A Comparative Analysis of Various Image Enhacement Techniques for Facial Images

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***Abstract*—Image enhancement is one of the most important pre-processing step used in a number of Computer Vision applications. Its importance can be judged by a number of image enhancement algorithms which have been developed over the time for different applications. All these algorithms differ from one another in terms of processing speed, computational complexity, and quality of image and so on. Therefore, in order to exploit the usefulness of these algorithms it is necessary to have their good understanding. With this objective in mind, this paper presents a comparative analysis of six different commonly used image enhancement algorithms. The performance of these algorithms has been measured both quantitatively and qualitatively for different test images. From our analysis, we found that Modified CLAHE outperforms all other techniques in terms of PSNR and AMBE which shows its better contrast enhancement and brightness preservation capabilities.**

Keywords*—*HE(Histogram Equalization); AHE(Adaptive Histogram Equalization; CLAHE(Contrast Limited Adaptive Histogram Equalization); PSNR(Peak Signal to Noise Ratio); AMBE(Absolute Mean Brightness Error).

I. INTRODUCTION

Nowadays, the visual information is becoming more and more prominent in our daily life. This includes television, computer, camera and many other electronic products like palmtops, etc., which are capable of displaying digital images [1]. However, due to many factors like poor environmental conditions, lack of expertise of the operator, use of an impaired device, etc. the image captured might of low quality. Tough, the quality of the digital cameras used nowadays has been improved a lot than those used in early days, there is still a need for some technique to further improve the quality of the image. Therefore, some pre-processing of the image is done before applying it to any electronic device, so that the image features like edges, boundaries or contrast may improve its display.

Image enhancement techniques play a significant role in the pre-processing step for a large number of signal processing applications which includes medical image processing, computer vision, radar and satellite image processing, remote sensing, under water image processing, human face detection and recognition, and many more. The objective of image enhancement is to bring out the hidden details in an image and also to increase the contrast in a low contrast image [2].

To deal with the illumination changes in facial images, this study presents a comparison of various image enhancement techniques that are available in literature. Here, our objective is to analyze which enhancement technique is suitable for improving the face detection rate in different illumination conditions. There are many methods for face detection. These methods strongly depend on the intensity values of image pixels. However, these methods sometimes fail to locate the faces accurately, when applied to images under different environmental conditions as there are drastic changes of pixel intensity values within the face regions. Thus, the image enhancement techniques play a vital role in reducing the problems by intensity transformation and act as important pre-processing steps in these applications [3].

The process of enhancing any particular image involves the change in the pixel's intensity of the image and therefore the output image looks quite better and visually clearer. The motivation of the work includes the improvement in the visual quality of the image for human viewers and to provide significantly better input for various image processing systems. There are a number of advanced image enhancement techniques that exist in literature, the important and the most commonly used techniques have been discussed in this paper.

The rest of the paper is organized as follows: In section II we have discussed various image enhancement techniques available in the literature. This is followed by section III where we have introduced different performance metrics which have been used in our experiments. Experimental results and discussion form the contents of section IV and finally we have concluded our paper in section V.

II. VARIOUS IMAGE ENHANCEMENT TECHNIQUES

In this section various image enhancement techniques has been discussed.

A. *Histogram Equalization*

Histogram equalization technique is a very popular and most commonly used technique for contrast enhancement. This algorithm is widely used due to its simplicity and effectiveness. The method increases the dynamic range corresponding to the image, equalizes the histogram of the image and is much less expensive compared to other methods. It works globally on the histogram and uses the histogram information of the entire input image to obtain its transformation function [4].

Let the input image be denoted by $X = \{X(i,j)\}$, which is composed of 'L' discrete gray levels in the dynamic range of $[0, L-1]$, denoted by $\{X_0, X_1, \ldots, X_{L-1}\}$ and $X(i,j)$ represents the intensity of the image at spatial location (i,j) which satisfies the condition $(i,j) \in \{X_0, X_1, \ldots, X_{L-1}\}$. The histogram 'h' is defined as the frequency of occurrence of gray levels in the image and is given by (1).

$$h(X_k) = n_k, for \quad k = 1, 2, \ldots L-1 \tag{1}$$

where X_k is the k[th] gray level and n_k is the number of times the gray level appears in the input image.

The Probability Density Function (PDF) is defined as shown in (2)

$$p(X_k) = \frac{h(X_k)}{(M \times N)}, for \quad k = 1, 2, \ldots, L-1 \tag{2}$$

where M x N is the size of the image X.

Next step is to calculate the Cumulative Distribution Function (CDF), which is given by (3).

$$c(X_k) = \sum_{j=0}^{k} p(X_j), for \quad k = 1, 2, \ldots, L-1 \tag{3}$$

The HE enhances the image X by using CDF as its transformation function, $T(X_k)$ which is defined by (4) below.

$$T(X_k) = (L-1) \times c(X_k), for \quad k = 1, 2, \ldots, L-1 \tag{4}$$

Finally, the output image $Y = \{Y(i,j)\}$ is obtained by (5).

$$Y = f(X) = \{f(X(i,j)) \mid \forall X(i,j) \in X\} \tag{5}$$

The algorithm successfully increases the image's contrast as the dynamic range is expanded. Although this method improves the contrast of the image significantly, it also introduces some artifacts, washed out appearance*,* impulse visual sense in video systems [5], loss of image details, some local areas become too bright and also it do not preserve the mean brightness of the image.

B. Adaptive Histogram Equalization

To overcome the disadvantages of the HE method discussed above, Adaptive Histogram Equalization has been developed. In the Adaptive Histogram Equalization (AHE) process, the input image is divided into number of sub-blocks or tiles. For each tile, the histogram of the contained pixels is calculated. Then, the histogram equalization method is applied for the center pixel using the CDF of that tile based on the pixel values in the neighborhood. This derivation of each tile for obtaining the transformation function is exactly the same as for ordinary histogram equalization. As it is a local operation, the regions occupying different gray scale ranges can be enhanced simultaneously. In this way, the drawbacks of HE process can be avoided by using this technique. The artifacts introduced due to the division of image into tiles can be minimized by filtering process or by the interpolation method.

However, this method has several disadvantages like it over amplifies the background noise in the homogeneous regions, the computational cost is also very high because using a perfect block size which enhances all parts of the image is not very easy and smooth task [6].

C. Contrast Limited Adaptive Histogram Equalization (CLAHE)

The Contrast Limited Adaptive Histogram Equalization (CLAHE) introduces a concept of clip limit besides the block size in the image to overcome the noise problems of AHE. The method limits the amplification by clipping the histogram at a predefined value before computing the CDF (Cumulative Distribution Function). The clip limit at which the histogram is clipped, depends on the normalization of the histogram and thus on the neighbourhood's region size [7]. The pixel values which are above the clip limit are redistributed among the histogram values which are below the clip limit. This redistribution process will push the pixel values over the clip limit again, resulting in an effective clip limit that is larger than the predefined clip limit. Therefore, the process of redistribution is applied iteratively till all the exceeded pixel values goes below the clip limit. Again the method of interpolation is applied in order to assemble the final CLAHE image.

The drawback of this algorithm is that the noise in the homogeneous regions is increased as the contrast is increased so a filtering mechanism after the CLAHE process can be employed to smooth the noise and to improve the overall quality of the image.

D. Modified CLAHE (M-CLAHE)

In order to remove the noise from the CLAHE-based enhancement techniques, a filtering operation is performed after the enhancement process. A straight forward low-pass filtering can create the loss of image details, therefore a discriminative low pass filtering process is applied on selected noisy regions while the other regions with signal variations remain untouched [8]. The algorithm can be overviewed by the block diagram shown in Fig. 1.

The first stage, called the pre-filtering stage, performs a slight smoothing operation using Gaussian smoothing. The next stage, i.e., the LP_1 can perform moderate filtering. The strength of low-pass filtering operation progresses in the next stages. The original source low contrast input image 'I' is fed to the HE-based enhancement block. The input image 'I' is also used to generate some binary masks that will indicate the areas of the enhanced image, where the selective filtering must take place. The noise generated through enhancement block is removed by the discriminative filtering process. For the pre-filtering operation, a simple Gaussian filter can be used to filter out the high frequency noise. In the next stages of discriminative filtering, a Bi-directional Multi-Stage Median (BMM) filter is used.

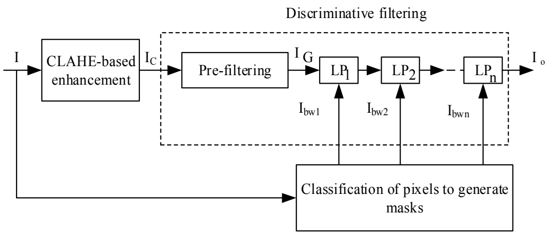


Fig. 1. Block Diagam of Modified CLAHE

The classification block classifies pixels between the homogeneous and the non-homogeneous regions, to generate binary masks of either ‘0’ or ‘1’. ‘0’ represents pixel position in the non-homogeneous regions and ‘1’ represents the pixel position in the homogeneous regions. These masks shield non-homogeneous pixels of the pre-filtered or filtered image from the low-pass operation in one of the stages. This block contains two sub-blocks, which are Gray-level Thresholding and Region Correction, respectively.

In the first sub-block, two threshold gray values are selected around a peak in the histogram, which shows the large amount of similar pixels and according to these threshold values, the histogram is divided into two regions to generate binary masks.

In the second sub-block, a correction method is applied to the generated binary masks, by checking the similarity of the central pixel with its neighbours.

E. Gaussian Based Image Enhancement (GBIE)

To account for the smoothness, lightness, color constancy and dynamic range properties of Human Visual System (HVS), this algorithm was proposed. The images enhanced by this algorithm are clearer than other enhancement techniques. The algorithm uses 5x5 pixel window, where a block of twenty five pixels of original image is convolved with Gaussian kernel of size 5x5. The 2D Gaussian function is defined by (6)

$$g(x,y)=\frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{6}$$

where σ is the standard deviation of the distribution and x and y are spatial coordinates.

The Gaussian convolution matrix is given by (7).

$$G(x,y)=I(x,y)\otimes g(x,y) \tag{7}$$

where, $\otimes$ denotes convolution, $g(x,y)$ is a Gaussian kernel, $I(x,y)$ is the original image and $G(x,y)$ is the convolved output. The convolution operation for a mask of 5x5 is given by (8).

$$P(x,y)=\frac{\sum_{i=0}^{4} W_i \times P_i}{\sum_{i=0}^{4} W_i} \tag{8}$$

where W_i is the 5x5 Gaussian mask, P_i is the 5x5 sliding window in the input image and P is the Gaussian convolved pixel.

For further processing, the log transformation operation is applied on the image which compresses the dynamic range of gray level input values to manageable levels. This processing on a 2D image is done by (9)

$$G_L(x,y)=K\times\log_2[1+G(x,y)] \tag{9}$$

where K is a constant and its value is calculated by conducting a number of experiments with various test images. Further, the logarithmic corrupted image is scaled by a scaling factor of 32 for getting pixel values in the range [0 255]. Then the final step in this method is gain/offset correction, which is given by (10).

$$I'(x,y)=\frac{d_{\max}}{G_{L\max}-G_{L\min}}[G_L(x,y)-G_{L\min}] \tag{10}$$

where $d_{\max}$ is the maximum intensity i.e. 255 for an 8-bit image, $G_L(x,y)$ is the log transformed image, $G_{L\min}$ is the minimum value of log transformed image, $G_{L\max}$ is the maximum value of log transformed image, $I'(x,y)$ is the enhanced image and the spatial coordinates are represented by x and y [9].

F. Brightness Preserving Bi-Histogram Equalization (BBHE)

The BBHE algorithm first decomposes an input image in two sub-images based on the mean of the input image. One sub-image is the set of samples less than or equal to the mean of the input image, while the other sub-image is the set of samples greater than the mean of the input image. Then this method performs histogram equalization independently on both the sub-images, thus preserving the mean brightness of the image [10]. Let X_m be the mean of the input image X, such that $X_m \in \{X_0, X_1, ..., X_{L-1}\}$. Based on the mean, the input image is decomposed as shown in (11).

$$X = X_L \cup X_U \tag{11}$$

where,

$$X_L = \{X(i,j) \mid X(i,j) \le X_m, \forall X(i,j) \in X\} \tag{12}$$

and $$X_U = \{X(i,j) \mid X(i,j) > X_m, \forall X(i,j) \in X\} \tag{13}$$

III. Performance Metrics

The comparison of various image enhancement techniques based on histogram equalization is carried out in objective manner for various images. Generally, Peak Signal to Noise Ratio (PSNR) and Absolute Mean Brightness Error (AMBE) are used as the objective measures for performance evaluation of various image enhancement methods and thus we have also used these metrics in our work.

A. PSNR (Peak Signal to Noise Ratio)

Assume that N is the total number of pixels in the input or output image, MSE (Mean Squared Error) is calculated by (14).

$$MSE = \frac{\sum_i \sum_j |x(i,j) - y(i,j)|^2}{N} \quad (14)$$

The PSNR is then calculated using (14) as shown in (15).

$$PSNR = 10\log_{10}\frac{(L-1)^2}{MSE} \quad (15)$$

where, L is the number of discrete grey levels.

The value of PSNR should be greater for estimating the degree of contrast enhancement and for better output image quality [11].

B. AMBE (Absolute Mean Brightness Error)

The absolute mean brightness error is defined by (16).

$$AMBE(x,y) = |X_m - Y_m| \quad (16)$$

where, X_m is mean intensity of input image $x = \{x(i,j)\}$ and Y_m is mean intensity of output image $y = \{y(i,j)\}$ [12]. The value of AMBE should be least for the better brightness preservation.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In this section, we demonstrate the performance of various image enhancement techniques that has been discussed in this work, i.e. HE, AHE, CLAHE, M-CLAHE, BBHE, and GBIE. For analysis, we selected 10 test images, which are mostly taken from CVG UGR database, each of size 256x256: beads, Donna, indor1, girl, indor7, p000, aerial2, barche, family, Einstein. To evaluate the performances of these enhancement techniques, we have employed the most widely used metrics, i.e. PSNR (Peak Signal to Noise Ratio) and AMBE (Absolute Mean Brightness Error). These are described in detail below.

A. Assessment of Contrast Enhancement

The comparison results of the PSNR (Peak Signal to Noise Ratio) value have been shown in table I. Here, we have taken the average of the PSNR values obtained for all the ten test images. For fair performance evaluation, the clip limit (CL) and block size (BS) in the CLAHE and Modified CLAHE techniques, are set to 0.001 and [8 8], respectively. As it is known that the greater the PSNR, the better is the quality of image, modified CLAHE technique shows the higher average PSNR value compared to other enhancement techniques. Therefore, it can be stated that the modified CLAHE algorithm gives better contrast enhancement than the other techniques. However, from the table we can find that there is not much difference in the value of average PSNR between the CLAHE and M-CLAHE, which shows that CLAHE is also capable of enhancing contrast of images.

TABLE I. PSNR VALUES CORRESPONDING TO DIFFERENT ALGORITHMS

Algorithms	Average PSNR (dB)
HE	14.4860
AHE	11.4646
CLAHE	31.4706
M-CLAHE	31.4941
GBIE	14.3910
BBHE	17.3608

B. Assessment of Brightness Preservation

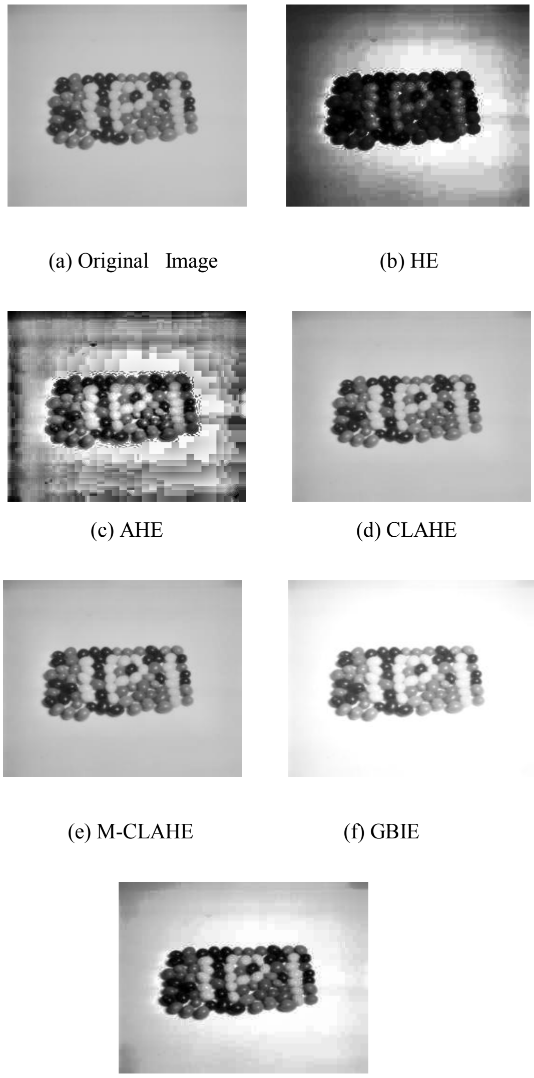
Comparison of the AMBE (Absolute Mean Brightness Error) values has been shown in table II. The size and structure of the test images are same as in table I. The clip limit and block size are also kept fixed as they were in table I. From the table II, we can easily observe that the Modified CLAHE technique has the lowest average AMBE. Thus, it can be said that the Modified CLAHE technique has the smallest brightness error as compared with other enhancement techniques.

TABLE II. AMBE VALUES CORRESPONDING TO DIFFERENT ALGORITHMS

Algorithms	Average AMBE
HE	31.1416
AHE	41.0424
CLAHE	4.0653
M-CLAHE	4.0300
GBIE	48.0640
BBHE	15.1158

C. Assessment of Visual Quality

In addition to the quantitative measurement of contrast enhancement and brightness preservation by the evaluating the parameters such as PSNR and AMBE, in this work, the qualitative analysis of various image enhancement techniques have been done. The visual comparison of the input image and the output image is shown in this section. The major goal of this inspection is to judge that the output image has a natural appearance and is visually acceptable to human eyes. The MATLAB implementation of the various image enhancement techniques which were discussed previously has been done and the results are shown in fig. 2 and fig. 3 for test image Beads and Donna respectively.



(a) Original Image (b) HE

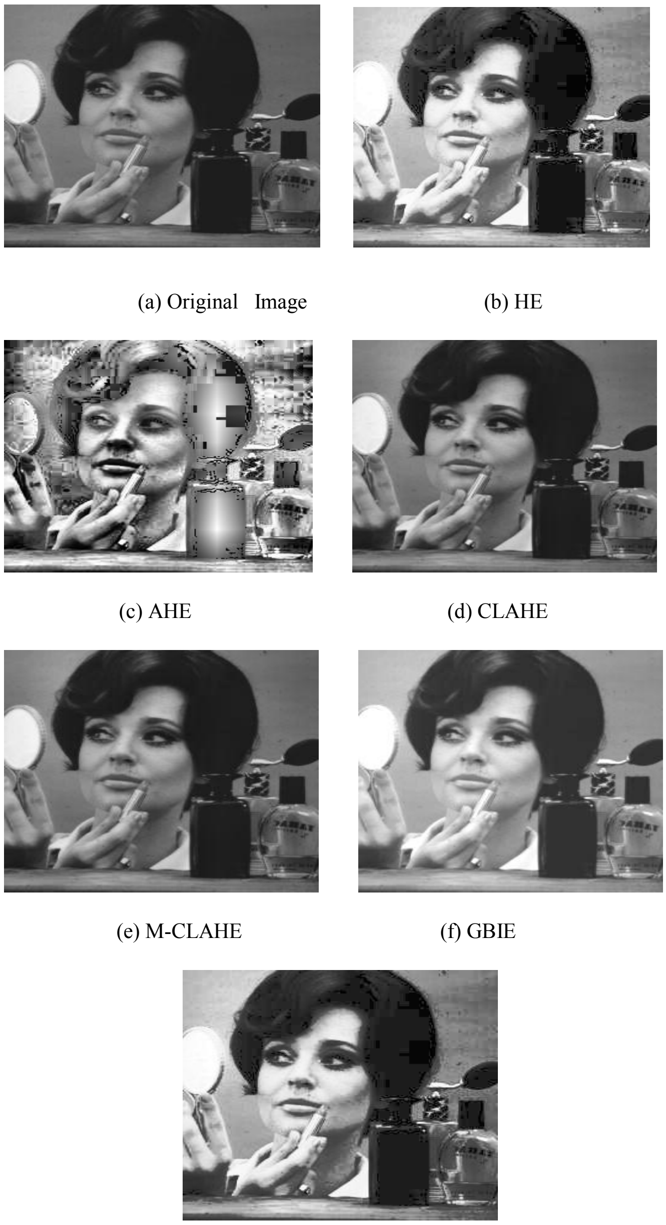
(c) AHE (d) CLAHE

(e) M-CLAHE (f) GBIE

(g) BBHE

Fig. 2. Visual result of different algorithms on Beads image

For the original Beads image shown in fig. 2 (a), the output of the histogram equalization (HE) algorithm has been shown in fig. 2 (b), has distorted type of the image view and same is the case with the AHE technique shown in fig. 2 (c). The output of CLAHE has been shown in fig. 2 (d) and it can be observed that the output image has a good contrast enhancement reducing some amount of noise. The output of the modified CLAHE has been shown in fig. 2 (e), which shows that the contrast enhancement is much advanced while reducing the noise effects. Fig. 2(f) shows the output of the Gaussian based image enhancement (GBIE) technique. The output of BBHE algorithm shown in the fig. 2(g), indicates that the method is capable of preserving the mean brightness of the input image to some extent but introduces some artifacts which makes the appearance unnatural. The enhancement result of different algorithms for the Donna image has been shown in the fig. 3.



(a) Original Image (b) HE

(c) AHE (d) CLAHE

(e) M-CLAHE (f) GBIE

(g) BBHE

Fig. 3. Visual result of different algorithms on Donna image

Based on these visual inspections, it can be concluded that CLAHE and Modified CLAHE gives better visual quality and more natural appearance compared to other techniques.

We also analyzed the impact of the clip-limit and block size of the CLAHE and M-CLAHE algorithm. We first fixed the block size to [8 8] and varied the clip-limit from 0.001 to 0.010 and calculated the PSNR values. The comparison results have been shown in Fig. 4. It can be seen from the figure that Modified CLAHE is having a higher value of PSNR than that of CLAHE for all values of the clip-limit.

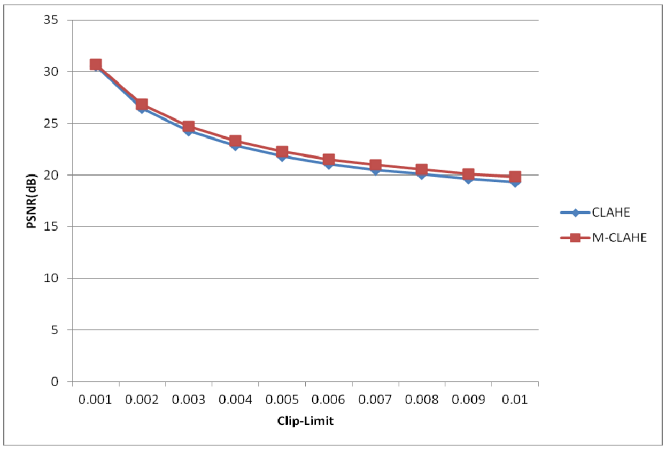


Fig. 4. Comparison of CLAHE and M-CLAHE with fixed BS= [8 8] and varying Clip-Limit

Next, the clip limit is kept fixed at 0.01 and the PSNR values are calculated by varying block size from [2 2] to [128 128] in multiples of 2. The experimental result is shown in fig. 5. It can be observed from the figure that the highest PSNR value is obtained using the block size of [8 8] for both CLAHE and Modified CLAHE.

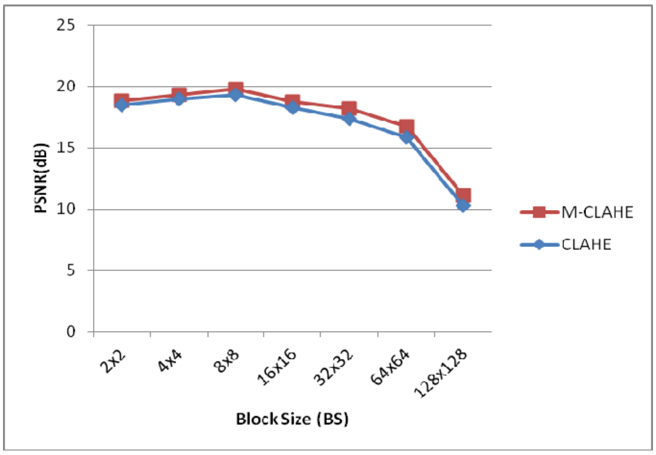


Fig. 5. Comparison of CLAHE and M-CLAHE with fixed CL=0.01 and varying BS.

V. CONCLUSION

In this paper, various contrast enhancement algorithms have been discussed. All these algorithms have been implemented using Matlab. A comparative study has been presented for all these techniques and the experimental results reveal that Modified CLAHE (M-CLAHE) algorithm improves the contrast of the image while preserving the image brightness more efficiently than the other existing enhancement techniques. However, the disadvantage of the modified CLAHE is its larger execution time than the other techniques. This is due to the fact that a number of filtering and classification operations are used in its implementation. Integrating these algorithms with the Viola and Jones face detection framework in order to investigate the performance of these algorithms on face detection accuracy in various lighting condition is the purpose of our future work. Moreover, in order to accelerate the execution time of the Modified CLAHE algorithm, its hardware implementation can also be carried out.

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