Fingerprint Recognition and Matching

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Abstract

Fingerprints are unique patterns which have gained prominence as a biometric key for diverse applications and thus, the recognition systems play a crucial role. Despite advancements, challenges persist in accurately matching fingerprint minutiae, especially when dealing with large databases and image transformations (rotations and translations). This paper addresses the alignment dependence and sensitivity to geometric changes by proposing a fast and robust fingerprint matching methodology that includes pre-processing techniques, minutiae extraction, creating a template to represent the minutiae using a polygon and minutiae matching through the polygon's features. The proposed approach alleviates alignment concerns, making strides towards more reliable and accurate fingerprint matching systems.

1 Introduction

Fingerprint impressions accompany all human being from birth. They are a biometric key composed of unique patterns present in the distal phalanges of the fingers, distinct for each person, and can be used for several purposes. Due to their unequivocal and invariant nature, fingerprint impressions have gained relevance in the field of forensic analysis, becoming an alternative to other traditional methods of authentication. Currently, there is a noticeable growth in the number of applications using fingerprint recognition systems, such as accessing mobile phones, monitoring employee presence in a company, or in forensic investigation to achieve the unequivocal identification of an individual [1].

Fingerprint features typically organize themselves into global features (singular points or the overall fingerprint pattern) or local features (minutiae). Fingerprint matching systems based on minutiae currently demonstrate a good ability to match minutiae, but here is still a need to improve their performance, especially when applied to large databases.

It has been observed that the quality of these systems degrades significantly, particularly when dealing with low-quality or noisy images, such as fingerprint impressions with scars. Most of these systems rely on aligning the fingerprint impressions, yielding weak results when the images undergo geometric changes like rotation or translation. In the field of forensics, matching collected images remains an open problem due to the lack of alignment. Therefore, automated systems are currently employed to reduce the number of images that need to be compared manually [2].

Some approaches are based on singular points in the image, but they are not very reliable because a partially obscured image could hide these points. Matching the general fingerprint pattern (loop, plain arch, tented arch and accidental) can be useful to reduce the number of matches but is not an option to identify if the fingerprint that is queried belongs to a subject whose fingerprints are registered in the database. In matching methods using minutiae, directly matching a single minutia between different images is inefficient and unreliable due to sensitivity to noise and geometric transformations. Therefore, to avoid dependence on image alignment, the creation of a template image is searched for the matching process. However, it has been demonstrated that considering the entire image and comparing the entire template leads to poorer system performance [2]. Kovacs-Vajna [3] introduces the use of minutiae triangulations for matching, noting that these triangulations are sensitive to false minutiae and that the same pattern (triangles with same features) often appears in different images. M.H. Ghaddab et al. [4] propose the use of an expanded Delaunay triangulation that considers all possible triangulations, treating each point as a potential spurious minutia. Trivedi A. K. [5] suggests using triangulations while considering the triangle's area and the relative angles of the minutiae as key characteristics obtaining reasonable results.

This study aims to propose a fingerprint minutiae recognition and matching methodology that does not rely on alignment and remains robust even where image transformations are applied.

2 Methodology

The proposed methodology follows the typical pipeline of a fingerprint matching system starting with image preprocessing, minutiae extraction, feature extraction, and ending with the matching process.

2.1 Pre-processing

Preprocessing is a crucial step when working with fingerprint images, as it highlights the distinction between ridges and valleys, enabling more reliable minutiae extraction. The techniques employed are the most common in fingerprint analysis: ridge segmentation, ridge orientation estimation, ridge frequency estimation, and ridge filtering (using oriented Gabor filters). In Figure 1 it is shown the effect of the preprocessing techniques.

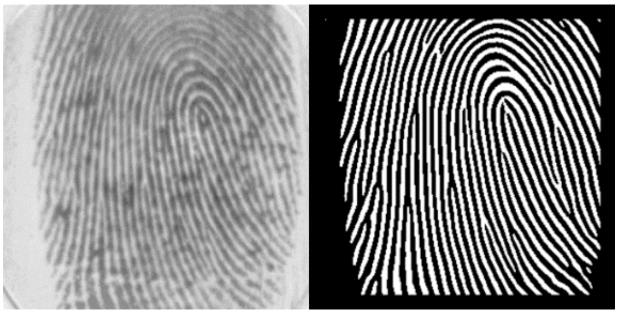

Figure 1 - (a) Original image (b) After preprocessing.

2.2 Minutiae Extraction

The process of minutiae extraction involves determining the ridge terminations and bifurcations. For each minutiae, a feature vector (x,y,θ,T) is extracted, where (x,y) are the coordinates in the Cartesian plane, θ is the orientation of the minutia and T is the type. Initially, the image is skeletonized to identify the structure of the ridges. Then, by analyzing the neighborhood of each pixel, terminations and bifurcations are identified. The detected minutiae are processed to remove false minutiae that may arise due to noise. The removal of false minutiae is carried out by computing the distance between all pairs of minutiae and remove the ones that are too close to each other. As shown in Figure 2 the minutiae are extracted using the ridge structure.

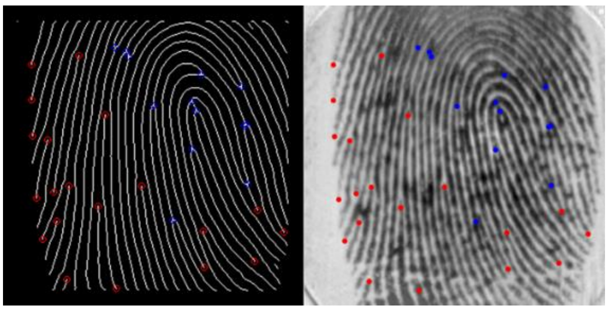

Figure 2 - (a) Extracted minutiae (b) Minutiae on original image.

2.3 Feature Extraction

Each extracted minutia is considered as a reference, and a polygon with n vertices is constructed to represent it, using neighbour minutiae. The polygon's characteristics are used to build the feature vector of the reference minutia. A circle of radius *r* is centred on the reference. Then, the remaining minutiae within the circle are checked. If at least *n* minutiae are not found or if there are no minutiae in both an upper quadrant and a lower quadrant, *r* is incremented. When the conditions are met, with *k* being the number of minutiae in the region of interest, combinations of *n* points are considered, and those that allow closed polygons including the reference are validated. The number of polygons for a reference was limited to 50 due to the potential increase in the number of combinations while allowing to keep several polygons which are reasonable to identify a minutia. Using combinations of the *k* points, the computational complexity increases but provides greater robustness against false minutiae and noise, as the polygons formed by true minutiae persist even in the presence of a spurious minutia. Figure 3 shows an example of a minutia considered as reference (red) and the search for possible polygon vertices inside a circumference.

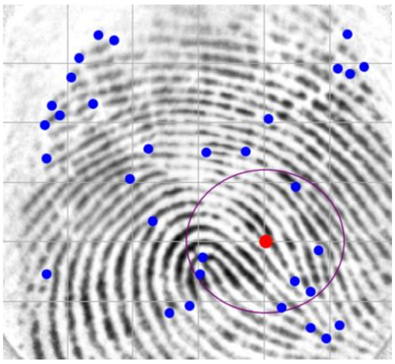

Figure 3 - Search for polygon vertices, stating at red dot.

For each polygon, its centroid is computed. Angles formed by the lines connecting the centroid to adjacent vertices are computed, as well as the lengths of the edges. Finally, to distinguish polygons that may share geometric similarities in different relative positions of the minutiae set in the image, the distance between the polygon's centroid and the centroid of the extracted minutiae is computed.

2.4 Matching

To achieve correspondence between two images, A and B, all the minutiae from the image with fewer registered minutiae (along with associated polygons) are considered. Subsequently, for each minutia in image A, its associated polygons are examined and among the minutiae in image B, the one with the most similar polygon characteristics is identified. Once the best match polygon is found, threshold values are applied to the differences in edge lengths and angles to ensure that the differences between polygons are constrained. Thus, by applying thresholds, we ensure that not all minutiae have a correspondence, thereby enhancing the algorithm's confidence when returning a minutiae match.

3 Results and Discussion

To conduct experiments, the public FVC2000 Db1 database was used. The images were acquired using a low-cost optical sensor, resulting in images with dimension 300x300 pixels with a resolution of 500 dpi. Random samples from this database were chosen to create a subset of nine images, five from the same finger and four from different fingers performing 20 comparisons where 10 are expected to match and 10 are expected to be correctly rejected. In this small dataset, the algorithm took 21.65 seconds to run all the pipeline across the images and matching, only identifying minutiae in non-matching images in one comparison.

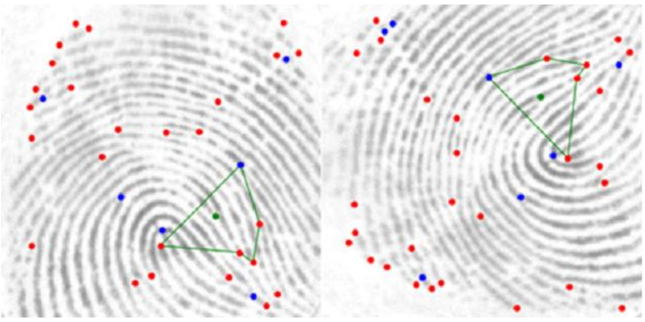

Figure 4 - Minutiae match between original and rotated image by 90º.

The figure 4 illustrates an identical polygon of *n* = 5 produced for the same reference in two images, being the second one rotated by 90º.

Also, some tests were carried out applying transformations to the images such as rotations and translations and the algorithm found its way to identify the unique polygons that represent a minutia.

A translation was applied to the image and the algorithm found the reference and its associated polygon, as shown in Figure 5.

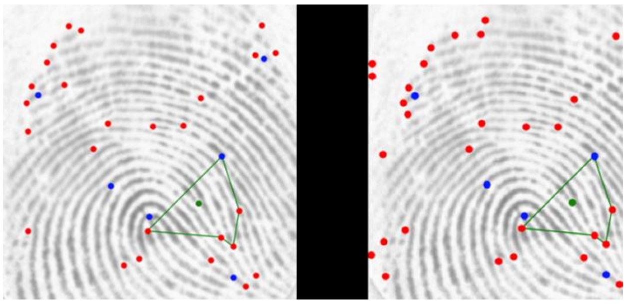

Figure 5 - Minutiae match between original and translated image.

The worst case where the algorithm could not find minutiae between images of the same finger it's due to strong brightness differences in the images which lead to an increased number of spurious minutiae. Having a few spurious minutiae too close to the reference makes another set of polygons to be found in a smaller radius and represent the minutia.

4 Conclusions

The present work is still ongoing, and therefore, the database will be expanded to conduct additional experiments and make improvements to the algorithm being used. However, the proposed methodology has proven to be fast and not computationally demanding, enabling its incorporation into portable devices that collect fingerprints in the field and allowing to quickly identify the match between two fingerprints, when applied to the forensic area. The capacity of the algorithm to reject false matches can also be used to reduce the number of possible matches that might have to be done manually. The presented methodology as space for improve and further studies will be carried out so that unique polygons identify a minutia and be used to match fingerprint impressions.

5 Acknowledgements

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