COMPARATIVE ANALYSIS OF IMAGE ENHANCEMENT TECHNIQUES FOR PRE-PROCESSING OF BIOMETRIC RECOGNITION SYSTEM

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Abstract*—This Image_ enhancement technique is related to the pre-processing method. The chief goal of image _enhancement is to increase image features like contrast, brightness, and sharpness etc. In this paper, our main motive is to provide an enhanced biometric trait to the biometric recognition system so that the accuracy of the system can be improved. Here, in this paper three different image enhancement techniques named as intensity enhanced (IE), HE (Histogram_equalization) technique and CLAHE (Contrast-limited _adaptive_ histogram equalization technique is used. Also, the comparative analyses of three enhancement techniques have been provided in terms of computation parameters such as PSNR (peak _signal to noise_ ratio), SNR (Signal to_ noise ratio), SSIM (Structure _similarity_ index), MSE (mean_ square_ error) and execution time. From the experiment, it is observed that the CLAHE technique provide a better quality image than the other two enhancement techniques (IE and HE).

***Keywords*—CLAHE, Histogram Equalization, Image Enhancement , Mean square Error, Signal to Noise Ratio**

I. INTRODUCTION

Image enhancement approach is most commonly used in several applications of image processing in which the image quality is primarily essential for the human viewer or to provide a better quality image in the biometric recognition system. Brightness and contrast are the main factors to improve the image quality [1-3]. Contrast is defined as the dissimilarity in luminance or color which creates an image clear. In the real world visual point of view, the contrast is measured by the variation in the color and brightness of the image and other images within the similar view area [4]. Image_enhancement may be categorized mainly into two types:

- **Spatial domain technique**: In this approach, image enhancement is performed directly on image pixels [5]. An example of image enhancement using spatial domain is shown below.

Here, P (i,j) represents a single pixel, then this process requires a pixel intensity for remapping [6]. In this case, the output pixel value is represented by the equation below:

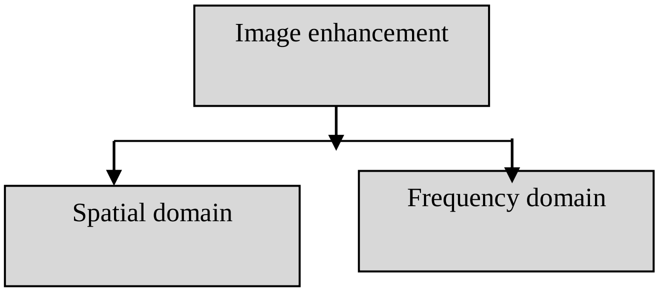

FIGURE 1: IMAGE ENHANCEMENT

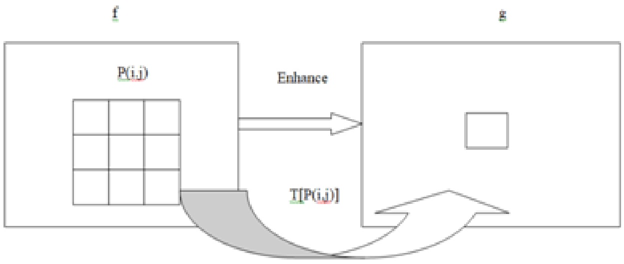

FIGURE 2: IMAGE_ ENHANCEMENT USING SPATIAL PROCESSING

Here, T signifies the monotonic mapping function which is defined between x and y.

$Y=T(x)$ (1)

$x= P(i,j)= f(i,j)$ (2)

And hence

$y= g(i,j)= t[f(i,j)]$ (3)

- **Frequency domain technique**: This technique is used on the "Fourier _Transform" of an image as the image is clearly visualized by using the concept of filtering used in the frequency domain [7]. The flow of the frequency domain method is shown in the image is initially converted into frequency distribution and then pre-processing is performed on the frequency distributed image. The output obtained from the pre-processing stage is not an image but it is simply a transformation. Thus to obtain the input image the inverse transformation is performed, which helps to obtain an image [8].

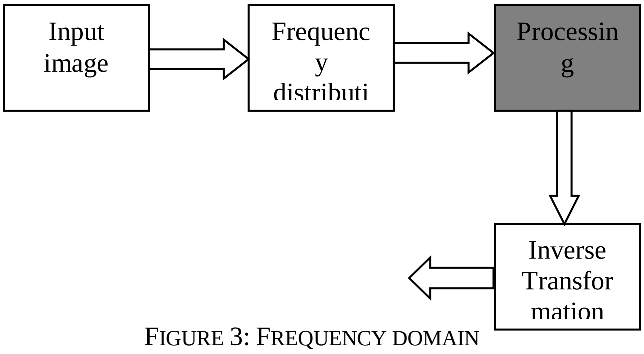

FIGURE 3: FREQUENCY DOMAIN

Unfortunately, when it comes to human perception, there is no common theory to determine what a high-quality image_ enhancement is. If it seems good, that would be great! Whenever the image _enhancement technology is utilized as a 'pre-processing' tool for additional image processing techniques, and then quantitative computations can find out which technology is most suitable to enhance the image quality in the biometric recognition system. In this research work, our main motive is to evaluate the outcomes of a variety of image_ enhancement techniques applied in a biometric recognition system [9]. The process of modifying a digital image is known as image enhancement, which helps to display image with higher quality. Image enhancement techniques can be categorized further into various types named as Filtering with morphological operators, Histogram equalization, noise removal using a Weiner filter, Linear contrast adjustment, CLAHE, and De-correlation stretch. In this research work, we are using three image enhancement techniques such as (i) Intensity-based (ii) CLAHE and (iii) Histogram equalization [10]. The description of these techniques is provided below:

A. IMAGE ENHANCEMENT

Image_enhancement methods are utilized to get a better image, in which 'quality improvement' may be defined neutrally and sometimes individually that means to create definite features which are easier to observe by adjusting the image's colors/ intensities values. Intensity enhancement is an image adjustment technique that maps an image's intensity values to a new range and creates an image with better quality [11]. Before applying the image_ enhancement on an image, it is essential to identify the upper pixel value along with lower pixel value limits over which the test image is to be regulated. We already know that for 8-bit 'grayscale image', the lower and upper limits of an image must be lies between 0 to 255 pixels. Let us consider the lower and the upper limits by letter L and H respectively. The normalization process then scans the image to determine available the minimum and maximum pixel values present in the image which needs to enhancement. These pixels are called LN and HN [12]. Then every pixel 'P' of the image is enhanced by the equation written below:

$P_E=(P_{Image}-L_N)((H-L)/(H_n-L_N))+L$………. (4)

Where 'E' is the enhanced pixels and P image is the original input image. To illustrate, below mentioned figure shows allow-intensity image with its histogram and enhanced the image with its histogram using the intensity enhancement approach [13].

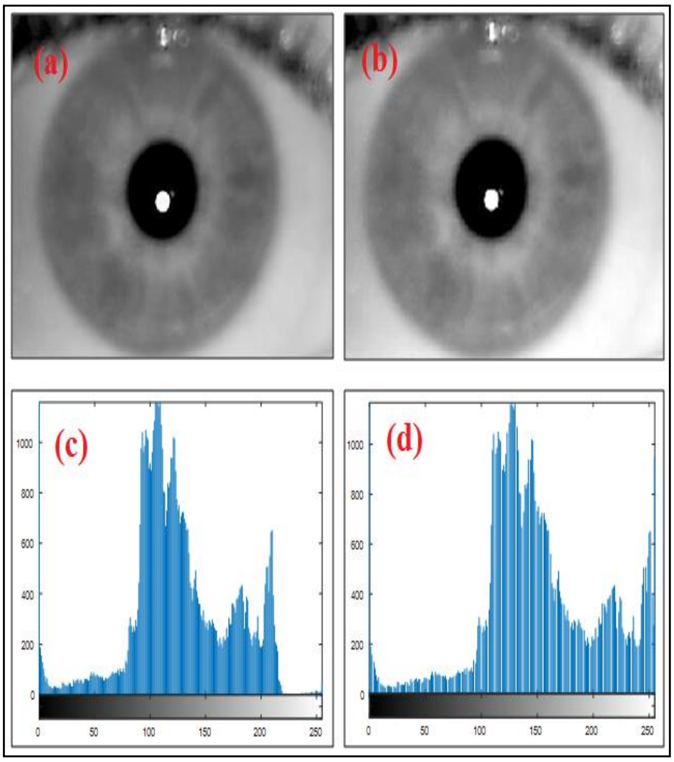

FIGURE 4: (A) ORIGINAL IMAGE, (B) ENHANCED IMAGE, (C) HISTOGRAM OF ORIGINAL IMAGE AND (D) HISTOGRAM OF ENHANCED IMAGE

Intensity enhancement approach amplifies the image intensity by converting every grayscale value to an updated with the help of "cumulative distribution_ function" that is obtained from the intensity_ histogram [14-27]. The figure 4, represents the process of intensity enhancement technique which displays the test image and improved image after the enhancement approach. The figure 4(A) represents the original biometric iris image, figure 4(B) represents the enhanced biometric image using the intensity enhancement technique, figure 4(C), 4(D) displays the histogram form of an original iris image and enhanced_iris image respectively. To enhance the biometric image, we use below mentioned intensity enhancement algorithm [26].

Algorithm 1: Intensity Enhancement Algorithm

Input: Original Image of Biometric

Output: Enhanced Image

Calculate the dimension (D) of Original Image (I)

If D==3

I_R=Red Part of I

I_G= Green Part of I

I_B= Blue Part of I

Using equation (1)

Red Enhanced=PE (I_R)

Green Enhanced = PE (I_G)

Blue Enhanced = PE (I_B)

Enhanced Image=cat (3, Red Enhanced, Green Enhanced, Blue Enhanced)

Else

Enhanced Image= PE (I)

End

Return: Enhanced Image

End

B. HISTOGRAM _EQUALIZATION TECHNIQUE

HE is a technique which is utilized for modifying the intensities of an image that helps to increase the image contrast. It is not essential that contrast will always increase in the histogram equalization technique. There may be some cases where the histogram equalization technique can be of poorer quality. In that case, the contrast of an image is decreased [15].
Let us suppose that X is a known biometric image which is represented as an 'R' having matrix 'C'. The integer pixel intensities of the 'X' image are ranging from '0 to Int – 1'. Where Int is the number of probable intensity values. Let, the letter 'H' defined the normalized histogram of image X with a bin for every probable intensity [16]. So

$$Hn = \frac{No.of\ pixels\ with\ n\ intensity}{Total\ Pixels}, n = 0, 1, 2 \ldots \ldots Int - 1 \ldots \quad (5)$$

The HE image H_E is written mathematically by

$$H_E(i,j) = round((Int - 1) \sum_{n=0}^{X(i,j)} H_E) \ldots \quad (6)$$

Where, ( ) signifies the function which is used to rounds down to the nearest integer. Let's start histogram equalization by taking an example of the biometric image as shown below.

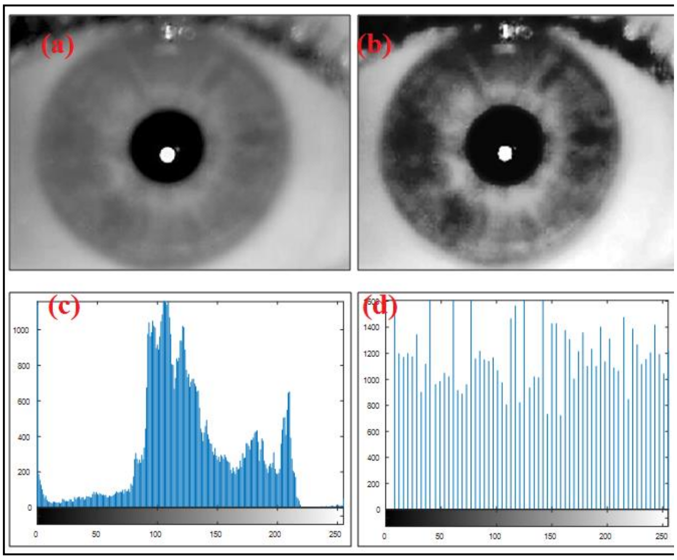

FIGURE 5: (A) ORIGINAL _IMAGE, (B) ENHANCED _IMAGE, (C) HISTOGRAM OF ORIGINAL _IMAGE AND (D) HISTOGRAM OF ENHANCED_ IMAGE

Figure 5 represents the process of histogram equalization technique, which represents the original image and enhanced image after the enhancement [17]. The figure 5(A) represents the original biometric image, (B) represents the enhanced biometric image using the histogram equalization technique, (C), (D) is the histogram of the original image and the histogram representation of the enhanced _image respectively. To enhance the biometric image the histogram equalization algorithm used is written below.

Algorithm 2: Histogram Equalization Algorithm

Input: Original Image of Biometric

Output: Enhanced Image

Calculate the dimension (D) of Original Image (I)

If D==3

I_R=Red Part of I

I_G= Green Part of I

I_B= Blue Part of I

Using equation (3)

Red Enhanced=HE (I_R)

Green Enhanced = HE (I_G)

Blue Enhanced = HE (I_B)

Enhanced Image=cat (3, Red Enhanced, Green Enhanced, Blue Enhanced)

Else

Enhanced Image= HE (I)

End

Return: Enhanced Image

End

C. CONTRAST-LIMITED ADAPTIVE HISTOGRAM EQUALIZATION (CLAHE) TECHNIQUE

CLAHE is the improvisation of the HE technique. The first HE technique we presently saw, by considering the large-scale contrast of an image in equation (6). In several cases, HE is not performing well for image _enhancement. An example of which is shown in the figure below[18].

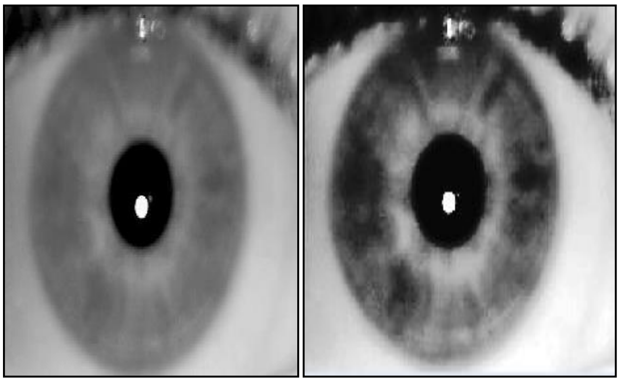

FIGURE 6: (A) BEFORE GLOBAL HISTOGRAM EQUALIZATION AND (B) AFTER GLOBAL HISTOGRAM EQUALIZATION

From the above figure 6, it is clear that HE enhanced the background contrast of the biometric image. But by comparing the iris part of the eye in both images, we analyzed that we lost a good number of the information due to over brightness problem. This is due to the fact that the histogram of the iris part is not confined to a particular area of the iris as we have seen in earlier cases. It is not essential that contrast will always be an increase in the histogram equalization technique. There may be some cases where the histogram equalization technique can be of poorer quality. In that case, the contrast of an image is decreased so we used limitation of contrast to enhance the image quality [19].

The steps of the CLAHE method used in biometric recognition system are defined below:

Step 1: Biometric image acquisition process for image enhancement.

Step 2: Obtain all input values that are utilized in an image_ enhancement process, for example, several regions in a row as well as in the column of an image discretely, numerous bins that are utilized in 'histogram transform' function, clip limit of an image, distribution parameter of an image.

Step 3: Apply pre-processing on the original biometric image to divide the image into regions.

Step 4: Process applied over the surface of an image (appropriate area).

Step 5: Produce 'gray level' plot and an abrupt histogram of the pre-processed part. In an appropriate region number of pixels is evenly separated in every 'gray level' and the average value of the number of pixels for the 'gray level' is explained using the given formula:

P_average=(P_((CR-Xp)) X P_((CR-Yp)))/P_Gray … (7)

Where P _average is an average value of pixels, PGray is the value of gray level in the appropriate area, PCR-XP is the pixel number represented along with the X-axis of the appropriate area and PCR-Yp is the pixel number along with the y-axis of appropriate area. After that, calculate the actual clip limit of an image using formula written below:

P_CL=P_ClipnP_average……………………….. (8)

Where PCL is the pixels clip limit which is used to set the contrast limitation of an image

Step 5: Apply histogram equalization technique using the equation (6) with a clip limit to enhance the image.

The HE technique with clip limit is called CLAHE. To illustrate, below mentioned figure shows limited contrast enhancement process with its histogram and compare with the original image [25].

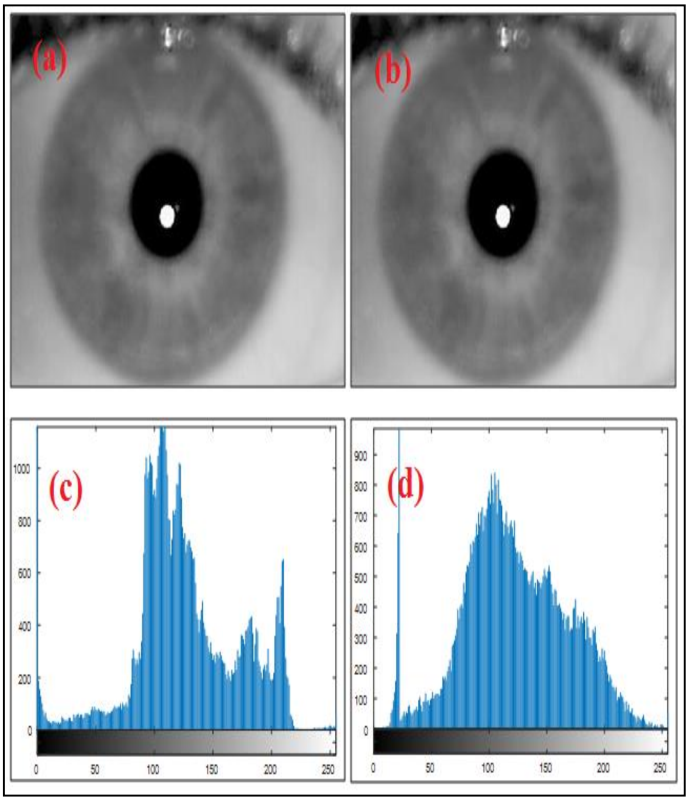

FIGURE 7: (A) ORIGINAL IMAGE, (B) ENHANCED IMAGE, (C) HISTOGRAM OF ORIGINAL IMAGE AND (D) HISTOGRAM OF ENHANCED IMAGE

Figure 7 represents the process of CLAHE technique that represents the original image and enhanced image after the enhancement. In this technique, the enhancement _function is applicable to the entire nearby pixels of an image and the 'transformation function' is obtained with limitation. This differs from the histogram equalization technique because of its contrast limiting. The figure 7(A), represents the original biometric image, figure 7(B) represents the enhanced biometric image using the histogram equalization technique, figure 7(C) is the histogram of the original_image followed by figure7 (D), which represents the histogram of an enhanced image. To enhance the biometric image, we use below-mentioned contrast limited adaptive histogram equalization algorithm.

TABLE 1. A GLANCE OF EXISTING TECHNIQUES

References	Proposed work	Proposed techniques	Advantages	Outcomes
[20]	Developed a novel "Convolutional_ Neural_ Network" (CNN) that helps to carry out fast image enhancement function.	CNN, histogram	• The computation time is small • High resolution • It can be run on a modern cell phone	The PSNR value of the existing and proposed work measured are31.8dB and 29.5 dB respectively. Thus it is clear that when CNN algorithm has been used in the proposed model the PSNR value is reduced and the hence quality of image increased.
[21]	Proposed a new ESIHE ('Exposure _based sub	Histogram equalization	• The method is used in underexposed images	The proposed ESIH technique performs better than normal histogram method. The

	image _HE) to increase contrasts for the low grayscale image. Explore method has been utilized to subdivide the original image into small parts with various levels of intensity. The process has been carried out in three phases such as Explore threshold computation, histogram clipping &sub-division, and equalization.		• Offers high entropy • Provide better contrast enhancement	entropy measured by using the ESIH technique is about 5.39 whereas the entropy observed for the normal HE technique is 4.82.
[22]	Proposed a Histogram equalization method to enhance the color image. The experiment has been carried out in MATLAB,2015 simulation tool.	Color channel stretching (converts RGB image into HIS space) HE Magnitude Compression	• Implementation is easy • Enhance the color image quality • Enhance contrast, sharpness.	Enhance color image in a usual way with the smallest artifact. Also, the image pixels with high quality have been achieved without affecting the sharpness and brightness of the image.
[23]	Proposed an integrated approach to enhance the contrast by using Local-global image statics along with MMF (Multi-scale morphological filtering). Initially, the RGB image has been converted into a grayscale image.	HE, CLAHE and MMF	The experiment has been performed on two different biometric trainers such as iris and fingerprint. The dataset for iris has been collected from "CASIA" and for fingerprint, the dataset has been collected from "NIST fingerprint". The main advantage of this work is that the presented system has been used to handle the less quality image effectively in less computation span.	The mean contrast obtained for the proposed technique is 8.4669/3.2142
[24]	Proposed a method to improve the image excellence of fingerprint using SIFT (Scale feature Transformation) algorithm. The experiment has been proceeding in two stages: in the first stage the enhancement of fingerprint has been performed by utilizing the fuzzy set and in the second phase, the features have been extracted by using SIFT approach.	SIFT, Euclidean distance		The comparison of Minutia score and SIFT approach have been analyzed on different dataset fingerprint images and it has been concluded that the match score determined using the SIFT algorithm is higher than minutiae score.

Algorithm 3: CLAHE Algorithm

```
Input: Original Image of Biometric
Output: Enhanced Image
Calculate the dimension (D) of Original Image (I)
If D==3
  I_R=Red Part of I
  I_G= Green Part of I
  I_B= Blue Part of I
  Using equation (5)
  For Clip Limit 1 to all
      Red Enhanced=HE (I_R, PCL)
      Green Enhanced = HE (I_G, PCL)
   Blue Enhanced = HE (I_B, PCL)
  End
      Enhanced Image=cat (3, Red Enhanced, Green Enhanced, Blue Enhanced)

  Else
     For Clip Limit 1 to all
        Enhanced Image= HE (I, PCL)
     End
  End
  Return: Enhanced Image
End
```

The organization of the paper is proceeded like in Section –I, a brief description of this research work along with three different image enhancement techniques namely intensity enhancement, histogram equalization, and CLAHE is illustrated. In section –II, the background of existing work in the field of image enhancement in a biometric recognition system is performed. In section –III, the experiment results measured in terms of various parameters are discussed for three image enhancement techniques. At last, the conclusion of the research work is explained in the section- IV which is followed by the references.

II. RELATED WORK

In this section, the work performed by various authors in the field of image enhancement using various techniques along with the advantages, the outcomes are discussed in tabular form. The related work has been shown in tabular form as depicted in table 1 as a glance of existing techniques.

III. EXPERIMENTAL RESULTS

In this research paper, we have proposed a comparative investigation of image enhancement technique using the intensity-based image enhancement; histogram-based image enhancement and CLAHE techniques. The comparative analysis of the biometric image enhancement technique is described in this section along with results. The design framework of the proposed work is illustrated in the figure below.

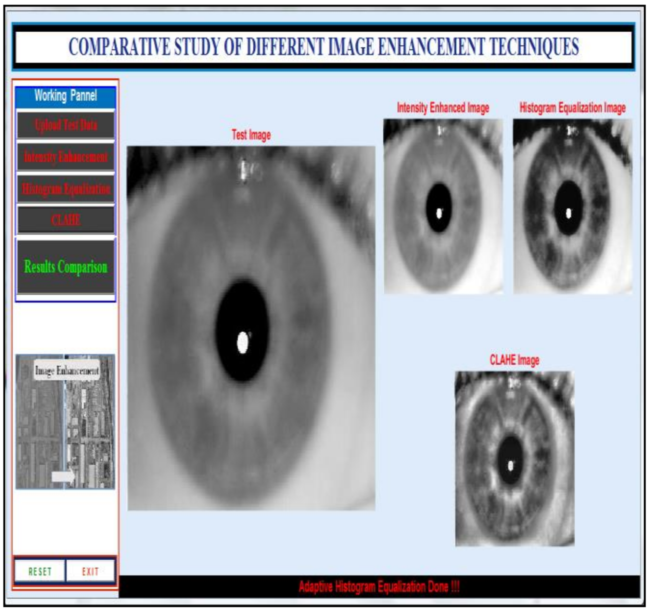

FIGURE 8: PROPOSED FRAMEWORK

Figure 8 represents the design framework of the proposed work to analyze the different image enhancement algorithm for biometric images. There are three algorithms that are used for biometric image enhancement. The comparison of proposed work on the basis of performance parameters like PSNR, SNR, MSE, SSIM, and Execution time is provided below.

The comparison graph of computed PSNR for the three different enhancement techniques are shown in the figure above. In this graph, the blue, red and green bar display the values of PSNR obtained for three enhancement techniques named as IE, HE and CLAHE respectively. The test images are represented along the X-axis whereas the y-axis represents the values of PSNR. From the above figure, it is observed that the average value of PSNR measured for IE, HE and CLAHE enhancement techniques are 16.33, 16.91 and 17.86 respectively. It is clear that the CLAHE enhancement technique performs better than the other two techniques. The value of PSNR using CLAHE enhancement technique increased by 9.37% and 5.62% from IE and HE techniques.

Number of test images	IE	HE	CLAHE
1	13.02	14.69	16.02
2	13.45	15.78	16.52
3	14.56	15.97	16.78
4	14.98	16.02	16.96
5	15.25	15.99	17.01

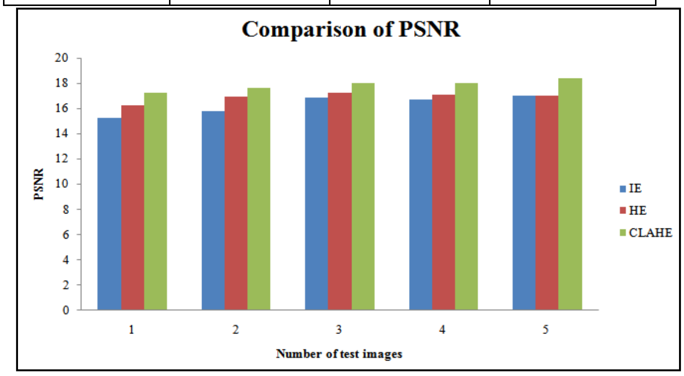

FIGURE 9: COMPARISON OF PSNR

TABLE 2. PSNR OF IE, HE, CLAHE

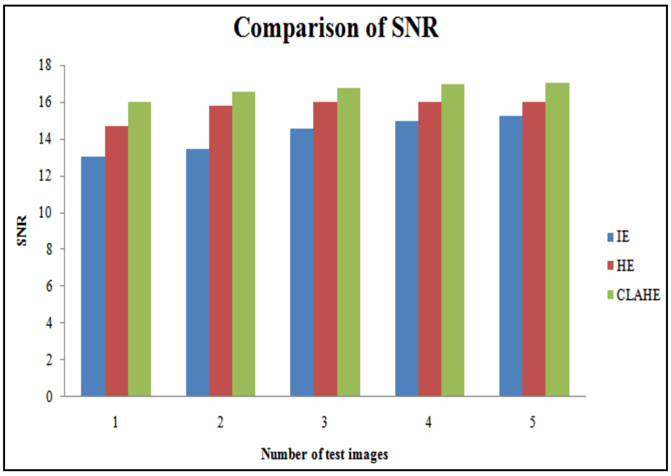

FIGURE 10: COMPARISON OF SNR

The above graph represents the observation of SNR observed for the proposed three image-enhancing techniques. From the above graph, it is observed that the average value of SNR measured for the three different techniques IE, HE and CLAHE are 14.25, 15.69 and 16.65 respectively. Thus, it is clear that the signal as compared to the noise present in the enhanced image using CLAHE is higher than the other two techniques. Thus it is concluded that there is an enhancement of 16.84% and 6.12% in the SNR values of the CLAHE technique from IE and HE techniques respectively.

Number of test images	IE	HE	CLAHE
1	15.23	16.27	17.26
2	15.78	16.96	17.63
3	16.89	17.25	18.02
4	16.73	17.06	17.98
5	17.02	17.04	18.42

TABLE 3: SNR OF IE, HE, CLAHE

Number of test images	IE	HE	CLAHE
1	600.253	512.236	449.658
2	657.893	555.896	444.697
3	692.125	597.256	436.258
4	700.689	625.235	422.789
5	700.123	649.876	405.475

TABLE 4: MSE OF IE, HE, CLAHE

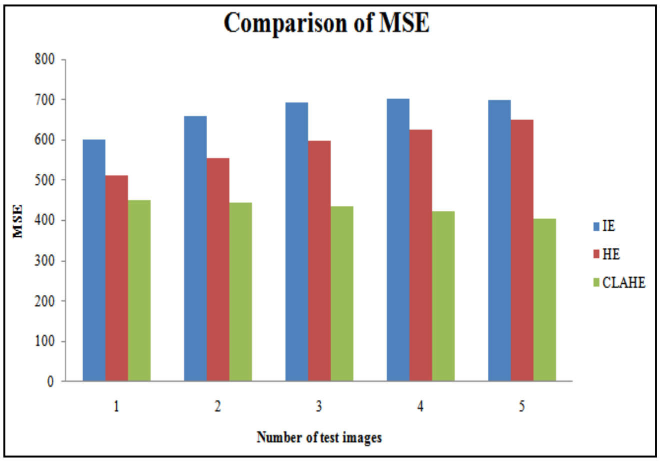

FIGURE 11: COMPARISON OF MSE

The comparison of "Mean square error" is shown in the graphical form for three various image enhancement algorithm applied in the biometric recognition system. From the above figure, the average values of MSE measured for five different test biometric images for IE, HE and CLAHE techniques are 670.216, 588.099 and 431.777 respectively. Thus it is clear that using the CLAHE technique, the biometric image is enhanced with higher quality than other two enhancement techniques.

TABLE 5: SSIM OF IE, HE, CLAHE

Number of test images	IE	HE	CLAHE
1	0.901	0.961	0.986
2	0.924	0.979	0.9842
3	0.932	0.987	0.9865
4	0.947	0.975	0.991
5	0.956	0.960	0.989

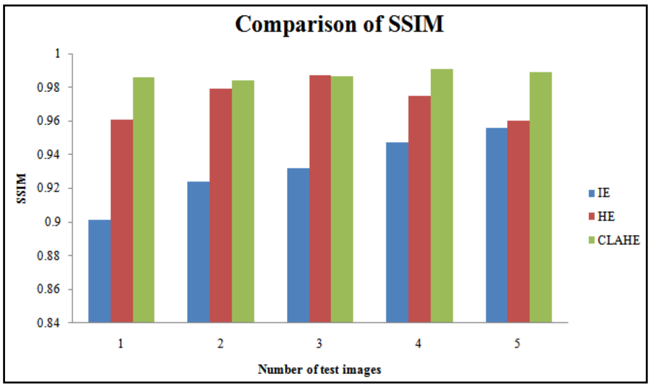

FIGURE12: COMPARISON OF SSIM

The graph shown in figure 12 represents the SSIM values measured for the proposed work for five different biometric images. The average values obtained for three different enhancement techniques namely IE, HE and CLAHE are 0.932, 0.972 and 0.987 respectively. The SSIM parameter is used to determine the similarity values between the images. Here the SSIM value measured by CLAHE is increased by 5.9 % and 1.54 % from the IE and HE techniques.

TABLE 6: EXECUTION TIME (MS) OF IE, HE, CLAHE

Number of test images	IE	HE	CLAHE
1	1.25	0.35	0.15
2	1.35	1.45	0.24
3	2.15	2.78	1.59
4	1.21	0.76	1.68
5	0.19	0.89	1.91

FIGURE 13: COMPARISON OF EXECUTION TIME

The above figure represents the comparison of execution time taken by three image enhancement algorithms to perform their operation. From the above graph, it is clear that the average value of execution time measured in ms for IE, HE and CLAHE are 1.23 ms, 1.24 ms, and 1.11 ms respectively.

IV. CONCLUSION

The qualities of biometric images have been required to improve before the images are being applied as an input to the biometric recognition system's pre-processing stage. In this research paper, a comparative investigation of three different image enhancement techniques such as IE, HE and CLAHE have been discussed. The entire experiment has been carried out in MATLAB, 2016 simulator tool and to determine the efficiency of the presented image enhance techniques, the computation metrics such as PSNR, SNR, MSE, SSIM and execution time have been measured. It has been concluded that the CLAHE image enhancement technique performs better with high PSNR, SNR and SSIM values and small MSE value. This indicates that the CLAHE technique enhanced the biometric image with high quality as compared to other two enhancement techniques (IE &HE) that help to improve the accuracy of any biometric recognition system. But, the information loss in CLAHE enhancement technique is more than results to increase MSE value and need improvement by using another concept of image enhancement techniques so that we can use an enhanced image in the biometric recognition system.

In the future, we can use atmospheric lightning condition based image enhancement technique to achieve a better quality of biometric image recognition system without information loss. In atmospheric lightning condition based image enhancement technique is a better option for biometric recognition system because the biometric recognition system is based on input data.

REFERENCES

[1]. Tan, X., & Triggs, B. (2010). Enhanced local texture feature sets for face recognition under difficult lighting conditions. IEEE transactions on image processing, 19(6), 1635-1650.

[2]. Parveen, R., Kulkarni, S., & Mytri, V. D. (2018). Implementation and Comparison of Image Enhancement Techniques Using Low-Resolution IRS-1C LISS III Image. Asian Journal of Computer Science and Technology, 7(1), 61-65.

[3]. Atli, İ., Saraçoğlu, A., & Gedik, O. S. (2017, May). The effect of contrast enhancement techniques on mutual information based image registration. In Signal Processing and Communications Applications Conference (SIU), 2017 25th(pp. 1-4). IEEE.

[4]. Makhija, S., Khatwani, A., & Roja, M. M. (2017, February). Performance analysis of latent fingerprint enhancement techniques. In Innovative Mechanisms for Industry Applications (ICYMI), 2017 International Conference on (pp. 96-100). IEEE.

[5]. Shih, F. Y. (2017). Digital watermarking and steganography: fundamentals and techniques. CRC press.

[6]. Grigoryan, A. M., & Agaian, S. S. (2017). Alpha-Rooting Method of Gray-scale Image Enhancement in The Quaternion Frequency Domain. Electronic Imaging, 2017(13), 131-142.

[7]. Grigoryan, A. M., & Agaian, S. S. (2017). Alpha-Rooting Method of Gray-scale Image Enhancement in The Quaternion Frequency Domain. Electronic Imaging, 2017(13), 131-142.

[8]. Yue, H., Yang, J., Sun, X., Wu, F., & Hou, C. (2017). Contrast enhancement based on intrinsic image decomposition. IEEE Transactions on Image Processing, 26(8), 3981-3994.

[9]. Samant, P., Agarwal, R., & Bansal, A. (2017, October). Enhanced Discrete Cosine Transformation feature based iris recognition using various scanning techniques. In Electrical, Computer and Electronics (UPCON), 2017 4th IEEE Uttar Pradesh Section International Conference on (pp. 660-665). IEEE.

[10]. Ghali, A. A., Jamel, S., Mohamad, K. M., Khalid, S. K. A., Pindar, Z. A., & Deris, M. M. (2018, February). An Improved Low Contrast Image in Normalization Process for Iris Recognition System. In International Conference on Soft Computing and Data Mining (pp. 495-505). Springer, Cham.

[11]. Kaur, G., Bhardwaj, N., & Singh, P. K. (2018). An Analytic Review on Image Enhancement Techniques Based on Soft Computing Approach. In Sensors and Image Processing (pp. 255-265). Springer, Singapore.

[12]. Jeevakala, S. (2018). Sharpening enhancement technique for MR images to enhance the segmentation. Biomedical Signal Processing and Control, 41, 21-30.

[13]. Temiatse, O. S., Misra, S., Dhawale, C., Ahuja, R., & Matthews, V. (2017, October). Image Enhancement of Lemon Grasses Using Image Processing

[14]. Techniques (Histogram Equalization). In International Conference on Recent Developments in Science, Engineering, and Technology (pp. 298-308). Springer, Singapore

[15]. Maerz, T., Newton, M. D., Matthew, H. W. T., & Baker, K. C. (2016). Surface roughness and thickness analysis of contrast-enhanced articular cartilage using mesh parameterization. Osteoarthritis and cartilage, 24(2), 290-298.

[16]. Gu, K. G. G. Z., Zhai, G., Lin, W., & Liu, M. (2016). The Analysis of Image Contrast: From Quality Assessment to Automatic Enhancement. IEEE Trans. Cybernetics, 46(1), 284-297.

[17]. Lidong, H., Wei, Z., Jun, W., & Zebin, S. (2015). Combination of contrast limited adaptive histogram equalization and discrete wavelet transform for image enhancement. IET Image Processing, 9(10), 908-915.

[18]. Senthilkumaran, N., & Thimmiaraja, J. (2014, February). Histogram equalization for image enhancement using MRI brain images. In Computing and Communication Technologies (WCCCT), 2014 World Congress on (pp. 80-83). IEEE.

[19]. Al-Ameen, Z., Sulong, G., Rehman, A., Al-Dhelaan, A., Saba, T., & Al-Rodhaan, M. (2015). An innovative technique for contrast enhancement of computed tomography images using normalized gamma-corrected contrast-limited adaptive histogram equalization. EURASIP Journal on Advances in Signal Processing, 2015(1), 32.

[20]. Zhang, Y., Wu, X., Lu, S., Wang, H., Phillips, P., & Wang, S. (2016). Smart detection on abnormal breasts in digital mammography based on contrast-limited adaptive histogram equalization and chaotic adaptive real-coded biogeography-based optimization. Simulation, 92(9), 873-885.

[21]. Gharbi, M., Chen, J., Barron, J. T., Hasinoff, S. W., & Durand, F. (2017). Deep bilateral learning for real-time image enhancement. ACM Transactions on Graphics (TOG), 36(4), 118.

[22]. Singh, K., & Kapoor, R. (2014). Image enhancement using exposure-based sub image histogram equalization. Pattern Recognition Letters, 36, 10-14.\

[23]. Wong, C. Y., Jiang, G., Rahman, M. A., Liu, S., Lin, S. C. F., Kwok, N., ... & Wu, T. (2016). Histogram equalization and optimal profile compression-based approach for color image enhancement. Journal of Visual Communication and Image Representation, 38, 802-813.

[24]. Gautam, G., & Mukhopadhyay, S. (2018). Efficient Contrast Enhancement Based on Local–Global Image Statistics and Multiscale Morphological Filtering. In Advanced Computational and Communication Paradigms (pp. 229-238). Springer, Singapore.