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Performances Enhancement of Fingerprint Recognition System Using Classifiers

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ABSTRACT Fingerprint recognition is best known and generally used as a biometric technology because of their high acceptability, immutability, and uniqueness. A fingerprint consists of ridges and valleys pattern also known as furrows. These patterns fully develop in the mother's womb and remain constant throughout the whole lifetime of the individual. The ridge bifurcation and ridge termination are the main minutiae features that are extracted for identification of individuals in fingerprint recognition system. The aim of this paper is to enhance the performance of the fingerprint recognition systems using classifiers. To achieve the aim, fingerprints from the FV2002 database are used, before these fingerprints are evaluated, image enhancement and binarization is applied as a pre-processing on fingerprints, by combining many methods to build a database of fingerprint features having minutia marking and minutia feature extraction. The fingerprint recognition is presented by image classification using MATLAB classifiers, i.e., Decision Tree, Linear Discriminant Analysis, medium Gaussian support vector machine (MG-SVM), fine K-nearest neighbor, and bagged tree ensemble. The aim of this paper is to make a comparison between classifiers for performance enhancement of the fingerprint recognition system. The MG-SVM classifiers significantly give the highest verification rate of 98.90% among all classifies used.

INDEX TERMS Biometrics, fingerprint recognition, decision tree, LDA, MG-SVM, K-NN, bagged tree ensemble classifiers.

I. INTRODUCTION

Personal identification is associated with individual identity, which is the requirement of our society. Question arising to the individual identity, such as ?does this individual is authentic to give access to our system? is asked by thousands of organizations every day in financial, educational, health and telecommunication Organizations etc. Due to rapid enhancement in information technology, people are more connected electronically to technology, which required accurate automatic individual identification, so fingerprint recognition is best known and generally used as a biometric technology. A fingerprint consists of ridges and valleys pattern also known as furrows. These patterns fully develop in the mother?s womb and remain constant throughout the whole lifetime of the individual. The surface of a fingertip, having prints patterns, called fingerprints. The fingerprints are Unchangeable and Unique which are the main characteristics. Damages like cuts and burns can temporarily reduce the quality of fingerprints, but when completely healed, those fingerprint patterns will restored.

The fingerprint pattern consists of ridge and valleys, these patterns of ridges and valleys on each finger is unique. The two main ridge characteristics (minutiae) of the fingerprint are ridge bifurcation and ridge termination, the space between two ridges called valleys. A ridge bifurcation is a point where a ridge splits into sub ridges from a single path and a ridge termination is the point where the ridge of fingerprint ends as shown in Figure.1 [1].

A. RELATED WORK

The developments in biometric recognition system for recognition of an individual lead to enhancements in accuracy

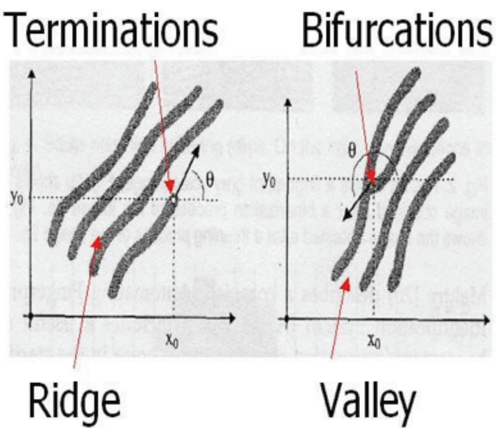

FIGURE 1. Ridge termination and ridge bifurcation [1].

and reliability. The following parameters are analyzed for the related work in Fingerprint recognition technologies, such as matching techniques, classification methods, recognition methods, enhancement methods retrieval concepts, security and many others. The fingerprint matching performance is evaluated by means of the following false accept rate (FAR), false reject rate (FRR), verification rate (VER) and equal error rate (EER).

The authentication system which uses the techniques of multimodality feature extraction with neural network classifier for Biometric Identification System using Fingerprint and Knuckle as Multimodality Features, which shows 100% classification, however this method give the recognition rate of 81.12% which is relevantly low as compared to other recognition techniques [2].

Fingerprint recognition system consists of fingerprint sensing, enhancement, feature extraction using Level-1 and Level-2 based on neural network, and fingerprint matching using BOZORTH3 matching techniques was proposed. The Coarse classification speed up the computation, giving 60% to 70% reduction in identification time and giving the Level-2 extraction accuracy of 98.64% on the mixed high quality and low quality fingerprint database but giving the overall recognition rate of 92% [3].

A novel algorithm was proposed for the separation of overlapped images using the ANFIS model, the overlapped images are identified automatically and classified. The experimental results show that the proposed method achieves a separation rate of 92.4% for the recognition of overlapped images on all overlapped fingerprint images in the SLF, NIST, and FVC datasets, however giving the classification rate of 88.6%, with the accuracy of 92% which is comparably low [4].

A fingerprint recognition system based on Fuzzy features and Invariant moment features which are non-minutia has been proposed. Two sets of features are extracted from region of Interest (ROI) and support vector machine (SVM) is used for verification using FVC2002 database. The experimental results show an accuracy of 95% with the invariant moment features using RBF kernel in support vector machine (SVM) though the fuzzy features give an accuracy of 87.5% which is low as compared to invariant moment features [5].

A method of Multimodal biometric recognition was proposed for biometric authentication system using three different set of veins images such as, finger vein, dorsal vein and palm vein. A feature level fusion is carried after extraction of features using Group Search Optimization (GSO). The recognition is done using different classifiers such as support vector machine (SVM), neural network, fuzzy, bayes classifier and k-nearest neighbour (KNN) classifiers. An accuracy above 90% was reported for all used classifies except Navie bayes classifier which provides the accuracy of around 80% which is low as compared to used classifiers [6].

A Novel Technique was proposed for Fingerprint Classification based on and Support Vector Machine (SVM) and Naive Bayes Classifier, fingerprint classification is done by the classifier used Naïve Bayes and SVM classifiers by comparing the results of classification, the best results are achieved using Naïve Bayes classifier as compared to SVM classifier. This technique only classifying the fingerprint images and comparing the classification of fingerprints but they did not find the fingerprint verification/recognition rates for both classifiers [7].

A Scheme based on (SURF) Speeded up Robust Features algorithm was proposed using knuckle print recognition. The results showing the identification taking average time of 0.106s which is less time but giving an accuracy of 96.91% of PolyU FKP database which is low relatively to the other methods [8].

A secured approach proposed for Fingerprint recognition system based on a set of assembled geometric and Zernike moment. By applying the results having EER=2.27%, taking average, match time of 0.19s but it is inefficient on enroll time that is 1.77s on FVC2002 database [9].

An algorithm of parallel architecture for fingerprint matching is presented based (BLPOC) Band Limited Phase only spatial Correlation. By using this method showing lowering FAR and FRR values on FVC2002 database [10].

A method is explained to control the problem of humidity and pressure in image acquiring. This method uses non-stationary analysis of short time Fourier transform (STFT) and negative Laplace filter. Shows the result for varying conditions the FRR of 1.34%-4.88%, FAR of 0%-1% and a RR of 95.12% - 98.2% [11].

A method using Column Principal Component Analysis (PCA) and Line Discrete Fourier Transform (Line-DFT) reduction techniques was proposed by compressing spectral minutiae feature for increasing matching speed. They report the reduction rate of 94% and the speed of 125,000 comparisons per/s. Using these techniques the result having EER of 3.72% and FAR of 95.6% on the FVC2002-DB2 database and having EER of 0.29% and FAR of 99.8% on MCYT database is reported [12].

A method proposed for considering the effect of fingers which are water induced that reduce the performance of

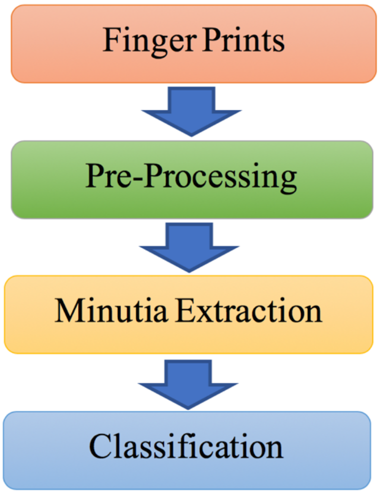

FIGURE 2. Proposed method block diagram.

minutiae based fingerprint recognition. The results show true positive rate (TPR) of 96.7% and equal error rate (EER) of 2.13% for dry fingers and equal error rate (EER) of 3.15% however true positive rate (TPR) is low of 72.4% for wrinkled fingers are reported [13].

An algorithm for Fingerprint recognition using EBFNN. The results show the recognition rate using Ellipsoidal basis function neural-network of 90.5% to 91.8% reported in FVC 2000/ FVC 2002/ FVC 2004 databases which is relatively low as compared to other methods as proposed and discussed in literature [14].

II. FINGERPRINT RECOGNITION SYSTEM DESIGN

A fingerprint recognition system mainly consists of image acquisition device (Sensor), preprocessing, minutia extractor and classifier as shown in figure. Optical sensors are widely used for fingerprint acquisition, which showing the efficiency and accuracy of fingerprint images and its efficiency and accuracy decreases for using dirty or dry fingerprints. However, the fingerprints, use in our project is the fingerprints from the FVC2002 database. So therefore, no acquisition of fingerprints has been implemented.

Pre-processing stage consists of Image enhancement, Binarization, Region of interest (ROI) extraction. The minutia extractor stage is used to extract the targeted minutiae and minutiae matcher stage is used to match the minutia of individual fingerprint with the database.

The fingerprint image is taken from the scanner is RGB image which should be converted into a gray image for further image processing [15]. After converting RGB to gray image, the image enhancement is required because the image obtained are not of good quality, which should be enhanced by increasing the contrast between ridges of fingerprint images and by filling the broken points of ridges of fingerprint images. In many projects they have implemented the following techniques for enhancing the fingerprint images. Histogram equalization is image enhancement technique,

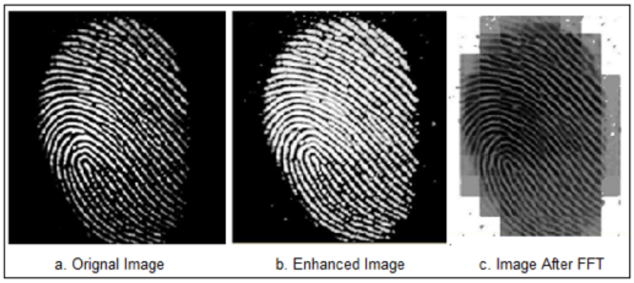

FIGURE 3. Image enhancement.

used to increase contrast of images by transforming the intensity as shown in Figure 3(b).Curved Gabor Filters used for enhancement and extraction of Gabor features. The Curved Gabor Filters are used for enhancing curved structures in noisy images [16]. For larger curved regions in fingerprints curved Gabor filters is used to enhance the cured regions without creating spurious features.

Histogram equalization, Fast Fourier transform and Image Binarization [17], are implemented for fingerprint recognition based matching system, where two stages are focused in recognition system designing i.e. minutiae extraction and minutiae matching.

Implementation of Fingerprint image enhancement and feature extracting for fingerprint recognition system by reconstructing fingerprint image information by combining Discrete Fourier Transform and histogram equalization [18]. They use discrete time Fourier transforms for decomposing an image into its components (sine and cosine). Coherence Diffusion Filter and Gabor Filter In [19], they use a novel method of fingerprint image enhancement for fingerprint recognition by combining spatial domain Gabor filter (two dimensional) and coherence diffusion filter. Moreover, the new technique of blocks overlapping is used for better results in high curving ridges (core point surrounding region of fingerprint image). It gives poor results for cut and broken ridges.

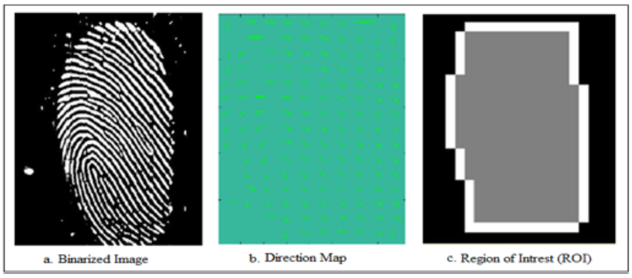

FIGURE 4. Direction flow estimation and ROI.

Image binarization is the next step, by converting the 8-bit Gray level fingerprint image to a 1 bit binary (0, 1) image with value '1' for valley and value '0' for the ridge as shown in Figure.4(a). After the image binarization process, valleys and ridges are highlighted with white and black color respectively.

Binarization is an important process for the thinning process as a binary image. After thinning the region of interest (ROI) is required to extract, for region of Interest a threshold is set for fingerprint to reject the background from the total area, the remaining area is Region of Interest as shown in Figure. 4(c), which is used to recognize the fingerprint image.

0	1	0
0	1	0
1	0	1

a

0	0	0
0	1	0
0	0	1

b

0	1	0
0	1	1
1	0	0

c

FIGURE 5. **(a) Ridge bifurcation, (b) ridge ending (c) triples counting branch.**

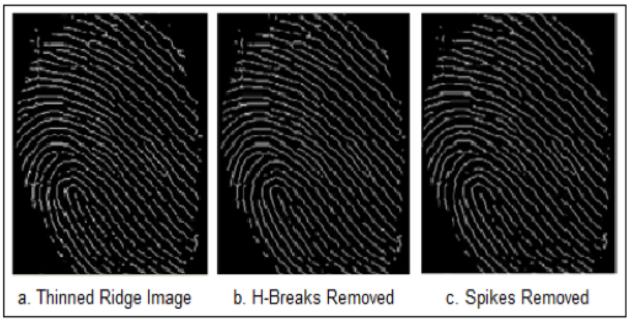

FIGURE 6. **Thinned ridge image with h-break and spikes removed [21].**

The redundant pixels are removed from the ridge using thinning process and make the ridge width just one pixel as shown in Figure 5(a). Minutiae marking is the step after ridge thinning, which is implemented by using of (3×3) pixel window, for Minutia marking the concept of Crossing Number is used, for bifurcation, Cn (p) =3 for a pixel 'p' and for termination, Cn (p) =1 for a pixel 'p' A special case occurs in minutia marking, a genuine branch is triple counted as shown in figure, the uppermost and the rightmost pixel having value '1' in selected (3×3) window having a neighbor outside the (3×3) selected window and marked those two pixels as a branches. But in small region only one branch is present, a check routine is required for considering none of the neighbors of the branches are added, as shown on Figure 5, The marking of minutiae is shown in Figure 7(a) [20].

After marking of minutia, false minutia is removed as shown in Figure 7(b). The complex fingerprint recognition system only one stage left that is feature matching stage. Minutia points are detected based on the number of neighbor pixels, by finding the ridges ending points and bifurcation

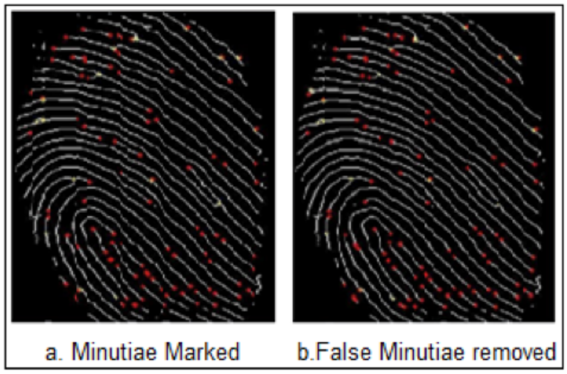

FIGURE 7. **Minutia marking [21].**

points on the thinned ridge surface. In minutiae matching stage, the minutiae of finger print were matched with already exist minutia in the database, the minutiae matching procedure determines whether the two minutia sets are from the same finger or from different.

After detecting minutia points for each fingerprint, a database is set for all fingerprints having 121 features for each fingerprint and also define the classes for the feature sets.

We will use different classifiers for image classification using the classifier Learner app of MatLab i.e. Decision Tree, Linear Discriminant Analysis, Medium Gaussian Support Vector Machine (MG-SVM), Fine K-Nearest Neighbor (K-NN), Bagged Tree Ensemble classifiers. There are three validation schemes in Classifier Learner, i.e. Cross-Validation, Holdout Validation and no validation Scheme. We have selected 10 folds cross Validation scheme for our models.

III. RESULTS AND DISCUSSIONS

In result and discussion the performance of the fingerprint recognition system using classifiers on FV2002 Data base is presented. In the database there are 80 fingerprints of 10 persons having 8 fingerprint samples per person. The evaluation of the system is done based on the error rates and Verification rate. Recognition rate reached peak value for correctly classified subjects when using decision threshold corresponding to EER point.

The value of minHTER, EER, FAR=0.1FRR and FAR=10FRR are obtained at different thresholds values, a similarity score which varies in the range 0?2500 (where 0 stands for no similarity and 2500 is the highest possible similarity measured).

A. CLASSIFICATION USING DECISION TREE CLASSIFIERS

Decision tree classifier model has been applied on training data we have got the scores of performance measures at min HTER, at EER, at FRR-0.1FAR and FRR-10FAR which are listed in Table 1. The result shows the Verification Rate of 98.60% which is relevantly low among used classifiers.

TABLE 1. Performance measure of decision tree classifiers.

Scores and Thresholds	EER%	TH	FRR%	VER%	FAR%
At HTER	4.9	1.9401	4.1	95.90	5.70
At EER	5.20	1.9079	5.2	94.80	5.20
At FRR-01FAR	7.70	2.4061	1.40	98.60	14.00
At FRR-10FAR	7.70	1.4312	14.00	86.00	1.40

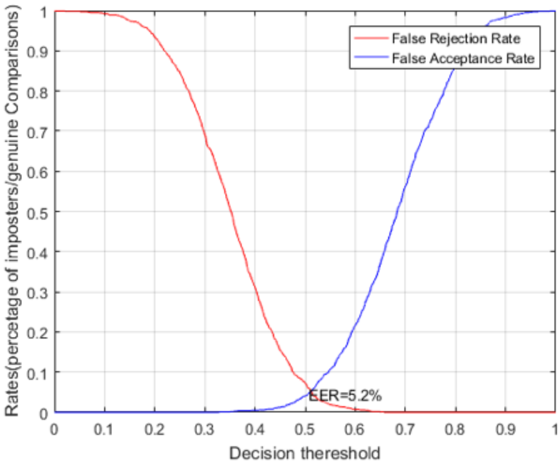

FIGURE 8. Decision tree classifier EER curve.

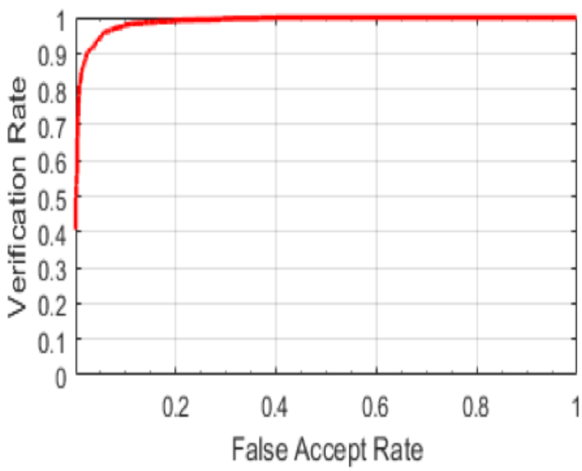

FIGURE 9. Decision tree classifier ROC curve.

B. CLASSIFICATION USING LINEAR DISCRIMINANT ANALYSIS (LDA)

Classifying the training data using Linear Discriminant Analysis (LDA) classifier we have got the scores of performance measures as listed in table (2) which shows the Verification Rate 0f 98.80% which is greater than decision tree classifier.

C. MEDIUM GAUSSIAN SUPPORT VECTOR MACHINES (MG-SVM)

Medium Gaussian Support Vector Machines (MG-SVM) classifier gives the Verification Rate of 98.90% which is significantly best among all classifiers, the performance measures of MG-SVM classifier is shown in Table 3.

TABLE 2. Performance measure of LDA.

Scores and Thresholds	EER%	TH	FRR%	VER%	FAR%
At HTER	4.20	2.0131	3.50	96.50	4.90
At EER	4.50	1.9569	4.50	95.50	4.50
At FRR-01FAR	6.60	2.4237	1.20	98.80	12.0
At FRR-10FAR	8.10	1.4270	14.70	85.30	1.50

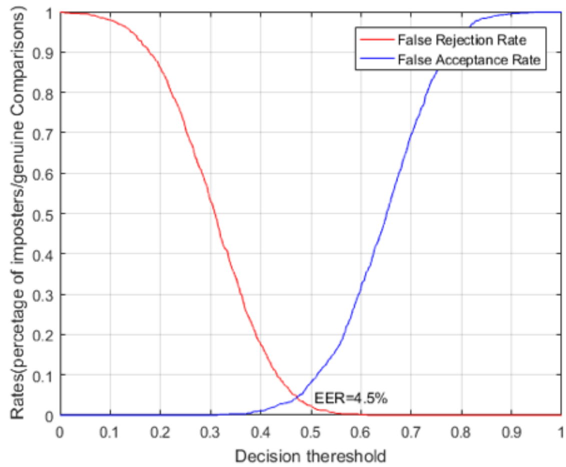

FIGURE 10. Linear discriminant analysis EER curve.

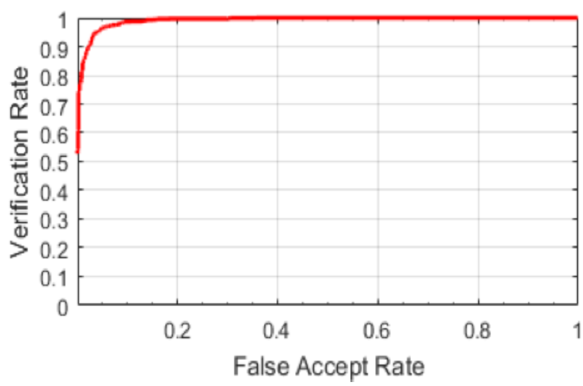

FIGURE 11. Linear discriminant analysis ROC curve.

TABLE 3. Performance measure of MG-SVM.

Scores and Thresholds	EER%	TH	FRR%	VER%	FAR%
At HTER	4.70	1.9638	5.00	95.00	4.40
At EER	4.80	1.99909	4.80	95.20	4.80
At FRR-01FAR	6.05	2.3857	1.10	98.90	11.0
At FRR-10FAR	7.85	1.4684	14.30	85.70	1.40

D. CLASSIFICATION USING FINE K-NEAREST NEIGHBOR (K-NN) CLASSIFIERS

Training data on Fine K-Nearest Neighbor (KNN) Classifier model showing the Verification Rate of 98.80% is

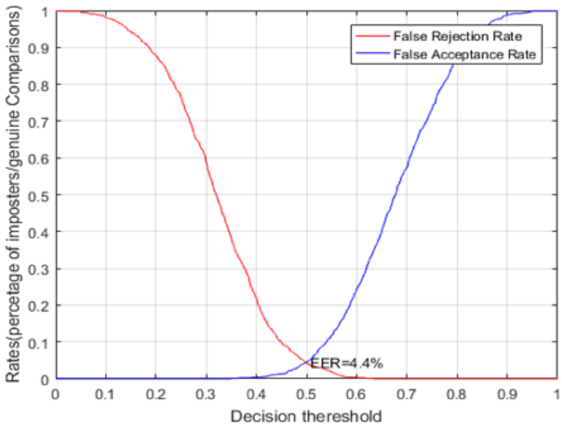

FIGURE 12. MG-SVM EER curve.

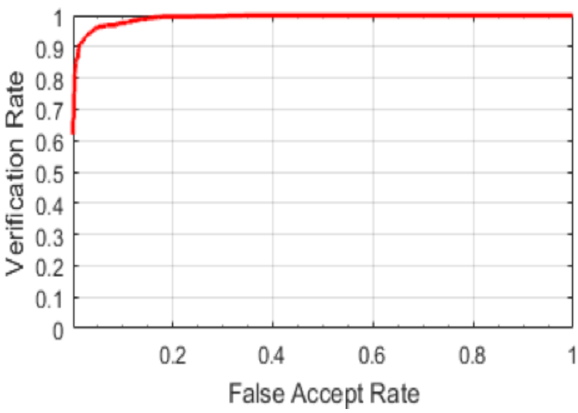

FIGURE 13. MG-SVM ROC curve.

TABLE 4. Performance measure of fine K-NN classifiers.

Scores and Thresholds	EER%	TH	FRR%	VER%	FAR%
At HTER	4.50	1.8529	6.30	93.70	2.80
At EER	5.0	2.0244	5.0	95.0	5.0
At FRR-01FAR	6.65	2.4588	1.20	98.80	12.10
At FRR-10FAR	7.15	1.5281	13.00	87.00	1.30

comparably equal to LDA classifier and greater than Decision tree classifiers.

E. BAGGED TREE ENSEMBLE CLASSIFIER

By applying Bagged Tree Ensemble Classifier model for training data we have got the Verification Rate of 98.80% which is merely less than MG-SVM classifier.

The ROC curve is used as the performance indicator in biometric system evaluation and specifically in fingerprint recognition system.

It is a plot of the genuine match rate to the false match rate for the different threshold values [22]. The ROC curve having verification rate to the false accept rate of all classifiers as shown in Figure.18 which shows that the MG-SVM having better results of verification among all classifiers.

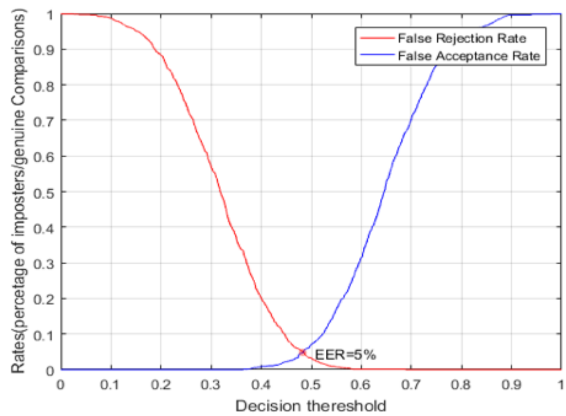

FIGURE 14. Fine KNN EER curve.

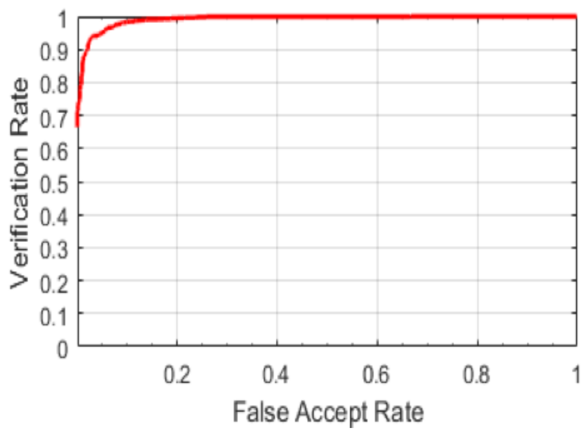

FIGURE 15. Fine KNN ROC curve.

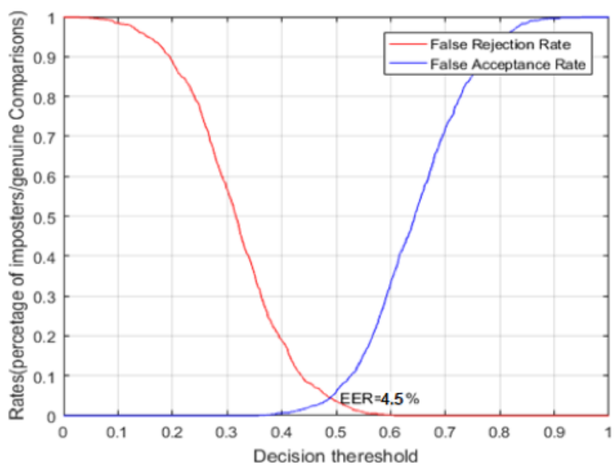

FIGURE 16. Bagged tree classifier EER curve.

Figure.19 shows the variation of verification rate with performance measure (min HTER), at an equal error rate (EER), at FRR-0.1FAR and FRR-10FAR of following classifiers i.e. Decision Tree, Linear Discriminant Analysis (LDA), Medium Gaussian Support Vector Machine (MG-SVM),

TABLE 5. Performance measure of bagged tree ensemble classifiers.

Scores and Thresholds	EER%	TH	FRR%	VER%	FAR%
At HTER	4.35	2.0340	3.60	96.40	5.10
At EER	4.50	1.9974	4.50	95.50	4.50
At FRR-01FAR	6.80	2.3974	1.20	98.80	12.40
At FRR-10FAR	7.45	1.5271	13.50	86.50	1.40

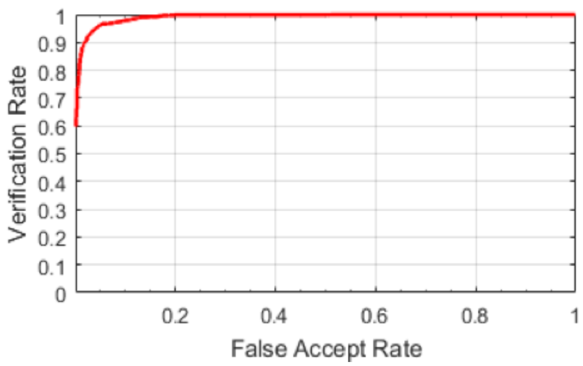

FIGURE 17. Bagged tree classifier ROC curve.

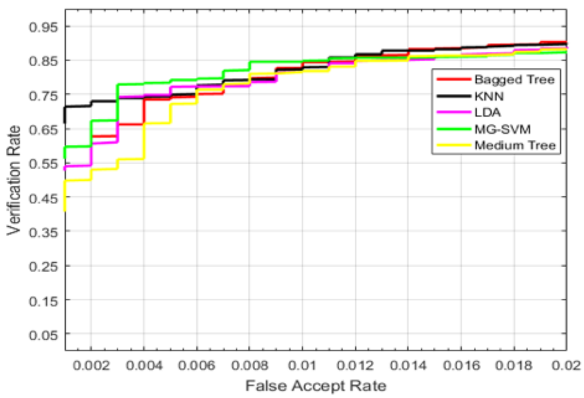

FIGURE 18. All classifiers ROC curves.

TABLE 6. Classifiers performance measures.

Classifiers	Decision Tree (VER%)	LDA (VER%)	MG-SVM (VER%)	Fine K-NN (VER%)	Bagged Tree Ensemble (VER%)
At HTER	4.35	2.0340	3.60	96.40	5.10
At EER	4.50	1.9974	4.50	95.50	4.50
At FRR-01FAR	6.80	2.3974	1.20	98.80	12.40
At FRR-10FAR	7.45	1.5271	13.50	86.50	1.40

Fine K-Nearest Neighbor (K-NN) and Bagged Tree Ensemble.

Table 7 shows The Verification Rates of the following classifier Decision tree, Linear Discriminant Analysis, Medium Gaussian Support vector machine (MG-SVM), Fine K-Nearest Neighbor (K-NN) and Bagged Tree Ensemble

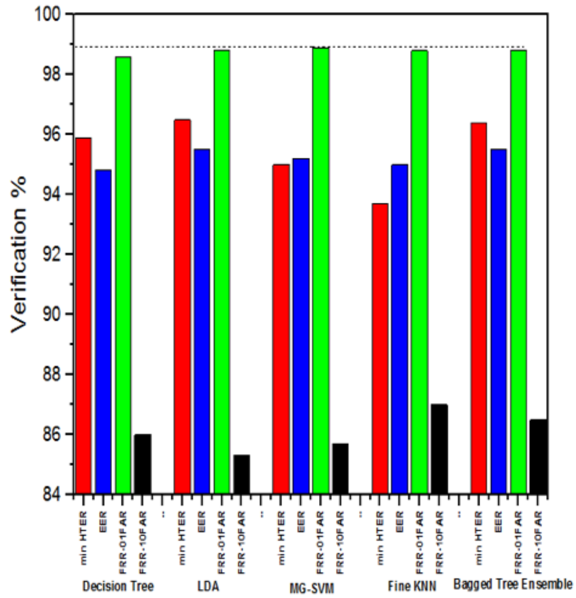

FIGURE 19. Classifier performance measure with verification %.

TABLE 7. Verification rates of all classifiers.

S. No.	Classifiers	VER%
1	Decision Tree	98.60%
2	LDA	98.80%
3	MG-SVM	**98.90%**
4	Fine K-NN	98.80%
5	Bagged Tree Ensemble	98.80%

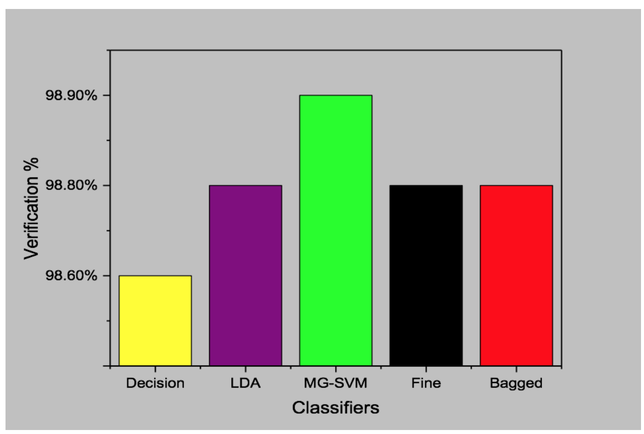

FIGURE 20. Classifiers verification percentage %.

which is shown in Figure 20. The result of verification is relatively good of all classifiers but MG-SVM showing better verification rate among all classifiers.

IV. CONCLUSION

The performance enhancement of fingerprint recognition system using classifiers are proposed that works in fingerprint verification and represents a complete fingerprint recognition system capable of fingerprint image enhancement followed by fingerprint feature extraction, feature database creation and classification using classifiers. For the performance enhancement of fingerprint recognition system we have done the classification of fingerprint images using different classifiers i.e. Decision Tree, Linear Discriminant Analysis (LDA), Medium Gaussian Support Vector Machine (MG-SVM), Fine K-Nearest Neighbor (K-NN) and Bagged Tree Ensemble classifiers. The performance measures VER, FAR, FRR, EER-Th and EER of all classifiers are listed in tables with classifiers its ROC and EER curves are drawn for comparisons of performance, the medium Gaussian support vector machine (MG-SVM) classifiers gives the highest verification rate of 98.90% among all classifies. Principal component analysis (PCA) can be used for improvement of verification rates of used classifiers. The Proposed Classifiers can be used for other images and signal recognitions systems. The fingerprint recognition system that uses classifiers for classification of fingerprints images with evaluation and comparison with the results from literature can be observed as a contribution to the field of biometric authentication.

REFERENCES

[1] M. Garg and E. H. Bansal, "Fingerprint recognition system using minutiae estimation," *Int. J. Appl. Innov. Eng. Manage.*, vol. 2, no. 5, pp. 31–36, 2013.

[2] N. Kudu, M. E. Student, and S. Karamchandani, "Biometric identification system using fingerprint and knuckle as multimodality features," in *Proc. IEEE Int. Conf. Elect., Electron., Optim. Techn. (ICEEOT)*, Mar. 2016, pp. 3279–3284.

[3] P. M.-A. Hambalık, "Fingerprint recognition system using artificial neural network as feature extractor: Design and performance evaluation," *Tatra Mountains Math. Publications*, vol. 67, pp. 117–134, Feb. 2016.

[4] S. Jeyanthi, N. U. Maheswari, and R. Venkatesh, "An efficient automatic overlapped fingerprint identification and recognition using ANFIS classifier," *Int. J. Fuzzy Syst.*, vol. 18, no. 3, pp. 478–491, 2016.

[5] J. Kour, M. Hanmandlu, and A. Ansari, "Biometrics in cyber security," *Defence Sci. J.*, vol. 66, no. 6, pp. 600–604, Nov. 2016.

[6] B. Subramaniam and S. Radhakrishnan, "Multiple features and classifiers for vein based biometric recognition," *Biomed. Res.*, vol. Special Issue, pp. 8–13, Feb. 2017.

[7] A. Mishra and P. Maheshwary, "A novel technique for fingerprint classification based on Naïve Bayes classifier and support vector machine," *Int. J. Comput. Appl.*, vol. 169, no. 7, pp. 58–62, Jul. 2017.

[8] L.-Q. Zhu, "Finger knuckle print recognition based on SURF algorithm," in *Proc. IEEE 8th Int. Conf. Fuzzy Syst. Knowl. Discovery (FSKD)*, vol. 3, Jul. 2011, pp. 1879–1883.

[9] J. Yang *et al.*, "A fingerprint recognition scheme based on assembling invariant moments for cloud computing communications," *IEEE Syst. J.*, vol. 5, no. 4, pp. 574–583, Dec. 2011.

[10] G. Danese, M. Giachero, F. Leporati, and N. Nazzicari, "A multicore embedded processor for fingerprint recognition," in *Proc. 13th IEEE Euromicro Conf. Digit. Syst. Design, Archit., Methods Tools (DSD)*, Sep. 2010, pp. 779–784.

[11] F. C. J. González, O. O. V. Villegas, V. G. C. Sanchez, and H. D. J. O. Dominguez, "Fingerprint recognition using open algorithms in frequency and spatial domain," in *Proc. IEEE Electron., Robot. Automot. Mech. Conf.*, Sep./Oct. 2010, pp. 469–474.

[12] H. Xu, R. N. J. Veldhuis, T. A. M. Kevenaar, and T. A. H. M. Akkermans, "A Fast Minutiae-Based Fingerprint Recognition System," *IEEE Syst. J.*, vol. 3, no. 4, pp. 418–427, Dec. 2009.

[13] H. Fakourfar and S. Belongie, "Fingerprint recognition system performance in the maritime environment," in *Proc. Workshop Appl. Comput. Vis. (WACV)*, Dec. 2009, pp. 1–5.

[14] J. Luo, S. Lin, J. Ni, and M. Lei, "An improved fingerprint recognition algorithm using EBFNN," in *Proc. IEEE 2nd Int. Conf. Genet. Evol. Comput. (WGEC)*, Sep. 2008, pp. 504–507.

[15] V. Awasthi, V. Awasthi, and K. K. Tiwari, "Finger print analysis using termination and bifurcation minutiae," *Int. J. Emerg. Technol. Adv. Eng.*, vol. 2, pp. 124–130, Feb. 2012.

[16] P. Deshmukh, S. Pathan, and R. Pathan, "Image enhancement techniques for fingerprint identification," *Int. J. Sci. Res. Publications*, vol. 3, no. 3, pp. 1–9, Mar. 2013.

[17] S. Bana and D. Kaur, "Fingerprint recognition using image segmentation," *Int. J. Adv. Eng. Sci. Technol.*, vol. 5, no. 1, pp. 12–23, 2011.

[18] P. Bhowmik, K. Bhowmik, M. N. Azam, and M. W. Rony, "Fingerprint image enhancement and its feature extraction for recognition," *Int. J. Sci. Technol. Res.*, vol. 1, no. 5, pp. 117–121, 2012.

[19] A. Ali, X. Jing, Z. Jie, and N. Saleem, "Fingerprint image enhancement using coherence diffusion filter and Gabor filter," *J. Inf. Comput. Sci.*, vol. 9, no. 1, pp. 153–160, 2012.

[20] A. A. Khindre and V. More, "Minutia based touchless fingerprint recognition," *Int. J. Adv. Res. Electron. Commun. Eng.*, vol. 4, no. 4, pp. 1–6, Apr. 2015.

[21] M. Kumar and H. S. Gouda, "Fingerprint recognition system to verify the identity of a person using an online database," M.S. thesis, Dept. Electron. Commun. Eng., Nat. Inst. Technol. Rourkela, Orissa, India, Apr. 2012.

[22] D. Maltoni, D. Maio, A. K. Jain, and S. Prabhakar, *Handbook of Fingerprint Recognition*. London, U.K.: Springer-Verlag, 2009, p. 494.

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