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A Review on Contactless Hand Verification Systems

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ABSTRACT

Biometric system is gaining popularity increasingly since it provides the most sophisticated technology for authentication, verification, and identification. This technology can identify each individual person on the basis of their biometric information such as their face, hand features, signatures, DNA, or iris pattern and thus can impart a secure and convenient method for authentication purposes. Hand biometrics is one of the most widely used biometric systems. There are two approaches for capturing hand biometrics: contact-based and contactless. In this paper, we present a thorough review of the state of the art contactless hand verification systems. We also present the various modules of the general contactless hand verification system and analyze various hand biometrics features.

Keywords : Hand Biometrics, Contactless, Hand Geometry, Palm Print, Hand Verification.

I. INTRODUCTION

In this modern world, every day most of us have to identify ourselves on numerous occasions – be it entering a code on a keypad to enter the workplace, a password to log onto our computer, or a pin number to access cash from the bank [1]. We usually recorded passwords or PIN numbers in the contacts section of our dairy or address books. However, in a world that is going to be a paperless, more advanced method of identifying individuals and identifying who they need to be developed. One such solution is biometric technology for authentication, verification, and identification of individuals. The human hand contains several physiological biometric features including fingerprints, the palm print, the geometry of the hand, etc. As a result, hand biometric-based verification systems are gaining popularity day by day.

The history of hand biometric-based technology/systems dates back over three decades. It is generally believed that the hand-geometry system—Identimat developed by Identimation [2]—is one of the earliest reported implementations of any biometric system for commercial applications. Since then, hand biometric-based systems have found applications in a wide variety of fields ranging from airports to nuclear power plants [2].

A number of techniques have been developed for person verification based on hand-biometrics features in the literature. In most of the proposed approach users need to put their hands on a flat surface fitted with pegs to minimize variations in the hand position.

Although these approaches make the feature extraction task easier and consequently results in lower error rates, such systems are not user-friendly. To make the system more user-friendly some researchers have proposed to do away with hand position restricting pegs. The feature extraction algorithm in their approaches takes care of possible rotation or translation of the hand images acquired without guiding pegs. However, users are still required to place their hand on a flat surface or a digital scanner. This type of contact may give rise to hygienic as well as security concerns among users. Security concern on the contact-based approaches arises from the possibility of picking up fingerprint or palm print impressions left on the surface by the user and thereby compromising the user's biometric traits. Hence considering all these issues some researchers proposed contactless hand verification system. In this paper, we present various state of the art a contactless hand verification systems. We also present the in-depth architecture of the general contactless hand verification system and analyze various hand biometrics features.

The remaining of the paper is organized as follows: Section II describes the various biometric traits from hands, section III describes various modules of a basic contactless hand verification system, section IV describes various state-of-the-art works in contactless hand verification system, section V evaluates the performance of the state of the works discussed in section IV and finally section VI concluded the paper.

II. BIOMETRIC TRAITS FROM HANDS

Hand biometrics has unique features that can be identified and extracted. Hand has many biometric traits such as fingerprint, palm print, finger knuckle print, vein structure, etc. This section describes these traits.

A. Finger Print

A fingerprint is made of a number of tiny ridges and valley pattern on the tip of each finger and usually considered to be unique. This uniqueness is achieved due to the unique pattern of ridges and furrows as well as the minutiae points. The ridges from the minutiae points are called the points of interest in a fingerprint, such as bifurcations and ridge endings. Minutiae also include a short ridge or independent ridge, island, ridge enclosure, spur, crossover or bridge, delta, core, etc. Fingerprint ridge patterns can be divided into three basic classes: arches, loops, and whorls. Fig. 1 shows the format of a fingerprint. The fingerprint is the oldest biometric technology used successfully in various applications. There are two ways of capturing fingerprint images: 1) scanning an inked impression and 2) live-scanning fingerprint by using a scanner.

B. Hand Geometry

Hand geometry is a biometric trait that is used to identify users by measuring the size and shape of a person's hand, including length, width, thickness, and surface area. Both contact-based and contactless sensors are available for measuring hand geometry. These devices measure only the size and shape of the human hand but ignore palm prints, fingerprints, or other traits.

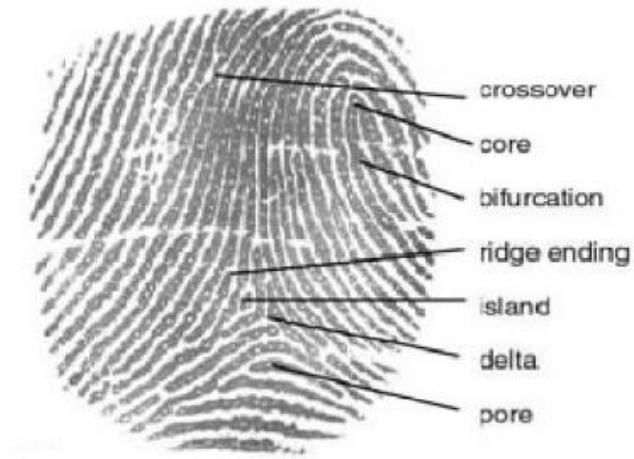
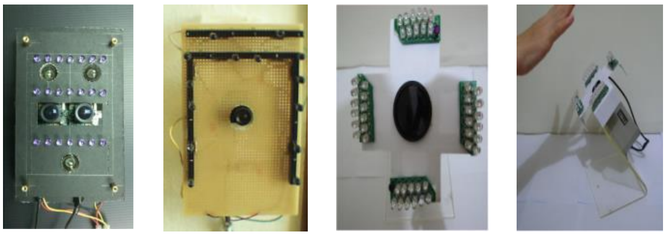


Figure 1: Fingerprint Format.



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

Figure 2: Prototype of several contactless hand geometry acquisition systems

C. Palm Print

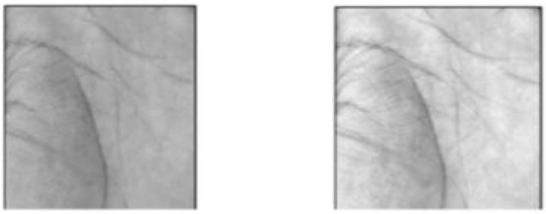
A palm print is an image obtained from the palm region of the hand. Palm print features are composed of principal lines, wrinkles, and ridges. It also contains other information such as texture, indents, and marks which can be used to compare one palm with another. By combining all features of the palms, such as palm geometry, ridge and valley features, and principal lines and wrinkles, it is possible to build a highly accurate biometric system. Fig. 4 shows the palm print captured from the human hand.

D. Hand Vein

Hand vein patterns are unique to every individual. In this technology, the image of vein pattern beneath the skin is captured and uses as the basis for individual identification. Near-infrared light is used to capture a palm vein pattern. Because veins are inside the human body, they are secure and it is hard for them to be stolen or duplicated. Unlike a fingerprint, a hand vein does not get impacted by age, environment, cuts, scrapes, bruises, scars, dirt, grime, and grease. It is considered to be extremely secure, reliable, and accurate to identify individuals. Fig. 5 shows the vein image captured from the human hand.

(a) (b)

Figure 3: Captured images with different sensors: (a) acquired with IR filter and infrared illumination device and (b) acquired without IR filter and infrared illumination device.



(a) (b)

Figure 4: Palm print image

Figure 5: Palm vein image

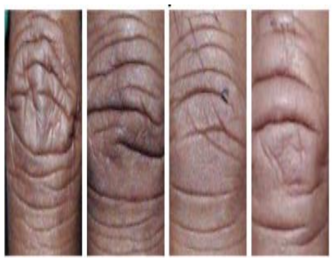


Figure 6: Image of finger knuckle print

E. Palm Knuckle Print

The outer surfaces of finger joints also have even more obvious line features than the palm surface and this biometric trait is called the finger knuckle print (FKP), which denotes the flexion shrinks on the inner skin of knuckles. Like a fingerprint, these dermal patterns are formed at birth and they rarely change throughout the life of a person. Fig. 6 shows the finger knuckle print image obtained from the hand.

III. COMPONENTS OF A CONTACTLESS HAND VERIFICATION SYSTEM

A hand biometric system operates according to Fig.7. In the enrollment phase, hand biometric data are acquired from the registered users using an image acquisition device, featured are extracted from the collected data, then one or multiple templates per individual are computed and stored in a database. In the verification module user's hand, biometric data is once again acquired and the system uses this to verify the claimed identity of the user. Verification involves comparison with only those templates corresponding to the claimed identity. Based on the comparison result, the claimed identity is accepted or denied. The verification system comprises the following modules: the image acquisition module, the preprocessing module, the feature extraction module, the matching module, the decision-making module, and two optional modules the template adaptation module and the fusion module.

A. Image Acquisition Module

Hand images can be captured by a widely used VGA resolution CCD camera, 3D based laser digitizer, infrared illumination device, leap motion sensor and even using mobile devices with the camera. CCD camera consists of a set of optical components that work together to obtain the data from the hand. The quality of the hand image depends highly on the camera technology used. The 2D and 3D based digitizer analyses object to collect data on its shape. Digital and video cameras can also be used to collect hand images and these images might cause recognition problems as their quality is low because they collect images in an uncontrolled environment [14] with illumination variations and distortions due to hand movement. The leap motion sensor is a small USB peripheral device that supports hand and finger motions as input with no hand contact or touching. Two monochromatic infrared cameras and three infrared LEDs, which generated a 3D dot pattern of IR light, compose the sensor [15].

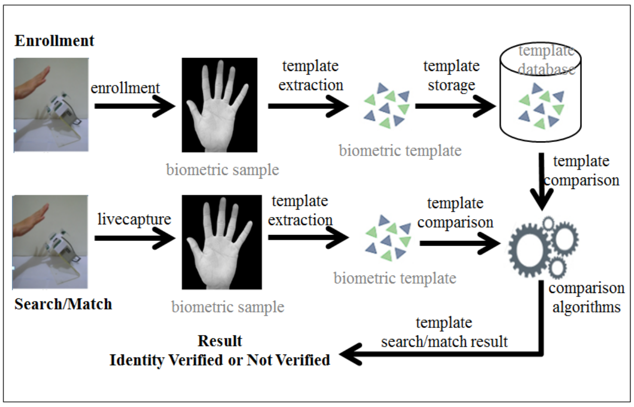


Figure 7: Processing steps in an identity verification system using hand

B. Preprocessing Module

Preprocessing is used to correct distortions, align different hand images, and crop the region of interest for feature extraction. Research on preprocessing commonly focuses on five steps. 1. Binarizing the palm images 2. Boundary tracking 3.Identification of key points 4.Establishing a coordination system and 5.Extracting the central part. Most of the research uses Otsu's method for binarizing the hand image [16]. Otsu's method calculates the suitable global threshold value for every hand image. According to the variances between the two classes, one of the classes is the background while the other one is the hand image. The boundary pixels of the hand image is traced using a boundary tracking algorithm [17]. The key points between fingers are detected using several different implementations including tangent [18], bisector [19], [20] and finger-based [21], [22]. Han and his team propose two approaches to establish the coordinate system, the first approach based on the middle finger [22] and the other based on the point, middle, and ring finger [21]. After establishing the coordinate systems, the central part of the palm prints is segmented using three classes: square based segmentation, circle-based segmentation, and elliptical based segmentation. Among all these methods most of the researchers use the Square-based method because it is easier for handling translation variation.

C. Feature Extraction Module

Feature extraction obtains discriminating features from the preprocessed hand image. Some authors investigated shape-based feature sets. The hand shape can be modeled either explicitly as a set of (2-D) coordinates of several landmark points along with the hand silhouette [35][36] or implicitly as a binary image of the hand over an empty background [23][37][28][31]. Most of the time, the feature vector is computed based on the entire hand or a sub-part of it although the individual fingers may have been extracted and aligned separately. One or several templates per user may be created during the enrollment stage and stored in the system's database. The templates are either the raw feature vectors computed from a user's hand images or the average of those feature vectors.

D. Matching Module

This module compares a user feature vector against user template(s) stored in the database in order to generate a matching score. Since the feature vectors are usually points in an N-dimensional Euclidean space, any metric distance can be used for computing a matching score: Euclidean distance [23][24], Mahalanobis distance [25][26], absolute distance [27][28], correlation coefficient [29][28], or a combination of those distances. A few studies explicitly model the class-conditional probabilities under Gaussian assumptions and use them as matching scores. As an exception [30][31] use the Procrustes shape distance and [32] uses a modified Hausdorff distance since the feature vectors are shapes corresponding to the hand silhouette. A different matching approach proposed in the literature consists of training a collection of two-class statistical classifiers (e.g. support vector machine—SVM) to predict a person's identity [33]. While a classifier approach may have a better discrimination power, it also requires that a separate classifier is trained for each of the enrolled persons. For large-population systems, that may become a computational challenge.

E. Decision-making Module

The final decision concerning the user's claimed identity (verification) is taken by the decision module. In verification mode, the decision is typically threshold-based: if the matching score is below a given threshold the claimed identity is accepted, otherwise, it is rejected. The threshold value is chosen such that the system satisfies some operating constraints (e.g. an upper bound on the false accept rate (FAR), an equal error rate (EER), etc.

F. Fusion Module

The fusion of multiple traits of an individual can improve the matching accuracy of a biometric system. Some of the limitations such as noisy data, intra-class variations, spoof attacks, and unacceptable error rates of a unibiometric system can be addressed by designing a system that consolidates multiple sources of biometric information. Multimodal biometric systems are those which utilize or are the capability of utilizing, more than one physiological or behavioral characteristic for enrollment, verification, or identification. Multimodal biometrics has drawn more and more attention in recent years due to its promising applications and theoretical challenges [34]. Although fusion increases accuracy, it generally increases computational costs and template sizes.

G. Template Adaptation Module

The long-term system performance can be improved by an optional template adaptation module that updates (by averaging for example) a user template after each successful authentication of that user. Thus, the system can accommodate slow changes in the user's physiology due to hand swelling, arthritis, and/or weight changes. The adaptation module is mostly present in the deployed systems.

IV. EXISTING WORKS IN CONTACTLESS HAND VERIFICATION SYSTEMS

Several works have been done on contactless hand verification system. Most of the works are unimodal in nature. They use a single piece of information for verifying identity. However, combining the information cues from different biometric sources using an effective fusion scheme can significantly improve the accuracy of a biometric system. Such systems are known as a multimodal system. Both the unimodal and multimodal systems are available in the literature.

Kanhangad et al [7] proposed a unified framework for contactless hand verification. This paper investigates a new approach to achieve performance improvement by simultaneously acquiring and combining three dimensional (3-D) and 2-D features from the human hand. 3-D digitizer is used for acquiring range and intense image of the presented hands of the user in a contact-free manner. Both the finger surface feature and palm surface features are used for feature extraction. It uses five biometric features, i.e., 2-D palmprint, 3-D palmprint, finger texture, along with 3-D and 2-D hand-geometry features, that are simultaneously extracted from the user's hand presented for authentication. In addition, a new representation for 3-D palm surface, namely SurfaceCode, is presented. The key advantage of the proposed SurfaceCode lies in the compact and effective representation of 3-D palm features. In this work, a 2-D Gabor filter-based competitive coding scheme has been used to extract features from the 2-D palm print.

Another approach was proposed by Bernardos et al [8]. The objective of this work is to explore the possibilities of delivering a functional identification method based on contactless hand shape analysis on a Leap Motion sensor. This paper has explored different classification algorithms that enable building a real-time in-air hand shape identification system, to be integrated with non-critical smart space applications.

Michael et al [9] proposed a system that could simultaneously extract five independent features, namely hand geometry, palm print, palmar knuckle print, palm vein, and finger vein, all originating from the same part of the body. This is the first paper that comparatively evaluates the combination of five different hand modalities. It also designs an evaluation method to accesses the richness of texture in the images by using the measures derived using Gray Level Co-occurrence Matrix (GLCM) [11] and then assign more weights to those with better quality. An acquisition device is designed which could capture both color and infrared hand images. The acquisition device consists of two low-cost imaging units that are mounted side by side in the device as shown in Figure 3. This paper used local-ridge enhancement (LRE) [10] to enhance the contrast and sharpness of the images. The sum-based fusion rule is used to consolidate the matching scores produced by the different hand modalities.

SIFT-based Image Alignment for Contactless Palmprint Verification has been proposed by Zhao et al in [12]. This paper proposes a method for accurate contactless SIFT-based Image Alignment for Contactless Palmprint Verification palm print verification. The contactless palmprint images are firstly aligned by a homography model estimated using SIFT features. The competitive code (CompCode) features are then extracted from the well-aligned images. The matching scores of the two features are fused to further improve the performance.

C. Xin et al proposed a contactless hand shape verification system in [39]. Hand images are captured by a self-developed device in a contactless manner. After that, geometry features are extracted based on key points, which are selected by sliding window filtering protocol.

In [40] R. Sanchez-Reillo et al proposed a contactless hand verification system where they use a commercial webcam for image acquisition. According to their proposed system, users can place their hand palm freely in the 3D space in front of the camera. They did not use any surface, the system is contact-free. They use a template for a correct position of the hands to reduce the projective distortions associated with the absence of a contact plane. Hand geometry features are used for verifying hands.

A. Morales et al proposed a new image acquisition system [41]. The proposed image acquisition system is composed of one commercial webcam, one InfraRed (IR) filter, and four sets of double-row GaAs infrared emitting diode with 12 diodes in each set. In this image acquisition system, users can place their hands-free in front of the camera without any contact and any restrictions like pegs or templates; moreover, this system can be utilized in the real environment and even in the dark because of the utilization of infrared light. They use hand geometrical features for verifying hands. To achieve better detection accuracy, in total 13 important points are detected from a palm image, and 34 features calculated from these points are used to further recognition. In this work, 34 features are extracted from all the fingers for palm identification, in which 13 important points should be located first, including the five tips of the fingers, four valleys between them, three auxiliary points, and the center of the palm point defined.

V. Kanhangad et al extended [7] in paper [42]. In this paper, they use the same image acquisition device as [7]. Here they propose a new dynamic fusion strategy for combining (2-D as well as 3-D) palm print and hand geometry individual matching score. They achieve performance improvement of 60% (in terms of EER) over the case when matching scores are combined using the weighted sum rule.

A comparison of all the discussed contactless hand verification system is shown in Table I.

V. PERFORMANCE EVALUATION

A. Performance Evaluation Metrices

There exist several types of testing for a biometric system considering a wide variety of aspects such as reliability, availability , and maintainability; security, including vulnerability; conformance; safety; human factors, including user acceptance; the relation between cost and benefit or privacy regulation compliance. The evaluation criteria are defined by the following rates [43][44]:

- False-Non Match Rate (FNMR): Proportion of genuine attempt samples falsely declared not to match the template of the same characters from the same user supplying the sample.
- False Match Rate (FMR): Proportion of zero-effort impostor attempt samples falsely declared to match the compared non-self template.
- Failure-to-enroll rate (FTE): Proportion of the population for whom the system fails to complete the enrollment process.
- Failure-to-acquire (FTA): Proportion of verification or identification attempts for which the system fails to capture or locate and an image or signal of sufficient quality.
- False Reject Rate (FRR): Proportion of verification transactions with truthful claims of identity that are incorrectly denied. Moreover, FRR is defined as follows: $FRR = FTA+FNMR\times(1-FTA)$
- False Accept Rate (FAR): Proportion of verification transactions with wrongful claims of identity that are incorrectly confirmed. Furthermore, FAR is calculated as follows: $FAR = FMR\times(1-FTA)$
- Equal Error Rate (EER): Rate at which both FAR and FRR coincides. In general, a system with the lowest EER is the most accurate.

B. Performance Review

Table I summarizes the performance of some research systems. Most of the authors report the EER figures while others report FAR reports. The evaluation result of any system largely depends on the population size of its test data. The third column of Table I shows the number of samples used for evaluation. The highest samples are used in [41], they used about 6000 different images for evaluating their verification system. Their system results in FAR=1.85%. Some authors [8][12][40][41]used only single features of hand biometrics. Among these [8] does not provide any EER, instead, it estimates an accuracy rate of 96%. In [12] EER of both left and right hand is provided. On them, the EER of the left hand is lower than the EER of the right hand. Some authors [7][9][39][42] combine two or more hand features and results in lower EER. Among these [9] has the lowest EER=0.0% that combined 5 different hand features. Among all the papers [40] has the highest EER=3.4%. This is because it uses only a single feature of the hand. According to our observation as shown in Table I the system that uses multiple hand features have a lower EER compared to the system that uses a single hand feature. However, only the use of multiple hand features can not improve the overall system performance, an effective technique is also necessary for the fusion of these multiple features. Hence, in the future, researcher can focus on improving these fusion techniques that will improve the overall performance of the system.

Table I: Comparison of various contactless hand verification systems

Reference	Year	Samples or persons	Hand biometric feature	Performance analysis
[7]	2011	177 persons, 3540 samples	hand geometry and palm texture	EER(%) 0.22
[8]	2015	21 samples	geometric palm feature, 52 geometric hand features	96% accurate
[9]	2012	136 persons	Hand geometry, palm print, palm vein, palmar knuckle print, and finger vein	EER(%) 0.00
[12]	2013	230 samples	Palm print	EER(%) left hand 0.5720, right hand 0.6486
[39]	2011	100 persons, 4000 samples	Hand shape, hand geometric feature	EER(%) 2.16
[40]	2008	20 persons, 200 samples	Hand geometry	EER(%)3.4
[41]	2012	100 persons, 6000 images	Hand geometry, 34 features	FAR(%) 1.85
[42]	2011	114 persons, 1140 samples	Palm print and hand geometry	EER(%) 0.28

VI. CONCLUSION

Contactless hand verification systems have been widely used for applications in access control, attendance tracking, and personal identity verification, etc. Although the history of contact-based hand verification systems dates back about 3 decades ago, the contactless hand verification system is quite a recent trend. Hence this is an active area of research that focuses on designing a better contactless image acquisition setup, that will be able to capture an image in all scenarios including dark and variant environment, new approaches to preprocessing for correcting the alignment of hand as there is no constrain in the positioning of the hand in the contactless systems, and new approaches to feature matching and matching score fusion as the accuracy of the system largely depends on fusion strategy.

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