Review of Fingerprint Recognition methods using Extended Features

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***Abstract*—This paper presents review of fingerprint recognition methods based on different extended features, compared to different latent and partial fingerprint database. Also, techniques used to extract features of a fingerprint as well as matching them with the database are specified in this paper. Some of the surveyed research papers have used traditional approach like minutiae based identification techniques and verification techniques. Whereas the other articles have used novel methods which combines minutiae and other extended features. To design and develop a fingerprint feature extraction method and to match them using pixel details and extended features, first of all fingerprints enhancement and thinning is done. Finally features are extracted and estimated. These estimated features are used to match with the template database using matching algorithm. The features are unique, which allows a single feature to be suitably matched with high possibility against a large database of features.**

***Index Terms*— Biometrics, extended features, fingerprint recognition.**

I. Introduction

The use of biometrics is an evolving component in today's society. Biometrics is an identification procedure that uses the unique behavioral and physiological individualities of the human body as identifiers. Fingerprints being the oldest and easily available trait of Biometrics, offers an infallible means of personal Identification. Even features such as persons gait, face or Signature may change with passage of time and may be Fabricated or imitated. However a fingerprint is completely Unique to an individual and stayed unchanged for lifetime. A fingerprint image consists of a pattern of the valleys and ridges on human fingertips. Ridges are dark whereas Valleys are bright. Ridges and valleys often run in parallel. Fingerprint identification is the procedure used to decide that both sets of fingerprints image are of the same finger. Fingerprint identification is a complex pattern recognition problem. There is a misconception that automatic fingerprint identification is a fully solved problem since it was one of the first applications of machine pattern recognition. There are number of techniques that perform fingerprint matching. Some methods encompass matching minutiae features between the two images, while others look for likeliness in the bigger structure of the fingerprint.

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II. LITERATURE SURVEY

Jin Fei Lim, Renee Ka Yin Chin [11], proposed a simple hybrid method that improves the performance of fingerprint recognition technique by fusing minutiae-based and image-based techniques, extracting features from both techniques to compensate the limitations of each of them. The proposed hybrid method is capable of achieving better recognition rate.

Minutiae-based technique is the backbone of many fingerprint recognition studies, where it utilizes the rich local features of a fingerprint, namely termination points and bifurcation. It is widely used as it is computationally inexpensive. This technique locates the maximum number of minutiae pairings between the template and an input set of minutiae extracted from the input image for matching purpose.

The image-based technique is generally used to match fingerprints based on global features, without the need to extract any reliable minutiae-features. This technique utilizes the ridge shape, texture information and local orientation for fingerprint verification. Image matching is done by computing the similarity between the template image and the input image. One of the main drawbacks of this technique is the lack of robustness when tracking variations of scale and orientation.

Monireh Abdoos, Nasser Mozayani [4], proposed the combined feature by combining the information of every two minutiae of the image and the ridge structure between them. This feature is defined based on the minutiae including ridge endings and bifurcations. The combined feature is invariant with respect to the global transformations such as rotation and transformation. Experimental results have shown efficiency in accuracy using this new feature on FVC 2004 Database.

The author introduces a combined localized feature for partial fingerprint matching. The combined features are derived from minutiae features. It does not depend on global ridges structure, so it is suitable for partial fingerprint matching. It can be assumed that minutiae extracted from partial image are "good enough" to authenticate a person accurately.

Arun Ross and Rajiv Mukherjee [5], propose an indexing framework based on minutiae triplets by utilizing ridge curve parameters in conjunction with minutiae information to enhance indexing performance. The proposed technique facilitates the indexing of fingerprint images acquired using different sensors.

The technique proposed in this work relies on the creation of a 9-dimensional index space model based on minutiae triplets and the associated ridge curves. The K-means clustering scheme is invoked to partition this index space into multiple clusters. Now, each fingerprint is viewed as a collection of points distributed in the index space with each point characterizing a 9-dimensional feature describing a triplet and the associated ridge curves. Each of the points is assigned to one of the pre-defined clusters based on the minimum distance rule. Thus, a cluster in index space will have a listing of all fingerprint identities that have at least one point assigned to that cluster. When a query print is presented to the system, it is first decomposed into triplets and ridge curves, and the 9-dimensional collection of points is generated. Next, these points are mapped to individual clusters in the index space. A set of possible matching identities corresponding to a small number of clusters is then determined.

Lin Hong, Yifei Wan, and Anil Jain [1], proposed a fingerprint Image Enhancement and Extraction using Gabor filter, Local Orientation, Ridge Frequency, and Image Filtering.

The main steps of the algorithm include:

- **Normalization:** An input fingerprint image is normalized so that it has a prespecified mean and variance.
- **Local orientation estimation:** The orientation image is estimated from the normalized input fingerprint image.
- **Local frequency estimation:** The frequency image is computed from the normalized input fingerprint image and the estimated orientation image.
- **Region mask estimation:** The region mask is obtained by classifying each block in the normalized input fingerprint image into a recoverable or a unrecoverable block.
- **Filtering:** A bank of Gabor filters which is tuned to local ridge orientation and ridge frequency is applied to the ridge-and-valley pixels in the normalized input fingerprint image to obtain an enhanced fingerprint image.

Satyabrata Swain, Banshidhar Majhi, Ratnakar Dash [13], proposed a technique for the extraction of dots and incipient ridges by tracing valleys for partial to full print matching of latent fingerprint.

In the proposed technique the author first finds the starting point on the valley by analyzing the frequencies present in the fingerprint. Valley is traced from the starting point using first marching method (FMM). Then an intensity check method is used for finding dots and incipient ridges features.

While tracing, take a window around the traced point. If $I(i, j) < \alpha$, where $I(i, j)$ is any pixel in the window, and α is a gray level intensity value, then a connected component is constructed by considering the range of the intensity value 0 to α. These connected components include dots, incipient ridge and noise. CDEFFS standardized that the size of dots and incipient ridges are less than 0.02 inch, so all the extracted components whose size is more than 0.02 inch (part of a ridge) are discarded. Centroid of rest of the extracted component and its direction are calculated. The extracted centroid of dots and incipient ridge are added with the minutiae to form a new set of feature vector.

CDEFFS ANSI/NIST Committee, consisting of various experts [7], proposed Data Format for the Interchange of Fingerprint, Facial, & Other Biometric Information (ANSI/NIST-ITL 1-2007) and is the most recent revision of a series of standards that began in 1983. These standards have been extensively used as the primary method of communicating biometric information for law enforcement and other large-scale identification purposes.

It defines a quantifiable, repeatable, and clear method of characterizing the information content of a fingerprint or other friction ridge image. A broader and more complete set of friction ridge features than has previously been defined in the ANSI/NIST standards or any other fingerprint standard. The features defined in this addendum are used to define the information content or features of latent or exemplar images from fingerprints, palmprints, or other friction ridge skin.

Uses may include, but are not limited to,

- Definition of the information content of a single friction ridge impression as discerned by an examiner during analysis, for archiving, interchanges with other examiners, validation and quality assurance processing, and quantitative analysis.
- Definition of the information content and determination of a comparison of two friction ridge impressions as discerned by an examiner during comparison and evaluation, for archiving, interchanges with other examiners, validation and quality assurance processing, and quantitative analysis.
- Interoperable interchange format for automated fingerprint or palmprint systems, for human-initiated searches, fully automated searches, data interchange between automated systems, and feedback to examiners from automated processing.

Alessandra A. Paulino, Eryun Liu, Kai Cao and Anil K. Jain [12], proposed an indexing technique, primarily for latent, that combines multiple level 1 and level 2 features to filter out a large portion of the background database while maintaining the latent matching accuracy. Approach consists of combining minutiae, singular points, and orientation field and frequency information. At a penetration rate of 20%, proposed approach can reach a hit rate of 90.3%, with a five-fold reduction in the latent search (indexing + matching) time, while maintaining the latent matching accuracy.

Authors propose to combine different features and techniques to improve latent fingerprint indexing performance. Approach consists of combining a constrained version of triplet indexing, MCC indexing and a new orientation field descriptor indexing technique that uses hash function, filtering based on singular points and averaged ridge period comparison. Basic triplet indexing technique is improved by applying a rotation constraint to the matched triplets. Orientation field descriptor indexing is carried out first by converting the descriptor to a binary vector, followed by a hash function. The indexing score based on each one of these specific features is combined to obtain the final indexing score.

R. Cappelli, M. Ferrara, and D. Maltoni [8], proposes a new hash-based indexing method to speed up fingerprint identification in large databases. A Locality-Sensitive Hashing (LSH) scheme has been designed relying on Minutiae Cylinder-Code (MCC), which proved to be very effective in mapping a minutiae-based representation (position/angle only) into a set of fixed-length transformation-invariant binary vectors.

In this paper, author proposes a novel fingerprint indexing technique based on the Minutia Cylinder-Code (MCC) representation. Starting from the minimal fingerprint representation (only minutiae positions and angles) defined by the ISO/IEC 19794-2 standard, MCC encodes the neighborhood of each minutia into a fixed length bit vector, which is invariant with respect to rotation and translation. The bit vectors are indexed by means of Locality-Sensitive Hashing (LSH) and fingerprints are retrieved using a novel effective search algorithm.

Heeseung Choi, Kyoungtaek Choi, and Jaihie Kim [9], proposed a novel fingerprint matching algorithm using both ridge features and the conventional minutiae feature to increase the recognition performance against nonlinear deformation in fingerprints. The proposed ridge features are composed of four elements: ridge count, ridge length, ridge curvature direction, and ridge type. These ridge features have some advantages in that they can represent the topology information in entire ridge patterns existing between two minutiae and are not changed by nonlinear deformation of the finger.

In this paper, author proposes a novel fingerprint matching algorithm for extracting ridge features. The author defines the ridge-based coordinate system in a skeletonized image. With the proposed ridge features and conventional minutiae features (minutiae type, orientation, and position), a novel matching scheme using a breadth-first search to detect the matched minutiae pairs incrementally has been proposed. Following that, the maximum score is computed and used as the final matching score of two fingerprints.

Chu-Chiao Liao Ching-Te Chiu [15], proposed a new fingerprint matching method which combines different features, including minutiae and ridge features. The ridge features contain ridge count, ridge length, ridge curvature direction and ridge frequency. All ridge features are extracted in blocks around each minutia. The similarity scores of the features are summed with different weighting values as the final score of two fingerprints.

In this paper, author proposes a simple hybrid method that improves the performance of fingerprint recognition technique by fusing minutiae and image-based features.

Marek Dusioa, Martin Aastrup Olsena,b, Christoph Buscha,b [14], proposed a new fingerprint sample quality measurement algorithm based on local fingerprint area analysis and ridge line counts. The proposed method determines ridge orientation of local areas with Principal Component Analysis, finds edges using the Laplacian of Gaussian and zero-crossings approach, and counts valley to ridge transitions across the center of the area to assign a local score. The local scores are aggregated to assign a single quality value for the fingerprint.

The proposed method produces a map of local area qualities. To produce a final quality scalar q, this map is aggregated as follows – the final quality is the ratio of local areas that feature a ridge count over a threshold to all local areas i.e. minimum 2.7 number of ridges expected to pass over 32 pixels.

Xuejun Tan and Bir Bhanu [2], proposed a formal framework to estimate the fundamental algorithm independent error rate of fingerprint matching. A simple framework is combination of minutiae and Ridge count. For Matching author has considered minutia pair (2-point model) and triplet (3-point model).

The proposed model do not make assumption and measure the relations, i.e. ridge counts, between different minutiae as well as minutiae's positions and orientations.

Julien Bohné and Vincent Despiégel [6], present a new fingerprint matching algorithm based on a local skeleton descriptor. This descriptor uses ridge count information to encode minutiae locations in a small neighborhood. The advantage of ridge count properties makes descriptor robust to distortions. Proposed algorithm is efficient to match local descriptor and combines many local descriptors which increase overall match probability.

The author also proposed a local coordinate system in which only one coordinates (1D) is sensitive to distortions by using the ridge count. The ridge count between two points is defined as the number of ridges crossed by the line segment linking these two points. When the line linking the two points is close to the orthogonal to the ridge flow it is very unlikely that any distortion could affect the ridge count. Local skeleton descriptor takes advantage of this property.

Lifeng Sha, Feng Zhao, and Xiaoou Tang [3], propose an effective fingerprint matching algorithm based on ridge count matching and minutiae subset combination. In the algorithm, the orientation-based ridge patterns are first utilized to remove the spuriously matched minutiae pairs. Then the reliable ridge counts between every two minutiae are estimated to improve the minutiae relationship, and finally the matched minutiae subsets corresponding to different alignments are selectively combined to reduce the influence caused by distortions in fingerprints.

The proposed algorithm is complex but calculate match score by finding match minutia pair and non-match minutia pairs by aligning every minutia to get overlap points and further this overlap minutia are match for ridge count features. This overlap set is subset of Alignment Module and for every subset match score is calculated and final score is combination of these scores. This increased the accuracy of an algorithm.

Kevin E. Hoyle, Nathan J. Short, Michael S. Hsiao, A. Lynn Abbott, Edward A. Fox [10], proposed an algorithm which uses minutia triplet-based features in a hierarchical fashion, where minutia points are used along with ridge information to establish relations between minutiae.

In the algorithm, ridge identification numbers is assigned to each minutia. This ID number indicates which ridge(s) are associated with a particular minutia point. Using these any combination of three minutiae forms a triplet, or triangle. From Triangle's following features are generated

1) Side lengths of the triangle, or pairwise distances between minutiae.
2) Ridge count or ridges crossed, between pairs of minutiae.
3) Whether each pairwise minutiae lies on a shared-ridge segment.

Author extended the concept of a single triangle to groups of 2 or 3 triangles (containing up to 6 or 9 minutiae) to generate more features like

1) Ridge count between pairwise minutiae between two different triangles (inter-triangle ridge count).
2) Shared-ridge segments between minutiae of different triangles (inter-triangle shared-ridge segments).

A performance comparison table of different techniques proposed earlier for fingerprint matching, evaluated on the various parameters is presented in Table 1. The Limitations of these approaches have also been highlighted.

TABLE 1: Performance Analysis of fingerprint matching techniques

Technique	**Result**	**Limitations**
On The Fundamental Performance For Fingerprint Matching[2]	Error Rate(diff between ridge count) is between 0 to 2 Ridges	a) Algorithm is not tested for low quality images. b) Error rate is less but should test for FAR/FRR.
Minutiae-based Fingerprint Matching Using Subset Combination[3]	GAR is 96% for FAR 0.01	a) Template Interoperability loses. b) Complex Algorithm.
A Combined Feature for Partial Fingerprint Recognition[4]	EER is between 0.58 to 0.75%	a) Interoperability loses. b) Huge Template size. c) Exhaustive search.
Fingerprint Skeleton Matching based on Local Descriptor[6]	FRR is 0.002% for FAR 0.1	a) Template Interoperability loses. b) Complex Algorithm. c) No standard format followed
Data Format for the Interchange of Extended Friction Ridge Features[7]		
Fingerprint Matching Incorporating Ridge Features With Minutiae[9]	GAR is 96.5% for FAR 0.01	a) Template Interoperability loses. b) Images with a small foreground area and low quality have less accuracy. c) Sized of the template increases
Minutiae + Friction Ridges = Triplet-Based Features for Determining Sufficiency in Fingerprints[10]	Matches increased from 291 to 19219	a) Template Interoperability loses. b) Complex Algorithm. c) More extraction time
Fingerprint sample quality assessment via ridge line count using laplacian of gaussian edge finding[14]	GAR is 70% FNMR 0.075	a) The proposed algorithm is exhaustive.
Fingerprint Recognition with Ridge Features and Minutiae on Distortion[15]	EER is between 0.43 to 1.39%	a) Template Interoperability loses. b) Images with a small foreground area and low quality have less accuracy. c) Template size has been increased.
Fingerprint Image Enhancement: Algorithm and Performance Evaluation[1]	GAR is 92% for FAR 0.01	a) Exhaustive Enhancement Algorithm. b) Time consuming.
Augmenting Ridge Curves with Minutiae Triplets for Fingerprint Indexing[5]	Penetration Rate is between 40 to 52% @ HR = 100%	a) Information loss as only few feature sets is stored for matching. b) More storage space.
Fingerprint Indexing Based on Minutia Cylinder-Code[8]	Penetration Rate is between 20 to 25% @ HR = 97%	a) Search time increases linearly as database increase. b) Index has to be generated beforehand for the searching.
Enhancing Fingerprint Recognition Using Minutiae-Based and Image-Based Matching Techniques[11]	Low Quality Images: 82.5% High Quality Images: 95%	a) Method has not been tested for False Acceptance Rate (FAR).
Latent Fingerprint Indexing: Fusion of Level 1 and Level 2 Features[12]	Hit Rate between 81.8% to 95.7% @ PR=39%	a) Fusion of Level 1 and Level 2 Features on good quality images is time consuming.
Extended Feature Extraction Technique From Fingerprint[13]	GAR is between 80 to 90% for FAR 0.01	a) Requires 100dpi sensor. b) Requires both 500 and 1000dpi sensor. c) Costly.

III. CONCLUSION

In this survey, author has presented only the most popular research on extended feature set but any unique feature can be used as a basis for subsequent fingerprint verification. Some extended feature sets which are gaining ground but are not a part of this survey include Ridge count between two minutiae points, Local Ridge Orientation, Ridge tracing, etc.

We have discussed various extended feature extraction methods used for fingerprint recognition that includes minutia extraction, dots, incipient ridges, etc. Among these pattern recognition techniques, minutia feature is mostly extracted. Various attributes of fingerprint and variety of features are also discussed in this paper.

But in existing techniques of feature extraction and pattern recognition, fingerprint recognition does not provide more accurate results in terms of acceptance rate and rejection rates for secure fingerprint recognition systems. So there is a need of research in extended feature extraction systems along with minutia feature extraction techniques to improve performance of the system.

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