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Fusion of Finger Inner Knuckle Print and Hand Geometry Features to Enhance the Performance of Biometric Verification System

M. L. Anitha, K. A. Radhakrishna Rao

Abstract**—**With the advent of modern computing technology, there is an increased demand for developing recognition systems that have the capability of verifying the identity of individuals. Recognition systems are required by several civilian and commercial applications for providing access to secured resources. Traditional recognition systems which are based on physical identities are not sufficiently reliable to satisfy the security requirements due to the use of several advances of forgery and identity impersonation methods. Recognizing individuals based on his/her unique physiological characteristics known as biometric traits is a reliable technique, since these traits are not transferable and they cannot be stolen or lost. Since the performance of biometric based recognition system depends on the particular trait that is utilized, the present work proposes a fusion approach which combines Inner knuckle print (IKP) trait of the middle, ring and index fingers with the geometrical features of hand. The hand image captured from a digital camera is preprocessed to find finger IKP as region of interest (ROI) and hand geometry features. Geometrical features are represented as the distances between different key points and IKP features are extracted by applying local binary pattern descriptor on the IKP ROI. The decision level AND fusion was adopted, which has shown improvement in performance of the combined scheme. The proposed approach is tested on the database collected at our institute. Proposed approach is of significance since both hand geometry and IKP features can be extracted from the palm region of the hand. The fusion of these features yields a false acceptance rate of 0.75%, false rejection rate of 0.86% for verification tests conducted, which is less when compared to the results obtained using individual traits. The results obtained confirm the usefulness of proposed approach and suitability of the selected features for developing biometric based recognition system based on features from palmar region of hand.

Keywords**—**Biometrics, hand geometry features, inner knuckle print, recognition.

I. Introduction

BIOMETRIC based recognition systems have been used in a wide variety of applications which requires reliable verification schemes to conform the identity of an individual requesting their services. A biometric system recognizes a person based on the features derived from physiological or behavioral trait associated with the person. Behavioral traits such as voice, gait, signature and physiological traits such as finger print, palm print, iris, ear and hand vein are being used in developing recognition systems. Biometric systems based on single trait (unimodal) suffer from problems like lack of distinctiveness, noise in captured biometric data and spoof attack. Hence, combinations of different types of biometric traits (multimodal) were explored by biometric research community. Work reported in biometric literature have suggested that by combining biometric traits problems of unimodal systems can be alleviated and overall recognition accuracy can be improved [1]-[4]. Among various biometric traits deployed, IKP has attracted researchers to develop recognition systems. IKP refers to the skin patterns that are found on the finger surface present on the palmar region of human hand at the joints of fingers particularly the second knuckle region for it contains more patterns than the first and third knuckle. This work presents a multimodal system which acquires a hand image of individual and extracts finger IKP as region of interest (ROI) and hand geometry features. A fusion approach is proposed which combines IKP trait of middle, ring and index finger with geometrical features of hand to improve recognition rates beyond the observed recognition rates for isolated biometric traits [5], [6].

Rest of the paper is organized as follows. Section II depicts the related works on finger knuckle-print recognition. Section III illustrates the proposed approach. Details of experimental work carried out are discussed in Section IV, followed by the last section that concludes the presented approach.

Anitha. M .L. is with Department of Computer science and Engineering, P.E.S. College of Engineering, Mandya -571401, India (phone: 91-9945576186, fax: 08232-222075, e-mail: m_l_anitha@ yahoo.co.in).

Radhakrishna Rao.K.A. is with Department of Electronics and Communication Engineering, P.E.S. College of Engineering, Mandya -571401, India (phone: +91-9886064102 fax: 08232-222075, e-mail: karkrao@yahoo.com).

II. Related Work

Several research work on hand related traits have been reported in biometric literature. The finger surface possesses unique patterns that have been utilized to build recognition systems. IKP recognition has only been introduced to biometric technology for a few years, but the methods used for finger knuckle print (FKP) finger surface present on the dorsal region of human hand at the joints of fingers particularly the second knuckle region and palm print is also applicable for IKP since all of them have line patterns.

Gabor transform is used by Li et al. in [7] to extract line features from all fingers except thumb finger images and Ribaric et al. in [8] have proposed an approach based on Eigen palm and Eigen finger features. Equal error rate of 0.58% is reported in the experimental results. In [9], features extraction is performed by Radon transform and Haar wavelet. Authors have proposed a multi matcher biometric approach with features extracted from middle finger and ring finger, with fusion applied at the match score level. Goh Kah et al. in [10] have identified valley points between adjacent fingers and finger tips points to extract the largest rectangle area lying inside the contour of the finger which is considered as IKP ROI. Finite Radon Transform which is defined as the summation of image pixel values along a set of lines is applied on IKP to find the ridgelet coefficients. Computed coefficients are used to find energy measures which are taken as IKP feature. To evaluate the performance a database is established consisting of 135 users hand images. Equal error rate of 1.95% is reported in the experimental results. IKP ROI's of all fingers except thumb is extracted from hand image captured by cameras equipped on portable devices by Xuemiao Xu et al. in [11]. An approach that simultaneously considers illumination invariance and deformation tolerance is evaluated on the two different data sets corresponding to calibrated and uncontrolled image acquisition environment. Equal error rate of 0.021 and 0.74% is reported in the experimental results for images acquired in calibrated and uncontrolled acquisition environment.

Major work reported in literature is evaluated using PolyU [12] finger knuckle pint database consisting of 7,920 images of four fingers of 165 users. The device being used to collect images has a peg to hold the finger. Hygienic concerns and self positioning issues greatly limit the applicability of the recognition systems when acquisition set up uses constrained environment to capture biometric data. Hence there exists greater demand for biometric systems which uses unconstrained and contact free image acquisition set up.

III. Proposed Work

The proposed system consists of two main modules, namely Enrollment and Verification module. Fig. 1 shows the structure of the proposed verification system. To enroll into the system database, the user of the recognition system has to provide a set of training images. This task is accomplished by capturing user biometric data using an image acquisition set up. Feature vectors that describe certain characteristics of the IKP are computed from the extracted ROI of finger image by using local binary pattern. Computed feature vectors are stored as templates in the database (also called as gallery templates). During recognition, biometric data (test data) of a user is captured by the image acquisition set up used during enrollment and multiple templates (also called as query templates) are computed. Since verification refers to confirming or denying a person's claimed identity. The recognition system performs one to one comparisons of the query template with the gallery templates of claimed identity stored in the database during enrollment. Proposed system works in two stages. First stage consists of image acquisition, preprocessing and feature extraction components. In the pre-processing stage the alignment and orientation of the hand images are corrected and image processing algorithms are utilized to locate key points on palm region of hand. Key points are used to crop middle, ring and index finger region from which ROI of IKP are extracted. Distance between two key points is considered as geometrical feature. IKP features are extracted using local binary pattern descriptor feature extraction method. The second stage consists of feature matching approach which utilizes minimum distance classifier according to Euclidean distance for confirming the identity as genuine or denying a user's claimed identity as imposter. Hand geometry features are used with IKP features to enhance the performance of verification system. The details of each stage are discussed in the subsequent sections.

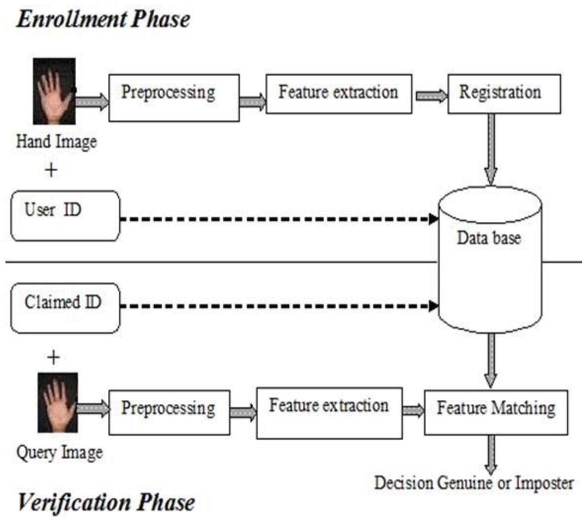


Fig. 1 Block diagram of proposed approach

A. Image Acquisition and Preprocessing

The image acquisition set up is designed to capture hand images. The set up is composed of a digital camera mounted on a tripod stand and is focused against a black panel. The panel is placed at a suitable distance from the camera and users are requested to place their hand in front of the panel with the palmar region of hand facing the camera lens. No guidance or pegs are used to restrict the users hand placement. Image collection process was carried at two different locations at our institute under normal room lighting conditions. The participants were mainly students and staff form our institute and 448 persons volunteered for the database. Images were captured in two sessions and in each session four images of right hand were captured. The acquisition process resulted in 3,584 images in the database. For both the session camera settings and camera to panel distance is maintained as same. Fig. 2 (a) shows a sample hand image. Complete image database is divided into two mutually exclusive gallery (training) and probe (test) sets. Let DBG = $\{IG_1, IG_2, \ldots\ldots IG_N\}$ be the gallery set database consisting of N hand images and DBP = $\{QP_1, QP_2, \ldots\ldots QP_M\}$ be the probe set database consisting of M hand images.

Pre-processing process involves the following steps.

i. Left edge of palm region is identified and the image is rotated either in clockwise or anticlockwise direction such that the orientation of left edge of palm region becomes straight. This is illustrated in Figs. 2 (b) and (c). This rotated image is considered for further preprocessing process.

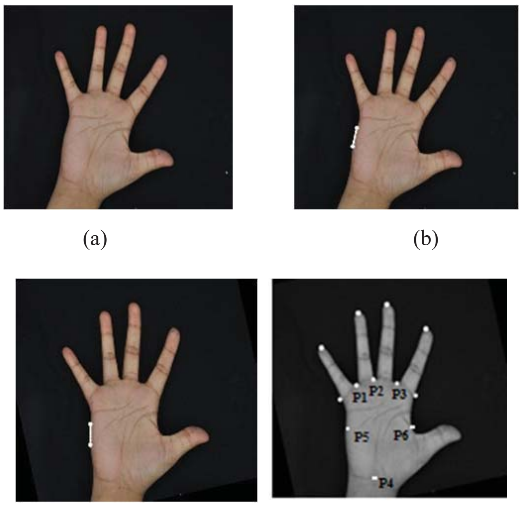
ii. Color image is converted to gray level image and a fixed threshold is applied to convert the gray image into a binary image.
iii. Hand contour is obtained and key points (finger valley and tip points) are identified as per the algorithm proposed in our previous work [13]. Identified points are shown in Fig. 2 (d).

B. ROI Extraction

Valley points identified on either side of the finger under consideration are used to crop the entire finger portion. For cropping IKP ROI of finger following steps are used.

i. Two valley points on either side of finger base region are selected as two anchor points. Tip of the finger is considered as the third anchor point.
ii. Finger length F is calculated as the distance between fingertip and midpoint of anchor points identified in step i.
iii. Second knuckle region is located from ½ to ¾ the length of the finger.
iv. Rectangular area lying inside the contour of the finger in the region bounded at second knuckle region is considered as IKP ROI. Identified ROI for middle finger is shown in Fig. 3 (a).
v. The ROI part containing the IKP is cropped out of the finger region. Cropped IKP ROI of middle finger is shown in Fig. 3 (b). Its size is normalized by resizing the ROI to a size of 40 X 150 pixels using bi cubic interpolation.

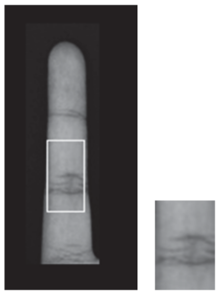
C. Feature Extraction



(a) (b)

(c) (d)

Fig. 2 (a) Input Image, (b) Left edge of palm region, (c) Rotated Image, (d) Key points



(a) (b)

Fig. 3 (a) Identified Rectangular region, (b) Cropped IKP ROI

Feature extraction algorithms are applied on the preprocessed input data to compute feature vectors. The local binary pattern operator transforms an image into labels describing small-scale appearance of the image. The LBP operator assigns a binary label to every pixel in the image by thresholding it against the eight neighborhood pixels [14]. If the pixel's value is greater than the neighbor pixel value then binary value 1 is assigned, otherwise 0 is assigned. For each pixel in the image the LBP operator is extracted. Image borders are ignored due to the fact that a 8x8 neighborhood is required. The derived binary numbers are referred to as Local Binary Patterns or LBP code which is invariant to monotonic gray-scale transformations preserving pixel intensity order in the local neighborhoods. To derive feature that is invariant or robust to rotations of the input image extension to the original operator called as uniform patterns is used in the present work. A binary label is considered as uniform if it consists of at most two bit-wise transitions from 0 to 1 or vice-versa. For example, the patterns 00000000 (zero transitions), 00001110 (two transitions) and 10001111 (two transitions) are uniform whereas the patterns 11010001 (four transitions) and 01010011 (six transitions) are not. The number of different output labels to map for patterns of P bits is $P*(P-1)+3$. Since 8x8 neighborhood is considered the uniform mapping produces 59 output labels for neighborhoods of eight sampling points. After the labels have been determined, a histogram H_l of the labels is constructed as:

$$H_l = \sum_{i,j}\{ L(i,j) = l \}, l = 0 \ldots.. q-1 \quad (1)$$

where q is the number of different labels produced by the LBP operator, while i and j refers to the pixel location. LBP histograms calculated from palm IKP ROI are stored as the feature vector of 59 dimensions each.

D. Hand Geometry Feature Extraction

Six points are selected from the set of key points identified during preprocessing stage are used for angle feature and palm breadth to height ratio calculation. The angle between the line joining the points P1, P2 and P2, P3 is calculated and is stored as angle feature vector of one dimension. Distance of line joining the points P5, P6 and P2, P4 are considered as palm breadth and palm height. Palm breadth to height ratio is computed and is stored as hand shape feature vector of one dimension. Let d(Tp,Tq) denote the difference in value computed for pair of templates, where Tp and Tq denotes gallery set and probe set templates, respectively. For each user Euclidean distance of every probe template with the gallery set templates of the same user are computed. Mean value of distances is computed using:

$$\mu_h = \frac{1}{n}\sum_{k=1}^{n} d_k \quad where \quad d_k = \sum_{i=1}^{4}\sum_{j=5}^{8} d(T_i, T_j) \tag{2}$$

where $d(T_i, T_j)$ is the Euclidean distance computed between templates T_i and T_j and n is the number of individuals considered. μ_h is computed by considering n value as 100. Equation (2) is used to compute mean value of distances for hand shape μ_{hs} and angle feature μ_{ha}.

E. Feature Matching

The matching of the image pair (gallery and probe image) is done by computing the distance between the gallery and probe templates. Since Euclidean distance metric achieves good results at low computational cost, in our work we have used this metric for template matching. Euclidean distance is defined as:

$$d(P, G) = \sqrt{\sum_{i=1}^{n}(P_i - G_i)^2} \tag{3}$$

where P and G are templates to be compared and value n refers to the dimension of a template. Since in our work more than one trait is considered, distance measure is converted to match score in the range 0 to 1. At the verification stage a threshold, T is used to regulate the system decision at matching stage. If the match score is greater than or equal to T, then the templates are considered to belong to the same user else they are considered to belong to different user.

F. Verification Module

Weighted sum rule is used to consolidate the matching scores produced by the three IKP traits to find the total similarity score (TSS). Sum rule is defined as:

$$TSS = \sum_{i=1}^{m}(W_i \times S_i) \tag{4}$$

where W_i and S_i are the weight assigned and match score of i^{th} trait respectively. Equal weights are assigned to all three traits. A sequential rule is formulated for decision making purpose by combining the TSS value with geometrical features. Steps carried out in this phase for verifying the claimed identity of an individual as either Genuine or Imposter is as follows:

i. For a query image q with claimed identity I_q perform preprocessing and feature extraction procedure to compute
a. IKP feature vectors T_{mq}, T_{rq}, T_{iq} of middle, ring and index finger, respectively.
b. Angle feature vector T_{aq}
c. Hand shape feature vector T_{sq}.

ii. Retrieve the angle feature vector T_{ap}, hand shape feature vector T_{sp} and IKP feature vector T_{mp}, T_{rp}, T_{ip} computed during enrolment for the identity claimed identity I_q from the database.
iii. Compute similarity score based on steps explained in feature matching section by comparing IKP feature vector of probe and gallery templates of corresponding fingers.
iv. Compute TSS using (4).
v. Compute $d_a(T_{aq}, T_{ap})$ as the difference between the two angle feature vector $d_a(T_{aq}, T_{ap}) = \|T_{aq} - T_{ap}\|$ where $\|\cdot\|$ is absolute value.
vi. Compute $d_s(T_{sq}, T_{sp})$ as the difference between the two hand shape feature vector $d_s(T_{sq}, T_{sp}) = \|T_{sq} - T_{sp}\|$ where $\|\cdot\|$ is an absolute value.
vii. If ($TSS > T$ && $d_s \leq \mu_{hs}$ && $d_a \leq \mu_{ha}$)
    then,
        label = Genuine
    else,
        label = Imposter

IV. Experimental Results

The performance evaluation of the proposed system is carried out by considering the individual inner finger knuckle, geometrical features and also through their combinations. Images captured during first session are considered as gallery set and second session images as probe set. Performance measures in terms of false acceptance rate (FAR) and false rejection rate (FRR) are computed. False acceptance rate (FAR) is the error rate of accepting imposter as genuine person. False reject rate (FRR) is the error rate of rejecting a genuine person as imposter. FAR and FRR are defined as:

$$FAR = \frac{Number\ of\ accepted\ imposter\ claims}{Total\ number\ of\ imposter\ access} \times 100\% \tag{5}$$

$$FRR = \frac{Number\ of\ rejected\ genuine\ claims}{Total\ number\ of\ genuine\ access} \times 100\% \tag{6}$$

Equal error rate equal error rate (ERR) is the error rate when FAR equal FRR and it is considered as important measure in verification experiments. ERR measures the likelihood of unauthorized accesses to the recognition system. Threshold value of the system is obtained based on ERR criteria, since both FAR and FRR must be as low as possible for the biometric system to work effectively. In the first experiment we investigated the performance of individual IKP traits and their combinations. The result expressed as FAR and FRR depending on the threshold is plotted as shown in Figs. 4 (a)-(d). The second experiment was carried out by combination of hand shape feature with weighted sum rule applied to IKP traits.

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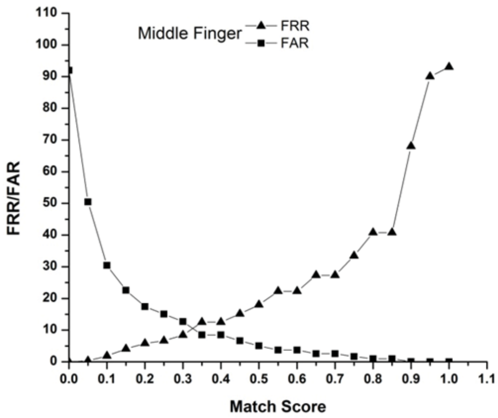

Fig. 4 (a) Dependency of FAR and FRR on match score for middle finger

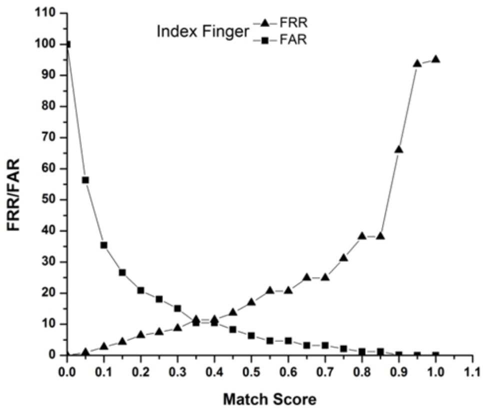

Fig. 4 (b) Dependency of FAR and FRR on match score for index finger

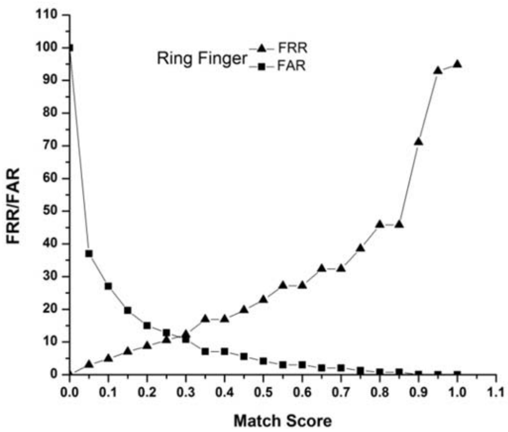

Fig. 4 (c) Dependency of FAR and FRR on match score for ring finger

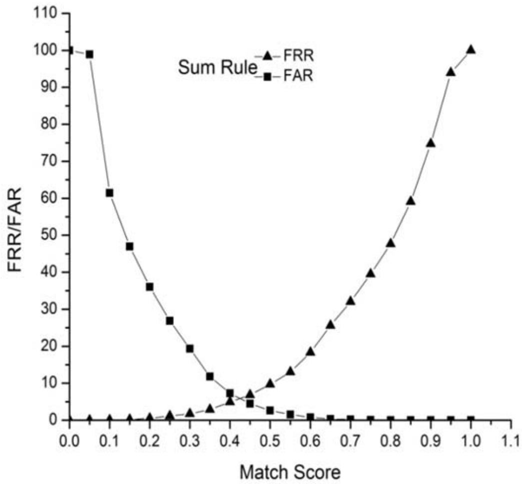

Fig. 4 (d) Dependency of FAR and FRR on match score for Sum rule

The third experiment was carried out with angle feature and weighted sum rule applied to IKP traits. The fourth experiment was conducted considering hand shape, angle and IKP features. The ERR value obtained for all the three experiments for verifying the identity of an individual are tabulated in Table I and plot of FAR versus FRR for the fourth experiment is shown in Fig. 5. Results obtained clearly indicate that by using more than one trait for verifying the identity, ERR can be reduced. Also with respect to verification scheme major work reported in literature is with images being acquired using scanners and pegs being used to fix the placement of hand. Images are captured under normal room lighting conditions. Due to the non availability of publicly available IKP database for benchmarking purpose, we built our own database. Proposed system with ERR of 0.8% is able to achieve nearer performance to that reported in [11] which uses a contactless image acquisition setup with ERR of verification system being 0.7%.

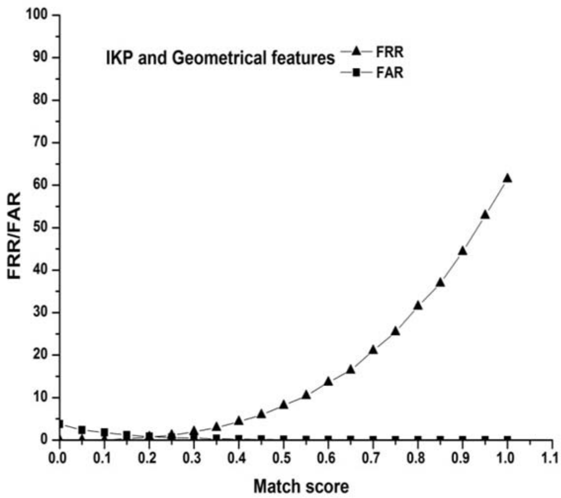

Fig. 5 Dependency of FAR and FRR on match score for the proposed approach

TABLE I
VERIFICATION PERFORMANCE OF THE PROPOSED APPROACH

Biometric trait used	ERR
Middle finger IKP	10.0 %
Ring finger IKP	10.5 %
Index finger IKP	10.5 %
Sum rule for IKP's	5.3 %
Sum rule for IKP's + Hand shape feature	3.0 %
Sum rule for IKP's + Angle feature	4.0 %
Sum rule for IKP's + Hand shape + Angle feature	0.8 %

V. CONCLUSIONS

An approach to develop a biometric verification system based on IKP and geometrical features from palm region of hand is proposed. Major advantage of proposed approach is all features can be extracted from the palmer region of the hand with the images being acquired with a contactless image acquisition set up. Another valuable advantage is that acquisition set up is user friendly. The proposed system is able to achieve similar performance when compared to the work reported in literature with low dimensional features. Experiments conducted on the database developed at our institute show that the proposed approach is able to produce promising result. Further investigation of this work includes identifying other hand related traits that can be combined with IKP traits to improve the performance of the verification system. Although the proposed system works satisfactorily, effectiveness of the proposed approach should be verified by capturing images in open environments.

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