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Image Enhancement Technique at Different Distance for Iris Recognition

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Abstract— **Capturing eye images within visible wavelength illumination in the non-cooperative environment lead to the low quality of eye images. Thus, this study is motivated to investigate the effectiveness of image enhancement technique that able to solve the abovementioned issue. A comparative study has been conducted in which three image enhancement techniques namely Histogram Equalization (HE), Adaptive Histogram Equalization (AHE) and Contrast Limited Adaptive Histogram Equalization (CLAHE) were evaluated and analysed. UBIRIS.v2 eye image database was used as a dataset to evaluate those techniques. Moreover, each of enhancement techniques was tested against the different distance of eye image captured. Results were compared in terms of image interpretation by using Peak-Signal Noise Ratio (PSNR), Absolute Mean Brightness Error (AMBE) and Mean Absolute Error (MAE). The effectiveness of the enhancement techniques on the different distance of image captured was evaluated using the False Acceptance Rate (FAR) and False Rejection Rate (FRR). As a result, CLAHE has proven to be the most reliable technique in enhancing the eye image which improved the localization accuracy by 7%. In addition, the results showed that by implementing CLAHE technique at a four-meter distance was an ideal distance to capture eye images in a non-cooperative environment where it provides high recognition accuracy, 74%.**

Keywords— **iris recognition; image enhancement; histogram equalization; CLAHE**

I. INTRODUCTION

All biometric system is an automatic identification on a unique feature or characteristic presented by the individual. Examples of biometrics systems are recognition of fingerprint, hand, face, iris, and speech. This system is considered as the most secure technology because it is unique, cannot be copied or shared and it is an individual permanent characteristic [1]. Hence, the biometric system is the very accurate and reliable user authentication method [2]. The high demand in the biometric system has gained a great attention towards iris recognition as it provides a trustworthy solution to a person validation.

Iris recognition uses the mathematical pattern-recognition technique to automate the biometric identification. However, an efficient iris recognition system must work with the challenge of handling noisy image, unconstrained environment, blurred image, inaccurate segmentation [23], problematic feature extraction [24] and more. Iris image captured contain noises from a variety of factors such as motion blur, covered by eyelid or eyelash, bad focus, reflection, out of the framework, wearing glasses or contact lenses [3].

The current development of iris recognition is focused on identifying the iris when the eye image is captured at a long-range distance and under lighting variation. While, in a cooperative environment, the eye is captured in the static position at a specific distance. The non-cooperative environment has produced data with low quality due to inflexibility condition during capturing the image. In addition, the performance of iris pattern also affected by the poor quality imaging specifically defocus blur, motion blur, off-angle, occlusion, specular reflection and low lighting which can affect recognition performance [4]. The eye image that has low lighting can cause inaccurate localization of limbic and pupillary which reduce the accuracy of iris segmentation. Proenca and Alexander [5] indicated one of iris segmentation challenge is pupillary localization that needs to be overcome. Roy [6] sum up that the accuracy of iris recognition depends on the accuracy of the iris segmentation. In other words, a good localized and segmented iris have a significant result on iris recognition performance.

Since the cost of implementing the technology is high [7], it is more practical to improve the algorithm instead of the device used to capture the images. Therefore, Sahmoud and Abuhaiba [8] stated to increase the visibility of pupil; a contrast enhancement technique is needed. The image enhancement technique which focusing on contrast adjustment can be implemented either on segmentation phase or normalization phase. In this study, the image enhancement technique is applied at segmentation stage with the aim to increase the accuracy of segmentation. The issues on eye image with low lighting and low contrast ratio between iris and pupil must take into consideration.

An image enhancement technique that focused on contrast enhancement is needed to make the pupil more visible and less the error caused by pupillary localization [8]. Santos and Hoyle [9] use HE techniques to find pupil boundaries in the local area of eye image. However, the low contrast ratio between iris and pupil in darkly pigmented iris has limited the HE result. Kaur and Juneja [10] use HE as a lighting correction to get well textured of the image.

HE is a technique that enhances the images based on the spatial domain. It improves the visual of the image by stretching the histogram while enhancing the image contrast. Histogram stretching can be applied on images of low contrast and low bright due to it based on the method of grey level grouping. HE is commonly used in image enhancement techniques because of high efficiency and simplicity. HE has a linear cumulative histogram that can distribute pixel values uniformly [11]. In another word, HE achieves a uniform distributed histogram by using the Cumulative density functions of the input image [12]. In contrast, "washed out" effect sometimes can be occurring to sink the quality of images. Another drawback of HE techniques is HE techniques are a global operation that does not preserve the brightness of an image as it tries to change the brightness the image. Moreover, the images that have a large grey level and strong peak, HE tends to produce bad or undesired result [13].

Adaptive Histogram Equalization (AHE) technique is used for enhancing the local contrast. AHE performs histogram equalization at each image's pixel that relates on its pixel neighbourhood. Therefore, it helps in enhancing the noise in relatively homogeneous regions [14]. However, AHE is not favourable for real-time application caused by high computational complexity. AHE technique may produce too enhanced image creating a contrast object which produces an object that is not visible in the original image [15]. Hence, AHE gave an important level of enhancement in improving the local contrast and maintaining the numbers of details of the image in a whole. Nevertheless, it majorly tends to create a significant level of noise in an image [16].

CLAHE is an extended version of Adaptive Histogram Equalization (AHE). CLAHE improved the AHE by considering both pixels in local and out of [14], [17], improving the speed and prevent the amplification of noise.

The histogram clipping step is an additional step in CLAHE. It is done before CDF computation. Noisy image distributed in the spatial domain and enhancement function is employed to all neighbourhood pixels. Yadav et al. [18] states CLAHE clip the histogram and redistribute the image by using the maximum values. The amplification of contrast in the pixels neighbourhood is given by the slope of the transformation function. This is related to the slope of the neighbour cumulative distribution function and thus to the histogram values at the pixel value. CLAHE can be applied to both grey scale and coloured images. The comparison of the image enhancement techniques is summarized in Table 1.

TABLE I
COMPARISON OF IMAGE ENHANCEMENT TECHNIQUE

Techniques	Advantages	Disadvantages
Basic HE [9]-[13]	Enhancing the image contrast. High efficiency and simplicity. Can be applied in low contrast and low bright colour image.	Produced "washed out" effect. Do not preserve the brightness of the image. Can produce undesired result cause of grey level.
AHE [14]-[16]	Good on enhancing the local contrast. Helps in enhancing the noise in relatively homogeneous regions. Maintaining the following number of details over the whole image.	AHE is not suitable for real-time application. High computational complexity. May produce an over-enhanced image. May produce an object that is not visible in the original image.
CLAHE [17]-[18]	Considered both pixels in the local region and that out of the region. Image and preventing over-amplification of noise signals.	Sometimes produce unwanted grey level artifact Creates an equal density in all histogram bins

II. MATERIAL AND METHOD

The UBIRIS.v2 database is selected as a dataset for this study. A total of 750 frontal eye image is randomly selected consist of both left and right eye. There are 75 subjects are selected for each distance, which are 8 meters, 7 meters, 6 meters, 5 meters and 4 meters. The 400x300 pixels resolution RGB eye image then is converted to 320x280 pixels, grayscale image and Bitmap image which was compatible with the code to produce the iris template. The flow of image acquisition and data preparation is shown in Fig. 1.

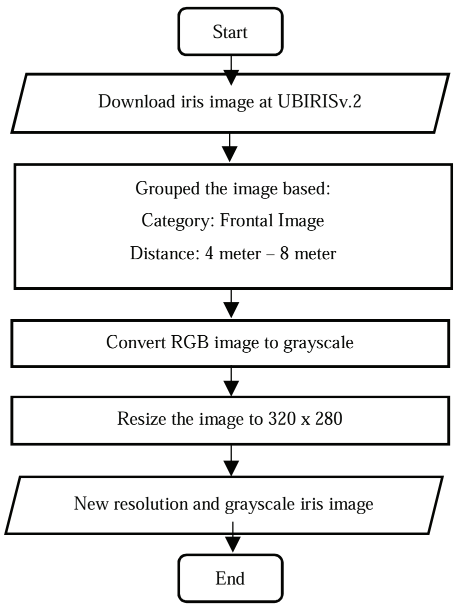

Fig. 1 Flowchart of image acquisition and data preparation

The accuracy performance for each distance is evaluated by percentage of iris recognition accuracy based on FAR and FRR. In addition, this study used the 2013a version of MATLAB that have built-in image processing toolbox to run all the algorithms in iris recognition framework. The research framework for iris recognition in this study is depicted in Fig. 2.

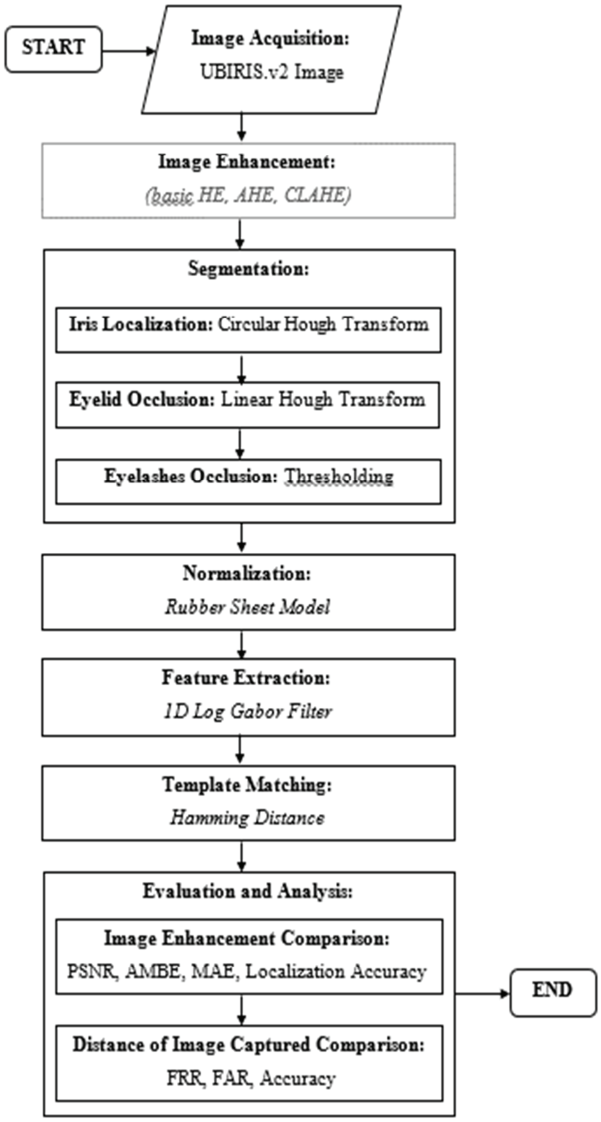

Fig. 2 The research framework

A. Histogram Equalization (HE)

A common enhancement technique used is HE. HE enhances the contrast of an image as overall by changing an original image into a uniform histogram [11]. Hence, this technique is a powerful global enhancement but may reduce the local details within an image. HE technique is a cumulative distribution transformation function. It is a process of transforming intensities of the original image into better distributed on the histogram. Fig. 3 shows the original histogram and the equalized histogram.

The enhanced image be likely to have a higher contrast than an original image (Sanpachai and Malisuwan, 2015). Let *r* be an input image and s be a processed image; a spatial domain process will be expressed as:

$$s = T[r] \qquad (1)$$

$$p_r(r_k) = \frac{n_k}{n},\ k = 0,1,2,\dots,L-1 \qquad (2)$$

$$S(k) = \sum_{j=0}^{k} p_r(r_j) \qquad (3)$$

Where *T[r]* represents a transformation function of r, $p_r(r_k)$ is the probability of occurrence of the grey level image, r_k, L is a number of grey level.

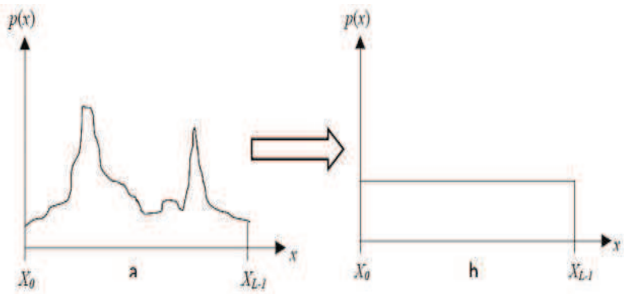

Fig. 3 Review of original histogram with equalized histogram [20]

The basic idea of HE is to map the input image's intensities in such a way that the output image's intensities cover the entire range of intensities. This is achieved by using the Cumulative Distribution Function (CDF) of the input image as the mapping function. Fig. 4 shows general algorithm of this HE algorithm:

Algorithms 1: HE algorithm

Calculate the CDF of the input image

For each pixel in the input image

Calculate the corresponding output pixel intensity by using the CDF as a lookup function

End For

Remap the value found by the last step to a range [*min:max*] and put in output image

Fig. 4 Histogram equalization algorithm

B. Adaptive Histogram Equalization (AHE)

AHE is an improved technique of traditional histogram equalization. AHE is used to improve contrast images, and it is suitable for improving the local contrast in more detail with over-amplified noise. A given pixel is improved based on the histogram equalization of the small neighbouring area. Noise amplification and boundary artefacts can be created in using adaptive histogram equalization. AHE use the small window to define the Contextual Region (CR) for the centre pixel of that window. This is shown in Fig. 5. When the window slide it modified the CDF and transform the function of the pixel that depends on its neighbour. The window sizes that use in this study is 198 where it can optimize the noise reduction. AHE works by considering only small regions and based on their local CDF, performs contrast enhancement of those regions. Fig. 6 shows the general algorithm of this AHE algorithm:

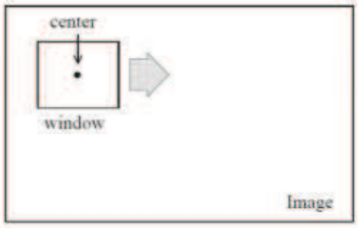

Fig. 5 Histogram equalization algorithm [21]

Algorithms 2: AHE algorithm

Calculate a grid size based on the maximum dimension of the image.
If size of window is not specified,
chose the grid size as default window size.
    Identify grid points on the image, start from the top-left corner.
    Each grid point is separated by grid size pixels.
End If
For each grid point
    Calculate the CDF of the region around it, having an area equal to window size and centred at the grid point.
    Calculate the mappings for each grid point,
    For each pixel find the four closest neighbouring grid points surround pixel.
        Using the intensity value of the pixel as an index, find its mapping at the four grid points based on their CDF.
        Interpolate among these values to get the mapping at the current pixel location.
    End For
End For
Map intensity to the range of [*min:max*] and set it in the output image.

Fig. 6 Adaptive histogram equalization algorithm

C. CLAHE

CLAHE has been developed to avoid the noise amplification. It is a generalization of adaptive histogram equalization. Contrast limitation in CLAHE made its differ from AHE. The undesired noise amplification can be reduced, and the boundary effect can also be reduced by background subtraction. The advantage of CLAHE is that the resulted image will not discard the histogram that exceeds the clip limit but it creates an equal density in all histogram bins. Fig. 7 shows the process of CLAHE where (a) is the original image; (b) plateau limit setting; (c) Histogram clipped based on plateau limit and (d) the modified histogram after clipped distribution.

In this study, all the CLAHE parameters are using a default value that implements in MATLAB toolbox. There are three main parameters for running CLAHE in MATLAB which are state as below:

1) NumTiles: is the specific numbers of division tiles (row by column) of an image. CLAHE calculates the contrast transform function for each tile individually, and the optimal number of tiles is based on the input image. The default value for assigned NumTiles is [8 8].

2) ClipLimit: is a parameter that important in contrast factor which can avoid image's over-saturation, especially in homogeneous areas. These are grouped by the high peak of the histogram which the tile is falling into same grey level range. The default value of ClipLimit is 0.01.

3) Distribution: is a parameter that specifically assigns the distribution for creating transform function. As the type of eye image is a normal type, a default value of histogram distribution is used which is a flat histogram or also known as uniform.

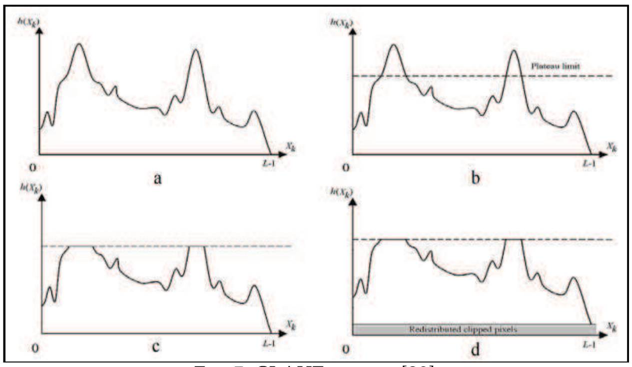

Fig. 7 CLAHE process [20]

CLAHE algorithm added one extra step from AHE which is to clip the histogram before the computation of its CDF as the mapping function is performed. At intensity level, the amount of contrast enhancement for some intensity is directly proportional to the slope of the CDF function. Hence slope of CDF can be a limitation for enhancement of contrast. The slope of CDF is determined by the height of the histogram for the corresponded bin. Therefore, with a limited height of the histogram to a certain level, the slope of the CDF can be limited as well so do the amount of contrast enhancement. Fig. 8 shows the general algorithm of this CLAHE algorithm:

Algorithms 3: CLAHE algorithm

Calculate a grid size based on the maximum dimension of the image.
If a window size is not specified, set the grid size to the default window size.
    Identify grid points on the image, start from the top-left corner.
    Each grid point is separated by grid size pixels.
End If
For each grid point
    Calculate the histogram of the region around it, set area equal to window size and centred the grid point.
    If a clipping level is a specified clip the histogram computed above to that level
        Use the new histogram to calculate the CDF
    End If
    For each pixel find the four closest neighbouring grid points surround pixel.
        Using the intensity value of the pixel as an index, find its mapping at the four grid points based on their CDF.
        Interpolate all the values to get the mapping at the current pixel location.
    End For
End For
Map this intensity to the range [*min:max*] and put it in the output image.

Fig. 8 Contrast limited adaptive histogram equalization algorithm

III. Result and Discussion

A total of 750 frontal eye image were randomly selected consist of both left and right eye. There were 75 subjects were selected for each distance in order to compare the performance at different distances of the image captured. The common image quality measurement such as Peak-Signal-Noise Ratio (PSNR), Absolute Mean Brightness Error (AMBE) and Mean Absolute Error were used to compare the performance the image enhancement techniques. The experimental result of image enhancement performance can be obtained in Table 2, and the comparison of the histogram for each technique is tabulated in Table 3. To analyze the performance of the iris recognition systems, measurements of the accuracy of iris localization were required as shown in Table 3.

PSNR used to measure the image quality. The higher the PSNR value, the better image quality is, while by the MAE is vice versa. MAE represent the absolute error between the enhanced at the input image and more robust than mean square error (MSE). The low value of MAE indicates the good quality of the image. To provide greater quality of enhanced image, the method must produce less error and preserve more brightness. The image that has good quality must have a low value of AMBE. CLAHE has the highest value of PSNR (17.459) and lowest value for AMBE (20.677) and MAE (27.340). Therefore, in terms of image quality, it can conclude that CLAHE is the best technique for image enhancement followed by HE and AHE respectively due to CLAHE can preserve more brightness, produce less error and provide a greater eye image quality.

TABLE II
PERFORMANCE OF IMAGE QUALITY FOR EACH TECHNIQUE

Image Quality Measurement (dB)	Method		
	HE	**AHE**	**CLAHE**
PSNR	14.725	14.148	17.459
AMBE	29.124	32.709	20.77
MAE	40.573	42.379	27.340

TABLE III
THE HISTOGRAM COMPARISON OF ORIGINAL IMAGE AND ENHANCED IMAGE ACCORDING TO DIFFERENT DISTANCES

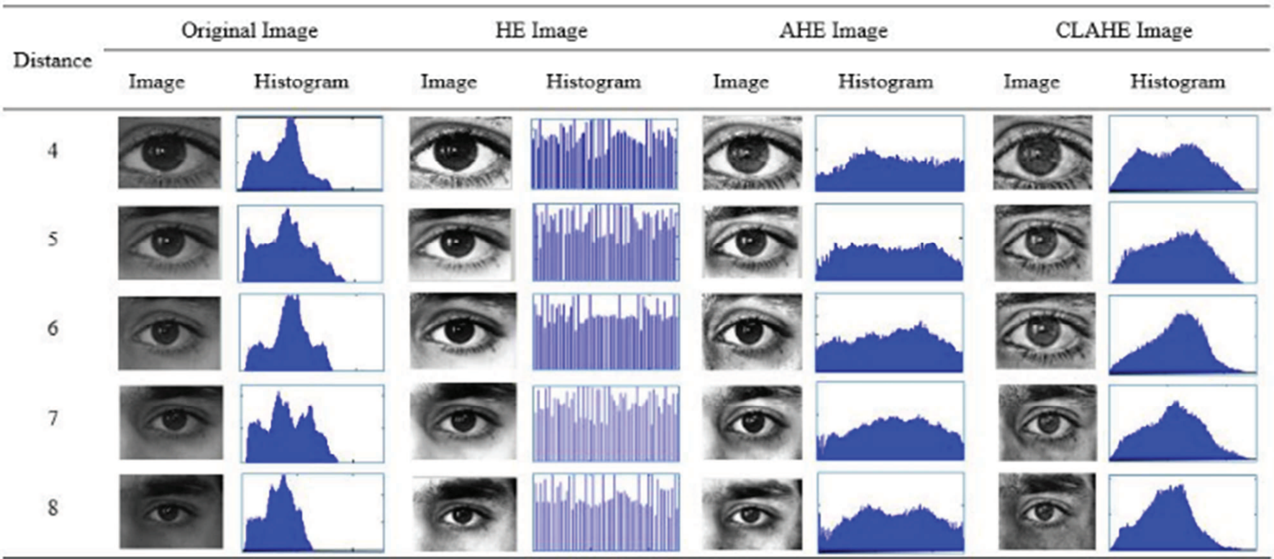

Table 4 presents the result of the accuracy of iris localization categorized by enhancement techniques. CLAHE and Original performed with more than 70% accuracy of localization for pupillary and limbic boundaries compared to other methods. In Fact, CLAHE technique achieved the highest accuracy of localization with 0.81 localization accuracy compared original eye image with 0.74 localization accuracy.

TABLE IV
ACCURACY OF IRIS LOCALIZATION FOR THE EYE IMAGE ACCORDING TO THE DIFFERENT TECHNIQUES

Segmented Iris	Localization Accuracy
Original	0.74
HE	0.46
AHE	0.58
CLAHE	0.81

Table 5 shows the results of the accuracy of the iris recognition system according to the different distances. For this study, different distances of capturing eye image are compared after image enhancement is implemented. The comparison result using iris recognition system using accuracy has been shown that at distance of four meters gave the highest performance in iris recognition at 73.6% with FRR and FAR 31.3% and 21.3% respectively. With the implementation of CLAHE, the accuracy of iris recognition at four meters is highest among the other distance.

TABLE V
THE PERFORMANCE OF DIFFERENT DISTANCE IN IRIS RECOGNITION SYSTEM

Distance	FRR (%)	FAR (%)	Accuracy (%)
4	31.3	21.3	73.7
5	49.3	28.0	61.3
4	36.0	36.7	63.7
7	28.0	27.3	72.3
8	39.3	33.3	63.7

IV. CONCLUSIONS

Throughout of this study, a suitable image enhancement and ideal distance for capture eye image have been justified to improve the accuracy of segmentation and the accuracy of iris recognition system in the non-cooperative environment under visible wavelength illumination. CLAHE technique is proven to be the best image enhancement technique compared to two other techniques by improving the localization accuracy at 7% from the original image. Besides, a distance of four meters is the most accurate distance to capture the eye image. The result of the study can help the other researcher on studying the iris recognition in the non-cooperative environment and hence can apply it on determining the accurate distance for eye image acquisition. Image enhancement technique was used in this study only can adjust the contrast and lighting of the eye image, yet it cannot reduce the reflection on the eye image. For future work, the study can be extended on investigating the effect of image enhancement on a different angle of eye images in the non-cooperative environment and also other works [25]-[33].

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REFERENCES

[1] S. PRABHAKAR, S. PANKANTI, and A. K. Jain, "Biometric recognition: Security and privacy concerns," *IEEE Secur. Priv.*, vol. 1, no. 2, pp. 33–42, 2003.

[2] N. S. Sarode and a M. Patil, "Review of Iris Recognition : An evolving Biometrics Identification Technology," *Int. J. Innov. Sci. Mod. Eng.*, vol. 2, no. 10, pp. 34–40, 2014.

[3] H. Ghodrati, M. J. Dehghani, and H. Danyali, "Shape adaptive, robust iris feature extraction from noisy iris images.," *J. Med. Signals Sens.*, vol. 3, no. 4, pp. 244–255, 2013.

[4] A. F. M. Raffei, H. Asmuni, R. Hassan, and R. M. Othman, "A low lighting or contrast ratio visible iris recognition using iso-contrast limited adaptive histogram equalization," *Knowledge-Based Syst.*, vol. 74, pp. 40–48, 2015.

[5] H. Proença and L. A. Alexandre, "Iris recognition: Analysis of the error rates regarding the accuracy of the segmentation stage," *Image Vis. Comput.*, vol. 28, no. 1, pp. 202–206, 2010.

[6] K. Roy, P. Bhattacharya, and C. Y. Suen, "Iris segmentation using variational level set method," *Opt. Lasers Eng.*, vol. 49, no. 4, pp. 578–588, 2011.

[7] K. Dharavath, F. a Talukdar, and R. H. Laskar, "Study on Biometric Authentication Systems , Challenges and Future Trends : A R eview," *Comput. Res. …*, 2013.

[8] S. A. Sahmoud and I. S. Abuhaiba, "Efficient iris segmentation method in unconstrained environments," *Pattern Recognit.*, vol. 46, no. 12, pp. 3174–3185, Dec. 2013.

[9] G. Santos and E. Hoyle, "A fusion approach to unconstrained iris recognition," *Pattern Recognit. Lett.*, vol. 33, no. 8, pp. 984–990, Jun. 2012.

[10] N. Kaur and M. Juneja, "A Novel Approach for Iris Recognition in Unconstrained Environment."

[11] R. Gonzalez and R. Woods, *Digital image processing.* 2002.

[12] P. Sharma and G. Garg, "Entropy based optimized weighted histogram equalization for Hazy Images," in *2014 9th International Conference on Industrial and Information Systems (ICIIS)*, 2014, pp. 1–6.

[13] G. Srivastava and T. K. Rawat, "Histogram equalization: A comparative analysis & a segmented approach to process digital images," in *2013 Sixth International Conference on Contemporary Computing (IC3)*, 2013, pp. 81–85.

[14] S. M. Pizer, E. P. Amburn, J. D. Austin, R. Cromartie, A. Geselowitz, T. Greer, B. ter Haar Romeny, J. B. Zimmerman, and K. Zuiderveld, "Adaptive histogram equalization and its variations," *Comput. Vision, Graph. Image Process.*, vol. 39, no. 3, pp. 355–368, Sep. 1987.

[15] S. Pizer, R. Johnston, and J. Ericksen, "Contrast-limited adaptive histogram equalization: speed and effectiveness," *., Proc. …*, 1990.

[16] S. Das, T. Gulati, and V. Mittal, "Histogram Equalization Techniques for Contrast Enhancement: A Review," *Int. J. Comput. Appl.*, vol. 114, no. 10, pp. 975–8887, 2015.

[17] W. Liu, H. Zhan, J. Zhao, T. Zhao, and H. Wang, "An improved histogram equalization approach for optical remote sensing images enhancement," in *2013 Chinese Automation Congress*, 2013, pp. 152–155.

[18] G. Yadav, S. Maheshwari, and A. Agarwal, "Foggy image enhancement using contrast limited adaptive histogram equalization of digitally filtered image: Performance improvement," in *2014 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, 2014, pp. 2225–2231.

[19] R. C. Gonzalez and R. E. (Richard E. Woods, *Digital image processing.* Prentice Hall, 2002.

[20] A. Raju, "A comparative analysis of histogram equalization based techniques for contrast enhancement and brightness preserving," 2013.

[21] N. Kong, H. Ibrahim, and S. Hoo, "A Literature Review on Histogram Equalization and Its Variations for Digital Image Enhancement," *Int. J.*, 2013.

[22] H. Sanpachai, "A Study of Image Enhancement for Iris Recognition," *J. Ind. Intell. Inf.*, vol. 3, no. 1, pp. 61–64, 2015.

[23] R. Nilakant, H. P. Menon, K Vikram, "A Survey on Advanced Segmentation Techniques for Brain MRI Image Segmentation," *International Journal on Advanced Science, Engineering and Information Technology*, vol 7, no. 4, 2017.

[24] Yuhandri, S. Madenda, E. P. Wibowo, Karmilasari, "Object Feature Extraction of Songket Image Using Chain Code Algorithm," *International Journal on Advanced Science, Engineering and Information Technology*, vol 7, no. 1, pp. 235-241, 2017.

[25] U. K. Hassan, N. M. Nawi, and S. Kasim, "Classify a protein domain using sigmoid support vector machine," in Information Science and Applications (ICISA), 2014 International Conference, IEEE, May. 2014. pp. 1-4.

[26] U. K. Hassan, N. M. Nawi, and S. Kasim, A. A, Ramli, M. F. M., Fudzee, and M. A. Salamat,"Classify a Protein Domain Using SVM Sigmoid Kernel". In Recent Advances on Soft Computing and Data Mining, pp. 143-151, Springer, Cham.

[27] S., Ismail, R. M., Othman, S., Kasim, R., Hassan, H., Asmuni, and J., Taliba, "Pairwise protein substring alignment with latent semantic analysis and support vector machines to detect remote protein homology", International Journal of Bio-Science and Bio-Technology, Volume 3, Issue 3, 2011, Pages 17-34.

[28] F. M., Abdullah, R. M., Othman, S., Kasim, R., Hashim, R., Hassan, H., Asmuni, and J., Taliba, "An Optimal Mesh Algorithm for Remote Protein Homology Detection", Communications in Computer and Information Science, Volume 151 CCIS, Issue PART 2, 2011, Pages 471-497.

[29] S., Ismail, R. M., Othman, S., Kasim, R., Hassan, H., Asmuni, and J., Taliba, "Pairwise protein substring alignment with latent semantic analysis and support vector machines to detect remote protein homology" Communications in Computer and Information Science,Volume 151 CCIS, Issue PART 2, 2011, Pages 526-546.

[30] F. M., Abdullah, R. M., Othman, S., Kasim, R., Hashim, R., Hassan, H., Asmuni, and J., Taliba, "An Optimal Mesh Algorithm for Remote Protein Homology Detection", International Journal of Bio-Science and Bio-Technology, Volume 3, Issue 2, June 2011, Pages 13-38.

[31] S., Kasim, M. F. M., Fudzee, S., Deris, S., and R. M., Othman, "Gene Function Prediction Using Improved Fuzzy c-Means Algorithm", In *Information Science and Applications (ICISA), 2014 International Conference on* (pp. 1-4). IEEE.

[32] S., Kasim, S., Deris, S., and R. M., Othman, "Multi-stage filtering for improving confidence level and determining dominant clusters in clustering algorithms of gene expression data", *Computers in biology and medicine*, *43*(9), 1120-1133, 2013.

[33] S., Kasim, S., Deris, S., and R. M., Othman, "A new computational framework for gene expression clustering", In *International Conference on Advanced Data Mining and Applications* (pp. 603-610). Springer, Berlin, Heidelberg, 2010.