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The discrete wavelet transform based iris recognition for eyes with non-cosmetic contact lens

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ABSTRACT

Iris recognition has been used as one of the biometric systems for user authentication, identification, and verification for quite some time. The basis of an iris recognition lies on the matching algorithm, which requires similarities of the iris data in the database with the captured one. In addition, nowadays using non-cosmetic or prescribed contact lenses becomes more popular and more preferred choice of many people, which makes the number of contact lens wearers significantly increases. These eyes with contact lenses add more complexity to the iris recognition process, since it can disturb the matching process which then affect the performance of the system. This situation has motivated this study to propose an iris recognition system that works for eyes with lenses. The proposed iris recognition system for eyes wearing non-cosmetic contact lenses was developed using circular hough transform (CHT) in the preprocessing phase for iris localization and discrete wavelet transform (DWT) for feature extraction. Experiments conducted on the proposed system has shown promising results with good accuracy of 0.95 for eyes with no contact lens and 0.8 for eyes with non-cosmetic lenses. The findings also suggested the importance of the iris localization process to the performance of the recognition system.

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1. INTRODUCTION

Biometrics, as an automated method to recognize a person based on their characteristics or behavior, has been used in some integral aspects of our life such as authentication systems, security systems, and user identifications. It is regarded as a secure identification and verification solution facilitated by their capability to identify every single person [1], [2]. Biometrics is divided into two categories, the first one is known as physiological biometrics and the second one is behavioral biometrics. Physiological biometrics includes face recognition, iris recognition, fingerprints, retina scans, and palm prints. Whereas behavioral biometrics includes keystroke, signature, and voice recognition [3]–[7].

Iris recognition as one of the biometric systems is used for user authentication, identification, and verification. Since it was firstly proposed by Flom and Safir in their 1987 patent [8] as a biometric modality, iris recognition has been developed as one of the most promising biometrics. The basic idea of this system is the fact that the iris in each human's eyes has a different pattern even for a twin, and the pattern never changes for a lifetime. This idea causes iris recognition to be an attractive biometrics recognition to identify a specific individual. To extract the unique iris pattern from an eye's digital image, image processing techniques can be utilized. The extracted pattern then is encoded to a biometrics template to be stored in a database. Each biometrics template contains unique information in the form of mathematical representation of characteristics/features from the iris that can be compared with each other in the matching process.

In 1990, John Daugman developed the first working iris recognition algorithm which then patented in 1994 [9], [10]. Since then, many studies have been done to work on iris recognition, and those studies mainly focused on improving the speed process and the accuracy of the matching algorithm. Some of those studies include [11]–[20] which show encouraging results in the development of iris recognition systems. On the other hand, there are several factors identified to affect the performance of the iris recognition system; one of which is the use of contact lenses, either cosmetic contact lenses or non-cosmetic ones. Studies showed the degradation of performance in the iris recognition system due to the presence of the contact lenses and eyeglasses [21]–[26] which tell us its importance to be studied further.

In addition, using non-cosmetic or prescribed contact lenses become more popular and more preferred choice of many people nowadays. U.S. Department of Health and Human Services - Centers for Disease Control and Prevention in 2019 estimated around 45 million U.S. residents are contact lens wearers [27]. This has increased from around 38 million wearers in the US in 2009 [28]. In the same year, the estimation number of contact lens wearers worldwide is more than 150 million people [29]. Furthermore, according to a market report [30] the Covid 19 pandemic has made many people shift to wear contact lenses, which make its market significantly increase. It is predicted that the contact lens market will grow from US$ 8.05 Bn in 2021 to US$ 13.19 Bn in 2029.

The high preference of people in wearing contact lenses and the effect from the presence of contact lenses to the performance of the iris recognition system have motivated the study done and presented in this paper to propose an iris recognition system for eyes with non-cosmetic contact lenses. The proposed recognition system has been developed using circular hough transform (CHT) in the preprocessing phase and discrete wavelet transform (DWT) for feature extraction. The performance of this proposed recognition system has also been evaluated and discussed in later part (section 4) of this paper.

2. RELATED WORK

Research works related to iris recognition have attracted many researchers since couple decades ago. Several approaches and techniques have been used to develop an iris recognition system. The study by [11] used a phase-based image matching approach which focused on the performance of the matching of images. The common challenge of matching images lies in the feature extraction process influenced by some parameters used. Those parameters include spatial position, orientation, size, and center frequencies for the 2D Gabor filter kernels. This study proposed to resolve the respective problem by utilizing the phase-based image matching. With this matching technique, the phase components in 2D discrete fourier transforms (DFTs) of given images are used in the matching processs. Furthermore, this study also proposed the use of the 2D fourier phase code (FPC) in order to decrease the size of iris data in an attempt to shorten the processing time. As well, this FPC is intended to hinder the visibility of individual iris images in the iris information. The idea of 2D FPC then was implemented in compact iris recognition devices using the essence of digital signal processing (DSP) technology.

Another study by [12] focused on a texture analysis-based recognition technique. A personal identification which is highly feasible and effective that involving iris sensor design and implementation of a specific method for iris liveness detection described by Daugman [10], [20] have been proposed in this research. This work used the iris image database for 2,255 images from 213 people. A spatial filter was employed for feature extraction. This process generated 1,536 feature components for the image matching of the iris recognition. Fisher linear discriminant was used to reduce the dimensionality of the feature vector to help in improving the computational efficiency and classification accuracy of the recognition process.

More study on iris recognition process also conducted by [14] which proposed a method for iris segmentation, quality enhancement, indexing, and match score fusion as an attempt to improve the performance of the recognition system. Then a study by [15] proposed a novel method for iris matching using zero crossings of a one-dimensional discrete cosine transform (DCT) in feature extraction to be used for the matching algorithm. DTC is a fast computation technique with a strong energy which very good to be used for feature extraction process. Another study focused on improving noisy iris images in iris recognition by deblurring method using Wiener filter [31].

An attempt for improving the performance of iris recognition system was also performed in a study by [32] which proposed a novel approach using DWT for feature extraction. This approach managed to show a very good accuracy for iris recognition of eyes with no contact lens. In addition, a proposed hybrid approach of fast wavelet transform (FWT) and Gabor filter was used in the study by [33] for iris recognition of eyes with no contact lens. This study showed a promising result on the performance of the iris recognition.

In addition, study by [16] proposed an approach for iris recognition which focus on fixing the accommodation of sensitive biometric information by using random projections and random permutations.

Another part of the proposed technique in the study was an algorithm for resolving issues in iris image acquisition such as errors in image segmentation, unclear image, and occlusions. Another research work performed by [34] focused on the effect of iris segmentation methods in the recognition system. The study reported that the most used methods is CHT.

Those previous mentioned studies performed iris recognition for eyes with no lens. With the widespread use of contact lens, some studies worked on detecting contact lens in iris recognition, like the work of [35] which applied weighted local binary pattern (LBP) for contact lens detection and the work by [36] which attempted to use thermos-vision for contact lens detection. However, the resulted accuracy of 66.7% from the work was still not as good. Then, a research work by [37] proposed a method with a two-phase traversal which utilizing local intensity profiles to improve the performance of non-cosmetic contact lens detection. This method showed better performance of 70%-72% of correct lens detection rate. The results suggest opportunities for further studies related to the iris recognition for eyes with non-cosmetic contact lens.

3. METHODOLOGY

In this study, the iris recognition process was basically divided into two phases: the first phase is preprocessing stage and the second phase is matching process stage. Preprocessing phase is started with capturing iris image, then iris localization, iris normalization, and followed with feature extraction. The second phase basically matching process of the iris code resulting from preprocessing stage with the one in the database. The matching process was done based on the Hamming distance calculation. This iris recognition system is presented as a flow diagram depicted in Figure 1.

3.1. Preprocessing

Processes in preprocessing phase are conducted with the main purpose to localize the iris region of the eye image that has been captured. The captured image usually contains parts that are not required for the recognition process, such as pupil, eyelid, eyelashes, and sclera. Significant disturbance in the matching process can be caused by these parts that then can decrease its recognition performance. Thus, removing these unnecessary parts from the captured image is required to be performed to focus only on the iris region in the next phase.

Furthermore, the size of the extracted iris usually varies depending on the camera-to-eye distance and the light brightness level. Thus, the size needs to be normalized prior to the matching operation. In general, the preprocessing phase consists of iris localization, and iris normalization, as depicted in Figure 2.

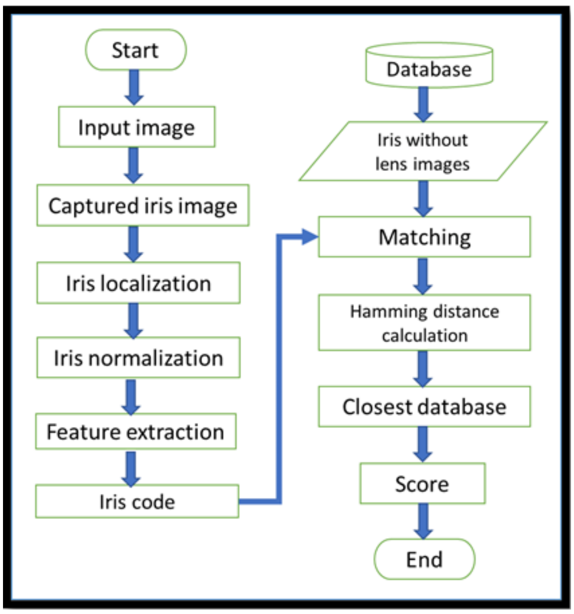


Figure 1. Flow of processes in the iris recognition system

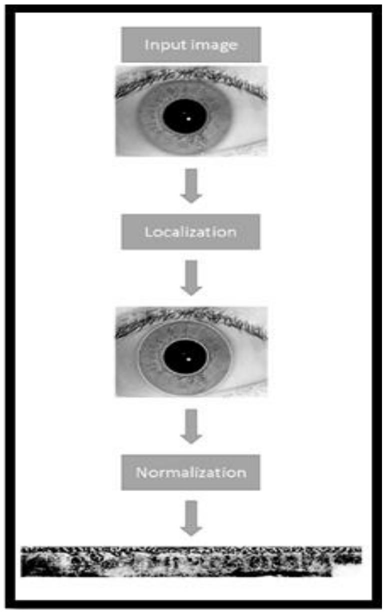


Figure 2. Preprocessing phase in iris recognition

3.2. Iris localization

Circular hough transform (CHT) and canny edge detection were used in this study for iris localization process. CHT was used for detecting the upper and the lower eyelids of the eye, the pupil boundaries, and the iris. This process produces generation of an edge map, which is done through Canny Edge Detection technique.

The equation for determining a circle of radius r and center (a, b) is given by,

$$(x-a)^2 + (y-b)^2 = r^2 \tag{1}$$

this circle could be detected by the two following equations,

$$x = a + r\cos(\theta) \tag{2(a)}$$

$$y = b + r\sin(\theta) \tag{2(b)}$$

The CHT process is to find the three parameters (a, b, r) which then determines the points (x_i, y_i). This step detects the inner boundary, i.e. the boundary between the iris and the pupil, and the outer boundary, i.e. the boundary between the iris and the sclera, in the original gray-scale image. In addition, Daugman's integro-differential operator formula was also used in this study to search the contour of the iris and the pupil.

$$\max\,(r0, x0, y0)\ |G\sigma(r)\frac{\partial}{\partial r}\oint_{(r0,x0,y0)}^{0}\frac{I(x,y)}{2\mu r}| \tag{3}$$

Where: $r0, x0, y0$ the center and radius of coarse circle for each of pupil and iris, Gσ (r) is the Gaussian function, and Δr: the radius range for searching. Further, I(x, y) is the original iris image. Gσ (r) is a smoothing function, the smoothed image specifies an edge by scanned for a circle with a maximum gradient change. With the same technique, the eyelid is localized by the path of contour integration which changed from circular to an arc.

3.3. Iris normalization

Processes done in iris normalization stage are to normalize the extracted iris region and to offset the elastic deformations in iris texture. As the iris's boundary has been identified in the previous stage, then the normalization process uses a rubber-sheet model to convert the iris texture from cartesian become polar coordinates. This process is well known as iris unwrapping, which produces a rectangular entity that will be used for subsequent processing. A binary mask is assigned for each unwrapped iris that splits the iris pixels from pixels correlates to the eyelashes and eyelids identified in segmentation process. Photometric transformations strengthen the unwrapped iris's textual structure after the normalization process.

The iris normalization process brings in the following advantages,

- It contributes for variations in pupil size according to the amount of light and distance of the camera that influence the iris size.
- It makes sure that the iris of each individual is mapped onto a general image domain regardless of the differences in pupil size for each subject.
- It allows the iris registration in the matching process through a simple translation operation that can explain head rotations and in-plane eye.

3.4. Feature extraction

Discrete wavelet transform (DWT) based features was used in this study for analyzing the features of the iris images. As the name suggested, DWT is the type of wavelet transform where the wavelets are sampled at discrete intervals. With this DWT, signals are decomposed into mutually orthogonal set of wavelets. The normalized images are processed through discrete haar transformation (DHT) which compresses the images into 8-bit matrix or pixels that has range value from 0 until 255.

In feature extraction process, some important features in iris such as freckles, stripes, and coronas, are extracted from the two-dimensional image to become the texture/the characteristics of the iris. The extraction process is based on the following algorithm,

Step 1: Normalizing the size of the image to 64×512. Then, dividing the normalized iris image to a basic cell region for generating the iris code. The pixels size of one cell region is 64×32. For calculation process, the value of a basic cell region is represented by a standard deviation of pixels value.

Step 2: Converting the 16-bit values generated in step 1 into 16-bit binary value by taking into account the threshold as mean from each block.

Step 3: Checking whether the pixel value is greater than the threshold; if so, then change the value to 1.

Step 4: Else change the value become 0. By following the previous step, this process obtains 16-bit binary iris code for verification.

3.5. Matching process

The matching stage produces a match score from comparing two iris images (in this study the eye image with contact lenses) by focusing on the feature from the area that has the same pattern with the iris pattern from the eye image with no contact lenses. Hamming distance is then used to calculate the number of corresponding bits that differ from the two iris codes. Before computing the Hamming distance to the registration procedure, the two iris codes should be aligned. A simple translation operation should be enough in most cases, where more advanced schemes can elaborate the elastic changes in the iris texture. The Hamming distance between vectors x = (x_1, $x_2 \cdots x_n$) and y = (y_1, $y_2 \cdots y_n$) denoted by d_H(x, y), is the number of positions where the symbols x_i and y_i differ.

$$dH\ (x,y) = \sum_{i=1}^{n} \delta(xi, yi) \tag{4}$$

Where,

$$\delta(xi, yi) = \begin{cases} 0 \ xi = yi \\ 1 \ xi \neq yi \end{cases}$$

Figure 3 presents a pseudocode of the complete iris recognition process from the preprocessing until the matching process. As can be seen in Figure 3, the preprocessing covers step 1-3, i.e. iris localization, iris normalization, and feature extraction. The next step is the recognition process which basically performs pattern matching with the one in the database using Hamming distance.

```
Input:    Iris eye image with contact lens
Output:   The Hamming Distance score of the iris recognition
 Step 1:  Iris Localization
 Step 2:  Iris Normalization
 Step 3:  Feature Extraction
 Step 4:  Database Load
 Step 5:  Recognition Process
 Step 6:  Do the pattern matching using Hamming Distance
          {
           If the score is close to the threshold:
           Output the matching score result
           Print ("The iris is authenticated")
          else
           Output the matching score result
           Print ("The iris is not authenticated")
          }
 Step 7:  End
```

Figure 3. Iris recognition system pseudocode (adapted from [38])

3.6. Datasets

The dataset used was from the Computer Vision Research Lab of the University of Notre Dame, United States, that was acquired through a license given to Sampoerna University for the purpose of this study. The size of the archive is 6.3 Gb labelled ND_Iris_Contact_Lenses_2010 consist of more than 30,000 images. The images resolution for the images is 96 dpi for vertical and horizontal resolution with 8 bits dept. This study used 180 images for training, 30 images as the database system and 80 images for testing data. The 80 images were randomly picked from 30 people within the database system and 10 people outside the database system. 180 images were taken from the 30 people within the database system, where 6 images were used per people for training data. The database system is the images that exist in the iris recognition system which are used to compare or match the testing data. Table 1 shows the testing data used in the system, and Figure 4 shows images of iris without contact lens as shown in Figure 4(a) from the same individual and iris with contact lens as shown in Figure 4(b).

Table 1. Details on testing data used

	Iris images within the database system	Iris images from outside the database system	Total
Iris images with no lens	30	10	40
Iris images with contact lens	30	10	40
	Total		80

(a) (b)

Figure 4. Sample images showing two kinds of dataset: (a) iris without contact lens and (b) iris with non-cosmetic contact lens from the same individual.

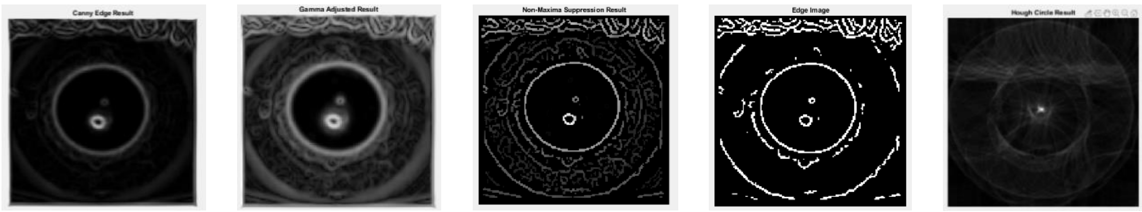
4. RESULTS AND DISCUSSION

This section presents the results of this study into two parts, which are: preprocessing results and experimental results conducted in the iris recognition system. Discussion of the results from processes done in the preprocessing stage is presented in the next sub-section 4.1. It is then followed by results from the experiments performed with the proposed iris recognition system.

4.1. Preprocessing results

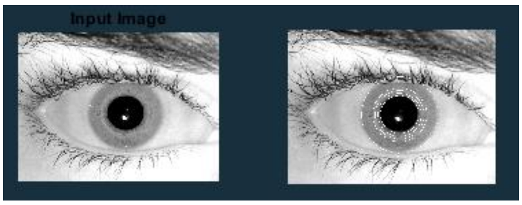
Preprocessing started with the process of iris localization. Figure 5 presents a sample from the result of the iris localization. There are 5 images consist of canny edge result as shown in Figure 5(a) gamma adjusted result as shown in Figure 5(b), non-maxima suppression result as shown in Figure 5(c), edge result as shown in Figure 5(d), and hough circle result as shown in Figure 5(e) from the iris localization using CHT.

Figure 6 shows the input of an iris image as shown in Figure 6(a) and the result after the localization process as shown in Figure 6(b). In the sample, the system could successfully find the circle of the eye from inner boundary and outer boundary. In addition, the result also produced the noise of the eye images which then processed to become the code matrices in iris normalization process.



(a) (b) (c) (d) (e)

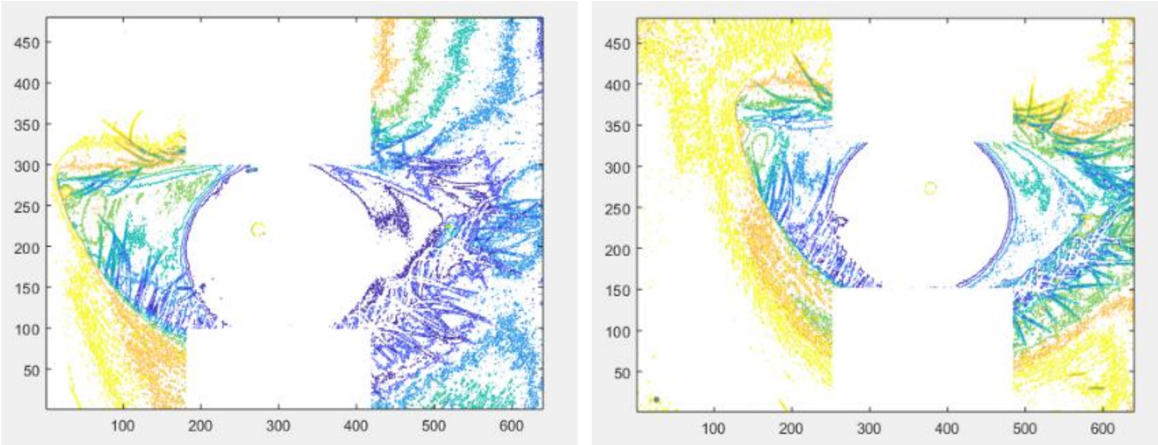
Figure 5. Five types iris localizatio n using circular hough transform (CHT): (a) canny edge result, (b) gamma adjusted result, (c) non-maxima suppression results, (d) edge result, (e) hough circle result



(a) (b)

Figure 6. The result of the iris localization from one of the sample, where, (a) the input image and (b) the localized iris image

The result of the localization process has 480×640 pixel of iris with noise images. Figure 7 shows the contour of the iris with noise images both from eye image with contact lens as shown in Figure 7(a) and iris images non-cosmetic contact lens as shown in Figure 7(b). By looking at the figures, it can be seen that the process has successfully detected the upper bound and the lower bound of the images. The area outside the bound would be ignored in feature extraction process.



(a)* (b)*

* Values shown on all axes are in pixels.

Figure 7. The contour of the iris localization result from one of the samples, where (a) iris with contact lens and (b) iris without contact lens

However, not all images have been successfully processed in iris localization, there are some images that failed to identify the circle due to the image quality and the size of the input images. This problem could decrease the accuracy of the system as the matrices of the images produced significant different numbers from the other images that used in the database. Figure 8 shows one of the eye images that failed to detect the circle of the boundary. A case like this is recommended to be further investigated in order to increase the accuracy of the iris recognition system either with or without contact lens.

Figure 8. Result from failed iris localization

4.2. Experimental results

Experiments were conducted using eye images from 40 individuals based on the experiment design presented in Table 2; whereas the eye images used was arranged as shown previously in Table 1. As can be seen in Table 2 that there are two independent variables with two values each: types of iris images (IV1 and IV2) and sources of images (IV3 and IV4). Thus, basically there are four different experiments done, with 100 repetitions for each experiment.

Summary of results in the form of confusion matrix from experiment 1 and experiment 2 is presented in Table 3. There are 40 iris images from 40 different people were tested in those experiments. Out of those 40 labels, 30 people were in the system's database (positive value) and 10 people were not in the system's database (negative value). Data in Table 3 show that the result has 27 for true positive (TP) value, 3 from false positive (FP) value, 0 from false negative (FN) value, and 10 images from true negative (TN) value. Based on those results, we can determine the matching accuracy is in the level of 92.5%, and the precision is 90%.

Table 2. Design of experiment for the iris recognition system

	Iris within database system (IV3)	Iris outside database system (IV4)
Iris with no lens (IV1)	IV1 IV3 (Experiment 1)	IV1 IV4 (Experiment 2)
Iris with non-cosmetic contact lens (IV2)	IV2 IV3 (Experiment 3)	IV2 IV4 (Experiment 4)

Table 3. Confusion matrix for iris recognition with no lens

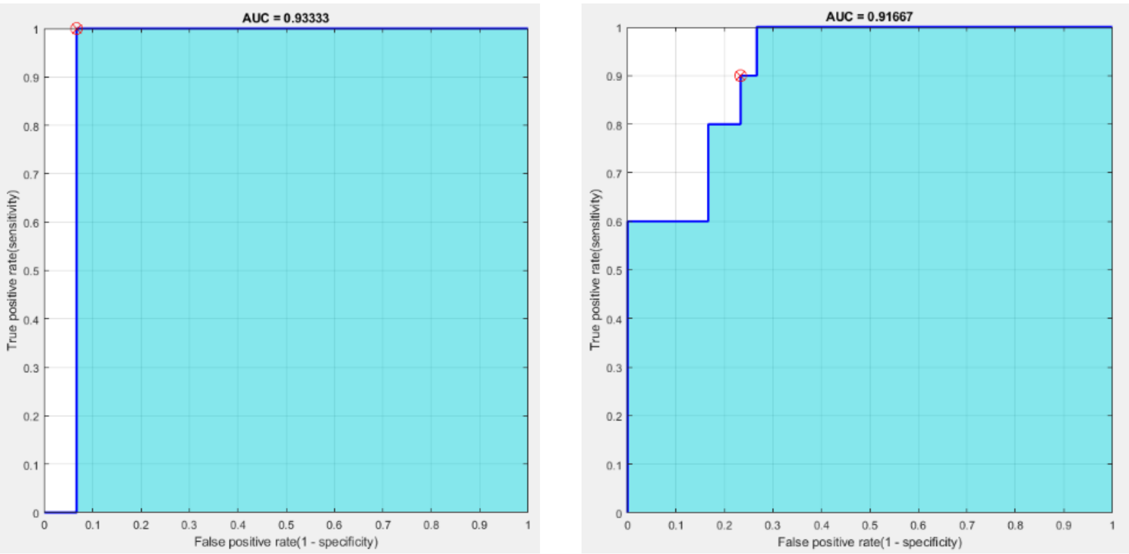
		Predicted value		
		True classification	False classification	Total
Actual values	True classification	27	3	30
	False classification	0	10	10
	Total	27	13	

For experiment 3 and experiment 4 which used images of iris with non-cosmetic contact lens, the confusion matrix is presented in Table 4. Data in Table 4 show that the system classifies 25 images for TP value, 5 images for FP value, 2 images for FN value, and 8 images for TN value. The matching accuracy for this process is 82.5% and the precision is 83%.

Table 4. Confusion matrix for iris recognition with contact lens

		Predicted value		
		True classification	False classification	Total
Actual values	True classification	25	5	30
	False classification	2	8	10
	Total	27	13	

The result of Hamming distance which determined using MATLAB code from this source [39] is presented in the form of receiver operating characteristic curve (ROC) and area under roc curve (AUC) as depicted in Figure 9. The curve in Figure 9(a) shows that the AUC for the recognition of iris with no lens is 0.9333, which shows that the model has a good prediction capability. For the case of iris with non-cosmetic contact lens, it can be seen in Figure 9(b) that the AUC is 0.9167 which also indicates its good prediction capability [40].



(a) (b)

Figure 9. The iris recognition system performance in ROC and AUC for, (a) iris with no lens and (b) iris with contact lens

5. CONCLUSION

This research work has developed an iris recognition system for eyes with non-cosmetic contact lenses using CHT for iris localization in the preprocessing phase and DWT for feature extraction. The experimental results done to the system have shown its good performance, whereby the accuracy is 92.5% for eyes without contact lens and 82.5% for eyes with contact lenses. In addition, the AUC value also supports the good prediction capability of the system with 0.9333 for eyes without contact lens and 0.9167 for eyes with contact lenses. Though the results are quite promising, improvements are still needed to increase its accuracy. Learning from the processes performed in the system, the preprocessing phase, especially iris localization, plays a very important role in making sure for a good performance of the recognition system. Further work in improving the iris localization technique is recommended to significantly improve the performance of the recognition system.

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REFERENCES

[1] M. A. Hendrawan, P. Y. Saputra, and C. Rahmad, "Identification of optimum segment in single channel EEG biometric system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 23, no. 3, pp. 1847–1854, 2021, doi: 10.11591/ijeecs.v23.i3.pp1847-1854.

[2] M. A. Elshahed, "Personal identity verification based ECG biometric using non-fiducial features," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 3, pp. 3007–3013, 2020, doi: 10.11591/ijece.v10i3.pp3007-3013.

[3] A. K. Jain, A. Ross, and S. Prabhakar, "An introduction to biometric recognition," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 14, no. 1, pp. 4–20, 2004, doi: 10.1109/TCSVT.2003.818349.

[4] A. J. Kehinde, O. T. Omolewa, A. O. Noah, and A. T. Taiwo, "Hand geometry recognition: an approach for closed and separated fingers," *International Journal of Electrical and Computer Engineering*, vol. 12, no. 6, pp. 6079–6089, 2022, doi: 10.11591/ijece.v12i6.pp6079-6089.

[5] K. Soumia, B. Mohammed, H. Aymen, and K. Ibrahim, "Biometric authentication using curvelet transform," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 20, no. 3, pp. 1332–1341, 2020, doi: 10.11591/ijeecs.v20.i3.pp1332-1341.

[6] S. A. Baker, H. H. Mohammed, and H. A. Aldabagh, "Improving face recognition by artificial neural network using principal component analysis," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 18, no. 6, pp. 3357–3364, 2020, doi: 10.12928/TELKOMNIKA.v18i6.16335.

[7] Q. A. Al-hussain Hadi, "Vein palm recognition model using fusion of features," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 18, no. 6, pp. 2921–2927, 2020, doi: 10.12928/TELKOMNIKA.v18i6.16149.

[8] L. F. and A. Safir, "US4641349_iris recognition system," 1987, [Online]. Available: https://www.freepatentsonline.com/4641349.html.

[9] J. G. Daugman, "High confidence visual recognition of persons by a test of statistical independence," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 15, no. 11, pp. 1148–1161, 1993, doi: 10.1109/34.244676.

[10] J. G. Daugman, "Biometric personal identification system based on iris analysis," *United States Patent*, pp. 1–24, 1994, [Online]. Available: https://www.google.com/patents/US5291560.

[11] K. Miyazawa, K. Ito, T. Aoki, K. Kobayashi, and H. Nakajima, "An effective approach for Iris recognition using phase-based image matching," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 30, no. 10, pp. 1741–1756, 2008, doi: 10.1109/TPAMI.2007.70833.

[12] L. Ma, T. Tan, Y. Wang, and D. Zhang, "Personal identification based on iris texture analysis," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 25, no. 12, pp. 1519–1533, 2003, doi: 10.1109/TPAMI.2003.1251145.

[13] L. Ma, T. Tan, Y. Wang, and D. Zhang, "Efficient iris recognition by characterizing key local variations," *IEEE Transactions on Image Processing*, vol. 13, no. 6, pp. 739–750, 2004, doi: 10.1109/TIP.2004.827237.

[14] M. Vatsa, R. Singh, and A. Noore, "Improving iris recognition performance using segmentation, quality enhancement, match score fusion, and indexing," *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*, vol. 38, no. 4, pp. 1021–1035, 2008, doi: 10.1109/TSMCB.2008.922059.

[15] D. M. Monro, S. Rakshit, and D. Zhang, "DCT-bsed iris recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 29, no. 4, pp. 586–595, 2007, doi: 10.1109/TPAMI.2007.1002.

[16] J. K. Pillai, V. M. Patel, R. Chellappa, and N. K. Ratha, "Secure and robust iris recognition using random projections and sparse representations," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 33, no. 9, pp. 1877–1893, 2011, doi: 10.1109/TPAMI.2011.34.

[17] A. Gangwar and A. Joshi, "DeepIrisNet: Deep iris representation with applications in iris recognition and cross-sensor iris recognition," *Proceedings - International Conference on Image Processing, ICIP*, vol. 2016-August, pp. 2301–2305, 2016, doi: 10.1109/ICIP.2016.7532769.

[18] S. Lei, B. Dong, A. Shan, Y. Li, W. Zhang, and F. Xiao, "Attention meta-transfer learning approach for few-shot iris recognition," *Computers and Electrical Engineering*, vol. 99, 2022, doi: 10.1016/j.compeleceng.2022.107848.

[19] A. Ferreira, A. Lourenço, B. Pinto, and J. Tendeiro, "Modifications and improvements on iris recognition," *BIOSIGNALS 2009 - Proceedings of the 2nd International Conference on Bio-Inspired Systems and Signal Processing*, pp. 72–79, 2009, doi: 10.5220/0001536100720079.

[20] J. Daugman, "How iris recognition works," *The Essential Guide to Image Processing*, pp. 715–739, 2009, doi: 10.1016/B978-0-12-374457-9.00025-1.

[21] S. E. Baker, A. Hentz, K. W. Bowyer, and P. J. Flynn, "Degradation of iris recognition performance due to non-cosmetic prescription contact lenses," *Computer Vision and Image Understanding*, vol. 114, no. 9, pp. 1030–1044, 2010, doi: 10.1016/j.cviu.2010.06.002.

[22] H. Rai and A. Yadav, "Iris recognition using combined support vector machine and Hamming distance approach," *Expert Systems with Applications*, vol. 41, no. 2, pp. 588–593, 2014, doi: 10.1016/j.eswa.2013.07.083.

[23] N. Kohli, D. Yadav, M. Vatsa, and R. Singh, "Revisiting iris recognition with color cosmetic contact lenses," *Proceedings - 2013 International Conference on Biometrics, ICB 2013*, 2013, doi: 10.1109/ICB.2013.6613021.

[24] K. W. Bowyer and J. S. Doyle, "Lenses and spoofing," pp. 96–98, 2014.

[25] R. Raghavendra, K. B. Raja, and C. Busch, "ContlensNet: Robust iris contact lens detection using deep convolutional neural networks," *Proceedings - 2017 IEEE Winter Conference on Applications of Computer Vision, WACV 2017*, pp. 1160–1167, 2017, doi: 10.1109/WACV.2017.134.

[26] Y. Jung, D. Kim, B. Son, and J. Kim, "An eye detection method robust to eyeglasses for mobile iris recognition," *Expert Systems with Applications*, vol. 67, pp. 178–188, 2017, doi: 10.1016/j.eswa.2016.09.036.

[27] N. M. Konne, S. A. Collier, J. Spangler, and J. R. Cope, "Healthy contact lens behaviors communicated by eye care providers and recalled by patients — United States, 2018," *MMWR. Morbidity and Mortality Weekly Report*, vol. 68, no. 32, pp. 693–697, 2019, doi: 10.15585/mmwr.mm6832a2.

[28] M. W. Swanson, "A cross-sectional analysis of U.S. contact lens user demographics," *Optometry and Vision Science*, vol. 89, no. 6, pp. 839–848, 2012, doi: 10.1097/OPX.0b013e318255da45.

[29] R. Moreddu, D. Vigolo, and A. K. Yetisen, "Contact lens technology: From fundamentals to applications," *Advanced Healthcare Materials*, vol. 8, no. 15, 2019, doi: 10.1002/adhm.201900368.

[30] "Contact lenses market: Global industry analysis and forecast (2022-2029)," 2022, [Online]. Available: https://www.maximizemarketresearch.com/market-report/global-contact-lenses-market/20661/#details. (Accessed on 17/05/2022)

[31] S. Jamaludin, N. Zainal, and W. M. D. W. Zaki, "Deblurring of noisy iris images in iris recognition," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 1, pp. 156–159, 2021, doi: 10.11591/eei.v10i1.2467.

[32] L. V. Birgale and M. Kokare, "Iris recognition using discrete wavelet transform," *Proceedings - 2009 International Conference on Digital Image Processing, ICDIP 2009*, pp. 147–151, 2009, doi: 10.1109/ICDIP.2009.30.

[33] A. Ullah, A. Salam, H. El Raoui, D. Sebai, and M. Rafie, "Towards more accurate iris recognition system by using hybrid approach for feature extraction along with classifier," *International Journal of Reconfigurable and Embedded Systems*, vol. 11, no. 1, pp. 59–70, 2022, doi: 10.11591/ijres.v11.i1.pp59-70.

[34] A. I. Mahameed, M. K. Ahmed, and N. B. Abdullah, "Iris recognition method based on segmentation," *EUREKA, Physics and Engineering*, vol. 2022, no. 2, pp. 166–176, 2022, doi: 10.21303/2461-4262.2022.002341.

[35] H. Zhang, Z. Sun, and T. Tan, "Contact lens detection based on weighted LBP," *Proceedings - International Conference on Pattern Recognition*, pp. 4279–4282, 2010, doi: 10.1109/ICPR.2010.1040.

[36] W. W. Kywe, M. Yoshida, and K. Murakami, "Contact lens extraction by using thermo-vision," *Proceedings - International Conference on Pattern Recognition*, vol. 4, pp. 570–573, 2006, doi: 10.1109/ICPR.2006.406.

[37] G. Erdogan and A. Ross, "Automatic detection of non-cosmetic soft contact lenses in ocular images," *Biometric and Surveillance Technology for Human and Activity Identification X*, vol. 8712, p. 87120C, 2013, doi: 10.1117/12.2018096.

[38] G. P. M Sujithra, "A survey of biometric iris recognition: Security, techniques and metrics," *Asian Journal of Information Technology*, vol. 14, no. 6, pp. 192–199, 2015, doi: 10.36478/ajit.2015.192.199.

[39] Víctor Martínez-Cagigal, "ROC curve - File exchange - MATLAB central," 2021, [Online]. Available: https://www.mathworks.com/matlabcentral/fileexchange/52442-roc-curve. (Accessed on 21/08/2021)

[40] F. Gorunescu, "Data mining: Concepts, models and techniques," *Intelligent Systems Reference Library*, vol. 12, pp. 323–324, 2011, doi: 10.1007/978-3-642-19721-5.

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