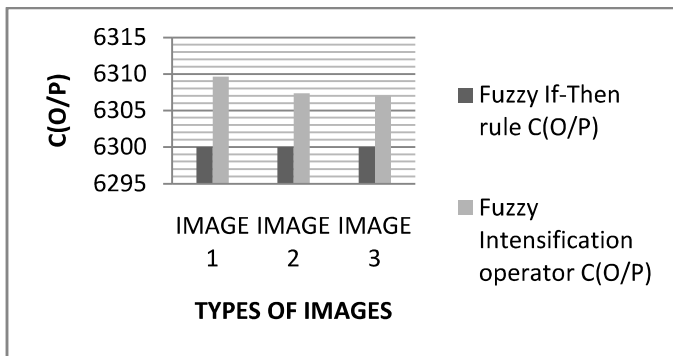


Fig 8: Image Contrast (O/P) values by using Fuzzy If-Then rule and Fuzzy Intensification operator

V. CONCLUSION AND FUTURE SCOPE

In this paper two different methods of Fuzzy contrast enhancement techniques have studied and compared on the basis of various image quality attributes, which are given in above two tables. Level of enhancement in images can be measured on the basis of PSNR values. Higher the PSNR and Image Contrast value and minimum MSE value shows better result. As a future scope this kind of methods are used to enhance images for better analysis in different applications. With the help of these methods analysis of images becomes faster, clear and enhanced.

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An Analysis of Fuzzy Contrast Enhancement Methods using Satellite Image

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Abstract – This paper presents an enhancement of images based on fuzzy contrast enhancement that addresses different fuzzy methods for contrast enhancement of satellite images. Analysis of satellite images are categorized on the basis of knowledge like different types of shapes, textures, color, scale etc. Fuzzy methods are based on human perception for better contrast improvement in the given images. As per literature, we evaluate the fuzzy contrast enhancement methods for the detailed image analysis using qualitative attributes like PSNR, and MSE of the images in the experimental study. The results show that the better contrast enhancements of an image are different as per different methods.

Keywords – Fuzzy Contrast enhancement, Fuzzy logic, Satellite image, Membership modification.

I. INTRODUCTION

Satellite images are combination of useful and rich information which contain valuable information. This information shows us changes in various conditions like changes in city environment, changes in greenery and in accidental condition. Images can be analyzed on the basis of shapes, textures, color, scale, and anterior knowledge. Fine details of images are important to analyze very small area of earth. For analyzing images, contrast enhancement is an important method to increase the quality of image to improve visual aspect and profile of the image. A different contrast enhancement technique to be used depends on particular application as per human perception. Contrast enhancement by using fuzzy is based on membership transformation in gray level mapping to know the degree of darkness or brightness in an image. Image enhancement by using fuzzy is based on contrast stretching method in such a way that it distributes contrast as an independent and identical representation to show the human perception and knowledge in form of fuzzy sets. Different methods like digital water marking is used cryptographic process to give protection against data piracy. Characteristics of water mark images are unobtrusiveness, robustness, common signal processing, common geometric distortions (such as rotation, translation, cropping and scaling) [1]. Other method is digital mammography which is used for diagnosis of various medical images where analyses of images are very critical like diagnosis of cancer etc. In this type of investigation fuzzy methods are better as compared to other non-linear techniques

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[2]. Fuzzy methods permit us to represent knowledge in the form of fuzzy sets to show human perception for image enhancement [4][5]. Different fuzzy filters used into a fuzzy rule-based system as a powerful and flexible image enhancement method [3]. On the basis of minimizing fuzziness a new contrast enhancement method proposed which is based on S- function to represent degree of brightness or darkness in the gray images [6]. Other methods are also used as an information processing tool for image enhancement like neural network, cellular neural network [7]. For analysis of images a fuzzy rule based system is able to remove noise, edge detection, and smoothing for enhancement of input images [11]. Some methods are available which can enhance dark area of images without increasing illumination of bright area [10].

II. FUZZY CONTRAST ENHANCEMENT TECHNIQUES

Fuzzy contrast enhancement is a mapping of gray plane into fuzzy plane using a membership transformation function. It applies the principle of contrast stretching where gray levels of input images are interpreted in such a way that dark pixels come out in a much darker form and bright pixels come out in a much brighter form. The contrast stretching operation looks on the choice of threshold T, so that the gray levels below the T will reduce and above the T gray levels will increase.

The contrast stretching operation:

$$\begin{aligned} C(x) &= (1 - a) \cdot x, & x > t \\ &= x & x = t \\ &= (1 + b) \cdot x & x < t, \end{aligned} \quad (1)$$

Where t is a threshold, C(x) is a stretching, a, b are the levels. The principle of fuzzy method is as in following figure.

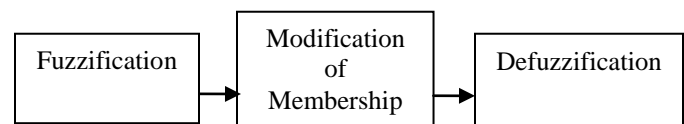


FIGURE 1: Model of Fuzzy Image Processing

Fuzzy enhancement method has three parts (i) Fuzzification (ii) Membership transformation (iii) Defuzzification. Here Fuzzification is the coding of the data while defuzzification is the decoding of data from normal plane to fuzzy plane and vice versa and the middle step is the very powerful and main step to enhance any fuzzy system. Various Membership functions are used for fuzzy method as follows:

A. Contrast Enhancement based on Fuzzy Rule Base System[3]

Fuzzy IF-THEN rules are based on fuzzy set theory [5]. It is a formulated form of human knowledge to represent a natural language expression. The formalized form of the rule is as follows:

IF A is B THEN C is D. Here B is antecedent and D is consequent. That means conclusion can be derived easily if facts are known. In the application of rule-based fuzzy logic, Principal steps are:

- i. Fuzzify the input: By using membership functions fuzzy values are calculated between the interval [0, 1].
- ii. Perform any required fuzzy logical operations:
- iii. Apply an implication method: we used AND for implication, which shows min operation.
- iv. Apply an aggregation method to the fuzzy sets from step iii: for aggregation OR is used, which shows max operation.
- v. Defuzzify the final output fuzzy set: This is a final step, after this step we find crisp scalar output. Defuzzification achieved by computing the centre of gravity of the aggregated fuzzy set.

The use of OR and AND is depend on the problem in which rules are stated. Fuzzy rule-based approach is non linear in nature that incorporates human intuitions. Image quality evaluation is highly subjective. It can be enhanced by using human knowledge. Contrast enhancement of a image is based on a very simple membership function modification mechanism, which is used as follows:

IF a pixel is dark, THEN make it darker.
 IF a pixel is gray, THEN make it gray.
 IF a pixel is bright, THEN make it brighter.

After it defuzzification is done by using the inverse of the fuzzification and gives enhanced output image.

B. Contrast Enhancement Based on Fuzzy Intensification Operator [2]

Fuzzy Intensification operator is used to increase the contrast of images and decrease the fuzziness. For an image I, the membership unction is defined as

$$\mu_{mn} = \left[1 + \frac{g_{max} - g_{mn}}{F_d} \right]^{-F_e} \quad (2)$$

Here F_d is denominational fuzzifiers, F_e is exponential fuzzifiers. $\mu_{mn=1}$ represents maximum brightness and $\mu_{mn=0}$ represents complete darkness. The intensity operation (INT) is written as

$$\mu'_{mn} = \begin{cases} 2 \cdot [\mu_{mn}]^2 & 0 \leq \mu_{mn} \leq 0.5 \\ 1 - 2 \cdot [1 - \mu_{mn}]^2 & 0.5 \leq \mu_{mn} \leq 1 \end{cases} \quad (3)$$

Modified membership values are transformed to spatial domain using an inverse function:

$$g'_{mn} = G^{-1}(\mu'_{mn}) = g_{max} - F_d \left[\mu'_{mn} \frac{1}{e} - 1 \right] \quad (4)$$

It depends only on the membership function.

C. Contrast Enhancement using Fuzzy Histogram Hyperbolization [9]

In this method following steps are used to enhance the contrast of input images:

- Selection of shape of membership function based on the user's demand.
- Setting the value of fuzzifier beta in the following range:

$$[0.5, 2]$$

- Calculation and modification of the membership values and then generation of new gray level using linguistic hedges.

$$g'_{mn} = \left(\frac{L-1}{e^{-1}-1} \right) \cdot \left[e^{-\mu(g_{mn})^\beta} - 1 \right] \quad (5)$$

Here L is the maximum gray level.

D. Contrast Enhancement using Fuzzy Expected values [8]

In this method following steps are used to enhance the contrast of input images:

- Determine fuzzy expected value (FEV) and compute the image histogram.
- Compute the distance of gray levels from FEV.

$$D_{mn} = \sqrt{|(FEV)^2 - (g_{mn})^2|} \quad (6)$$

- Compute new gray levels:

$$\begin{aligned} g'_{mn} &= \max(0, FEV - D_{mn}) && \text{if } g_{mn} < FEV, \\ g_{mn} &= \min(L - 1, FEV + D_{mn}) && \text{if } g_{mn} > FEV, \\ g_{mn} &= FEV && \text{otherwise.} \end{aligned} \quad (7)$$

E. Contrast Enhancement using Locally Adaptive Method

- Locally adaptive method is used to achieve better results due to failure of global fuzzy technique.
- In this method image is divided into sub blocks, and all the sub blocks enhanced by algorithm individually.
- Performance of this method may be improved by increasing the number of sub blocks.

F. Contrast Enhancement using Possibility Distribution [2]

- Possibility distribution function of original image can be characterized on the basis of five parameter ($\alpha, \beta, \gamma, B_2, \max$), for calculating membership values. Possibility distribution algorithm has following steps:
- Step 1: Parameter Initialization.
- Step 2: Fuzzification.
- Step 3: Modification.
- Step 4: Defuzzification.

I.

II. III. IMAGE QUALITY ATTRIBUTES

Image quality attributes are used to proved enhancement of images on the basis of numerical values. Here three attributes like PSNR, MSE, and Image Contrast are:

A. Peak Signal-To Noise Ratio (PSNR)

In this case original data and noise represents signal and noise respectively. PSNR is defined as [12]:

$$PSNR = 10 \text{Log}_{10} \left(\frac{255}{\sqrt{MSE}} \right) \quad (8)$$

B. Mean Square Error (MSE)

The MSE between the compressed and the original image is expressed as

$$MSE = \frac{1}{mn} \sum_0^{m-1} \sum_0^{n-1} |f(i, j) - g(i, j)|^2 \quad (9)$$

Here, f denotes original image data and g degraded image data in matrix, form. While m, n denotes number of rows and column belongs to picture of image. I, j represents indexing of rows and column respectively.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In the experiment result different Fuzzy contrast enhancement techniques have taken to test different images. Better contrast of image is based on the minimum MSE value and maximum PSNR value. Table I and Table II shows quality attributes values.

TABLE I: MSE value of Different Images using various Fuzzy contrast enhancement methods

	IMAGE 1	IMAGE 2	IMAGE 3	IMAGE 4
Fuzzy If-Then rule	1752.37	1318.01	4069.41	3044.83
Fuzzy INT Operator	494.63	367.82	506.07	408.27
Fuzzy Histogram Hyperbolization	31887.23	51262.68	22748.44	15377.01
Probability Distribution	7839.06	11901.97	6243.94	4398.32

TABLE II: PSNR value of Different Images using various Fuzzy contrast enhancement methods

	IMAGE 1	IMAGE 2	IMAGE 3	IMAGE 4
Fuzzy If-Then rule	8.47	2.78	-2.12	-0.86
Fuzzy INT Operator	14.64	8.32	6.94	7.87

Fuzzy Histogram Hyperbolization	-5.48	-13.12	-9.59	-7.89
Probability Distribution	1.06	-6.78	-3.98	-2.45

On the basis of FIGURE 2, fuzzy INT operator method gives better results for visual perception and after it fuzzy if-then rule method gives results for visual perception as compare to remaining two methods. After result analysis of above two methods probability distribution method gives better visual results as compare to fuzzy histogram hyperbolization.

IX. CONCLUSION AND FUTURE SCOPE

In this paper, different methods of Fuzzy contrast enhancement technique have studied and compared on the basis of various image quality attributes, which are given in above two tables. Level of enhancement in images can be measured on the basis of PSNR values. As per table I and table II, Higher the PSNR and minimum MSE value shows better result. As a future scope this kind of methods are used to enhance images for better analysis in different applications. With the help of these methods analysis of images becomes faster, clear and enhanced.

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	IMAGE 1	IMAGE 2	IMAGE 3	IMAGE 4
Input Image				





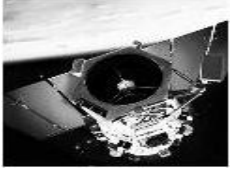


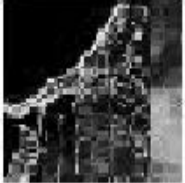








<p>Fuzzy If-Then rule</p>				
<p>Fuzzy INT Operator</p>				
<p>Fuzzy Histogram Hyperbolization</p>				
<p>Probability Distribution</p>				

FIGURE 2: Fuzzy Contrast Enhancement Results.