

Iris recognition using improved Xor-Sum Code

Neeru Bala, Ritesh Vyas*, Rashmi Gupta, and Anil Kumar

Abstract Iris recognition has been among the most secure and reliable biometric traits, because of its permanent and unique features. Amongst the various essential modules of an iris recognition framework, feature extraction has been the most sought for module, where numerous research works have been carried out to yield an effective representation of iris features. This paper is an attempt to propose an improved version of a famous feature descriptor, called Xor-Sum Code, to obtain an enhanced recognition accuracy. The proposed approach incorporates the curvature information into the conventional Gabor filter, to facilitate discriminative iris feature representation. A rigorous experimentation, with two challenging benchmark iris datasets, has been performed to approve the viability of suggested strategy. The approach proposed under this work is also generalized to work with both the near infrared and visible wavelength images.

1 Introduction

Biometric authentication had been used in personal identification frameworks since decades. The automated identification of persons relying upon behavioural and physical features is termed as Biometric authentication [1]. Embracing innovative methods

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to furnish greater accuracy, extra security and promptness, biometric authentication system has grown as a novel arena to be explored. Biometric authentication framework can be driven in two manners i.e. Identification and verification mode. DNA, ear, face, fingerprint, palmprint, iris, keystrokes, odour, retinal scan, signature, periocular, gait, ECG, EEG, palm vein, finger vein, hand geometry and voice are some physical and behavioural traits which can be used in human authentication [2]. Biometric system is expedient in terms of validation, secrecy or data concealment, access control, and non-abandonment. The most persistent trait in biometrics is iris [3]. Iris is the shaded circle around the pupil which controls the entering of light in eye [4].

One of the most encouraging fields in biometrics is iris recognition as the attributes of iris are essentially distinctive which can be perceived even from certain distance. The False acceptance/rejection rates are perceptibly lower than the other traits, that's why forgery and spoofing are a very perplexing chore in case of iris. The key stages of an iris recognition system comprise of image acquirement, pre-processing of image, feature extraction and classification. A general block diagram of iris recognition framework is depicted in Fig. 1.

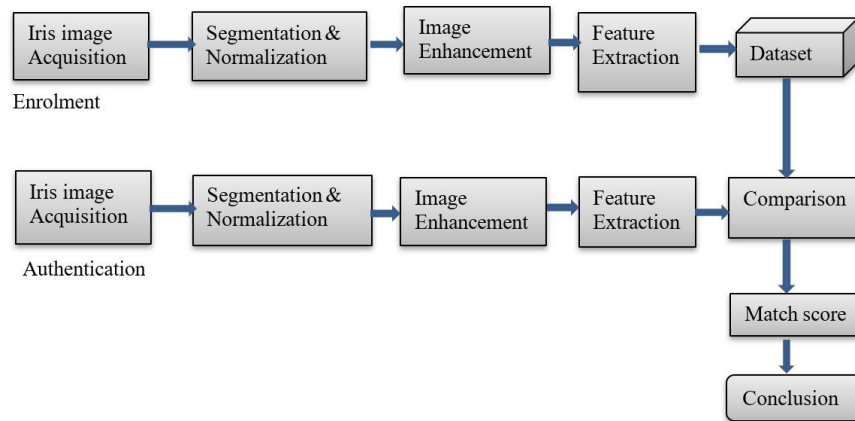


Fig. 1 A common iris recognition system

Following are the various indispensable pluses of iris recognition system:

1. Precision: Iris is the extraordinary modality as compared to other biometric modalities regarding precision. FAR and FRR are perceptibly lesser in iris recognition system, which certifies the greater precision.
2. Adaptability: This technique is profoundly adaptable and can be utilized in both huge and little scope programs. That's why it has been deployed in many person authentication systems as well as in various governments' authentication systems.
3. Permanence: The texture of Iris designs stays invariant all through a person's life.
4. Accessible: Iris recognition system is modest to utilize related to other biometric traits. The only requirement is to stand facing camera for image acquisition.

5. Contactless: Authentication: The acquisition system in iris recognition acquires the image without having any substantial contact of individual with the machine hence this method is sterile.

2 Related work

Firstly, Flom and Safir [5] anticipated the idea of an iris recognition system based upon inimitable characteristics of iris and pupil. Subsequently, Daugman [6] developed an iris recognition system which applies Gabor filters for texture feature extraction of iris and encrypts iris data into series of 2D Gabor wavelet coefficients and then for recognition it applies hamming distance method. Successively many outstanding research works based on iris recognition were proposed. Zhao et al. [7] proposed negative iris recognition system that was solely focussed on the security of confidentiality of iris database, irrespective of augmenting the accuracy of segmentation or the efficiency of recognition. Shifting and masking strategies were applied for efficient matching in addition to matching rule. Dhage et al. [8] extracted features employing Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) and swarm optimization for selecting features.

Chen et al. [9] introduced a novel iris recognition system for identification and matching of iris crypts automatically regardless of their sizes. To manage the possible topological variations in the extraction of identical crypt in dissimilar images Earth Mover's Distance matching model has been used. Hofbauer et al. [10] proposed an experimental analysis to check the effect of segmentation and feature extraction techniques on recognition rate of the system and proved that decision for selecting segmentation and feature extraction technique must be done together as these are interdependent.

Nalla and Kumar [11] developed a novel algorithm based on Markov random field model to enhance the iris recognition rate and an EDA-NBNN based classification structure for matching of cross-domain images. The efficacy of the proposed framework has been evaluated on two public datasets. Ahmadi and Akbarizadeh [12] introduced an effective and robust iris recognition system that uses MLPNN and PSO for classification of images. For feature extraction it employs 2D Gabor kernel algorithm and results are validated on on publicly available datasets.

Chen et al. [13] presented an innovative technique for efficiently extracting distinctive feature vectors of iris. Amalgamation of T-Center loss and traditional softmax loss functions augmented the discerning capability of CNN based deep features. Nguyen et al. [14] suggested a novel approach on the basis of artificial intelligence. Their experimental outcomes demonstrate that even though the network was primarily trained with features of general things, it performs well in representation of iris images, validation of proposed approach has been done on two publicly available datasets. Daugman and Downing [15] investigated the correlation of texture features amid radially scattered bits of Iris codes acquired from iris images instead of correlation between raw pixels. Two-dimensional wavelet is employed to obtain iris codes.

Vyas et al. [16] introduced a novel feature extractor, derived through sub-bands of curvelet transform, for better iris recognition.

Liu et al. [17] applied collaborative representation method for feature detection and categorisation of iris images. Ahmadi et al. [18] suggested amalgamation of step filter, polynomial filter and 2-D Gabor filter, for extracting features of iris images and employed combination of radial basis function neural network (RBFNN) and genetic algorithm (GA) for classification of images, which results in efficient iris recognition system. Sahu et al. [19] introduced a novel feature reduction technique for Phase Intensive Local Pattern (PILP) by employing density-based clustering technique (DBSCAN), which results in feature vector of five times lesser dimensionality with same recognition accuracy.

Barpanda et al. [20] proposed wavelet mel-cepstrum for extracting features of iris images and employed MFCC for classification of iris patterns. They also compared the outcome of their suggested approach with another existent approaches and proved that proposed system beat the others. Galdi and Dugelay [21] amalgamated color and texture features and proposed a novel approach for smartphones with lesser computational power. Oktiana et al. [22] employed homomorphic filters for conquering the reflection and phase based classifier for categorizing images in order to design a cross-spectral iris recognition system with augmented recognition accuracy.

In this paper, the existing Xor-Sum Code is modified by including the curvature information in the 2D Gabor filters. This curvature information aids to the uniqueness of the extracted iris features, which in turn leads to the performance improvement of the overall recognition system. Further, inclusion of curvature information may prove to be effective with images acquired under visible wavelength illumination, which are otherwise more challenging to represent. Hence, this paper provides a comprehensive evaluation of iris recognition system. Rest of the paper is organized in the following manner: introduction and related works are discussed in Sections 1 and 2, respectively. Whereas, the proposed approach through curvature Gabor filter is elucidated in Section 3. Subsequently, discussions of database, performance metrics and obtained results are completed in Section 4. Lastly, Section 5 concludes the paper along with specifying few future directions of work.

3 Proposed approach

This paper presents an improved version of Xor-Sum code (IXSC) [23], making it more suitable to iris recognition application both in visible wavelength (VW) and near infrared (NIR) spectrums. As was apparent from the original approach [23] that the use of two-dimensional (2D) Gabor filters could facilitate the task of iris recognition in an effective manner. This efficacy could be attributed to the ability of Gabor filters to model the receptive fields of a simple cell in the primary visual cortex [24]. It is due to this property only that the Gabor filter could yield unprecedented performance by highlighting the micro textures present in the normalized iris templates.

However, after carrying out the outperforming legacy of the aforementioned approach [23] into the datasets acquired through modern-era devices, we have observed that the approach could not deliver to the fullest of its capabilities. This may be happening because of the extended challenges in case of visible wavelength iris images (which are very popular in more recent datasets). Some of the common challenges are huge reflections, illumination variations, blur and off-focus. All these challenges make it hard for the conventional Gabor filters to perform in an epochal way. Hence, there has been a need to have an efficient feature descriptor that can perform well for both NIR and VW images.

The conventional Gabor filter has been effectively used to capture the orientation of micro-textural regions present in the iris template. However, if the curvature of these regions can also be taken into account, then the recognition accuracy can be enhanced to a considerable extent. These small curvatures present in the textural edges can aid to the distinctiveness of Xor-Sum Code features, hence making it a more suitable descriptors for VW images as well.

3.1 Curvature Gabor Filter (CGF)

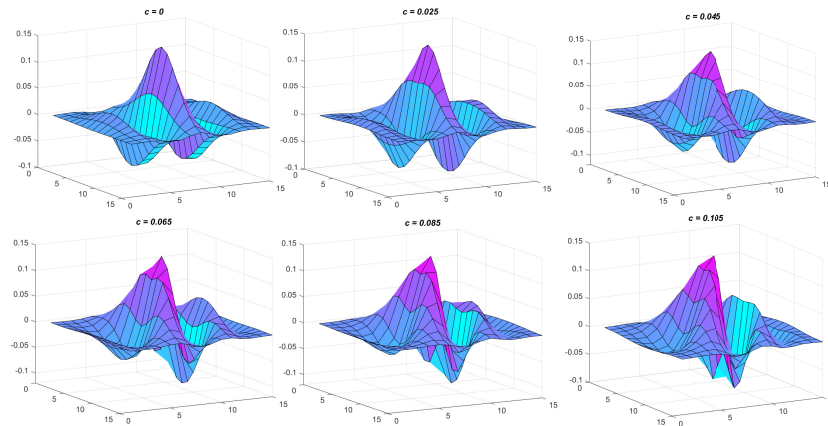


Fig. 2 Effect of curvature control parameter (c)

CGF is a modified form of the traditional 2D Gabor filter, where a curvature parameter gets included in the mathematical expression itself [25], as shown in the equation below:

$$\xi(x, y, \sigma, \nu, \phi, c) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-\frac{x^2+y^2}{2\sigma^2}\right\} \times \exp\left\{2\pi i \left(\nu(x \cos(\phi) + y \sin(\phi)) + c\sqrt{x^2+y^2}\right)\right\} \quad (1)$$

In addition to the known parameters from [23], above equation is equipped with a curvature control parameter, ‘ c ’, which usually defines the degree of curvature in the filter responses. Figure 2 illustrates the varying curvature with different values of ‘ c ’, where smaller ‘ c ’ tends to a smaller degree of curvature and vice-versa. Notably, if curvature control parameter (‘ c ’) becomes zero, the filter turns into a conventional Gabor filter (i.e. with no curvature information). Whereas, Fig. 3 illustrates the 2D surface plots of CGF, where the curvature degrees can be easily visualized.

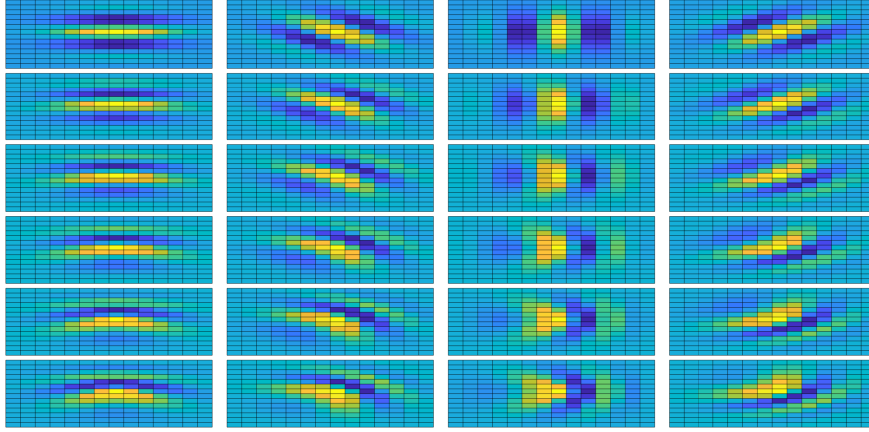


Fig. 3 2D surface plots of CGF; (rows) ‘ c ’ = [0,0.025,0.045,0.065,0.085,0.105]; (columns) orientations (in degrees) = [0,45,90,135]

4 Results and discussion

In this paper, two challenging databases, namely IITD [26, 27] and CrossEyed iris databases [28, 29], are employed for the purpose of experimentation. Out of these two databases, the IITD iris database consists of eye images acquired in NIR wavelength. Furthermore, the images of this database were acquired in a constrained environment i.e. with minimal illumination variations and nominal challenges like specular reflections and/or blur. Further, this database provides 2240 eye images from 224 subjects, with five images from each eye of the subject. On the other hand, the second employed database, the CrossEyed database is a more contemporary one, providing eye images in both NIR and VW wavelengths, that too possessing pixel-to-pixel correspondence among different wavelength images. The images in

this database suffer from more real-life challenges, such as larger reflections and off-focus error. Moreover, this database consists of 960 iris images captured in NIR and VW wavelengths from both the left and right eyes of 120 subjects, respectively. However, current work employs only 500 images from 50 subjects from both the VW and NIR illuminations.

Notably, before the feature extraction stage, all the employed eye images are processed through the segmentation procedure followed by normalization of the iris regions into rectangular templates of dimensions 64×512 . These constant dimensions of iris templates facilitate the invariable matching irrespective of the dilation and contraction of pupil. The sample eye images from both the employed databases and their corresponding normalized iris templates are shown in Fig. 4. Readers are advised to refer to [30] for details of the segmentation procedure. For comparison purpose, the famous performance metrics of the biometrics domain are utilized, especially the equal error rate (EER), genuine acceptance rate (GAR), false acceptance rate (FAR) and decidability index (DI). Notably, all the GAR's are reported at FAR of 1%. The receiver operating characteristics (ROC) curves are also exhibited for enhanced visualization of the recognition performance. Another vital metric is the area under the ROC curve (AUC).

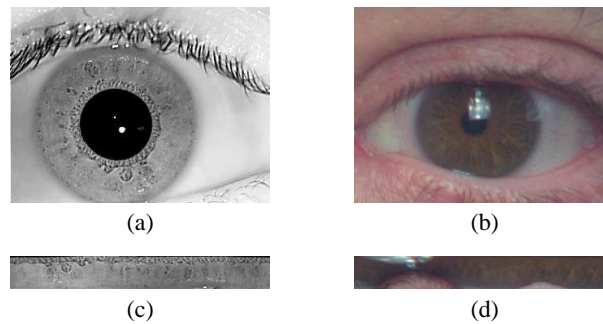


Fig. 4 Sample images; (a) Eye image from IITD database, (b) Eye image from CrossEyed-VW database, (c) Iris template corresponding to eye image in (a), (d) Iris template corresponding to eye image in (b)

4.1 IITD iris database

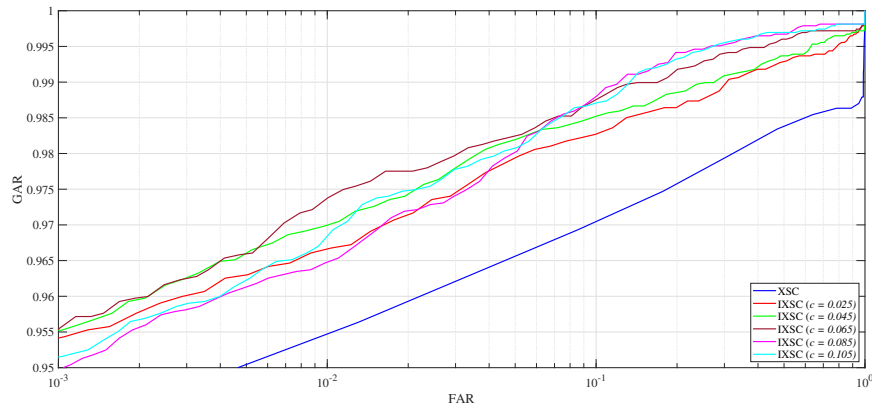
The investigations in this paper first considers the IITD iris database, where multiple values of curvature control parameters are explored to identify the best suited value. The obtained performance metrics and corresponding ROC curves are demonstrated in Table 1 and Fig. 5.

It is apparent from the Table 1 that inclusion of curvature information into the Gabor filter has certainly led to improvements in all the performance metrics. How-

Table 1 Performance metrics for IITD database

Approach	EER (%)	DI	GAR (%)	AUC
Xor-Sum Code (XSC)	3.62	2.7427	95.48	0.9807
Improved XSC ($c = 0.025$)	2.55	2.5599	96.67	0.9907
Improved XSC ($c = 0.045$)	2.36	2.6882	97	0.9919
Improved XSC ($c = 0.065$)	2.28	2.7326	97.38	0.9938
Improved XSC ($c = 0.085$)	2.7	2.6541	96.48	0.9946
Improved XSC ($c = 0.105$)	2.43	2.6285	96.84	0.9945

ever, for ascertaining the optimal degree of curvature, experiments are performed with five different values of parameter ‘ c ’. However, larger values of ‘ c ’ are not tested because of absence of huge curvatures in the iris texture. From the employed values, it can be noticed from the ROC curves that curvature of 0.065 proves to be suitable for the problem on hand. As is evident from Table 1, this optimal value of curvature yields approximately 37% improvement in EER when compared with that of original XSC. This huge improvement can be vital and decisive, looking at the large number of classes of the IITD database. At the same time, incorporation of this curvature also enhances the GAR value from 95.48% to 97.38%, which is also quite significant.

**Fig. 5** ROC curves for IITD iris database using various curvature degrees

In addition to EER and GAR, the other two performance metrics (DI and AUC) for CGF with ‘ c ’ = 0.065 are reported as 2.7326 and 0.9938, respectively. This points towards improvement in AUC and almost similar DI, as compared to the original XSC. Furthermore, it is interesting to see that every degree of curvature, which is investigated in the current work, has contributed towards the improvement in almost all the performance metrics. This fact can be validated through the ROC

curves shown in Fig. 5, where all the curves corresponding to the improved XSC (IXSC) lies above that of XSC. This clearly supports the hypothesis of gathering the curvature information about the textural edges of iris for improved performance.

4.2 CrossEyed iris database

This database has more challenging eye images, emerging from the visible wavelength as well. Moreover, this database comes up with registered NIR and VW images, which means that there is pixel-to-pixel correspondence within the NIR and VW versions of images for every eye. Hence, this database can be suitable for investigations on cross-spectral iris recognition. However, the current work is focused towards establishing the generalized capability of IXSC approach to both the NIR and VW matching scenarios individually, and not towards the cross-spectral matching framework. Hence, only individual VW results are reported here, which are subsequently reflected in the NIR counterpart as well.

Table 2 Performance metrics for CrossEyed-VW database

Approach	EER (%)	DI	GAR (%)	AUC
Xor-Sum Code (XSC)	9.75	1.8581	83.16	0.9509
Improved XSC (c = 0.025)	11.79	1.5416	79.03	0.9353
Improved XSC (c = 0.045)	7.96	2.0513	86.72	0.9654
Improved XSC (c = 0.065)	8.48	2.2301	86.59	0.9619
Improved XSC (c = 0.085)	9.07	2.19	86.08	0.954
Improved XSC (c = 0.105)	8.82	2.3002	87.32	0.9514

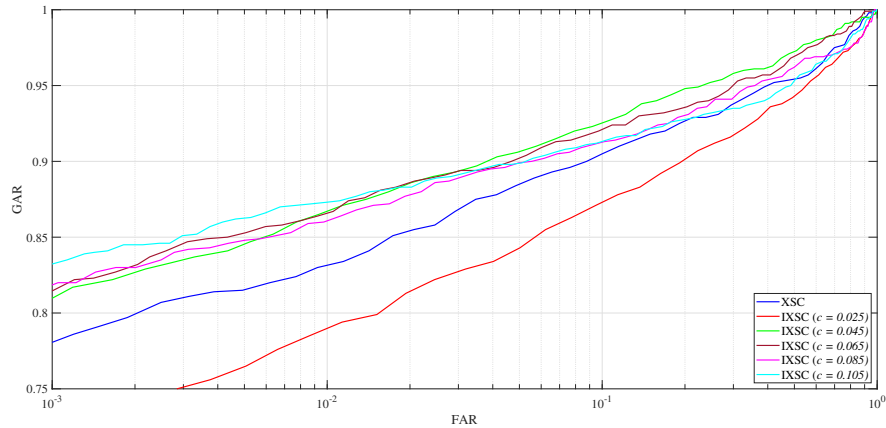


Fig. 6 ROC curves for CrossEyed-VW iris database using various curvature degrees

After careful inspection of Table 2, it is observed that the CrossEyed database exhibits better performance with IXSC for the curvature control parameter value of 0.045, most of the other values also display improvements though. For this optimal curvature, the improvements in EER and GAR are counted to be approximately 18% and 4%, respectively. These improvements are clear indication of the discriminative capability of curvature Gabor filters. Concurrently, the other metrics, namely DI and AUC also get improved substantially. Similar trends of improvements after incorporation curvature property are illustrated in the ROC curves shown in Fig. 6 below.

Just in order to evaluate the proposed IXSC approach on NIR images, we have conducted the experiments with the optimal value of ‘ c ’ obtained from the experiments with VW images i.e. 0.045. Notably, IXSC has outperformed XSC for NIR images as well. The corresponding performance metrics are tabulated in Table 3, where the IXSC has again produced better, though slightly, results as compared with XSC.

Table 3 Quick comparison of performance for CrossEyed-NIR database

Approach	EER (%)	DI	GAR (%)	AUC
Xor-Sum Code (XSC)	8.74	2.2712	84.91	0.9504
Improved XSC ($c = 0.045$)	8.58	2.3982	85.44	0.9611

5 Conclusion

In this article, an improved Xor-Sum Code feature descriptor is proposed for the problem of iris recognition. Laid on the basis of original Xor-Sum Code, the proposed approach makes it inclusive of the curvature information along with the orientation information. Inclusion of curvature information leads to extraction of increased discriminatory features from the normalized iris templates. The proposed approach is hypothesized to work well for both types of iris images, acquired in near infrared and visible wavelength. The same fact is validated through extensive experiments with two publicly available databases, namely IITD and CrossEyed database. Huge improvements are reflected through the proposed approach in terms of common performance metrics, like EER, GAR and AUC. The largest improvement achieved is in EER for IITD iris database, where the proposed approach exhibits an improvement of almost 37%. This proves the promising nature of the proposed IXSC approach. In future, the proposed approach can be tested for more challenging frameworks, like cross-spectral and smartphone-based iris recognition.

References

1. Jain, A.K., Ross, A., Prabhakar, S.: An Introduction to Biometric Recognition. *IEEE Transactions on Circuits and Systems for Video Technology* **14**(1), 4–20 (2004)
2. Jain, A.K., Nandakumar, K., Ross, A.: 50 years of biometric research: Accomplishments, challenges, and opportunities. *Pattern Recognition Letters* **79**, 80–105 (2016)
3. McGinn, K., Tarin, S., Bowyer, K.W.: Identity verification using iris images: Performance of human examiners. In: *IEEE 6th International Conference on Biometrics: Theory, Applications and Systems, BTAS 2013*, pp. 1–6 (2013)
4. Bowyer, K.W., Hollingsworth, K., Flynn, P.J.: Image understanding for iris biometrics: A survey. *Computer Vision and Image Understanding* **110**(2), 281–307 (2008)
5. Flom, L., Safir, A.: Iris recognition system (1987). US Patent 4,641,349
6. Daugman, J.G.: High Confidence Visual Recognition of Persons by a test of statistical independence. *IEEE Transactions on Pattern Analysis and Machine Intelligence* **15**(11), 1148–1161 (1993)
7. Zhao, D., Luo, W., Liu, R., Yue, L.: Negative Iris Recognition. *IEEE Transactions on Dependable and Secure Computing* **15**(1), 112–125 (2018)
8. Dhage, S.S., Hegde, S.S., Manikantan, K., Ramachandran, S.: DWT-based Feature Extraction and Radon Transform Based Contrast Enhancement for Improved Iris Recognition. In: *International Conference on Advanced Computing Technologies and Applications*, vol. 45, pp. 256–265 (2015)
9. Chen, J.X., Shen, F., Chen, D.Z., Flynn, P.J.: Iris Recognition Based on Human-Interpretable Features. *IEEE Transactions on Information Forensics and Security* **11**(7), 1476–1485 (2016)
10. Hofbauer, H., Alonso-Fernandez, F., Bigun, J., Uhl, A.: Experimental analysis regarding the influence of iris segmentation on the recognition rate. *IET Biometrics* **5**, 200–211 (2016)
11. Nalla, P.R., Kumar, A.: Towards More Accurate Iris Recognition using Cross-Spectral Matching. *IEEE Transactions on Image Processing* **26**(1), 208–221 (2017)
12. Ahmadi, N., Akbarizadeh, G.: Hybrid robust iris recognition approach using iris image pre-processing, two-dimensional gabor features and multi-layer perceptron neural network/PSO. *IET Biometrics* **7**(2), 153–162 (2018)
13. Chen, Y., Wu, C., Wang, Y.: T-Center: A Novel Feature Extraction Approach towards Large-Scale Iris Recognition. *IEEE Access* **8**, 32365–32375 (2020)
14. Nguyen, K., Fookes, C., Ross, A., Sridharan, S.: Iris Recognition with Off-the-Shelf CNN Features: A Deep Learning Perspective. *IEEE Access* **6**, 18848–18855 (2017)
15. Daugman, J., Downing, C.: Radial correlations in iris patterns, and mutual information within IrisCodes. *IET Biometrics* **8**(3), 185–189 (2019)
16. Vyas, R., Kanumuri, T., Sheoran, G., Dubey, P.: Efficient iris recognition through curvelet transform and polynomial fitting. *Optik* **185**, 859–867 (2019)
17. Liu, X., Bai, Y., Luo, Y., Yang, Z., Liu, Y.: Iris recognition in visible spectrum based on multi-layer analogous convolution and collaborative representation. *Pattern Recognition Letters* **117**, 66–73 (2019)
18. Ahmadi, N., Nilashi, M., Samad, S., Rashid, T.A., Ahmadi, H.: An intelligent method for iris recognition using supervised machine learning techniques. *Optics and Laser Technology* **120**, 105701 (2019)
19. Sahu, B., Kumar Sa, P., Bakshi, S., Sangaiah, A.K.: Reducing dense local feature key-points for faster iris recognition. *Computers and Electrical Engineering* **70**, 939–949 (2018)
20. Barpanda, S.S., Majhi, B., Sa, P.K., Sangaiah, A.K., Bakshi, S.: Iris feature extraction through wavelet mel-frequency cepstrum coefficients. *Optics and Laser Technology* **110**, 13–23 (2018)
21. Galdi, C., Dugelay, J.L.: FIRE: Fast Iris REcognition on mobile phones by combining colour and texture features. *Pattern Recognition Letters* **91**, 44–51 (2017)
22. Oktiana, M., Horiuchi, T., Hirai, K., Saddami, K., Arnia, F., Away, Y., Munadi, K.: Cross-spectral iris recognition using phase-based matching and homomorphic filtering. *Heliyon* **6**(2), e03407 (2020)

23. Vyas, R., Kanumuri, T., Sheoran, G.: Iris Recognition using 2-D Gabor Filter and XOR- SUM Code. In: 2016 1st India International Conference on Information Processing (IICIP), pp. 1–5 (2016)
24. Kong, W.K., Zhang, D., Li, W.: Palmprint feature extraction using 2-D Gabor filters. *Pattern Recognition* **36**(10), 2339–2347 (2003)
25. Wang, H., Du, M., Zhou, J., Tao, L.: Weber Local Descriptors with Variable Curvature Gabor Filter for Finger Vein Recognition. *IEEE Access* **7**, 108261–108277 (2019)
26. Kumar, A., Passi, A.: Comparison and combination of iris matchers for reliable personal authentication. *Pattern Recognition* **43**, 1016–1026 (2010)
27. IITD iris database. URL http://www4.comp.polyu.edu.hk/~csajaykr/IITD/Database_Iris.htm
28. Sequeira, A.F., Chen, L., Ferryman, J., Alonso-Fernandez, F., Bigun, J., Raja, K.B., Raghavendra, R., Busch, C., Wild, P.: Cross-Eyed - Cross-Spectral Iris/Periocular Recognition Database and Competition. In: 5th International conference of the Biometrics Special Interest Group (BIOSIG 2016), pp. 1–5. Sequeira2016 (2016). URL <https://sites.google.com/site/crossspectrumcompetition/home>
29. Sequeira, A.F., Chen, L., Ferryman, J., Wild, P., Alonso-fernandez, F., Bigun, J., Raja, K.B., Raghavendra, R., Busch, C., Pereira, T.D.F., Marcel, S., Behera, S.S., Gour, M., Kanhangad, V.: Cross-Eyed 2017 : Cross-Spectral Iris / Periocular Recognition Competition. In: IEEE International Joint Conference on Biometrics (IJCB), pp. 725–732 (2017)
30. Vyas, R., Kanumuri, T., Sheoran, G., Dubey, P.: Efficient features for smartphone-based iris recognition. *Turkish Journal of Electrical Engineering and Computer Sciences* **27**(3), 1589–1602 (2019)