CHAPTER 6

QUADRANT DYNAMIC WITH AUTOMATIC PLATEAU LIMIT HISTOGRAM EQUALIZATION (QDAPLHE)

6.1 INTRODUCTION

In image processing, image enhancement is used to improve the image quality through a broad range of techniques such as contrast enhancement, color enhancement, dynamic range expansion and edge emphasis and so on. In consumer electronics, many histogram equalization based methods have been used in recent years. Many of these methods are complicated to implement and also some method will produce blocking artifacts and over enhancement. In order to increase the brightness preservation and to reduce the over enhancement, a hybrid of dynamic and clipped histogram equalization method named Quadrant Dynamic Automatic Plateau Limit Histogram Equalization method (QDAPLHE) is proposed.

The proposed method produces better brightness preservation with natural looking compared to other existing methods.

6.2 RELATED WORKS

For constant enhancement, histogram equalization (Gonzalez et al 2008) is simple and widely utilized method in literature. The fundamental idea of Histogram equalization is to remap the intensity values of the input image into new intensity levels through a transform function created by
cumulative density function. Even this method increases the contrast of an image, the enhanced image tends to have unnatural enhancement and intensity saturation artifacts, due to error in brightness mean shifting (Kim et al 2008)

Generally, these enhancement methods can be classified into two types.

1) Partitioned histogram equalization (PHE)
2) Dynamic partitioned histogram equalization (DPHE)

In these methods, the original histogram is divided into several sub histograms based on the histogram statistical information. The difference between the DPHE and PHE is each sub histogram in the DPHE is assigned to a new enhanced dynamic range instead of using the original dynamic range.

One of the popular PHE based method is the mean brightness preserving bi-histogram equalization (BBHE) introduced by Kim et al (1997). To achieve the brightness preserving, the BBHE segments the original histogram into two portions by the mean of the input histogram. Wan et al (1999) proposed a method, called the Dualistic sub-image histogram equalization (DSIHE). This algorithm separates the histogram into two sub-histograms based on median of the input image.

In order to optimize the mean brightness preservation of the input image, Chen and Ramli (2003) proposed a method named minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE). In this method, the separating point is set by finding the minimum mean brightness error between the input and the enhanced images. Chen and Ramli (2003) proposed another method called Recursive mean separate Histogram Equalization (RMSHE). This algorithm divides the original histogram into $2^r$ sub histograms, where ‘r’ is the integer value. A similar approach is proposed by
Sim et al (2007) named as Recursive Sub-Image Histogram Equalization (RSIHE). In RSIHE original histogram is segmented by median of each sub histogram.

For DPHE, there are two methods existing in literature.

1) Dynamic histogram Equalization(DHE) proposed by Wadud et al (2007)
2) Brightness preserving Dynamic Histogram Equalization (BPDHE) proposed by Ibrahim and Kang et al (2007)

The DHE partitions the histogram of input image based on local minimal and assigns a new dynamic range for each sub-histogram. To ensure many dominating portions, the DHE further segments the large sub-histogram through a repartitioning test. The DHE neglects the mean brightness preserving and leads to intensity saturation artifact.

To overcome the drawback of the DHE, brightness preserving dynamic histogram equalization (BPDHE) has been introduced by Ibrahim et al (2007). The BPDHE uses the local maximal as the separating point rather than the local minimal. For this reason, Ibrahim and Kang claim that the local maximals are better for mean brightness preservation.

Finally histogram equalization is implemented after assigning a new dynamic range for each sub histogram. In order to maintain the mean brightness, brightness normalization is applied to ensure that the enhanced image has the similar mean brightness of the input image.

Recently Ooi and Kong et al (2009) proposed a Bi-Histogram Equalization Plateau Limit (BHEPL) as the hybrid of the BBHE and clipped histogram equalization BHEPL divides the histogram of input image by the
value of mean brightness of the input image. Both sub histograms are clipped by each mean of the occupied intensity values in each sub histogram respectively. Conventional histogram equalization methods are able to control the enhancement rate. Also these methods can avoid over-amplification of noise in the image.

Some examples of clipped histogram equalization methods are given below.

1) **Histogram Equalization with Bin Underflow and Bin Overflow (BUBOHE)** proposed by Seungjoon et al (2003)

2) **Weighted and Threshold Histogram Equalization (WTHE)** developed by Qing Wang et al (2007)


4) Bing-Jain Wang et al (2006) implemented a method named Self Adaptive Plateau Histogram Equalization (SAPHE) and the modified SAPHE is presented by Nicholas Sia Pik Kong (2009)

First three methods require the user to manually set the parameters value. Hence, these methods are not so suitable to be used in an automated image enhancement system. In SAPHE, the parameters values are automatically selected based on the median value of the local peaks of the corresponding input histogram. In some cases, SAPHE fails to detect any local peaks in the image and therefore fails to set its parameter. To overcome this problem, MSAPHE is introduced. In MSAPHE, the plateau limit is set by the median value of the non-empty histogram bins.
Chen Hee Ooi et al (2010) proposed the extension of the RSIHE method, called dynamic quadrants histogram equalization plateau limit (DQHEPL). This method divides the histogram of input image into four sub histograms and assigns a new dynamic range for each sub-histogram. Then clipping process is implemented. Chen Hee Ooi et al (2010) also proposed a second method called Bi-Histogram equalization median plateau limit (BHEPL-D). This algorithm clips the histogram using the median of the occupied intensity.

In this thesis, the extension of the BHEPL is proposed. A novel method is proposed as the extension of the RSIHE, called Quadrant Dynamic with Automatic Plateau Limit Histogram Equalization (QDAPLHE). First, the input image is passed through a median filter to remove the noises present in the image. Then the histogram of the filtered image is divided into four sub-histograms while maintaining second separated point as the mean brightness. Then the clipping process is implemented by calculating automatically the plateau limit as the clipped level. The clipped portion of the histogram is modified to reduce the loss of image intensity value. Finally the clipped portion is redistributed uniformly to the entire dynamic range and the conventional histogram equalization is executed in each sub-histogram independently.

6.3 QUADRANT DYNAMIC WITH AUTOMATIC PLATEAU LIMIT HISTOGRAM EQUALIZATION (QDAPLHE)

The proposed QDAPLHE method uses the fundamental idea of the RMSHE. In RMSHE the number of decomposed sub-histograms increases in a power of two. Although it will produce better brightness preservation, it declines the effectiveness of the histogram equalization and yields an output image without a good enhancement i.e., the output will be same as the input. Thus in this work, the input histogram is divided into four sub-histogram. The
proposed QDAPLHE consists of five processes, namely filtering process, histogram partitioning process, clipping process, redistribution process and histogram equalization.

### 6.3.1 Filtering Process

In many signal and image processing applications, it is necessary to smooth the noisy signals while at the same time preserving the edge information. The most commonly used smoothing techniques are linear filtering, averaging filtering and median filtering. The linear filters smooth the noisy signals and also the sharp edges. The median of a group, containing an odd number of elements, is defined as the middle element when the elements of the group are sorted. The median computed at this operation is called the running or the moving median. Since the size of the window is constant, the number of incoming elements is equal to the number of outgoing elements.

#### 6.3.1.1 Median filtering

A median filter finds the median of a number of elements at its input. The median of a group, containing an odd number of elements, is defined as the middle element when the elements of the group are sorted. In the standard median filtering applications, a window of size $W$ is moved along the sampled values of the signal or the image, where $W$ is odd. For each position of the window, the median of the elements within the window is computed and then written at the output pixel located at the same position as the central element of the window. The median computed at this operation is called the running or the moving median. Since the size of the window is constant, the number of incoming elements is equal to the number of outgoing elements. The dimensions of the filter mask must be odd. Mask sizes are 3x3, 5x5 or 7x7. Minimum mask size is preferred in many cases. In this thesis, the mask size is 3x3.
The averaging filters have some undesirable features like outlier points that distort the filtered signal and edge information loss. The median filters have proved to be good because they have some very interesting properties: 1) they can smoothen the transient changes in signal intensity (e.g., noise); 2) they are very effective for removing the impulse noise from the signals; 3) they can preserve the edge information in the filtered signal; and 4) they can be implemented by using very simple digital nonlinear operations. Because of these properties of the median filters, they are frequently used in various signal and image processing applications.

6.3.1.2 Padding

When the center of the mask moves closer to the border, one or more rows or columns of the mask will be located outside the image plane. There are several ways to handle this situation. One such approach is padding. Padding is the process of adding rows and columns of ‘0’s. Padding is stripped off at the end of the process so that the size of the filtered image is same as the original image.

6.3.1.3 Advantages of median filter

- They provide excellent noise reduction capabilities, with considerably less blurring than linear smoothing filters of similar size.
- Median filters are particularly effective in the presence of both bipolar and unipolar impulse noise.
- Median value must be one of the pixel values present in the neighborhood. So median does not create new unrealistic pixel value.
6.3.2 Histogram Partitioning Process

Each image has different histograms which depend on the brightness and darkness of the image (intensity value) and this histogram is partitioned to enhance the image. The proposed QDAPLHE method divides the histogram into four sub histograms based on mean value. The mean-based partition approach tends to segment the number of pixels equally in each sub histogram. Hence, each separating point can be calculated using the following equations:

\[
S_1 = .25 \times \{I_w \times I_h\} \tag{6.1}
\]

\[
S_2 = .50 \times \{I_w \times I_h\} \tag{6.2}
\]

\[
S_3 = .75 \times \{I_w \times I_h\} \tag{6.3}
\]

where \(s_1\), \(s_2\) and \(s_3\) are intensities set to 0.25, 0.50 and 0.75, respectively, for the total number of pixels in the histogram of the input image. \(I_w\) and \(I_h\) represent the width and height of the input image, respectively.

6.3.3 Clipping Process

Histogram equalization stretches the high contrast region of the histogram and compresses the low contrast region of the histogram. As a consequence when the object of interest in an image only occupies a small portion of the image, this object will not be successfully enhanced by histogram equalization. Histogram equalization method causes level saturation effects as it extremely pushes the intensities towards the right or the left side of the histogram.
A clipped histogram equalization method tends to overcome these problems by restricting the enhancement rate. It is known that the enhancement from histogram equalization is heavily dependent on the cumulative density function \( c(x) \). Therefore the enhancement rate is proportional to the rate of \( c(x) \). The rate of \( c(x) \) is given by the following equations 6.4 and 6.5.

\[
\frac{d}{dx} c(x) = p(x) 
\]  

(6.4)

The probability density function \( p(x) \) is given by

\[
p(x) = \frac{h(x)}{N} 
\]  

(6.5)

where \( h(x) \) is the histogram for intensity value ‘x’ and ‘N’ is the total number of pixels in the image. The enhancement rate is limited by limiting the value of \( p(x) \), or \( h(x) \).

Therefore, clipped histogram equalization modifies the shape of the input histogram by reducing or increasing the value in the histogram’s bins based on a threshold limit before the equalization is taking place. This threshold limit is also known as the clipping limit, or clipping threshold \( (T_c) \) or the plateau level of the histogram and based on this threshold value, the histograms will be clipped.

An automatic clipping process, self-adaptive plateau histogram equalization (SAPHE) is introduced by Wang et al (2005) for the infrared image contrast enhancement. However, this algorithm fails to implement in the natural image due to unsuccessful local peak detection. Thus, a modified-SAPHE is introduced by Kong et al (2009) to locate median value of the non-empty bins as the clipping threshold, \( T_c \). However, in order to reduce the
computational complexity, $T_c$ is replaced by the average of the number of intensity is proposed by Chen Hee Ooi (2010) in Quadrants Dynamic Histogram Equalization (QDHE).

To avoid the intensity saturation and over enhancement problem, the proposed QDAPLHE method adopts the clipped histogram equalization to control the enhancement rate by defining a plateau limits automatically to each sub histogram. Here, the plateau limit (or $T_c$) is determined automatically by calculating the average occupied intensity in each sub-histogram.

Each plateau limit is identified as follows

$$P_i = \frac{1}{s_i - s_{i-1}} \times \sum_{k=m_{i-1}}^{m_i} h(X_k)$$  \hspace{1cm} (6.6)

where $h(X_k)$ is the histogram at the intensity level ‘$k$’.

Clipping process is applied after finding this plateau limit. The clipped portion can be determined as follows.

$$h_{ci}(X_k) = \begin{cases} h(X_k) & h(X_k) \leq P_i \\ P_i & h(X_k) > P_i \end{cases}$$  \hspace{1cm} (6.7)

where $h_{ci}(X_k)$ is the clipped histogram at intensity level ‘$k$’.

While using the clipping process, all the values above the plateau limit ($T_c$) are removed which may lead to loss on original intensity value of the image. Hence the histogram in the clipped portion is adjusted using the following formula.
\[
\begin{align*}
    h_{mci}(X_k) = \begin{cases} 
    h_{ci}(X_k) & ,h_{ci}(X_k) \leq P_i \\
    \frac{P_i + h_{ci}(X_k) - P_i}{3} & ,h_{ci}(X_k) > P_i
    \end{cases} 
\end{align*}
\]  

(6.8)

where \( h_{mci}(X_k) \) is the modified clipped histogram at intensity level ‘k’.

This type of clipping process has the effect of the contrast enhancement and reduces the noise amplifying artifacts.

6.3.4 Redistribution Process

Because of this clipping process, the sub histograms may not ensure the balance space in each sub-histogram for sufficient contrast enhancement. When the side of the sub-histogram is narrow, contrast enhancement obtained in narrow stretching space is less significant and wide stretching space introduces redundant contrast enhancement. Consequently, the processed image tends to suffer from loss of image details and intensity saturation artifact. To overcome this drawback, the clipped portion is redistributed over the entire dynamic range. For this, the proposed QDAPLHE method maintains the point \( s_2 \) as the brightness preserving. The separating points of \( s_1, s_2 \) and \( s_3 \) are reassigned to a new grey level represented as \( t_1, t_2, \) and \( t_3 \) respectively.

\[
t_1 \equiv s_2 \times \frac{s_1 - s_0}{s_2 - s_0} 
\]  

(6.9)

\[
t_2 \equiv s_2 
\]  

(6.10)

\[
t_3 \equiv (L - 1 - S_2) \times \frac{s_3 - s_1}{s_4 - s_2} + S_2 
\]  

(6.11)
where \( s_0 \) and \( s_4 \) are assigned to the minimum and maximum output intensity value. (ie., \( s_0 = 0 \) and \( s_4 = L-1 \) (255)). The new dynamic ranges are determined for all the quadrant sub-histograms.

### 6.3.5 Histogram Equalization

The final step in the proposed QDAPLHE method is to equalize each new quadrant sub-histogram independently. The output of histogram equalization, \( Y(X) \) of this sub-histogram can be determined by using the equation (6.12).

\[
Y(X) = t_{i-1} + \left( t_i - t_{i-1} \right) \left( \sum_{k=m_i}^{m} h_{mci}(X_k) \right) / M_i
\]  

(6.12)

The total of the clipped histogram at \( i^{th} \) sub-histogram \( M_i \) is given by

\[
M_i = \sum_{k=m_i}^{m} h_{mci}(X_k)
\]

(6.13)

### 6.3.6 Step by Step Procedure for Developing the Proposed QDAPLHE Method

By combining the above four process is algorithm has been developed and the step by step procedure to implement the proposed QDAPLHE technique is given in Figure 6.1. First, the input image was taken and the impulse noises present in this image was filtered using median filter. The filtered image was then passed to the histogram partitioning process where the image histogram was partitioned into four sub-histograms using the equations (6.1) to (6.3). In each sub-histogram, to avoid the over-enhancement problem, clipping of histogram process was performed. For this, initially the clipping levels (plateau limits) for each sub-histograms were
calculated using the equation (6.6). Depending on the clipping level in each sub-histogram, histogram clipping was performed using equation (6.7).

Figure 6.1 Block Diagram of proposed QDAPLHE method
Due to this clipping process, some information in histogram will be lost and to avoid this problem, histogram adjustment process was performed using the equation 6.8. The clipped portion was redistributed over the entire dynamic range using the equations (6.9) to (6.11). Finally, histogram equalization was performed using the equation (6.12).

6.4 RESULTS AND DISCUSSIONS

The functions of the proposed QDAPLHE method were tested on numerous images. The images like Einstein, girl, House, couple, copter, F16, and jet were taken from database (http://decsai.ugr.es/cvg/dbimagenes/) and CT chest, CT brain, and CT abdomen images were obtained from Kanyakumari Government medical college, Asaripallam, TamilNadu, India with the help of Dr.J.Ravindran. In this work three out of these sampling images of size 256x256 pixels namely CT chest, CT brain, CT abdomen were selected to evaluate the capability of the proposed methods. The proposed QDAPLHE method was qualitatively and quantitatively analyzed.

6.4.1 Qualitative Analysis

The qualitative analysis involves performance comparison with existing brightness preserving methods, namely HE, BBHE, DSIHE, MMBEBHE, RMSHE, CSRSHE-A and CSRSHE-B. Figures 6.2, 6.3 and 6.4 shows, for the CT chest, CT abdomen and CT brain image, the output images produced by these histogram equalization methods.
Figure 6.2 Results for CT Chest image
Figure 6.3 Results for CT abdomen image
Figure 6.4 Results for CT Brain image
The enhancement produced by existing methods and proposed methods are shown in Figures 6.2(a) to 6.2(i), 6.3(a) to 6.3(i) and 6.4(a) to 6.4(i) respectively. In general, the conventional histogram equalization algorithms are prone to missing luminance levels due to the mapping function calculation. To overcome this shortcoming, clipping based method (QDAPLHE) is developed in this chapter and the output results are shown in Figures 6.2(i), 6.3(i) and 6.4(i).

Based on Figures 6.2(b), 6.3(b), and 6.4(b), it is clear that the histogram equalization method enhances the images but it also amplifies the noise level of the images. From the Figures 6.2, 6.3, and 6.4 (c and f) (BBHE, RMSHE), the drawback of these methods was observed that they preserves the mean brightness of the images without emphasizing on the image details significantly i.e., the problem of intensity saturation occurs in some regions of the image even though this methods improve the contrast of the image.

In the proposed DQAPLHE method, the Figures 6.2, 6.3, and 6.4 (i) shows that the contrast of the images is enhanced successfully for all the tested images and also this method preserves the image details successfully. From Figures 6.2, 6.3, and 6.4 (g and h), CSRSHE-A & CSRSHE-B methods are produced acceptable and natural enhanced images. Compared to these CSRSHE-A and CSRSHE-B methods, the proposed QDAPLHE method reduces the intensity saturation problem and also it can significantly improve the performance. The related samples are detailed in Appendix 1.

### 6.4.2 Quantitative Analysis

To prove the robustness of the proposed methods, three kinds of quantitative comparison tests which are the absolute mean brightness error, Standard deviation and Peak signal to noise ratio have been evaluated and tabulated in Tables 6.1 to 6.3 and Figures 6.5 to 6.7 respectively.
Table 6.1 Absolute Mean Brightness Error (AMBE)

<table>
<thead>
<tr>
<th>Images</th>
<th>HE</th>
<th>BBHE</th>
<th>DSIHE</th>
<th>MMBEBHE</th>
<th>RMSHE $,(r=2)$</th>
<th>CSRSHE- A</th>
<th>CSRSHE- B</th>
<th>QDAPLHE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Einstein</td>
<td>17.17</td>
<td>19.27</td>
<td>12.07</td>
<td>14.27</td>
<td>10.17</td>
<td>2.14</td>
<td>3.08</td>
<td>1.97</td>
</tr>
<tr>
<td>girl</td>
<td>5.29</td>
<td>23.51</td>
<td>4.46</td>
<td>3.04</td>
<td>0.45</td>
<td>0.05</td>
<td>1.4</td>
<td>0.07</td>
</tr>
<tr>
<td>House</td>
<td>58.81</td>
<td>25.09</td>
<td>31.92</td>
<td>25.06</td>
<td>8.07</td>
<td>2.68</td>
<td>3.91</td>
<td>2.54</td>
</tr>
<tr>
<td>couple</td>
<td>96.42</td>
<td>33.17</td>
<td>43.81</td>
<td>18.45</td>
<td>10.28</td>
<td>1.95</td>
<td>2.65</td>
<td>1.72</td>
</tr>
<tr>
<td>copter</td>
<td>62.72</td>
<td>17.21</td>
<td>26.91</td>
<td>32.14</td>
<td>3.08</td>
<td>0.24</td>
<td>2.07</td>
<td>0.22</td>
</tr>
<tr>
<td>F16</td>
<td>49.72</td>
<td>1.09</td>
<td>13.5</td>
<td>15.31</td>
<td>1.24</td>
<td>2.52</td>
<td>0.19</td>
<td>1.89</td>
</tr>
<tr>
<td>jet</td>
<td>71.76</td>
<td>4.91</td>
<td>26.84</td>
<td>2.07</td>
<td>0.64</td>
<td>0.29</td>
<td>0.31</td>
<td>0.34</td>
</tr>
<tr>
<td>CT chest</td>
<td>53.19</td>
<td>24.05</td>
<td>19.23</td>
<td>16.71</td>
<td>4.19</td>
<td>0.71</td>
<td>0.31</td>
<td>0.67</td>
</tr>
<tr>
<td>CT Brain</td>
<td>62.08</td>
<td>34.21</td>
<td>29.71</td>
<td>19.31</td>
<td>5.84</td>
<td>1.73</td>
<td>3.65</td>
<td>1.58</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>59.34</td>
<td>24.73</td>
<td>31.35</td>
<td>13.08</td>
<td>3.71</td>
<td>1.05</td>
<td>2.56</td>
<td>0.97</td>
</tr>
<tr>
<td>Average</td>
<td>53.65</td>
<td>20.72</td>
<td>23.98</td>
<td>15.94</td>
<td>4.78</td>
<td>1.37</td>
<td>2.19</td>
<td>1.19</td>
</tr>
</tbody>
</table>

Figure 6.5  Different AMBE values for different image enhancement methods
### Table 6.2 Standard Deviation (STD)

<table>
<thead>
<tr>
<th>Images</th>
<th>HE</th>
<th>BBHE</th>
<th>DSIHE</th>
<th>MMBEBHE</th>
<th>RMSHE((r=2))</th>
<th>CSRSHE-A</th>
<th>CSRSHE-B</th>
<th>QDAPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Einstein</td>
<td>73.59</td>
<td>73.81</td>
<td>73.94</td>
<td>62.31</td>
<td>57.95</td>
<td>39.28</td>
<td>43.65</td>
<td>35.51</td>
</tr>
<tr>
<td>girl</td>
<td>75.41</td>
<td>70.12</td>
<td>75.49</td>
<td>68.73</td>
<td>37.85</td>
<td>29.34</td>
<td>32.78</td>
<td>28.13</td>
</tr>
<tr>
<td>House</td>
<td>73.65</td>
<td>75.13</td>
<td>75.51</td>
<td>55.43</td>
<td>56.79</td>
<td>42.65</td>
<td>51.2</td>
<td>38.54</td>
</tr>
<tr>
<td>couple</td>
<td>71.86</td>
<td>74.15</td>
<td>79.61</td>
<td>48.41</td>
<td>53.29</td>
<td>35.38</td>
<td>39.17</td>
<td>32.17</td>
</tr>
<tr>
<td>copter</td>
<td>73.17</td>
<td>72.73</td>
<td>76.72</td>
<td>52.59</td>
<td>52.07</td>
<td>46.51</td>
<td>49.23</td>
<td>45.39</td>
</tr>
<tr>
<td>F16</td>
<td>74.56</td>
<td>67.61</td>
<td>77.41</td>
<td>68.71</td>
<td>61.05</td>
<td>43.27</td>
<td>50.13</td>
<td>60.25</td>
</tr>
<tr>
<td>jet</td>
<td>74.32</td>
<td>64.72</td>
<td>78.31</td>
<td>54.31</td>
<td>56.74</td>
<td>31.27</td>
<td>40.25</td>
<td>29.21</td>
</tr>
<tr>
<td>CT chest</td>
<td>85.12</td>
<td>74.19</td>
<td>81.29</td>
<td>56.23</td>
<td>49.16</td>
<td>35.19</td>
<td>42.35</td>
<td>34.31</td>
</tr>
<tr>
<td>CT brain</td>
<td>80.24</td>
<td>70.27</td>
<td>76.34</td>
<td>62.16</td>
<td>57.34</td>
<td>39.54</td>
<td>48.97</td>
<td>38.10</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>82.34</td>
<td>76.35</td>
<td>79.56</td>
<td>69.13</td>
<td>50.37</td>
<td>32.19</td>
<td>39.37</td>
<td>29.74</td>
</tr>
<tr>
<td>Average</td>
<td>76.43</td>
<td>71.91</td>
<td>77.42</td>
<td>59.80</td>
<td>53.26</td>
<td>37.46</td>
<td>43.71</td>
<td>37.13</td>
</tr>
</tbody>
</table>

![Figure 6.6](image)

**Figure 6.6** Different STD values for different image enhancement methods
Table 6.3 Peak Signal to Noise Ratio (PSNR)

<table>
<thead>
<tr>
<th>Images</th>
<th>HE</th>
<th>BBHE</th>
<th>DSIHE</th>
<th>MMBEBHE</th>
<th>RMSHE (r=2)</th>
<th>CSRSHE-A</th>
<th>CSRSHE-B</th>
<th>QDAPLHE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Einstein</td>
<td>15.27</td>
<td>15.19</td>
<td>15.53</td>
<td>18.97</td>
<td>19.52</td>
<td>31.47</td>
<td>29.63</td>
<td>32.59</td>
</tr>
<tr>
<td>girl</td>
<td>13.05</td>
<td>13.3</td>
<td>13.04</td>
<td>14.25</td>
<td>27.98</td>
<td>35.34</td>
<td>32.19</td>
<td>35.37</td>
</tr>
<tr>
<td>couple</td>
<td>7.56</td>
<td>13.16</td>
<td>11.64</td>
<td>19.56</td>
<td>19.64</td>
<td>39.25</td>
<td>32.73</td>
<td>42.34</td>
</tr>
<tr>
<td>copter</td>
<td>10.62</td>
<td>15.96</td>
<td>14.25</td>
<td>25.43</td>
<td>25.67</td>
<td>33.38</td>
<td>29.67</td>
<td>35.54</td>
</tr>
<tr>
<td>F16</td>
<td>11.94</td>
<td>20.67</td>
<td>16.05</td>
<td>20.37</td>
<td>22.78</td>
<td>40.31</td>
<td>35.13</td>
<td>41.22</td>
</tr>
<tr>
<td>jet</td>
<td>9.52</td>
<td>22.53</td>
<td>14.38</td>
<td>30.72</td>
<td>27.82</td>
<td>29.37</td>
<td>23.71</td>
<td>33.48</td>
</tr>
<tr>
<td>CT chest</td>
<td>14.35</td>
<td>19.53</td>
<td>15.37</td>
<td>29.73</td>
<td>33.46</td>
<td>35.19</td>
<td>26.82</td>
<td>36.24</td>
</tr>
<tr>
<td>CT brain</td>
<td>17.35</td>
<td>24.61</td>
<td>19.73</td>
<td>25.37</td>
<td>34.61</td>
<td>39.45</td>
<td>35.46</td>
<td>41.27</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>16.54</td>
<td>23.25</td>
<td>18.16</td>
<td>23.45</td>
<td>31.23</td>
<td>35.64</td>
<td>33.17</td>
<td>37.19</td>
</tr>
<tr>
<td>Average</td>
<td>12.74</td>
<td>18.25</td>
<td>15.20</td>
<td>20.39</td>
<td>26.40</td>
<td>34.90</td>
<td>30.74</td>
<td>36.47</td>
</tr>
</tbody>
</table>

Figure 6.7 Different PSNR values for different image enhancement methods
6.4.2.1 Absolute Mean Brightness Error (AMBE)

The first test which is used as the performance measure is Absolute Mean Brightness error (AMBE). AMBE is used to evaluate the ability of the enhancement method to maintain the mean brightness.

\[
AMBE = \{ X_m - Y_m \} \quad (6.14)
\]

where, \( X_m \) = Mean of the input image
\( Y_m \) = Mean of the output image

The minimum value of AMBE results that the mean brightness of the input is successfully maintained in the output image. Table 6.1 and Figure 6.5 shows the AMBE measure obtained from the sample images.

The AMBE values calculated by the existing methods HE, BBHE, RMSHE are compared with the AMBE value of proposed method. From the Table 6.1 and Figure 6.5, it can be readily observed that the proposed method QDAPLHE has 13.13\% less AMBE average value when compared to CSRSHE-A, the method with second minimum average value.

6.4.2.2 Standard Deviation (Image Contrast)

By measuring the standard deviation, the contrast of the image can be studied.

Standard Deviation is given by

\[
\sigma = \sqrt{\sum_{l=0}^{L-1} (l - \mu) \times p(l)} \quad (6.15)
\]

where \( \mu \) = \( \sum_{l=0}^{L-1} l \times p(l) \) \quad (6.16)

‘\( l \)’ represents the pixel value in the image.
From the Table 6.2 and Figure 6.6, the standard deviation value obtained by the proposed QDAPLHE method is less compared to all the existing methods for all the images.

6.4.2.3 Peak signal to noise ratio (PSNR)

Another quantitative test used was to measure the richness of details and appropriateness peak signal to noise ratio (PSNR). Based on mean squared errors (MSE), PSNR is defined as

$$\text{PSNR} = 10 \log_{10} \frac{(L-1)^2}{\text{MSE}}$$  \hspace{1cm} (6.17)

where

$$\text{MSE} = \frac{\sum \sum |X(i,j) - Y(i,j)|^2}{N}$$  \hspace{1cm} (6.18)

$X(i,j)$ and $Y(i,j)$ are the input and output images respectively.

$N$ is the total number of pixels in the input or output images

$L$ is the number of intensity values.

The PSNR values for different images are tabulated in Table 6.3 and Figure 6.7. From this table the PSNR values of three proposed methods CSRSHE-B, CSRSHE-A and QDAPLHE are ranked the first, second and third highest values respectively.

From the table it can be observed that the images processed by proposed QDAPLHE method produces the best PSNR values as they are within the range [31 dB to 42 dB]. From these values it can be concluded that the proposed method performs image contrast enhancement and also produce images with a natural looking with less noise amplifying.
Thus overall, both qualitative and the quantitative tests favor the proposed method DQAPLHE as the best among all the existing methods. Thus it can be stated that the proposed algorithm produces the best image enhancement.

6.5 CONCLUSION

Although the histogram equalization is simple and effective algorithm for enhancement, it leads to over enhancement and intensity saturation problem. To overcome this effect, dynamic histogram equalization is used as powerful method for enhancing the low contrast images, also in some cases it leads to noise amplifying and intensity saturation problems. To overcome the level saturation effects occurred in histogram equalization, clipped histogram equalization methods were developed by restricting the enhancement rate. Hence a new method QDAPLHE is proposed as a hybrid of Dynamic histogram equalization method and Clipped histogram equalization method. The qualitative and the quantitative analysis were performed on the proposed method and the results represented in the Figures 6.2 to 6.4 and the Tables 6.1 to 6.3. From the experimental results, both qualitative and the quantitative tests favor the proposed method DQAPLHE as the best among all the existing methods.