CHAPTER 3

COLOR IMAGE ENHANCEMENT BASED ON
MODIFIED CONTRAST LIMITED ADAPTIVE
HISTOGRAM EQUALIZATION

3.1 INTRODUCTION

In this chapter, enhancement of contrast of color images using modified contrast limited adaptive histogram equalization method is proposed. This method is an improvement over the traditional adaptive histogram equalization. First the image is decomposed into R, G and B components. G component of the color image alone is taken for enhancement. By calculating Local Contrast Modification (LCM) function and objective function, a decision is made whether to increase or not the value of G value for a pixel in an image. Little amount of contrast stretching is also performed on the image.

It is observed that modified CLAHE preserves brightness, enhances the contrast of the input image and produces natural looking output images. It is also observed that the best clip limit for this method is 0.0001 and the number of tiles as [20 20]. This method is compared with HE, DSIHE and BBHE. The PSNR table shows that modified CLAHE is better when compared to HE, DSIHE and BBHE as the PSNR value of the former method is high.
3.2 HISTOGRAM BASED IMAGE ENHANCEMENT

The digital camera is the most widely used device to capture images. This device has been included in mobile phones, personal digital assistants, robots and in many other systems. There has been a significant improvement in the quality of images obtained using digital cameras. However, still, a variety of problems need to be addressed about the quality of the images obtained. The problems include contrast defects, chromatic aberrations, inclusion of various noises, vignetting, geometrical distortions, color demosacing and focus effects. A few problems are related to the type of capturing device where as other problems are dependent on the environment conditions under which the image was captured. For the later problem, the time required to correct the effected pictures is a big issue. Several methods have been developed to enhance the contrast of an image. One of the most popular methods is histogram equalization.

The basic idea of HE is to find the intensity transformation such that histogram of transformed image is uniform. Suppose for an image \( f(x,y) \) and its histogram \( h(i) \), we have accumulative function of \( h(i) \) as

\[
c(i) = \int_0^i h(t) \, dt
\]

(3.1)

It can be proved that such a transform makes the variable \( y=(ci) \) follows a uniform distribution. Thus for a 256 gray level image, histogram equalization can be performed by the equation

\[
f = \frac{256}{m} \cdot c(f(x, y))
\]

(3.2)

where \( n \) is the total number of pixels in the image.
For gray-level image enhancement, several methods based on HE have been proposed. Apart from various advantages, HE does not maintain the brightness of the input image on to the output image. This drawback makes HE techniques not suitable for enhancing consumer electronic products such as TV (R.Gonzalez and R.Woods 2008). For consumer products, maintaining original brightness is the essential one to avoid the production of artifacts in the output image (D.Menotti et al 2007) and (D.Menotti 2008).

Various classical HE techniques have been proposed to eliminate the above mentioned problem. Such techniques first decompose the input image into two sub images and then perform HE on each sub image independently. This method is said to be Bi-Histogram Equalization (Y.T.Kim 1997). Though Bi-Histogram Equalization method works fine and also preserves brightness to some extent, the output images do not look natural (D.Menotti et al 2007). Images of consumer electronic products are unacceptable if they are unnatural (D.Menotti 2008).

In order to produce the output image with enhanced contrast, brightness preserved and natural looking, multi-Histogram Equalization method is proposed. This method decomposes the input image into several sub-images and then HE is applied to each sub image independently (M F Khan et al 2006).

Regarding color image enhancement, the methods are also based on HE. However, color images are not enhanced in the same manner the gray-level images are enhanced as the former contains various properties. These properties include luminance
or intensity, saturation and hue (Sarif Kumar and C.A.Murty 2003). Color spaces such as HSV, HIS, CIELUV and CIELAB were conceived based on these three properties. Moreover working on these color spaces, especially in LHS needs a solution to handle gamut problem (Naik and Murty 2003).

Many histogram based methods have been proposed for the decomposition of an image into sub images by using statistical measures (Y.Wang et al 1999). These methods aim to preserve the brightness in the sub-images. There are certain methods where the focus is not to maintain brightness, but to have natural appearance in sub images (Laurent Najman et al 2007). This can be seen as the minimization of within-histogram class variance where this variance is the total squared error of each histogram class (N.Otsu 1979).

3.3 MODIFIED CONTRAST LIMITED ADAPTIVE HISTOGRAM EQUALIZATION

The noise problem which prevails in the traditional adaptive histogram equalization can be reduced by limiting the contrast enhancement in homogenous areas. This improved version of adaptive histogram equalization is said to be Contrast Limited Adaptive Histogram Equalization (CLAHE). This method works by adjusting the intensity values of the image.

CLAHE divides the image into small portions and each portion is referred as one tile. CLAHE applies bilinear interpolation to eliminate region boundaries and this makes small neighbouring areas look smoother. CLAHE produces less noise and it can
prevent brightness saturation that commonly occurs when performing histogram equalization. Apart from this, CLAHE is easy to use and gives good result.

Color images are often represented in RBG color space and CLAHE is applied to each component of the RGB color space such as r, g and b individually. For the resultant image, all the components are combined. It is observed from the experimental results that the output image is corrupted and lack human sense of color. Since adaptive histogram equalization is applied to all the channels, the results get corrupted.

**Figure 3.1 Original Image in RGB color space**
Figure 3.2 CLAHE applied to all the channels

3.3.1 APPLYING CLAHE TO ONLY G COMPONENT

In order to eliminate the above problem, CLAHE is applied to only green component and other two components, viz. R and B are kept unchanged. Since modified CLAHE method uses adaptive histogram equalization technique, number of small regions (tiles) of an image is considered. Two element vectors of positive integers represent the number of tiles, M and N. The minimum tiles should be at least two and the total number of tiles of an image is equal to M * N.

The overall procedure is as follows: The input image is read first. Two parameters viz. Enhancement Parameter (Ep) and Best parameter (Bp) is used. Bp is
the best value for the enhancement parameter EP. Then enhancement function for Bp and its fitness function are called. The enhancement function for the enhancement parameters Ep and its fitness function is calculated using LCM and objective function. Then the enhancement function for p and its fitness function are calculated.

If Ep is greater than Epbest, then p is assigned to pbest and its fitness value. Then the enhancement parameter is incremented and again the entire process is repeated till Ep become 1. The image is reconstructed with old R, B components and new G components. Finally the adaptive histogram equalization is applied with contrast threshold value and the resultant image is enhanced image. The overall procedure is depicted in the figure 3.1
Figure 3.3 Overall process of Modified CLAHE
3.3.2 LOCAL CONTRAST MODIFICATION (LCM)

For local contrast modification, mean and standard deviation of the whole image is used. The mean value is calculated using the expression

\[ m = \frac{1}{n \times n} \sum_{x=0}^{n-1} \sum_{y=0}^{n-1} f(x, y) \quad (3.3) \]

where \( n \) is the size of the image, \( f(x, y) \) indicates the product of reflectance and intensity values and \( m \) is the mean for the whole image. The standard deviation is calculated using

\[ \sigma = \sqrt{m} = \sqrt{\frac{1}{n \times n} \sum_{x=0}^{n-1} \sum_{y=0}^{n-1} (f(x, y) - m(x, y))^2} \quad (3.4) \]

The transformation function is calculated using the equation

\[ T = \frac{E \cdot M}{\sigma} \quad (3.5) \]

where \( E \) is the enhancement parameter and its value is between 0 and 1 and \( M \) is the global mean of the image.

3.3.3 OBJECTIVE FUNCTION

This function is based on entropy of the image, sum of edge intensities and number of edge pixels. It is observed that enhanced image has more number of edge pixels and higher intensity value at edges than the original image.

\[ F(I_s) = \log(\log(E(I_s))) \times \frac{n_{edgels(I_s)}}{M \times N} \times H(I_s) \quad (3.6) \]
where $I_g$ is the green component enhanced image. The edges and edgegels are determined by using Sobel edge detector. $E(l_g)$ represents the sum of $M \times N$ pixel intensities of Sobel image edge $I_g$, $n_{\text{edgel}}$ indicates the number of pixels whose intensity value is higher than threshold value used in Sobel edge image.

### 3.3.4 CONTRAST STRETCHING

Finally, contrast stretching is applied to the output image for overall improvement of the image visibility. This process depends on the intensity value of an image (A. Mahiddine et al 2012). For gray level images, contrast stretching for each pixel is calculated using the equation

$$P_{out} = (P_{in} - c) \frac{(b - a)}{(d - c)} + a$$

(3.7)

where $P_{out}$ is the normalized pixel value, $P_{in}$ is the current pixel value, $a$ is the lower pixel value, $b$ is the upper pixel value, $c$ is the lowest pixel value in the input image and $d$ is the highest pixel value in the input image. The above equation is modified for $G$ component alone and it can be expressed as

$$P_{G_{out}} = (P_{G_{in}} - c) \frac{(b - a)}{(d - c)} + a$$

(3.8)

where $P_{G_{out}}$ is the normalized green pixel value, $P_{G_{in}}$ is the current green pixel value, $a$ is the lower green pixel value, $b$ is the upper green pixel value, $c$ is the lowest green pixel value in the image and $d$ is the highest green pixel value in the image.
3.4 RESULTS AND DISCUSSION

The input images used are girl, building and industry. The appropriateness of the method is assessed using PSNR for each input image. PSNR is used to evaluate and compare compression and segmentation algorithms (M.Rabbani and P.Jones 1991).

As the first step towards this method, the given input images are decomposed and only G component alone is taken for experiment. The following figure represents the G component of three input images.

![Figure 3.4 G component of three input images](image)

Modified CLAHE is applied to these three sub images, one after another, with varying mean and standard deviation values. The mean for the girl image is calculated with n values as 423 and 1683. The standard deviation of the girl image is 117.099. The enhancement process is initiated with these input values. For each step, objective function values are used to determine whether enhancement is needed or not.

CLAHE works by using adaptive histogram equalization which enhances the contrast of the gray scale image. Here G component is used instead of gray level values for adaptive histogram equalization. Implementation of CLAHE is done by tiles (small
parts of the image) and not on the entire image. Hence it is important to mention the number of tiles for the input image and the minimum value is [8 8] which indicates rows and columns. Here we are using [20 20] for better enhancement.

The next parameter that needs to be assigned is the clip limit. This is a real scalar value in the range 0 to 1. This value specifies a contrast enhancement limit. Higher values will result in more contrast of output image. Here many clip limits are used for better output image.

A positive integer is used to specify the number of bins of histogram which is to be used for building a contrast enhancing transformation. The higher values will result in greater dynamic range at the cost of lower processing speed. The default value for this parameter is 256 and for our experimentation, we are using the default value.

Distribution is the string, specifying the desired shape of histogram for the image tiles. By default, uniform (flat) histogram is produced in CLAHE. Shape can be changed by mentioning ‘rayleigh’ for bell shaped histogram and ‘exponential for curved shaped histogram. The inputs which we have used for the experiment are:

<table>
<thead>
<tr>
<th>No. of tiles for input image</th>
<th>: [20 20]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clip limit</td>
<td>: [0.005]</td>
</tr>
<tr>
<td>Number of bins</td>
<td>: 256</td>
</tr>
</tbody>
</table>
The contrast level of the output image is very high and it is very bright. Since the green component of the image dominating, the output image is little bit greenish. And also white color of the output image has been modified to light pink color.

![Figure 3.5 Output image with 0.005 clip limit](image)

The experiment is conducted by modifying the clip limit to 0.002. The resulting image looks as below.
Figure 3.6 Output image with 0.002 clip limit

Contrast enhancement of the output image is moderate. It is also soft and vivid. Again the output image is greenish but not like the image with 0.005 as clip limit. There is no modification in white color and it is the same like input image. But grey color has been modified to pink color.

The experiment is continued with clip limit as 0.001. The purpose of modifying clip limit is to indicate the important parameter for image enhancement using adaptive histogram equalization.
The above image is good in terms of visibility and brightness. It is also very natural. Enhancement is also good. The white color of the image has not been modified and it is same like input image. The shadow area is grey like the normal image. The experiment is continued with 0.0001 as clip limit and the following image has been produced.
This clip limit (0.0001) is the best limit for contrast enhancement of color images. By keeping the same clip limit, the experiment is continued by maximizing the number of tiles of the image. In all our above experiments, the No. of tiles is [20 20]. This has been modified by adding value 20 for each iteration and the resulting output images are presented below.

![Figure 3.9 Output images with No. of tiles [40 40], [60 60] and [80 80]](image)

It is observed from the above images that number of tiles with [20 20] produce natural, soft looking, contrast enhanced images whereas the output images get corrupted when the tiles limit increases. Moreover, the output image with [60 60] as tiles limit produces green artifacts in the neck region of the girl image which is not available in the actual image. Tiles limit with [40 40] is over enhanced and the contrast is too high. Tiles limit with [80 80] produces unrealistic and blurred like image. Hence it is concluded that the tiles limit [20 20] is the best one for image enhancement.
The same experiment is continued for the other two images viz. industry and building. The output images are presented below. These output images are the results of industry image with [40 40], [60 60] and [80 80] as number of tiles.

![Output images of industry with No. of tiles [40 40], [60 60] and [80 80]](image)

**Figure 3.10 Output images of industry with No. of tiles [40 40], [60 60] and [80 80]**

![Output images of building with No. of tiles [40 40], [60 60] and [80 80]](image)

**Figure 3.11 Output images of building with No. of tiles [40 40], [60 60] and [80 80]**

The output images with [20 20] as tiles limit are further enhanced by using contrast stretching process. It is a common operation for a slight enhancement of images. The modified equation described in section 3.3.4 is used for contrast stretching. Again, contrast stretching is applied only to the G component of the
resultant image and finally the enhanced image is produced by combining enhanced G component and old R and B components.

For each image green pixel value, a new normalized value is obtained using the current green pixel value, lower green pixel value in the image, upper green pixel value in the image, lowest green pixel value and highest green pixel value in the image. For our girl image, the parameters contain the following values. 0 is the lower green value and 255 is the higher green value.

The following images are the output of contrast stretching process. The images are enhanced one with good natural look and soft. The effectiveness of this modified enhancement process is evaluated using PSNR (Peak Signal to Noise Ration) values. To calculate PSNR, we have to calculate MSE (Mean Square Error) first. MSE is calculated using the below formula

$$MSE = \frac{\sum_{m,n}[I_1(m,n) - I_2(m,n)]^2}{MN}$$

(3.9)

where M and N are the number of rows and columns respectively, I_1 and I_2 represents two images for comparison and m,n representing current row and column value of a pixel. The PSNR value is calculated using the below equation.

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

(3.10)

where MSE is the mean square error computed using the previously mentioned formula and R represents the maximum fluctuation in the input image data type.
Table 3.1 PSNR values of three images

<table>
<thead>
<tr>
<th></th>
<th>HE</th>
<th>DSIHE</th>
<th>BBHE</th>
<th>Modified CLAHE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girl</td>
<td>13.66</td>
<td>18.34</td>
<td>18.52</td>
<td>24.01</td>
</tr>
<tr>
<td>Building</td>
<td>11.63</td>
<td>14.88</td>
<td>15.08</td>
<td>19.34</td>
</tr>
</tbody>
</table>

From the above table, it is clear that this method works fine as the PSNR value is high. The method is best when the PSNR value is high. From the table, it is concluded that our method enhances the image in an effective way.

After analyzing the data in the table and visually observing the processed images, it is concluded that modified CLAHE produce images with good quality than other methods with respect to PSNR calculation. It is also concluded that for modified CLAHE preserves brightness and produces natural looking images. If we want to increase contrast, clip limit with 0.005 should be employed.

Clip limit and number of sub images (tiles) play a vital role in modified CLAHE method. As clip limit and number of tiles increase, the image slowly gets converted from natural looking and soft to unrealistic and blurred type images. Moreover, the number of tiles with [60 60] produces artifacts in the output image which is not seen in
input image and with [80 80] as number of tiles, the output image is over contrasted and unnatural.

On the other hand, if the clip limit is kept to 0.0001, the output images are good looking and natural. If it is increased, the image becomes unnatural and if this limit is 0.005, blurred type image is produced.
3.5 SUMMARY

In this work, modified Contrast Limited Adaptive Histogram Equalization technique for image enhancement and brightness preserving is proposed and tested. The experimental results are tabulated and it shows that HE method enhances contrast with lesser amount. On the other hand, DSIHE and BBHE methods perform better in enhancing contrast and preserving brightness. But PSNR values of modified CLAHE is high when compared to HE, DSIHE and BBHE

Modified CLAHE is not directly applied to RGB components. RGB Image is decomposed to three separate components and only G component is taken for enhancement. The time and space complexity of our method comply with real time application requirements.