

International Journal of Control Theory and Applications

ISSN : 0974-5572

© International Science Press

Volume 10 • Number 19 • 2017

A Hybrid Multibiometric Approach for Fusion of Iris and Face

Sheetal Chaudhary¹ and Rajender Nath¹

¹ Department of Computer Science & Applications, Kurukshetra University, Kurukshetra, Haryana, India,
Email: sheetalkuk@rediffmail.com, rnath_2k3@rediffmail.com

Abstract: In this paper, a hybrid approach for fusion of iris and face is presented using multi-instance and multi-modal sources of biometric information. Fusion is performed at feature level as well as match score level. It provides security at two steps. At first step, multiple instances of iris (left iris and right iris) are combined at feature level to generate a single merged feature set of iris. Instead of storing actual features in database, this resultant feature set obtained after fusion of left iris and right iris is stored as a template in the database. Thus, iris template becomes more secure and rich in information. At second step, match scores of merged iris and face are combined at match score level to generate the final decision whether the person is accepted or rejected. The proposed fusion strategy is blend of two fusion approaches (multi-instance and multi-modal) making it capable to overcome the drawbacks of unimodal biometric systems. Experimental results show that hybrid multibiometric system outperforms unimodal biometric systems.

Keywords: Score normalization, Iris recognition, Face recognition, Sum rule, Product rule, Fusion

1. INTRODUCTION

Biometrics is one of the most extensively used approaches for the authentication of an individual using physiological (face, fingerprint, iris, hand geometry etc.) or behavioral characteristic (signature, voice, gait etc.) [1]. Biometric systems are beneficial because they do not require a person to carry cards or remember information, unlike traditional authentication systems based on smart cards or passwords. These systems require the person being authenticated to be present at the time and point of authentication, so it is difficult to forge biometrics. Biometric systems can be more convenient for the users since there is no password to be forgotten or key to be lost and a single biometric trait (e.g., fingerprint) can be used to access a number of accounts without the trouble of remembering passwords. Therefore, a biometrics-based authentication scheme is a strong alternative to traditional authentication schemes and has been accepted in many applications [2].

Biometric system that uses a single biometric trait to establish identity is known as a unibiometric system. The limitations faced by these systems can be improved by fusing the information presented by multiple sources. A system that integrates the evidence presented by multiple biometric sources is known as a multibiometric system. These systems are estimated to be more reliable due to the availability of multiple pieces of evidence and also improves matching performance, increase population coverage and deter spoofing activities [3]. Based

upon the evidence presented by multiple sources of biometric information, a multibiometric system can be classified into five categories as shown in figure 1 – Multi-sensor systems, Multi-algorithm systems, Multi-instance systems, Multi-sample systems and Multi-modal systems [4].

- (i) Multi-sensor biometric systems capture information from different biometric sensors for the same trait. For example, optical, solid-state, and ultrasound based sensors can be used to capture fingerprints [5]; an infrared sensor may be used in conjunction with a visible-light sensor to acquire the face image of a person [6].
- (ii) Multi-algorithm systems use either multiple feature sets extracted from the same biometric data or multiple matching methods operating on a single feature set. Using multiple feature extractor and/or matcher algorithms may increase the computational requirements of these systems. For example, Lu et al. [7] has discussed a face recognition system that integrates three different face feature set extraction methods (Principal Component Analysis (PCA), Independent Component Analysis (ICA) and Linear Discriminant Analysis (LDA)).
- (iii) Multi-instance systems utilize multiple instances of the same biometric trait. For example, the left and right index fingers, or the left and right irises of an individual may be used to validate authenticity of a person [8]. These systems are helpful for those users whose biometric traits cannot be reliably captured due to natural problems. These systems also make sure the presence of a live user by asking the user to provide a random subset of biometric measurements (e.g., right middle finger followed by right index finger).
- (iv) Multi-sample systems use a single sensor to acquire multiple samples of the same biometric trait in order to find the variations that can occur in the trait. For example, a face biometric system may

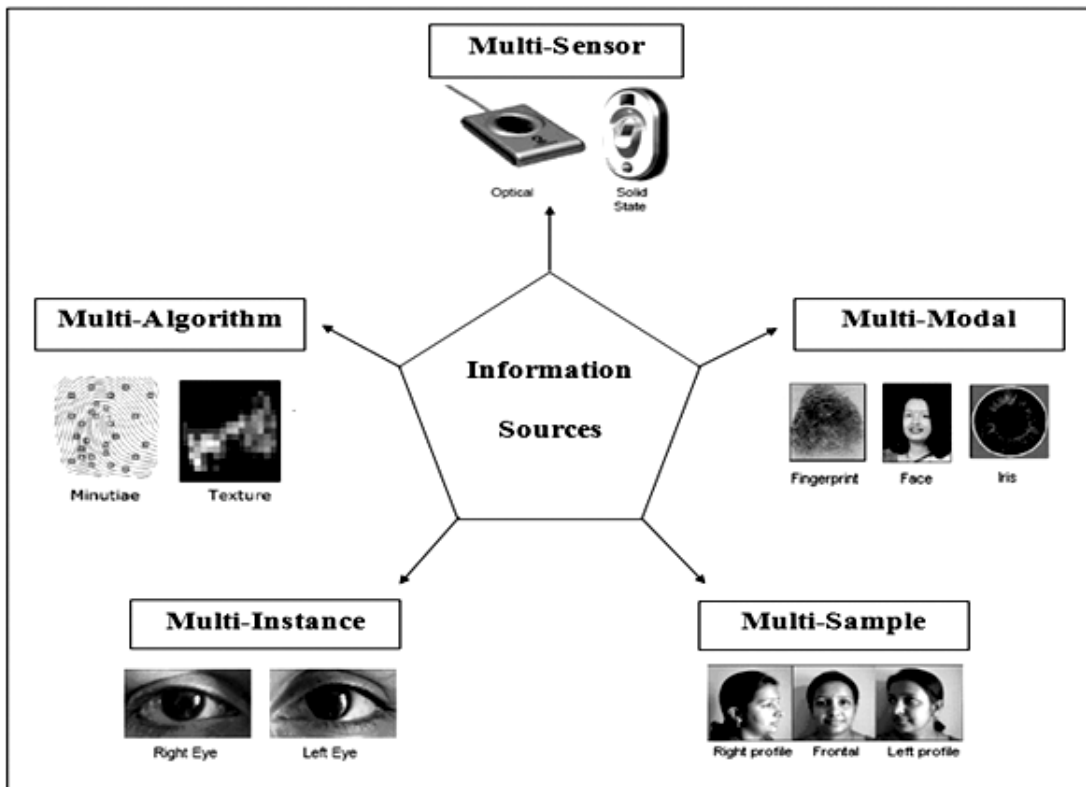


Figure 1: Various sources of information for fusion in a multibiometric system

capture the frontal profile along with the left and right profiles so as to find the variations in the facial pose [9][10].

- (v) Multi-modal systems recognize an individual by using two or more biometric traits [11]. Such systems utilize multiple sensors to acquire data of different biometric traits. For example, Brunelli et al. [12] used the face and voice traits of an individual for identification. The number of biometric traits to be enrolled in a particular application is dependent upon various factors such as nature of the application, cost of deployment, overhead introduced by computational requirements of multiple traits, correlation between the traits, enrollment time etc.

Multi-modal biometric system based on multiple biometric traits is expected to be more robust to noise, address the problem of non-universality, improve the matching accuracy, and provide reasonable security against spoof attacks. Thus, the development of biometric systems based on multiple biometric traits has received significant consideration from researchers [13]. The rest of the paper is organized as follows. In section II related works are presented. In section III the architecture of the proposed hybrid multibiometric approach for fusion of iris and face is described. Results are discussed in section IV. Finally, the summary and conclusions are given in section V.

2. RELATED WORK

Multibiometrics has attracted a lot of attention in last years and many researchers have proposed various approaches yielding mature hybrid biometric systems. Maryam et al. [14] have proposed a robust recognition system based on fusion of face and iris. They used local binary pattern local feature extractor and subspace linear discriminant analysis global feature extractor on face and iris respectively. Face and iris scores were normalized using tanh normalization and weighted sum rule was applied for the fusion. Fan Yang and Baofeng Ma [15] have combined fingerprint, palm-print and hand-geometry for person identity verification. To extract the features from fingerprint and palm-print wavelet transform was used and hand-geometry features were extracted after the pre-processing phase. Feature fusion and much score fusion were employed together to establish identity. Mohamed et al. [16] proposed a multi-modal biometric system based on fusion of fingerprint and iris at decision level. Fuzzy logic was used for the effect of each biometric result combination. Yillbyung and Byungjun [17] have proposed a biometric authentication system based on fusion of iris and face. They applied 2-D discrete wavelet transform to extract the feature sets from iris and face. To show experimental results, ORL database were used for face images and for iris database the images were acquired using CCD camera under indoor light. Ajita and Massimo [18] used face and iris to perform the feature level fusion of multi-modal and multi-unit sources of information by proposing an approach which has computed the SIFT (Scale Invariant Feature Transform) features from both biometric sources. Experimental results were shown using face and iris standard biometric databases. L.Latha and S.Thangasamy [19] have used left and right irises and retinal features, and after matching process the scores are combined using weighted sum rule. Ross et al. [20] described a fingerprint recognition system that utilized minutiae as well as texture-based information to represent and match fingerprint images. Ben-Yacoub et al. [21] considered several fusion strategies, such as support vector machines, tree classifiers and multi-layer perceptron, for fusion of face and voice biometrics. Ross and Jain [22] used face, fingerprint and hand geometry biometrics for fusion with sum, decision tree and linear discriminant-based methods.

3. PROPOSED WORK

Unibiometric systems are always not able to meet the system performance requirements due to the availability of only single biometric trait and several other problems such as noisy data, non-universality, spoof attacks etc. Multibiometric systems are based on the fusion or integration of evidence presented by multiple sources of biometric information. They combine the evidence presented by multiple biometric sensors, algorithms, instances, samples, or traits. Fusion of multiple biometric evidences plays a very important role in enhancing the recognition

accuracy of human authentication systems. Thus, a hybrid multibiometric approach for fusion of iris and face is presented in this paper which overcomes a number of inherent difficulties of the individual biometrics. Besides enhancing matching performance and recognition accuracy, the proposed approach also improves population coverage and provides protection against spoof attacks.

3.1. Iris feature set extraction

The process of iris feature set extraction shown in figure 2 consists of segmentation, normalization, enhancement of normalized iris region, feature encoding and matching by hamming distance. First of all segmentation is performed to locate the iris region in the acquired eye image. The iris region is surrounded by two circles (iris boundary and pupil boundary). To recognize these two circles the Circular Hough transform (CHT) has been used [23]. After segmentation, normalization is carried out for creating a dimensionally consistent representation of the iris region. Daugman's rubber sheet model has been used for normalization which remaps the annular iris image $I(x,y)$ from original Cartesian coordinates (x,y) to a dimensionless pseudo polar coordinate system $I(r, \theta)$ where r is in the interval $[0,1]$ with 1 corresponding to the outermost boundary and θ is the angle in the interval $[0,2\pi]$. Normalization generates a 2D array with horizontal dimensions of angular resolution and vertical dimensions of radial resolution [24]. After normalization, enhancement of normalized iris region is done by histogram equalization which improves the contrast of the image by mapping one distribution (the given histogram) to another distribution. Feature encoding extracts the most discriminating features of the iris from the normalized iris pattern and generates the binary iris template (i.e. the IrisCode which is 2048-bit binary representation of the iris) which will be used in matching. For feature set extraction, gabor filter with isotropic 2D gaussian function has been used [25]. The hamming distance between stored iris template and current iris template is calculated to generate the matching score for making a decision of acceptance or rejection [26, 27].

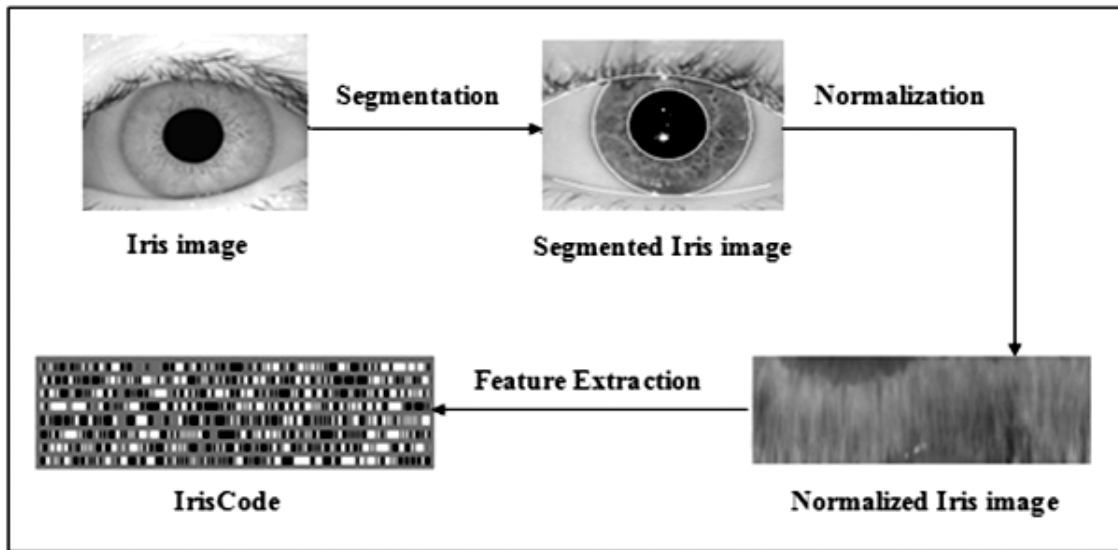


Figure 2: Steps of iris feature set extraction

3.2. Face feature set extraction

The face feature set extraction process consists of image acquisition, preprocessing, face detection, feature extraction and face recognition as shown in figure 3. The two major tasks involved in face recognition are face detection and to recognize the located faces. A number of face recognition algorithms have been discussed in the literature but appearance-based approaches are the most popular which utilizes the pixel intensity features [28]. In this paper, the PCA (Principal Component Analysis) method using eigenfaces has been used for face recognition.

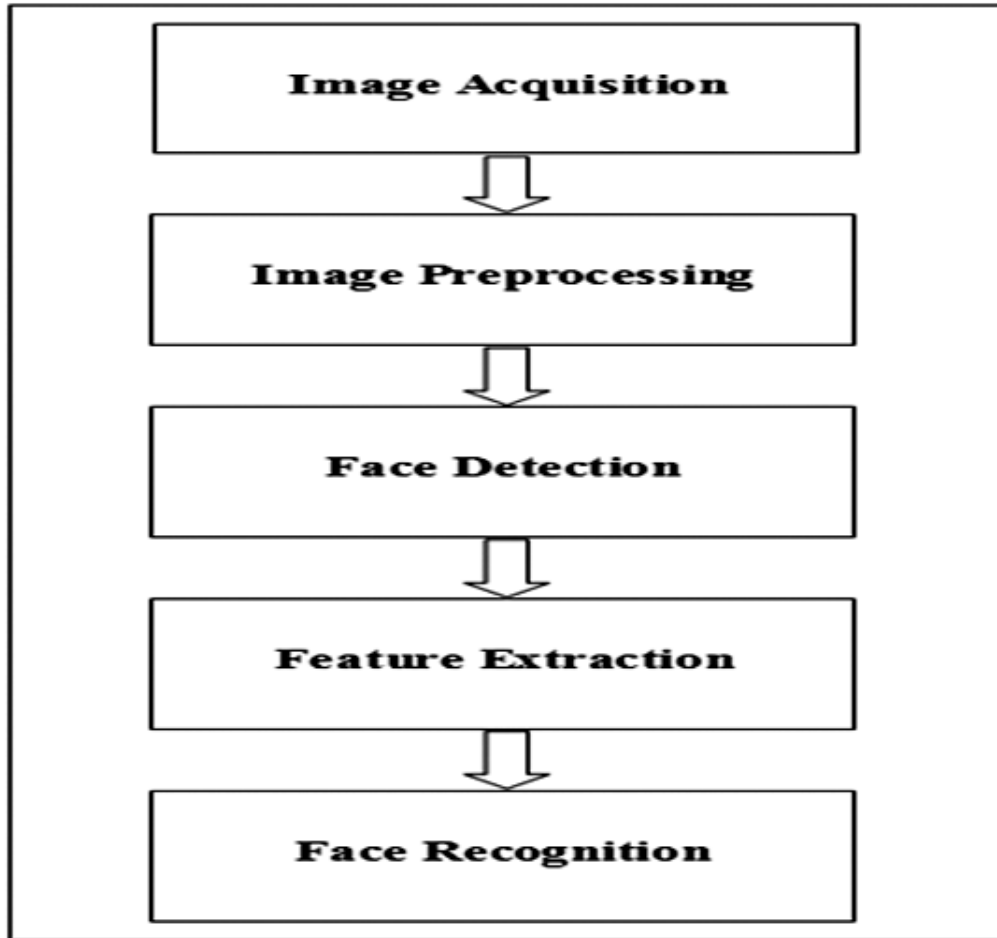


Figure 3: Steps of face feature set extraction

The eigenface based face recognition method consists of two stages [29]: (i) training stage and (ii) operational stage. In the training stage, a set of N training face images are collected. From this set of images, eigenfaces are computed that correspond to the M highest eigenvalues by projecting training facial images onto the M dimensional eigenspace. It generates the representation of each training facial image in the eigenspace. In the operational stage, a detected face image is projected onto the same eigenspace. The main idea of the principal component analysis is to find the eigenvectors or eigenfaces which best account for the distribution of face images within the entire image space or eigenspace [30]. The matching score is produced by calculating the Euclidean distance between the eigenface coefficients of the detected face and the template.

3.3. Proposed approach architecture

The architecture of proposed approach integrating iris and face using multi-instance and multi-modal sources of biometric information is shown in figure 4. It is clear from the architecture that in the beginning, the raw samples of left iris, right iris and face are captured using suitable sensors. These sample images are then given to the corresponding feature extraction modules to generate feature sets of left iris, right iris and face respectively. In this hybrid multibiometric approach, first fusion is carried out at the feature level based on multi-instance source of biometric information and second fusion is carried out at the match score level based on multi-modal source of biometric information. For feature level fusion, multiple instances of iris i.e. left iris and right iris are taken. The feature sets of left iris and right iris are combined to create a single merged

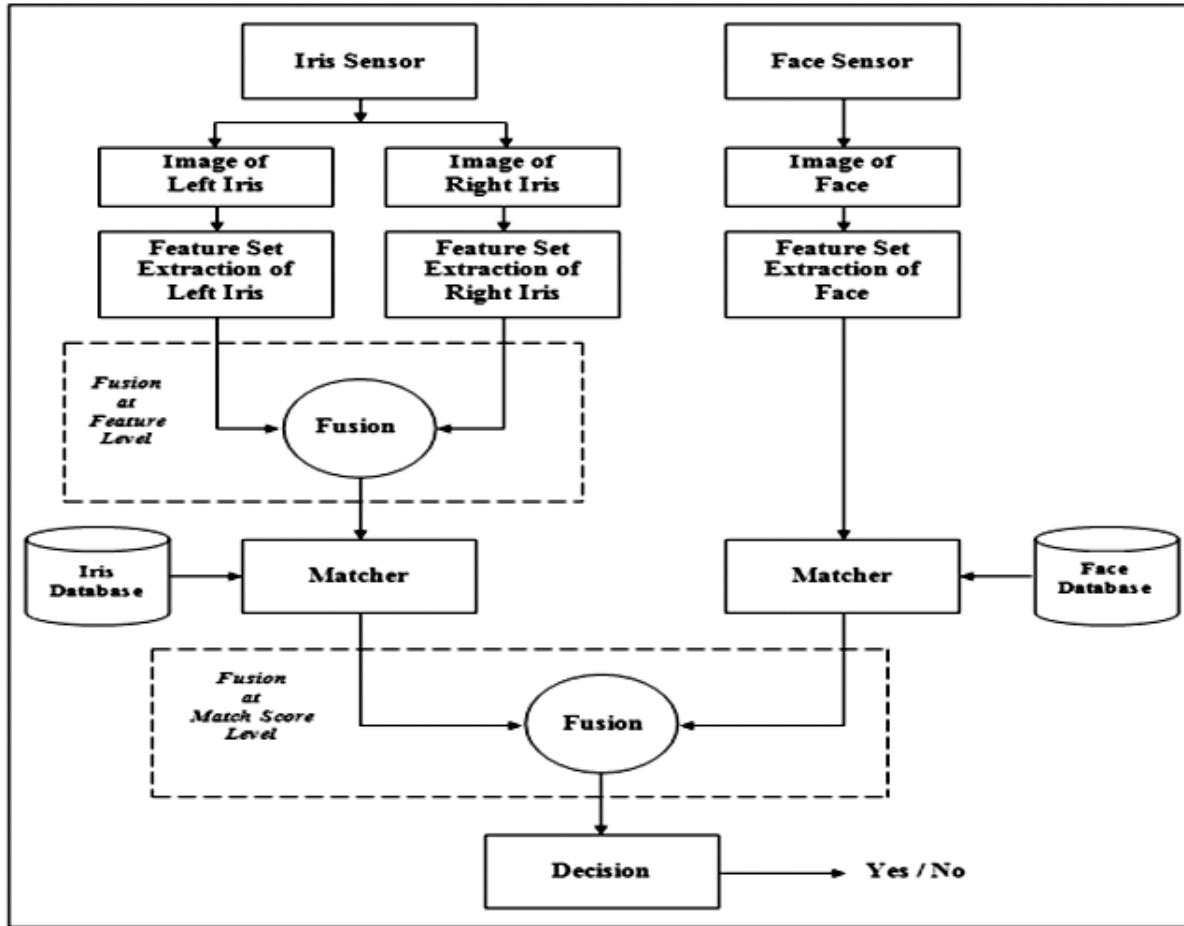


Figure 4: Architecture of proposed approach

feature set of iris. This resultant feature set is stored as a template in the iris database. It is rich in information and more secure than individual left iris or right iris template. At match score level, the matching scores of merged iris and face are combined to produce a final match score which is then passed to the decision module for final decision. Finally, a fixed threshold is utilized by the decision module to declare a person as genuine or an imposter. This hybrid approach provides security at two levels – feature level and match score level, thus making difficult for an imposter to spoof multiple biometric traits (i.e. left iris, right iris, and face) simultaneously.

1) *Multi-Instance fusion at feature level*: Fusion at feature level consists of combining the evidence presented by two biometric feature sets of the same person. Here, multiple instances of the same trait i.e. left iris and right

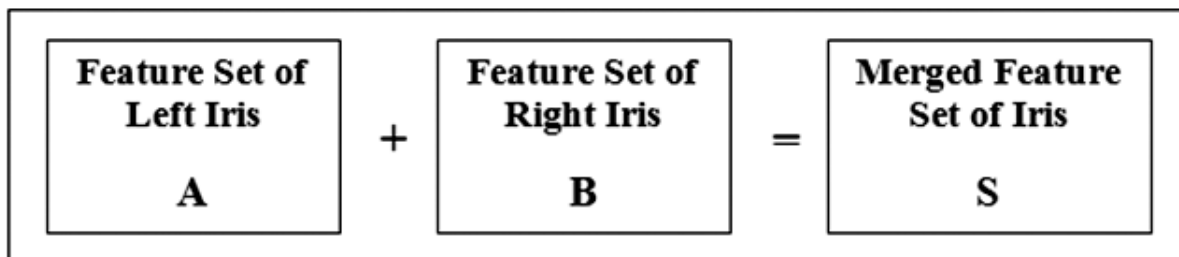


Figure 5: Fusion of left iris and right iris at feature level

iris are combined at feature level as shown in figure 5. Fusion is carried out by a simple concatenation of the two feature sets followed by feature selection or dimensionality reduction process.

Let $A = \{a_1, a_2, \dots, a_m\}$ and $B = \{b_1, b_2, \dots, b_n\}$ represents the feature vectors of left iris and right iris respectively. Fusion module shown in architecture combines these two feature vectors A (left iris) and B (right iris) in order to generate a new feature vector X of dimensionality, $k < (m + n)$. Min-max normalization [31] technique may be used in this work to modify the location and scale of the feature values via a transformation function in order to map them into a common domain. Normalization of the feature vectors A and B results in modified feature vectors $A' = \{a'_1, a'_2, \dots, a'_m\}$ and $B' = \{b'_1, b'_2, \dots, b'_m\}$ as given below:

$$A' = \frac{A - \min(F_A)}{\max(F_A) - \min(F_A)}$$

$$B' = \frac{B - \min(F_B)}{\max(F_B) - \min(F_B)} \tag{1}$$

where F_A and F_B are the functions which generates A and B . The normalized feature vectors A' and B' are concatenated which results in a new feature vector $S' = \{a'_1, a'_2, \dots, a'_m, b'_1, b'_2, \dots, b'_n\}$. Now, feature selection process [31] is applied on S' to reduce its dimensionality which results in a minimal feature set $S' = \{s_1, s_2, \dots, s_k\}$, where $k < (m + n)$.

2) *Multi-Modal fusion at match score level*: Fusion at match score level consists of combining the match scores output by different biometric matchers. Here, match scores of merged iris (left iris + right iris) and face are combined at match score level as shown in figure 6.

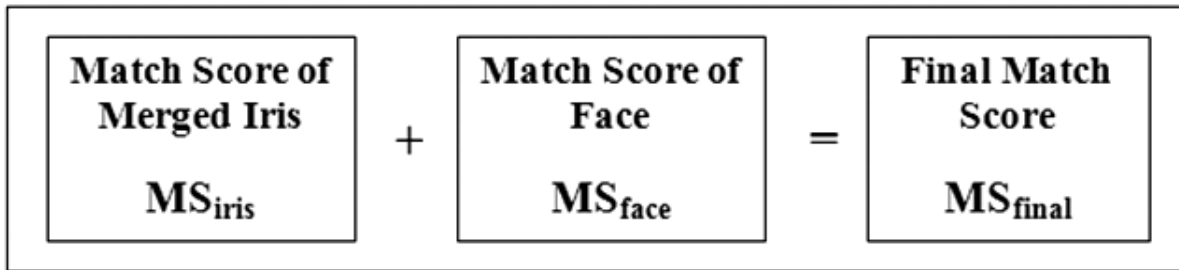


Figure 6: Fusion of merged iris and face at match score level

Let MS_{iris} and MS_{face} are the matching scores produced by merged iris and face biometric matchers respectively. The match scores of merged iris and face are heterogeneous because they are not on the same numerical range. So, it is necessary to transform these scores into a common domain before combining them by carrying out score normalization. Min-max normalization [32] may be used in this work to transform these scores (MS_{iris} and MS_{face}) into a common range $[0, 1]$. The normalized scores produced by min-max equation are given below:

$$N_{iris} = \frac{MS_{iris} - \min_{iris}}{\max_{iris} - \min_{iris}}$$

$$N_{face} = \frac{MS_{face} - \min_{face}}{\max_{face} - \min_{face}} \tag{2}$$

where $[\min_{iris}, \max_{iris}]$ are the minimum and maximum scores for iris biometric, $[\min_{face}, \max_{face}]$ are the minimum and maximum scores for face biometric, N_{iris} and N_{face} are the normalized matching scores of iris and face biometrics respectively.

The normalized scores of iris and face are combined using simple sum [32] rule to produce final match score (MS_{final}) as given below:

$$MS_{final} = N_{iris} + N_{face} \tag{3}$$

The final matching score MS_{final} is passed to the decision module and is compared against a certain threshold value to declare the person as genuine or an imposter.

4. RESULTS AND DISCUSSION

In this paper, a hybrid approach for fusion of iris and face at feature level and match score level is presented. It was implemented using MATLAB. The sample biometric data for iris and face was taken from CASIA database [33] and NIST website [34] respectively. The performance of proposed approach has been evaluated using the FAR (False Accept Rate) and FRR (False Reject Rate) measures. It is represented by the ROC (Receiver Operating Characteristic) curve which plots FAR probability versus FRR probability for different values of the decision threshold. FAR is the probability that the biometric system wrongly declares a successful match between the input pattern and a non-matching pattern in the database. FRR is the probability that the biometric system wrongly declares failure of match between the input pattern and a matching pattern in the database. Thus, FAR calculates the percentage of invalid inputs which are incorrectly accepted and FRR calculates the percentage of valid inputs which are incorrectly rejected [35].

To evaluate the effectiveness of proposed fusion strategy, two biometric traits (iris and face) have been used. It provides security at two levels- feature level and match score level. At feature level, multiple instances of iris i.e. left iris and right iris are taken and merged together to form a template that is rich in information and more protected than single instance of iris. One of the key benefits of carrying out fusion at feature level is that redundant feature values are detected and removed before moving to the next step. Then, normalized scores of merged iris and face are combined using simple sum rule to carry out fusion at match score level. Table 1 shows the experimental results for multi-instance fusion (left iris + right iris). Table 2 presents the experimental results for face recognition system. Table 3 shows the results for multi-modal fusion (merged iris (left iris + right iris)

Table 1
FAR and FRR at Various Thresholds in Multi-Instance Fusion (Left Iris + Right Iris)

Threshold	Fusion (Left Iris + Right Iris)	
	FAR %	FRR %
0.40	12.3	0.8
0.41	10	1.4
0.42	9.7	2.7
0.43	7.3	3.2
0.44	5.8	5.5
0.45	3.5	6.4
0.46	2.6	8.3
0.47	1.1	10.4
0.48	0.7	13.6
0.49	0.2	15

Table 2
FAR and FRR at Various Thresholds in Face Recognition System

<i>Threshold</i>	<i>Face</i>	
	<i>FAR %</i>	<i>FRR %</i>
0.8	25	2.0
0.9	21.07	2.99
1.0	17.5	3.46
1.1	13.2	5.12
1.2	8.53	7.8
1.3	4.78	9.7
1.4	2.16	11.25
1.5	0.98	15.43
1.6	0.56	19.76
1.7	0.25	22

Table 3
FAR and FRR at Various Thresholds in Multi-Modal Fusion (Merged Iris (Left Iris + Right Iris) + Face)

<i>Threshold</i>	<i>Fusion (Fusion (Left Iris + Right Iris) + Face)</i>	
	<i>FAR %</i>	<i>FRR %</i>
0.40	11.8	0.5
0.41	9.8	1.04
0.42	9.2	2.25
0.43	7.0	3.12
0.44	5.4	5.39
0.45	3.0	5.99
0.46	2.3	7.95
0.47	1.04	9.85
0.48	0.6	11.23
0.49	0.19	13.5

+ face). The Receiver Operating Characteristic (ROC) curves for the proposed system are presented in figure 7. The Equal Error Rate (EER) is a point on the ROC curve where FAR and FRR are equal. The lower the value of equal error rate, the higher the accuracy of biometric system. Figure 7 shows three ROC curves corresponding to the face recognition with EER 8.6%, fusion of left iris and right iris with EER 5.8%, fusion of merged iris (left iris + right iris) and face with EER 5.4% respectively. It is apparent from figure 7 that the multi-modal fusion has more accuracy than multi-instance fusion and face recognition system. Thus, it can be estimated from figure 7 and table 3 that the proposed approach has improved matching performance and better recognition accuracy than iris or face recognition system in alone.

5. CONCLUSION

This paper has proposed a hybrid fusion strategy based on multi-instance and multi-modal sources of biometric information using a unique combination of iris and face. Here, iris template is generated by combining multiple instances of iris. It makes iris template protected and rich in information. Final decision is produced by the

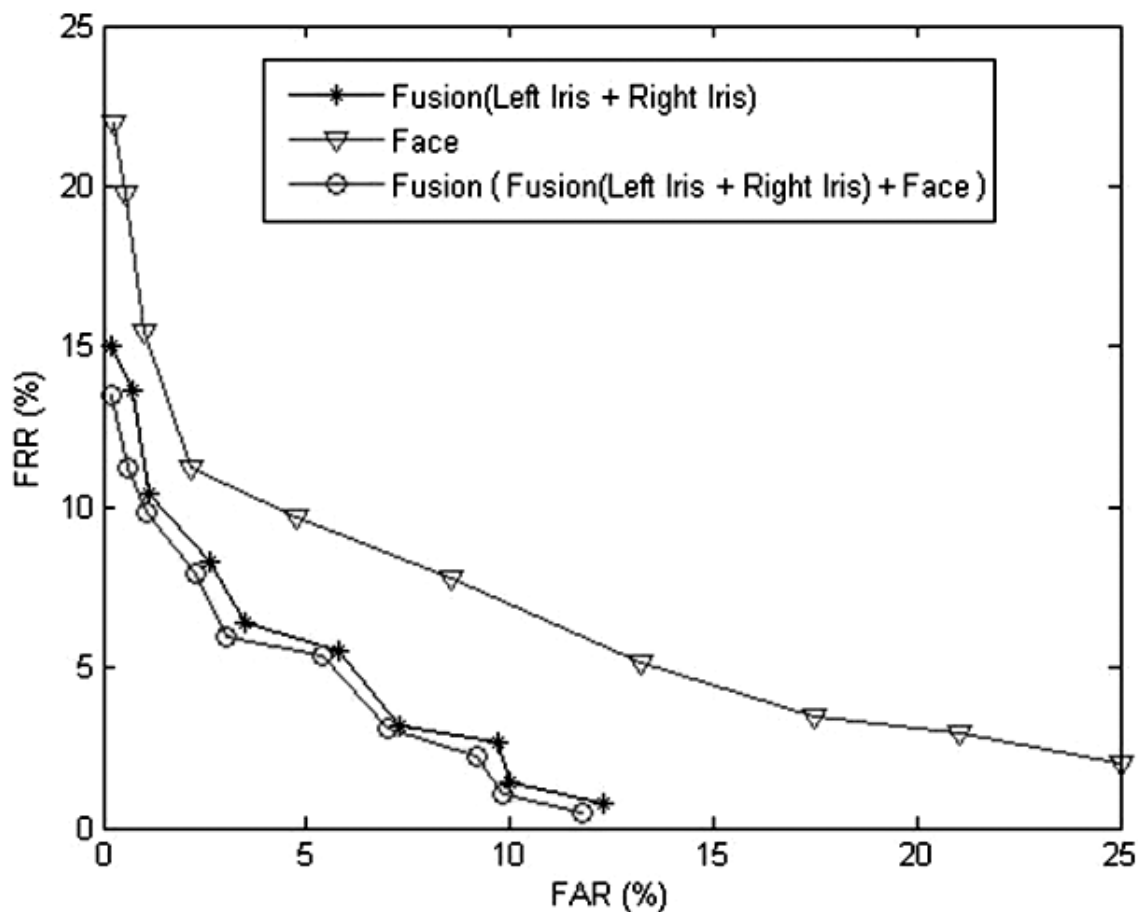


Figure 7: Receiver Operating Characteristic (ROC) curves showing the performance of proposed approach

match score generated after fusion of matching scores of merged iris and face biometric traits. Thus, this hybrid multibiometric fusion strategy provides two fold security. It is multi-instance and multi-modal in its design and hence it becomes difficult for an intruder to spoof multiple biometric traits simultaneously. Experimental results show that the proposed system performs better than iris or face recognition in isolation. The future work will focus on making face template more secure by applying some cancelable technique. Liveness detection mechanism could also be incorporated in the proposed approach to provide a better solution for increased security requirements.

REFERENCES

- [1] S. Prabhakar, S. Pankanti, and A. K. Jain, "Biometric Recognition: Security & Privacy Concerns", IEEE Security and Privacy Magazine, Vol. 1, No. 2, pp. 33-42, March-April 2003.
- [2] L. O'Gorman, "Comparing passwords, tokens, and biometrics for user authentication", Proceedings of the IEEE, Vol. 91, No. 12, Dec. 2003, pp. 2019-40.
- [3] Arun Ross and Anil K. Jain, "Multimodal biometrics: An overview", appeared in Proc. of 12th European Signal Processing Conference (EUSIPCO), pp. 1221-1224, September 2004.
- [4] Arun Ross, "An introduction to multibiometrics", In Proceedings of the 15th European Signal Processing Conference (EUSIPCO), pages 20-24, Poznan, Poland, 2007.
- [5] G. L. Marcialis and F. Roli, "Fingerprint Verification by Fusion of Optical and Capacitive Sensors", Pattern Recognition Letters, 25(11):1315-1322, August 2004.

- [6] X. Chen, P. J. Flynn, and K. W. Bowyer., "IR and Visible Light Face Recognition", *Computer Vision and Image Understanding*, 99(3), pp.332–358, September 2005.
- [7] X. Lu, Y. Wang, and A. K. Jain, "Combining Classifiers for Face Recognition", In *IEEE International Conference on Multimedia and Expo (ICME)*, volume 3, pages 13-16, Baltimore, USA, July 2003.
- [8] J. Jang, K. R. Park, J. Son, and Y. Lee, "Multi-unit Iris Recognition System by Image Check Algorithm", In *Proceedings of International Conference on Biometric Authentication (ICBA)*, pages 450–457, Hong Kong, July 2004.
- [9] G.Gordon, "Face Recognition from Frontal and Profile Views," *Proceedings Int'l Workshop on Face and Gesture Gesture Recognition*, Zurich, pp.47-52, 1995.
- [10] A. O'Toole, H. Bulthoff, N. Troje, and T. Vetter, "Face Recognition across Large Viewpoint Changes", In *Proceedings of the International Workshop on Automatic Face- and Gesture-Recognition (IWAAGR)*, pages 326–331, Zurich, Switzerland, June 1995.
- [11] R. Frischholz and U. Dieckmann, "BioID: A Multimodal Biometric Identification System", *IEEE Computer*, vol. 33(2), pages 64-68, February 2000.
- [12] R. Brunelli and D. Falavigna, "Person identification using multiple cues," *IEEE Transactions on PAMI*, vol. 12, pp. 955–966, Oct 1995.
- [13] A. K. Jain and A. Ross, "Multibiometric Systems", *Communications of the ACM*, Special Issue on Multimodal Interfaces, vol. 47(1), pp.34–40, January 2004.
- [14] Maryam Eskandari and Onsen Toygar, "Fusion of face and iris biometrics using local and global feature extraction methods" *Signal, Image and Video Processing*, pages 1–12, 2012.
- [15] Fan Yang and Baofeng Ma, "A new mixed-mode biometrics information fusion based-on fingerprint, hand-geometry and palm-print" In *Fourth International Conference on Image and Graphics*, pages 689–693. IEEE, 2007.
- [16] Mohamad Abdolahi, Majid Mohamadi, and Mehdi Jafari, "Multimodal biometric system fusion using fingerprint and iris with fuzzy logic", *International Journal of Soft Computing and Engineering*, 2(6):504–510, 2013.
- [17] Byungjun Son and Yillbyung Lee, "Biometric authentication system using reduced joint feature vector of iris and face", In *Audio-and Video-Based Biometric Person Authentication*, vol 3546 of the series *Lecture Notes in Computer Science*, pages 513–522, Springer, 2005.
- [18] Ajita Rattani and Massimo Tistarelli, "Robust multimodal and multiunit feature level fusion of face and iris biometrics", In *Advances in Biometrics*, pages 960–969, Springer, 2009.
- [19] L Latha and S Thangasamy, "A robust person authentication system based on score level fusion of left and right irises and retinal features", *Procedia Computer Science*, 2:111–120, 2010.
- [20] A. Ross, A. K. Jain, and J. Reisman, "A Hybrid Fingerprint Matcher", *Pattern Recognition*, vol. 36(7), pages 1661-1673, July 2003.
- [21] S. Ben-Yacoub, Y. Abdeljaoued, and E. Mayoraz, "Fusion of Face and Speech Data for Person Identity Verification", *IEEE Trans. Neural Networks*, vol. 10, no. 5, pp. 1065-1075, 1999.
- [22] A. Ross and A.K. Jain, "Information Fusion in Biometrics", *Pattern Recognition Letters*, vol. 24, no. 13, pp. 2115-2125, 2003.
- [23] R. Wildes, J. Asmuth, G. Green, S. Hsu, and S. McBride. "A System for Automated Iris Recognition", *Proceedings IEEE Workshop on Applications of Computer Vision*, Sarasota, FL, USA, 1994.
- [24] R. Schalkoff., "Pattern Recognition: Statistical, Structural and Neural Approaches", John Wiley and Sons Inc., pp. 55-63 (2003).
- [25] Chong Siew Chin, Andrew Teoh Beng Jin, and David Ngo Chek Ling., "High security iris verification system based on random secret integration", *Computer Vision and Image Understanding*, 102(2):169–177, 2006.
- [26] J. Daugman. "Statistical Richness of Visual Phase Information: Update on Recognizing Persons by Iris Patterns". *International Journal of Computer Vision*, 45(1): 25-38, 2001.

- [27] John Daugman, "How iris recognition works", *Circuits and Systems for Video Technology*, IEEE Transactions on, 14(1):21–30, 2004.
- [28] Xiaoguang Lu, "Image Analysis for Face Recognition – A brief survey", Dept. of Computer Science & Engineering, Michigan State University, personal notes, May 2003.
- [29] M. Turk and A. Pentland, "Eigenfaces for Recognition," *J. Cognitive Neuroscience*, vol. 3, no. 1, pp. 71–86, 1991.
- [30] Y. Vijaya Lata, Chandra Kiran Bharadwaj Tungathurthi, H. Ram Mohan Rao, A. Govardhan, L. P. Reddy, "Facial Recognition using Eigenfaces by PCA", *International Journal of Recent Trends in Engineering*, Vol. 1, No. 1, May 2009.
- [31] Arun Ross and Rohin Govindarajan, " Feature Level Fusion using Hand and Face Biometrics", appeared in proceedings of SPIE Conference on Biometric Technology for Human Identification II, Vol. 5779, pp. 196-204, (Orlando, USA), March 2005.
- [32] A. K. & A. Ro. Jain, K. Nandakumar , "Score Normalization in multimodal biometric systems", *The Journal of Pattern Recognition Society*, 38(12), 2005, 2270-2285.
- [33] Chinese Academy of Sciences, Center of Biometrics and Security Research, Database of Eye Images. <http://www.cbsr.ia.ac.cn/IrisDatabase.htm>
- [34] National Institute of Standards and Technology (NIST), U.S. Department of Commerce.
- [35] A.K. Jain, A. Ross, S. Prabhakar, "An introduction to biometric recognition", *IEEE Transactions on Circuits and Systems for Video Technology*, Vol.14, 2004, 4-20.