CHAPTER 3
CONTRAST ENHANCEMENT TECHNIQUES

3.1 Introduction

X-ray film mammography is one of the widely-adopted screening techniques to ascertain early breast cancer. However due to hypothetical concerns raised on the onset breast cancer due to the adverse effect of higher X-ray dosage or repeated exposure to X-ray; the choice of low energy level X-ray imaging - digital mammography is widely opted for breast cancer detection. Recently Automatic Exposure Control (AEC) is used wherein appropriate dosage of X-ray is regulated to levels where the energy gradient will be either at or near its maximum value and the viewing contrast brightness and other characteristics can be adjusted separately by the computer console [Sharyl J. Nass et al. 2001].

The improvement of contrast will enable the physician in identifying the cancerous/suspicious mass with improved standards [Maxine Jochelson, 2014]. In many cases, the exposure to radiation for medical imaging has been identified as a statistically detectable risk factor in the detection of breast cancer and hence, this detection is very much required to process the image with enhanced contrast. This image-dependent and image-specific contrast, in turn will provide a clear view in identification of the severity of the masses present in the mammograms [Fallenberg EM et al., 2014].

The low energy mammogram poorly depicts the vital information of the tissues of interest as well as the stage severity of cancerous tissues. Hence it is essential to improve the image
contrast in order to combat cascading effects of poor contrast in the subsequent processing steps [Mark A. Francescone et al, 2014].

The identification of severity of breast cancer could be done based on the clear understanding of the characteristics of digital mammograms. The identification of masses is achieved through the following sequence of processes such as contrast enhancement, mass segmentation, feature extraction and classification.

The quality of the images can be improved by the preprocessing techniques such as contrast stretching, density slicing, edge enhancement and spatial filtering. Contrast generally refers to the difference in luminescence or gray level values in an image and it is an important parameter in the analysis of medical images. It can be defined as the ratio of maximum intensity to the minimum intensity over an image. This technique is also known as contrast enhancement [Rafael C. Gonzalez et al. 2008] wherein the images of poor contrast/brightness are converted to an expected as well as acceptable level of enhancement.

The degree of contrast enhancement can be measured by various metrics. However, it is important to record that the contrast enhanced digital mammograms are used as source images to perform the segmentation of RoI. The subsequent image processing elements namely feature extraction, classification and analysis are
typically applied on the original intensity values of RoI, with reference to the spatial coordinates of the enhanced ones.

3.2 CONTRAST ENHANCEMENT METHODS

The low dense X-ray tends to produce poor contrast digital mammograms, which ultimately requires a suitable contrast enhancement technique, in order to highlight the essential image characteristics. The objective of this enhancement is to distinguish the objects of our concern from the background or neighbouring region.

The contrast enhancement techniques should necessarily have provision to adaptively increase or decrease the intensity of an input image based on its local and global characteristics. In this research work, five contrast enhancement techniques, listed below are devised, as the prerequisite for digital mammogram analysis.

I. Local Thresholding based Contrast Enhancement (LTCE);
II. Adaptive Histogram Equalization based Contrast Enhancement (AHECE);
III. Black Top-Hat Transformation and Gauss Distribution based Local Contrast Enhancement (BHTGD);
IV. Modified Full Width Half Maximum based Contrast Enhancement (MFCE); and
V. Modified Saturation based Contrast Enhancement (MSCE)

The first two methods LTCE and AHECE exploit the intensity distribution of the mammogram for contrast enhancement whereas the third method, BHTGD is processing pixels of the image, where results are based on the combination of gauss distribution and
morphological operations. The MFCE and MSCE enhance through the properties of the input mammograms, which leads to the provision of unmodified information of the original input mammogram.

The computational effectiveness and merits of these proposed contrast enhancement methods are outlined in comparison with visualized maps of histograms of input original image with contrasted images, in terms of the widely used metrics.

A. Michelson Contrast (C_M)

The standard contrast measure, Michelson contrast is calculated from the minimum and maximum values of the contrast. This specification returns a value between 0 and 1, which is conveniently represented as percentage between 0 and 100.

Contrast Measure \( C_M = \frac{I_{\text{Max}} - I_{\text{Min}}}{I_{\text{Max}} + I_{\text{Min}}} \) ....(3.1)

B. Absolute Mean Brightness Error (AMBE)

AMBE being a conventional contrast enhancement measure estimates the absolute mean difference between input and its corresponding enhanced image.

\[
\text{AMBE} = |E[y] - E[x]| \quad \text{....(3.2)}
\]

\[
E[x] = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} A(i, j)
\]

\[
E[y] = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} B(i, j)
\]

where A and B refer to the original and enhanced images respectively.
This measure is validated by observing results on same data. The measures cannot be compared with different scales. The AMBE indicates better brightness preservation of the images.

C. Enhancement Measure (EME)

\[
EME_{rc} = \frac{1}{r \times c} \sum_{l=1}^{r} \sum_{k=1}^{c} \ln \left( \frac{I_{\text{max}(k,l)}}{I_{\text{min}(k,l)}} \right) 
\]

\ ...

(3.3)

where, \(r\) and \(c\) are the input image rows and columns.

The Enhancement Measure (EME) [M Sundaram et al. 2011] is used in this research as a parameter to evaluate the efficiency of the enhancement techniques being devised. When the value of EME is significantly high, it indicates over-enhancement that attributes loss of local information leading to washed-out effect or otherwise, it may be inferred as inclusion of artifacts in the processed image. On the other hand, a very low value of EME indicates that the local information are being hidden. Hence, it is necessary to find an optimum value of EME in order to have appropriate contrast enhancement with due potential for image presentation.

3.3 Local Thresholding based Contrast Enhancement (LTCE)

Threshold is an intensity limit that serves as a point of reference for the contrast enhance procedure to choose among computational alternatives. If a single threshold governs the enhancement of the entire image, the approach is referred to as global thresholding and if it is dynamically altered, it is known as local thresholding.
3.3.1 Methodology of LTCE

This technique focuses to enhance the masses present in the mammogram images, by tracing each pixels of the mammogram. The contrast enhancement of the image is done by increasing the intensities of the image using local thresholding method.

The input mammogram is treated by a technique called Local Thresholding based Contrast Enhancement (LTCE) which enhances the image using its local mean, which is a simple intensity modification strategy.

3.3.2 Algorithmic Description of LTCE

In this method, the mean ($I_{\text{mean}}$) of the input image as well the row mean ($IR_{\text{mean}}$) are computed. If the current pixel value ($f(x,y)$) is equal to $IR_{\text{max}}$, which is the maximum intensity in the row under investigation then the intensity of the pixel is preserved. If $f(x,y)$ is greater than $IR_{\text{max}}$, the difference of $f(x,y)$ and $I_{\text{mean}}$ is used to augment its intensity. This process is repeated for the entire image, which substantially modifies the original intensity profile of the input image. The resultant enhanced image is denoted as $I_{E}$. It is evident from the results that the histogram pattern gets ideally stretched within the limit of $I_{\text{min}}$ and $I_{\text{max}}$ of the input image.
Algorithmic description of LTCE

**Input**: A digital mammogram (I)

**Output**: Enhanced Image (I_E)

1. Read the input image I
2. Compute the mean of I: \(I_{\text{mean}}\)
3. For the entire image of size \(M \times N\) do
   i. Read \(f(x,y)\) /* \(f(x,y) \in I\) */
   ii. Compute row-mean as \(IR_{\text{mean}}\)
   iii. Find the maximum intensity of the row: \(IR_{\text{max}}\)
   iv. If \(f(x,y) = IR_{\text{max}}\) then \(I_E(x,y) = f(x,y)\) /* \(I_E(x,y) \in I_E\) */
       /* maximum intensity of the original image is preserved */
       elseif \(f(x,y) > I_{\text{mean}}\)
         Compute \(I_E(x,y) = f(x,y) + [f(x,y) - I_{\text{mean}}]\)
       /* intensity modification by LTCE*/
4. Stop

3.3.3 Results and Discussion

The results of LTCE are illustrated using five sample images [mdb013, mdb032, mdb134, mdb148 and mdb226] in terms of test, enhanced, histogram of test and histogram of enhanced images. The five test images are given in Fig.3.2 (a) to (e) and the respective enhanced images are labeled as (f) to (j). The histogram maps of the both the test and enhanced images are shown in (k)-(o) and (p)-(t) respectively.

It is visually evident that the devised local contrast enhancement is achieved with varying intensities indicating varying disorders of different sizes in various locations. The histogram of the enhanced images shows that the values are not equally distributed in histogram mapping and the distribution of this enhancement is questioning that it affects the information present in test images.
Fig. 3.2. (a)-(e) Original input mammograms mdb013, mdb032, mdb134, mdb148 and mdb226 respectively.
(f)-(j) LTCE of (a)-(e) respectively.
(k)-(o) Histogram Map of (a)-(e) respectively and (p)-(t) Histogram Map of (f)-(j) respectively.
The metrics for $C_M$, AMBE and EME that are measured for the proposed method viz., LTCE are shown in Table 3.1.

Table 3.1 Image Enhancement Measure of LTCE

<table>
<thead>
<tr>
<th>Metrics Images</th>
<th>$C_M$</th>
<th>AMBE</th>
<th>EME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Input</td>
</tr>
<tr>
<td>mdb013</td>
<td>1</td>
<td>5.74</td>
<td>0.72</td>
</tr>
<tr>
<td>mdb032</td>
<td>1</td>
<td>7.17</td>
<td>1.05</td>
</tr>
<tr>
<td>mdb134</td>
<td>1</td>
<td>9.48</td>
<td>1.84</td>
</tr>
<tr>
<td>mdb148</td>
<td>1</td>
<td>6.32</td>
<td>0.19</td>
</tr>
<tr>
<td>mdb226</td>
<td>1</td>
<td>4.60</td>
<td>1.75</td>
</tr>
</tbody>
</table>

The degree of enhancement measured by $C_M$ implies that the contrast level is maximum for all the test images, which suggests that the enhancement of LTCE is appreciable.

AMBE measures the average brightness change observed among input and the enhanced images. The values of AMBE are image dependent and hence the AMBE results obtained for those images are observed to range between 4.60 and 9.48, depending upon the varying sizes of the abnormality seen in the breast.

The Enhancement measure EME justifies the optimality of contrast brightness being carried out on the input image. The EME measure is best suitable for those images with traits such as non-complexity and uniformity in the background of the mammogram images. The EME is evaluated by using a comparative analysis between the original input mammogram and the enhanced mammogram.

From the Table 3.1, the decreased values of EME for the enhanced images in comparison with the original input image ensures that the processed enhanced images possess more contrast brightness preservation than the original image.
Moreover, from Fig. 3.2, it is evident that the distribution of intensities observed in the histogram map is not even for all the enhanced images. In order to achieve this even distribution in the histogram maps of the enhanced images and to make the EME measure values still lesser to achieve more contrast brightness level with details preservation, the researcher has gone for the development of another preprocessing technique, Adaptive Histogram Equalization based Contrast Enhancement (AHECE) for the better enhancement of digital mammograms.

3.4 Adaptive Histogram Equalization based Contrast Enhancement (AHECE)

The traditional histogram equalization only transforms all the pixels which is derived from the image histogram. This method is reliable only when the distribution of pixels is uniform. Hence, images with uneven distribution of intensity values require a better enhancement approach as provided by Adaptive Histogram Equalization (AHE), in which the equalization procedure is determined by local-intensity information instead of the global area.

The transformation function is similar to the histogram equalization, which is directly proportional to the cumulative distribution function.

3.4.1 Methodology of AHECE

This approach transforms each pixel with a transformation function derived, from the property of neighbourhood region. Each pixel is transformed based on the histogram of its window, such that the transformation function is proportional to the cumulative distribution function of pixel values in the neighbourhood.
3.4.2 Algorithmic Description of AHECE

The algorithm reads the input mammogram image (I). The histogram reads all the intensities present in the image and organizes the intensities as per the occurrence as $I_{Count}$ and calculates the mean of the input image ($I_{Mean}$), which is used to identify the mean average difference for the entire image (k). The size of the image has been taken and considered for the window. The process starts from the top-left corner. The starting point is marked as grid point and the cumulative distribution $F(A_k)$ is identified. The computation has taken by neighbours of the four adjacency ($N_4$) and this process is being computed for entire image intensities $k(x,y)$. The interpolation of distribution of all values of this computation is ordered and indexed from minimum to maximum of the computation as $I_E$.

<table>
<thead>
<tr>
<th>Algorithmic Description of AHECE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong>: A digital mammogram (I)</td>
</tr>
<tr>
<td><strong>Output</strong>: Enhanced Image ($I_E$)</td>
</tr>
</tbody>
</table>

1. Read the input image $I$
2. Compute and count the occurrence of each intensity value in $I$: $I_{count}$
3. For the entire image of size $M \times N$ do
   i. Read $f(x,y)$ /* $f(x,y) \in I$ */
   ii. Compute $I_{mean}$
   iii. $K(x,y)=abs((I_{mean}-f)/M \times N)$
   iv. $A$ is initial grid point
   v. $F(A_k) = P(A_{sk})$ /* $A \in k(x,y)$ */
   vi. Index $k(x,y)$ based on $F(A_k)$ Map all $N_4$ of $A$
   vii. $I_E$ = Interpolate all values of Index by (min;max)
   viii. Output $I_E$
4. Stop
3.4.3 Results and Discussion

The performance of AHECE is evaluated on 100 digital mammograms of different shapes, sizes and orientations. The capability of this method is portrayed in Fig. 3.3 for the images mdb013, mdb032, mdb134, mdb148 and mdb226. It is observed that this proposed method has objectively improved the contrast of the input mammograms. The input images and the respective enhanced images are shown in (a)-(f) and (f)-(i) respectively. From the results of the study it could be confirmed that the AHECE was robust on all those images.

The intensity distribution of input mammograms and the corresponding enhanced images are graphically depicted as histograms in Fig. 3.3 (k)-(o) and (p)-(t) respectively. It can be observed that the histogram of the enhanced image is stretched by AHECE, across the gray scale of the images as contained.
Fig. 3.3. (a)-(e) Original input mammograms mdb013, mdb032, mdb134, mdb148 and mdb226 respectively. 
(f)-(j) AHECE of (a)-(e) respectively. 
(k)-(o) Histogram Map of (a)-(e) respectively and 
(p)-(t) Histogram Map of (f)-(j) respectively.

The performance analysis of AHECE for enhancement level with details preservation is depicted in Table 3.2 in terms of $C_M$, AMBE and EME.

Table 3.2 Image Enhancement measure of AHECE

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Images</th>
<th>$C_M$</th>
<th>AMBE</th>
<th>EME</th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>mdb013</td>
<td>1</td>
<td>4.24</td>
<td></td>
<td>0.72</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>mdb032</td>
<td>1</td>
<td>5.09</td>
<td></td>
<td>1.05</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>mdb134</td>
<td>1</td>
<td>13.13</td>
<td></td>
<td>1.84</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>mdb148</td>
<td>1</td>
<td>4.54</td>
<td></td>
<td>0.19</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>mdb226</td>
<td>1</td>
<td>7.08</td>
<td></td>
<td>1.75</td>
<td>0.14</td>
<td></td>
</tr>
</tbody>
</table>
By comparing Table 3.1 and Table 3.2, it is clear that the $C_M$ provides maximum level of contrast for all the test images which justifies the standard of the contrast enhancement being carried out by the AHECE method. Further, the histogram map provided by AHECE for all the test images are even, which overcomes the problem of uneven distribution of intensities being observed in the histogram map by LTCE method.

However, the EME values projected by AHECE for few images with minimized size of masses are not compromising completely in comparison with the prior results already reported. Hence to achieve better results both in the distribution level of intensities and lesser EME values, another contrast enhancement technique BHTGD is proposed, which is discussed in the next section.

3.5 Black Top-Hat Transformation and Gauss Distribution based Local Contrast Enhancement (BHTGD)

The top-hat transform is a procedure which extracts small elements of images and deduces the details of those elements. It finds place in various image processing operations such as, background/foreground equalization, image enhancement, feature extraction and analysis. The two categories of these procedures are white and black top-hat transformations. The proposed BHTGD techniques combine the potential of Top-hat transformation and Gauss distribution, to achieve image enhancement.

The former transformation uses *opening* for morphological processing and the latter uses *closing*. In BHTGD, the image elements of the input mammogram obtained out of black top-hat transformations are delineated in to smaller elements than the structuring elements with better contrast. A structuring element is
a shape which is used to study the input image to acquire necessary information based on different shapes like ball, line, square etc., to identify the information by tracing hit or miss the shapes in the input image. The element is mostly applied in the morphological closing and opening to test the miss or hit in an image.

3.5.1 Methodology of BHTGD

The Black Top Hat Transform (BHT) operates with the closing operation. This method transforms the intensity component of the image using a suitable structuring element using

\[ \text{BHT}(f) = f \bullet b - f \]  

.....(3.4)

where \( f \) is a Euclidean space or discrete grid of the image, \( b \) is the structuring element \( b(x) \) being the gray value of the image, traced by a certain shape. The operation ‘\( \bullet \)' denotes the closing operation. This BHT operation extracts the enhanced image elements. The closing can be performed by using the erosion and dilation operations which is represented by \( x \bullet y = (x \oplus y) \ominus y \).

The necessity for enhancing the image is to provide prominence of the hidden objects present in the original image are taken by the BHT. This processed image further implements the best possible enhancement. Gauss Distribution average difference is used to enhance the original image. The formula for gauss normalization is

\[ GD = \frac{1}{\sigma} \times \frac{1}{2\pi} \times e^{-\frac{1}{2}\left(\frac{S-\mu}{\sigma}\right)^2} \]  

.....(3.5)

where, \( \mu \) is the mean of the image which can be derived from the formula, \( \sigma^2 \) is the variance of the image and \( S \) are pixel values. The
 gauss distribution average difference is calculated by \( \text{GAD} = \frac{\text{abs}(\text{GD} - f(x,y))/M \times N}{\text{M} \times \text{N}} \), where \( f(x,y) \) is the intensities of input image, \( M \) and \( N \) are maximum elements of the image. The enhanced image is used to locate the brighter spot in the original image which would help in increasing the intensity of each pixel value. This produces a better visual effect for the original image.

### 3.5.2 Algorithmic Description of BHTGD

The contrast enhancement of digital mammogram by the method BHTGD, has following steps. The first step is to read the entire image intensities and compute the mean (\( I_{\text{mean}} \)), variance (\( I_{\text{variance}} \)) and gauss distribution of the image (\( I_{\text{GD}} \)). For the morphological operation, the structuring element is used to detect the image information. \( b \) acts as structuring element by using the dimension size 2 and the shape considered for the process is square. The hit and miss of this structuring element is compared from the original image in T2 and the BHT of the input process is identified based on T2 and the image function \( f \).

The outcome of the object information after this morphological process is further implemented by the computation of gauss average difference (GAD) which can be computed with the BHT (f). Then the process enhances the contrast of the intensities further by checking the condition with \( I_{\text{GD}}, I_{\text{min}} \) and \( I_{\text{max}} \) values. The resulted output is \( I_{\text{E}} \).
Algorithm description of BHTGD

Input : A digital mammogram (I)
Output : Enhanced Image (IE)

1. Read the input image I of size M x N
2. Consider the entire image do
   i. Read L(x,y) /* L(x,y) ε I */
   ii. Compute
        a. I_{Mean} = Mean(I)
        b. I_{Var} = Variance(I)
        c. I_{GD} = Gauss Distribution
        d. X = erosion(I)
        e. Y = dialation(I)
   iii. Set structuring element size as 2 and the shape as square
   iv. T1 = x • y = (x ⊕ y) θ y
   v. Compute T2 = f • b /* b is structuring element */
   vi. BHT(f) = T2 − f /* f ε I */
   vii. Compute GAD = abs(I_{GD} - BHT(f)) / M x N
   viii. if L(x,y) > I_{GD} and k(x,y) < I_{Rmax} then
         IE = L(x,y) + GAD
             else
         IE = L(x,y) + I_{Rmin}
3. Stop

3.5.3 Results and Discussion

The results obtained for five different images [mdb013, mdb032, mdb134, mdb148 and mdb226] are presented in Fig.3.4 (a) to (e). These figures depict the process of contrast enhancement and the enhanced results are shown in Fig.3.4 (f) to (j). The histogram mapping of test and enhanced images are depicted in (k)-(o) and (p)-(t) respectively.
Fig. 3.4. (a)-(e) Original input mammograms mdb013, mdb032, mdb134, mdb148 and mdb226 respectively. (f)-(j) BHTGD of (a)-(e) respectively. (k)-(o) Histogram Map of (a)-(e) respectively and (p)-(t) Histogram Map of (f)-(j) respectively.
The performance of BHTGD being measured through the metrics $C_M$, AMBE and EME is projected in the following Table 3.3.

Table 3.3 Image Enhancement measure of BHTGD

<table>
<thead>
<tr>
<th>Images</th>
<th>$C_M$</th>
<th>AMBE</th>
<th>EME</th>
</tr>
</thead>
<tbody>
<tr>
<td>mdb013</td>
<td>1</td>
<td>4.56</td>
<td>0.72</td>
</tr>
<tr>
<td>mdb032</td>
<td>1</td>
<td>5.41</td>
<td>1.05</td>
</tr>
<tr>
<td>mdb134</td>
<td>1</td>
<td>13.46</td>
<td>1.84</td>
</tr>
<tr>
<td>mdb148</td>
<td>1</td>
<td>4.86</td>
<td>0.19</td>
</tr>
<tr>
<td>mdb226</td>
<td>1</td>
<td>7.40</td>
<td>1.75</td>
</tr>
</tbody>
</table>

The comparative analysis of Tables 3.2 and 3.3 depicts the fact that $C_M$ maintains its standard pertaining to the contrast enhancement, distribution level of intensities for the histogram maps are even for the proposed BHTGD. The EME values of BHTGD too are found to be lesser than the values being produced by AHECE method.

However, to have still lesser EME values to achieve best contrast enhancement among all the proposed methods, MFCE method is being devised.

3.6 Modified Full Width Half Maximum based Contrast Enhancement (MFCE)

The objective of this method is to enhance the mammograms by applying contrast enhancement using their intensity values for the process. In earlier approaches, the contrast enhancement was done based on intensity distribution of the pixels in process and the respective neighbour. The newly devised MFCE used these modified techniques to enhance the input image.

The full width at half maximum (FWHM) is the function, which extends the difference by identifying the intensity values
distribution of the intensities and average values. The values are computed by the distribution function in equation 3.6 and the computation of FWHM is derived from the equation 3.7 [Jackson A, 2014].

### 3.6.1 Methodology of MFCE

The FWHM is used to identify the width and in many cases in physical sciences it is used to measure the density of objects. In the same line, the density of mammogram pixels measured using FWHM with added value of intensity average is used for image enhancement.

The bandwidth of a signal is a measure of its peak and valley [Jackson A, 2014]. The notational convention of a normally distributed signal is:

$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp \left[ -\frac{(x - x_0)^2}{2\sigma^2} \right]$$

....(3.6)

where, $\sigma$ is standard deviation, $x$ is a pixel value, $x_0$ is computed value from the input image and the relation between FWHM and Normal distribution is

$$\text{FWHM} = 2\sqrt{2 \ln 2} \sigma \approx 2.355 \sigma$$

....(3.7)

This relation is exploited to enhance the quality of digital mammogram.

### 3.6.2 Algorithmic Description of MFCE

The input mammogram is processed by identifying the minimum value except that the non-zero is taken as $T_2$ and maximum as $T_1$. The mean average difference (MAD) of the input image is computed from the modified FWHM by using the
equations (3.6) and (3.7). The $T_1$ and $T_2$ are used to find the locations to enhance ($I_{EM}$) the test image.

**Algorithmic description of MFCE**

**Input**: A digital mammogram ($I$)

**Output**: Enhanced Image ($I_{EM}$)

1. Read $f(x,y)$ /* $f(x,y) \in I$ */
2. Compute
   a. $MAD = (f - \text{mean}) / R \times C$ /* $R$ and $C$ are row and column size of $I$ */
   b. $T1 = \max(f)$
   c. $T2 = \min(f)$
   d. $X_0 = \text{abs}(MAD)$
3. If ($X_0 > T2$ and $X_0 < T1$) then
   $I_{EM} = f + \text{FWHM}$
   else
   $I_{EM} = f$
4. Stop.

**3.6.3 Results and Discussion**

The results obtained for five different images [mdb013, mdb032, mdb134, mdb148 and mdb226] are presented in Fig.3.5 (a) to (e). These figures depict the process of contrast enhancement and the enhanced results are shown in Fig.3.5 (f) to (j). The picture representation of histogram mapping of test and enhanced images of MFCE are shown in (k)-(o) and (p)-(t) respectively.

It is visually evident that the devised contrast enhancement with varying intensities indicate varying disorders of different sizes in various locations based on the nearest neighbours. These enhanced results are compared with the metrics mentioned above in the equations (1)-(3) and EME.
Fig. 3.5. (a)-(e) Original input mammograms mdb013, mdb032, mdb134, mdb148 and mdb226 respectively.
(f)-(j) MFCE of (a)-(e) respectively.
(k)-(o) Histogram Map of (a)-(e) respectively and (p)-(t) Histogram Map of (f)-(j) respectively.
The performance analysis of MFCE for contrast enhancement is depicted in Table 3.4 in terms of \( C_M \), AMBE and EME.

<table>
<thead>
<tr>
<th>Images</th>
<th>( C_M )</th>
<th>AMBE</th>
<th>EME</th>
</tr>
</thead>
<tbody>
<tr>
<td>mdb013</td>
<td>1</td>
<td>75.75</td>
<td>0.72</td>
</tr>
<tr>
<td>mdb032</td>
<td>1</td>
<td>78.94</td>
<td>1.05</td>
</tr>
<tr>
<td>mdb134</td>
<td>1</td>
<td>63.99</td>
<td>1.84</td>
</tr>
<tr>
<td>mdb148</td>
<td>1</td>
<td>69.47</td>
<td>0.19</td>
</tr>
<tr>
<td>mdb226</td>
<td>1</td>
<td>52.95</td>
<td>1.75</td>
</tr>
</tbody>
</table>

From Fig. 3.5 it is clear that MFCE maintains evenness in the distribution level of intensities for enhanced images. Further, by analyzing the values of Table 3.3 and Table 3.4, it is understood that the contrast enhancement standard is being justified by \( C_M \) and the EME values are lesser than the prior methods.

To achieve lowest EME values and to ensure best contrast enhancement among all the proposed methods, MSCE method is proposed, which is being discussed in the following section.

**3.7 Modified Saturation based Contrast Enhancement (MSCE)**

The purpose of this method is to enhance the mammograms by altering the contrast of the input image. From the previously devised enhancement, the output may reach the saturation level by any chance of contrast enhancement.

In image processing, saturation is the perceived brightness of an image with reference to its colour scheme. The MSCE is devised to tap the pattern of saturation of a given mammogram for contrast improvement.

In a RGB colour gamut, the combination of two colour schemes and the choroma values are used to distinguish the
colour values. The idea of avoiding saturation level is based on this colour schemas. Based on this Hue, Saturation and Luminance/Lightness (HSL), Hue Saturation value (HSV) colour schemes are identified. In these colour schemes, the choroma is always in the range of [0,1]. The formulation of HSV and HSL are shown in the following equations as;

\[
S_{HSV} = \begin{cases} 
0, & \text{if } V = 0 \\
\frac{C}{V}, & \text{otherwise}
\end{cases} \quad \text{....(3.8)}
\]

\[
S_{HSL} = \begin{cases} 
\frac{C}{1 - |2L - 1|}, & \text{if } L \neq 1 \\
0, & \text{otherwise}
\end{cases} \quad \text{....(3.9)}
\]

### 3.7.1 Methodology of MSCE

In MSCE, the alternation of saturation is performed using the principle of equation (3.10), which is a modification of equations (3.8) and (3.9).

\[
S_{\text{Modified}} = \begin{cases} 
1 - \frac{2}{w + q}(w), & \text{if } f(x,y) > h \\
0, & \text{otherwise}
\end{cases} \quad \text{....(3.10)}
\]

where \(f(x,y)\) is input image intensity

\(w = \min(g,h)\),

\(g\) is the difference between the maximum with average point,

\(h\) is the difference between the minimum with average point and

\(q\) is the maximum of \(g\) and \(h\).

The formulation of any modification will ensure that the brightness of the modified methods is not overdraft beyond the saturation point [Kuldeep Sing and Rajiv Kapoor, 2014]. In many of the enhancements methods, the local thresholding values will affect
brightness and provide more brightness. The modified saturation enables the values within the maximum saturation value.

### 3.7.2 Algorithmic Description of MSCE

In the algorithm, mammogram $I$ has been taken as the input and the minimum, maximum and average intensities of $I$ are calculated. From these statistical measures, the values of $g, h, w$ and $q$ are computed as described in the previous section. The threshold factor of MSCE is computed, using (3.10).

It is evident from the computational procedure of MSCE, that the statistical details of the input image is explored for contrast enhancement. Hence this method is very generic and image specific.

<table>
<thead>
<tr>
<th>Algorithmic description of MSCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong> : A digital mammogram ($I$)</td>
</tr>
<tr>
<td><strong>Output</strong> : Enhanced Image ($I_{EM}$)</td>
</tr>
<tr>
<td>1. Read $f(x,y)$ /* $f(x,y)$ ∈ $I$ */</td>
</tr>
<tr>
<td>2. Compute</td>
</tr>
<tr>
<td>a. $I_{Max}$ = Max ($I$)</td>
</tr>
<tr>
<td>b. $I_{Min}$ = Min ($I$)</td>
</tr>
<tr>
<td>c. $I_{Avg}$ = Average ($I$)</td>
</tr>
<tr>
<td>d. $T_1$ = Row Minimum $R_{min}$</td>
</tr>
<tr>
<td>e. $T_2$ = Row Maximum $R_{max}$</td>
</tr>
<tr>
<td>3. Compute</td>
</tr>
<tr>
<td>a. $g$ = ($I_{Max}$ - $I_{Avg}$)</td>
</tr>
<tr>
<td>b. $h$ = ($I_{Avg}$ - $I_{Min}$)</td>
</tr>
<tr>
<td>c. $w$ = min($g, h$)</td>
</tr>
<tr>
<td>a. $q$ = max($g, h$)</td>
</tr>
<tr>
<td>4. If ($f(x,y) &gt; T_1$ and $f(x,y) &lt; T_2$) then</td>
</tr>
<tr>
<td>$I_{EM}$ = $S_{Modified}$</td>
</tr>
<tr>
<td>else</td>
</tr>
<tr>
<td>otherwise</td>
</tr>
<tr>
<td>5. Stop</td>
</tr>
</tbody>
</table>
3.7.3 Results and Discussion

The results obtained for five different images [mdb013, mdb032, mdb134, mdb148 and mdb226] are presented in Fig.3.6 (a) to (e). These figures depict the process of contrast enhancement and the enhanced results are shown (Fig.3.6 (f) to (j)).

It is visually evident that the devised contrast enhancement with varying intensities indicate the modification of saturation values of the input image. These enhanced results are compared with the metrics mentioned above in the equations (1)-(3) and EME.
Fig. 3.6. (a)-(e) Original input mammograms mdb013, mdb032, mdb134, mdb148 and mdb226 respectively.
(f)-(j) MSCE of (a)-(e) respectively.
(k)-(o) Histogram Map of (a)-(e) respectively and (p)-(t) Histogram Map of (f)-(j) respectively.

The metrics for MSCE in terms of CM, AMBE and EME for the tested images are depicted in the following Table 3.5.

Table 3.5 Image enhancement measures of MSCE

<table>
<thead>
<tr>
<th>Images</th>
<th>C_M</th>
<th>AMBE</th>
<th>EME Input</th>
<th>EME Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>mdb013</td>
<td>1</td>
<td>27.99</td>
<td>0.72</td>
<td>0.11</td>
</tr>
<tr>
<td>mdb032</td>
<td>1</td>
<td>35.99</td>
<td>1.05</td>
<td>0.12</td>
</tr>
<tr>
<td>mdb134</td>
<td>1</td>
<td>32</td>
<td>1.84</td>
<td>0.06</td>
</tr>
<tr>
<td>mdb148</td>
<td>1</td>
<td>67.55</td>
<td>0.19</td>
<td>0.05</td>
</tr>
<tr>
<td>mdb226</td>
<td>1</td>
<td>36</td>
<td>1.75</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Fig. 3.6 and Table 3.5 make it clear that MSCE is best among all the other four proposed contrast enhanced techniques in view of the justified results obtained for C_M, AMBE and EME.
3.8 Conclusion

The five different proposed methods have produced different perspectives on the given input image and those methods are organized based on their level of binder with the original mammogram images.

LTCE, the first method has been developed based on the local contrast of the input image which yields a reliable outcome of enhanced mammogram.

The improvement of LTCE by modifying the adaptive histogram through AHECE, produced good relevant enhanced values for further process, which is also compared with histogram mappings and different metrics.

The advancement of background and foreground characteristics of input mammogram are analyzed using morphological based enhancement process BHTGD. In this method, the Black top-hat transformation is applied which provides an efficient enhancement for any kind of input mammograms. Moreover, the gauss distribution restricts the enhancement process to not reach over enhancement.

It is visually evident from MFCE that the contrast enhancement with varying intensities which indicate varying disorders of different sizes is enhanced in such a way that the distribution of intensity levels are evenly got distributed. The results of the performance analysis in terms of lesser EME values vouch its efficiency in contrast enhancement.
The development of MSCE attains its saturation by projecting the lowest EME values closer to Zero in comparison with all other proposed contrast enhancement techniques. All the above-mentioned algorithms are tested with large number of datasets and for illustration, only representative samples are shown.