Efficient and effective content-based image retrieval framework for fingerprint databases

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Abstract. *Two kinds of fingerprint identification approaches have been proposed in the literature to reduce the number of one-to-many comparisons during fingerprint image retrieval, namely, exclusive and continuous classification. Although exclusive classification approaches reduce the number of comparisons, they present some shortcomings, including fingerprint ambiguous classification, and unbalanced fingerprint classification distribution. On the other side, continuous classification approaches have not been further studied. In this context, we propose an original continuous approach to guide the search and the retrieval in fingerprint image databases considering both effectiveness and retrieval speed. For that purposes, we use feature extraction and indexing methods considering the textural and directional information contained in fingerprint images. Preliminary results of our work involves a comparative study of several textural image descriptors obtained by combining different types of the Wavelet Transform with similarity measures. From our experiments we can conclude that the best retrieval accuracy was achieved by combining Gabor Wavelets (GWs) with the Square Chord similarity measure. Furthermore, the presence of noise and distortions in fingerprint images have affected the overall retrieval accuracy.*

1. Theoretical Background

Fingerprints are considered nowadays one of the most reliable biometric characteristic for human identification among other physical and behavioral characteristics [Anil K. Jain and Prabhakar 2004], such as face and iris , or voice and signature. Several fingerprint recognition applications in civilian, commercial, and forensic systems are based on two elementary fingerprint properties [Pankanti et al. 2002], (1) persistence: basic fingerprint characteristics do not change with time, and (2) individuality: each person has an unique fingerprint. Automatic fingerprint recognition often involves four important steps [Anil K. Jain and Prabhakar 2004]: (1) acquisition, (2) classification, (3) identification, and (4) verification. Fingerprint acquisition is refered to the capture and representation of fingerprints. Fingerprint classification consists in assigning a fingerprint to a pre-defined class, whereas fingerprint identification is referred to the retrieval of fingerprints that correspond to a given fingerprint query image (one-to-many comparisons). Fingerprint verification is used to determine whether two fingerprint images are the same or not (one-to-one comparisons). Considering the large size of fingerprint databases and the computational cost of fingerprint verification algorithms, it is necessary to reduce the number of one-to-many comparisons during fingerprint identification, seeking both accuracy and retrieval speed.

Two kinds of approaches can be employed to reduce the number of one-to-many comparisons during fingerprint identification, namely, exclusive and continuous [Alessandra Lumini and Maltoni 1997]. The former uses some high-level characteristics to partitionate the fingerprint database into mutual exclusive bins according to some fingerprint pre-defined classes. Once the fingerprint query image is classified, it will be searched only in its corresponding bin. In the latter, fingerprint images are represented by feature vectors. Similarities among fingerprint images are established by the distance in the feature space of their corresponding feature vectors. In our work, we propose a continuous approach to guide the search and the retrieval in fingerprint image databases considering both effectiveness and retrieval speed. For that purposes, we use feature extraction and indexing methods considering the textural and directional information contained in fingerprint images (Table 1 shows a brief comparison of the fingerprint database indexing approaches found in the literature, including our proposal).

2. Contributions

Although search spaces can be reduced in exclusive classification approaches, there are some shortcomings that should be considered: (1) some fingerprints present properties of more than one class and therefore they cannot be assigned into just one bin, (2) the natural distribution of fingerprints is not uniform and therefore even performing binning in the original database, the number of one-to-many comparisons can still be high, and (3) some of the fingerprint characteristics used for binning are not easy to detect due to the presence of noise and distortions. Therefore, there are still some open questions that should be answered, such as: (1) is it possible to reduce the searching space considerably without classifying fingerprints? (2) which fingerprint information should be considered for that purposes? (3) how can the query processing time be improved? and (4) how can fingerprint images be stored and indexed efficiently?

In our work, we plan to address all this opening challenges. For that purposes, we propose a method to characterize fingerprints by using feature vectors to summarize their principal textural and directional properties. The fingerprint candidates are then retrieved from the database by comparing the distance of their feature vectors. The shorter the distance is, the more similar the images are. Theoretically, our approach will present the following advantages over exclusive classification: (1) since fingerprints are represented by feature vectors, the ambiguity of classification is resolved, because they are not represented by a single class, (2) depending on the accuracy expected for the system, some parameters referred to search radius and number of nearest neighbors can be configured and adjusted and (3) continuous classification can be treated as a fingerprint image retrieval problem and therefore we want to prove the suitability of Content-based Image Retrieval (CBIR) techniques for fingerprint indexing and retrieval.

3. Our Proposal

The architecture of our proposed framework can be divided into two main subsystems, namely, the enrollment- and the query-subsystem (see Figure 1). The enrollment-subsystem is responsible for acquiring the information that will be stored in the database for later use. On the other side, the query subsystem is responsible for retrieving similar fingerprints from the database according to the user's fingerprint query image. Our system operates as follows:

1. Enrollment-subsystem: several fingerprint images are first captured (arrow labeled 1 in Figure 1) and then processed by a center point area detection module, which finds and marks a Region of Interest (ROI) within the fingerprint (module 1, arrow 2). The fingerprint ROI is represented by its central part, since most of the category information is contained in it. A region of 64 x 64 pixels is used for marking the ROI. The feature extraction module uses the feature extraction algorithms in the descriptor library (module B, arrow 3) for extracting the features (arrow 4) that are indexed by a metric access method for later use.
2. Query-subsystem: it receives as input a fingerprint query image from the user (arrow 1). The fingerprint ROI is then detected (module A, arrow 2) and the feature extraction module uses the feature extraction algorithms in the descriptor library to extract the feature vectors from the query image (module B with arrows 3 and 4, respectively). The query image feature vector is used to rank the database images according to their similarity to the query image (module C). For that purposes, a distance computation algorithm is selected from the descriptor library (arrow 5) and a metric access method is used to speed up the retrieval process (arrow 6). Finally, the most similar database images are ranked (arrow 7) and returned to the user (arrow 8).

4. Related Work

To the best of our knowledge, only two works are addressing the problem of fingerprint identification as a fingerprint database indexing problem (see Table 1).

Author	Year	Fingerprint properties	Indexing method
Germain et al. [R. S. Germain and Colville 1997]	1997	Singularities	Flash Hashing
Xuejun and Bhanu [Tan et al. 2003]	2003	Singularities	Flash Hashing
Javier Montoya	2006	Textural and directional information	Metric Access Methods

Table 1. Fingerprint database indexing approaches.

Germain et al. [R. S. Germain and Colville 1997] proposed a continuous system to index fingerprint databases using flash hashing. Their system is composed by two associative memory structures, namely, multimap and map. During the fingerprint feature

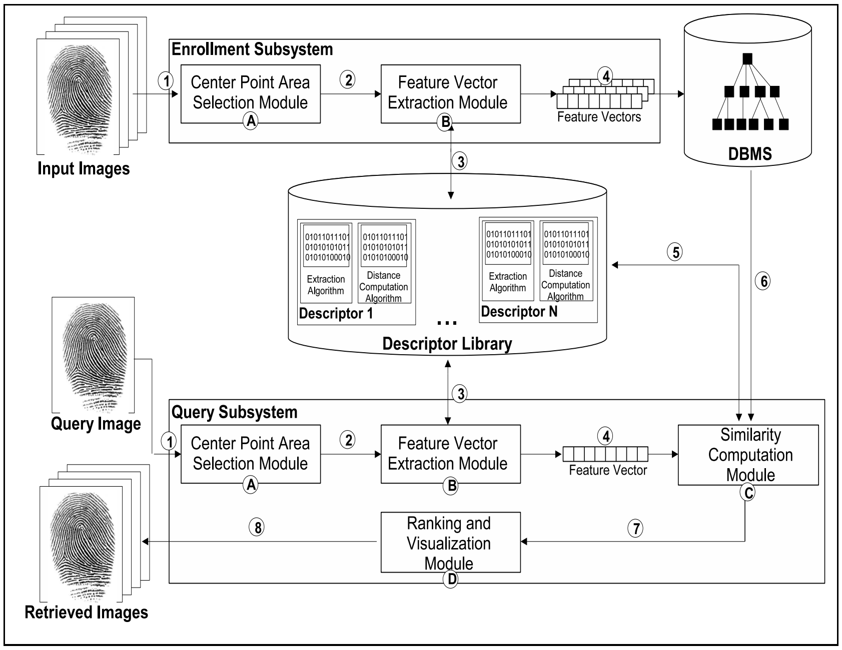

Figure 1. Architecture of our proposed system.

extraction process, some information related to the feature vectors is generated in order to create indices that could be the same for different fingerprints. Each of these indices is then added to the multimap memory structure. During the retrieval process, the generated indices of the query image is used to retrieve the image candidates, that are presented by the same indices. The map memory structure is then used to store the references of the image candidates together with some parameters that characterize the geometric transformation between two pairs of feature vectors as well as a score value used for sorting the list of image candidates. The feature vectors are composed by a set of triplets (x, y, θ), where the three parameters represent the location and orientation of each of the minutiaes. In order to create a more robust method, they also considered the number of ridges between minutiaes. Thus, a set of triangles that resembles each another can be constructed. The number of matching triangles serves as the basis for determining whether two pair of fingerprints are the same or not. They showed also that by using this approach the average query time decreased mainly due to the reduction of I/O operations.

Another example is the work proposed by Tan [Tan et al. 2003]. It presents a comparison between an exclusive and a continuous classification method. For the exclusive classification method, they used Genetic Programming to generate some compositing operators that are applied to the features extracted from the orientation field of the image. For classification purposes, a Bayesian classifier was used. The fitness parameter value was adjusted considering the classification result. The continuous classification method used, followed the work proposed by Germain et al. [R. S. Germain and Colville 1997]. The main difference is that their system has two steps, instead of just one. As a result of the indexing process, a list of candidates is retrieved according to the similarity between feature values. For verification purposes only the top N candidates are used. The identification score is calculated as the number of corresponding triangles between the query image and the candidates. The triangles are formed by the location of the minutiaes. They also concluded that the search space and the false acceptance rate (FAR) were reduced when comparing the continuous classification method with the exclusive one.

Although the search spaces are reduced in both approaches ([R. S. Germain and Colville 1997, Tan et al. 2003]), they are mainly based on some singularities presented in fingerprint images. Besides, the accurate detection of these singularities depend highly on the quality of the fingerprint images and their computation often involves some computational resources that will affect directly the fingerprint recognition time. On the other hand, they both use flash hashing for indexing purposes and we believe that by using metric access methods the query processing time will be improved. More specifically, we used a dynamic (Metric Access Method) MAM known as Slim-tree [Jr. et al. 2002]. The use of the Slim-tree in the fingerprint domain is attractive, since: (1) fingerprints can be inserted and deleted even after the tree's creation, due to their dynamicity, (2) similarity queries such kNN and range queries are supported and therefore CBIR applications are possible, (3) overlapping between nodes is minimized and thus the retrieval speed is increased and (4) due to the MAM's scalability, that is, it can handle large amount of data in an efficient manner even after growing the database size. As seen in Table 1, we will consider more specifically the textural and directional information presented in fingerprints for feature extraction purposes, since it is easy to compute and retains the discriminating power of fingerprints and Metric Access Methods for their indexing.

5. Preliminary Results

Preliminary results of our work involves a comparative study of different textural image descriptors used for fingerprint image indexing and retrieval. For that purposes, we have explored different combinations of wavelet-based feature extraction algorithms with similarity measures. Six different types of Wavelets were considered [Ma and Manjunath 1995]: Gabor Wavelets, Tree-Stuctured Wavelet Transform (TSWT) using Haar, Daub (4-Tap, 8-Tap, and Daub 16-Tap) and Spline Wavelets. The use of the Wavelet transform is motivated by its decomposition property. Fingerprint images are decomposed into different spatial/frequency sub-images and some statistical analysis is performed to generate textural feature vectors. For computing the distance among the feature vectors, we have studied the following similarity measures [M. et al. 2003]: Bray-Curtis, Canberra, Euclidean, Manhattan, Squared Chord, and Square Chi-Squared. Our study was conducted in the FVC 2002 Database [1] and from our experiments can be concluded that the Gabor Wavelets (GWs) combined with the Square Chord similarity measure achieves the best retrieval effectiveness. This fact relies basically on the flexibility of GWs to control the orientation and scale information in fingerprint images, so that depending on the application a more effective retrieval can be performed. Figure 2 shows the best retrieval effectiveness achieved by each wavelet-based feature extraction methods for one of the four databases contained in the FVC 2002 Database. Considering that, the fingerprint database images are characterized by their noise and their distortions, and that Wavelets are non translation and rotation-invariant, we are still investigating some other feature extraction methods, that: (1) retain the discriminating power of fingerprints (individuality), (2) are stable and invariant to noise and distortions, (3) easy to compute, and

[1] FVC2002: Second Fingerprint Verification Competition Database available at: http://bias.csr.unibo.it/fvc2002/ (accessed on June 9, 2006.)

(4) present an efficient and compact representation.

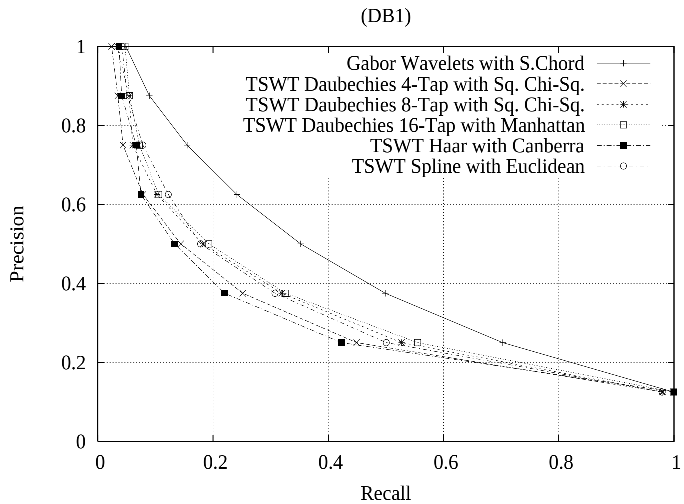

Figure 2. Average Precision vs. Recall curves of the best image descriptors for the DB1.

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