A Hybrid Fingerprint Matcher on Card

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Abstract: Hybrid fingerprint matchers are well known as a powerful tool for high security applications where the reliability of a single fingerprint characteristic is not high enough for the intended application. In this paper, we propose a novel method, which due to its compressibility can be applied in memory constrained environments. This is important for application in smart cards and independent identification modules, which recently gained popularity. The proposed method uses minutia point matcher as the first stage of matching, and, after successfully completing this stage, the second stage of matching is based on comparing the homogeneity of a direction map. The direction map is compressed using a quad tree.

1. Introduction

Fingerprint-based verification and recognition systems have gained in popularity in recent years due to the greater need for a simple identification tool, their robustness and simplicity of use. There are numerous solid-state fingerprint sensors on the market, making fingerprint authentication systems available to almost everyone. Such sensors are applied as user identification tools for mobile computers, cellular phones, and most recently for identification in so-called smart cards or identification modules. The trend on the market is to reduce the size of all mobile units, so the process of miniaturization is also applied to the sensors. This has resulted in smaller sensors and (even with higher sensor resolution) smaller fingerprint images. Since a smaller area of the finger is captured by the sensor there is a strong need for sophisticated algorithms, because the amount of fingerprint input information has been reduced. This problem can be solved in the enrollment process with several fingerprint fusion algorithms like in [JR02], but that does not help in the authentication phase. These algorithms also cannot be applied if the memory space on a smart card or a module is so limited that one or more merged fingerprint images cannot be stored.

Hybrid systems use several methods for fingerprint verification, usually combining matching of minutia lists with some other methods, such as a correlation of fingerprint images or a ridge analysis. One good example of a hybrid matcher using minutia information and ridge analysis is given in [RJR02]. Though the minutia lists can be compressed to fit on smart cards or identification modules, it is a problem to compress an image or a ridge structure to achieve such limits without significant loss of its identification capabilities.

This work will present a system, which uses a novel method based on the homogeneity of the ridge structure of fingerprints. The method does not need to find singularities or other characteristic points on fingerprints, and uses a quad tree procedure for compression to achieve the limits of memory constrained environments without losing its identification capabilities.

The first part of this article is a description of the minutia matcher and the problems which can occur in memory constrained environments. In the second part we propose the hybrid matcher as a solution for matching in memory constrained environments, and the third part of this article presents the results obtained with this hybrid matcher.

2. Minutia matcher

The most popular fingerprint matching system is definitely the minutia point matcher due to its implementation simplicity and the uniqueness of minutiae on human fingerprints even those of monozygotic twins [Pr01]. The minutia segmentation from a fingerprint image is described in [MM99]. The principle of the minutia point matcher is to find a correlation between two minutia lists, one from a reference fingerprint, and another from a request (query) fingerprint. The correlation takes the relative position of minutiae on the fingerprint, their orientation and type into consideration. The minutia correlation coefficient Θ_m can be calculated as a simple relation between the number of minutiae that are considered to be common to both fingerprints and the total number of minutiae on both fingerprints. There are numerous procedures to find common minutiae on the reference and request fingerprint (see [Pr01] for a good overview).

However, the problem becomes more difficult when there are not enough minutiae on the scanned fingerprint to perform a reliable matching. This is a common situation with modern fingerprint solid-state sensors. There is a need for fingerprint authentication with higher reliability than a reduced minutia set can give. For those cases, the logical solution is to combine a minutia point matcher with a matching of other fingerprint features. This results in a so-called hybrid matcher, where one level is usually a minutia point matcher and the other level is e.g. gray scale image correlation, ridge structure correlation, etc [RJR02]. Most of these methods need to store the entire fingerprint image. This causes problems if there is no space for additional data storage (smart card devices, identification modules). Also, storage of an image is much more memory consuming than minutia lists, and image compression at high rates can cause artifacts which can worsen the performance of the whole system.

The solution, which is suggested here, can use the global (ridge structure) and the local (minutiae) fingerprint features combined in a hybrid matcher without the need for additional memory resources (at least, not for storing a whole image or images).

3. Hybrid fingerprint matcher

The hybrid matcher has two parts, but they are not completely independent. It is better to call them first and second stage matcher. The first stage is a minutia point matcher, and the second stage can be called a homogeneity structure matcher. The minutia point matcher is well known and described in (among others) [Pr01] and the homogeneity structure matcher will be described in this work.

Only when the first stage (minutiae matching) is successful is the second stage of the hybrid matcher performed. There are two reasons for such a concept: (i) as commonly done in hybrid matching, both conditions must be satisfied to have a positive authentication, and (ii) the by-products of the first stage are used for the second stage.

The match scheme is shown in Figure 1 and may be broken down into the following steps:

I. Acquisition of a request fingerprint image.

II. Encoding of the request print and transmission of the associated minutia list to the matcher (smart card, ID module).

III. Smart card rejects or considers the request for acceptance. In the latter case it also delivers rotation and translation parameters and the outline of the fingerprint.

IV. The system reorients the request's direction map and breaks it down into a temporary quad tree structure.

V. The quad tree representation of the request is sent to the matcher (smart card, ID module) where the actual match is performed.

VI. The smart card reports acceptance or rejection based on the combined minutia and direction map match scores.

Steps I and II are well known, and described in literature [Pr01], [HJE99]. In step III, after matching is successfully completed with a minutia point matcher we have a list of matched minutiae from both fingerprints. These lists contain the relative position of minutiae, their orientation and type. We use the minutiae positions to calculate the spatial difference between the reference and request fingerprint image, described with dx, dy and $d\varphi$. These three deltas are used in the transformation matrix

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos d\varphi & \pm \sin d\varphi \\ \mp \sin d\varphi & \cos d\varphi \end{pmatrix} \begin{pmatrix} x - x_0 \\ y - y_0 \end{pmatrix} + \begin{pmatrix} dx \\ dy \end{pmatrix} \tag{1}$$

to get the same orientation and position for both fingerprint images. At this point the correspondence can be calculated on alignment of both fingerprint images using an affine transform x' = Ax + t.

The next step (IV) is to compress the directional image of the request fingerprint according to the homogeneity structure of the reference image. The reference homogeneity structure is obtained by applying a quad tree decomposing process. The generation of the directional image is described in [HJE99], so we will only explain the compressing process.

The first step is to obtain the direction map image from the encoder, and the calculation of the outline. The calculation of the outline is important to define which pixels belong to the direction map and which to the background. The outline is defined as a two-dimensional vector whose elements represent the absolute distance between the margin of the image and the margin of the fingerprint on this image. To save memory, the outline vector is compressed in the encoder into a one-dimensional vector, but it can also be represented as a binary outline mask image. The outlines are necessary to set an appropriate "weight" for areas which are on the boundary of the directional image. Areas where the total number of pixels is under a preset minimum can not be considered for further partitioning.

The second step is to find the areas in the direction map which have the lowest homogeneity coefficient *hc*, which is defined as a sum of the x and y components of each vector $\vec{Vi}$ divided by the sum of their length, or, in other words, as a norm of a sum of all vectors, divided by the sum of all vector norms:

$$hc = \frac{\left\| \sum_{i=1,n} \vec{Vi} \right\|}{\sum_{i=1,n} \left\| \vec{Vi} \right\|} \tag{2}$$

For a better description of the homogeneity of the image, the system divides the tile that has the lowest homogeneity coefficient *hc* into four new tiles of the same size, forming quad trees. With such a strategy, the result is smaller tiles on image areas where homogeneity is the lowest, and fewer (and bigger) tiles on more homogeneous parts of the image. Such partitioning represents global characteristics of a direction image with dense branches where the image is less homogenous (typical example is the neighborhood of a singular point).

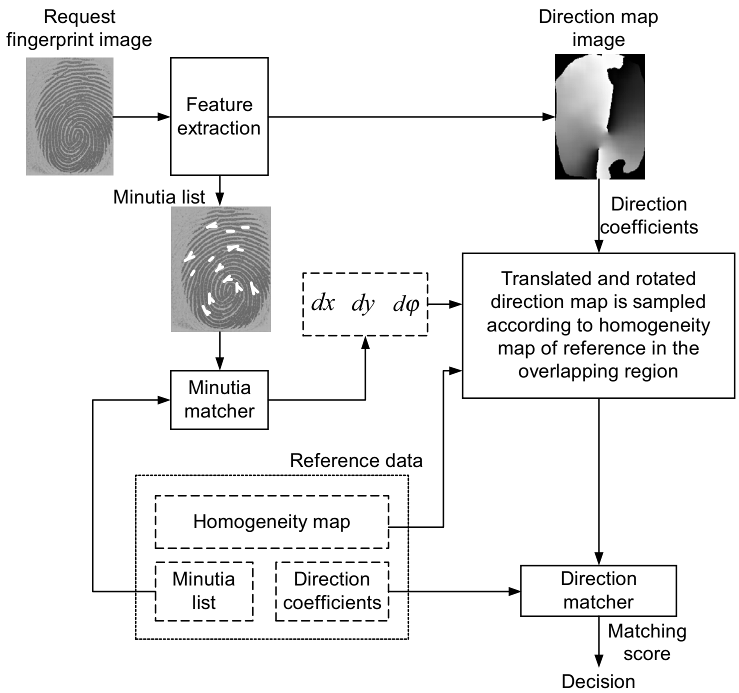

Figure 1. Matching scheme

The integral of the scalar product of the orientation field vectors over their shared area gives a natural measure of similarity that converges to unity in cases where the two orientation fields are identical. In practice, the integral is replaced by an area weighted sum over tiles where the orientation field was found constant (within a prescribed error tolerance). The result is the correlation coefficient between two directional images partitioned with the same homogeneity map (obtained from the reference and forced on the request directional image). The correlation coefficient Θ_d is calculated as the relation between a sum of scalar products of directions in the same tile in the directional image and a sum of norms (where all vectors have the same length), both "corrected" with weight factor w_i, which represents a number of pixels in a specified tile:

$$\Theta_d = \frac{\sum_{i=0}^{N-1} (\overrightarrow{V_i^{\mathrm{Ref}}} \otimes \overrightarrow{V_i^{\mathrm{Req}}} \cdot w_i)}{\sum_{i=0}^{N-1} \left(\left\| \overrightarrow{V_i^{\mathrm{Ref}}} \right\| \cdot \left\| \overrightarrow{V_i^{\mathrm{Req}}} \right\| \cdot w_i \right)} = \frac{\sum_{i=0}^{N-1} (\overrightarrow{V_i^{\mathrm{Ref}}} \otimes \overrightarrow{V_i^{\mathrm{Req}}} \cdot w_i)}{\left\| \overrightarrow{V} \right\|^2 \sum_{i=0}^{N-1} w_i} \qquad (3)$$

Figure 2. shows the fingerprint image (a), the corresponding direction map image (b), and the homogeneity image (c).

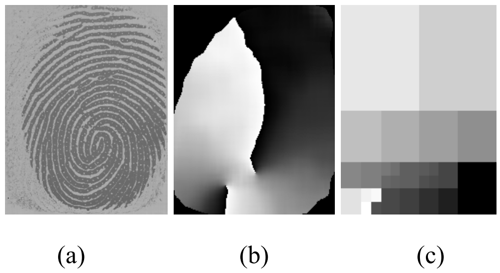

Figure 2. Fingerprint image (a), direction map image (b), homogeneity image (c)

4. Experimental results

The hybrid matcher was tested on 81 reference fingerprints, each obtained from 20 fingerprint images, merged into one single fingerprint image, and 8100 request fingerprint images, exactly 100 requests for each finger.

The database is difficult for a fingerprint matcher due to the following reasons: (i) The small-sized (288x224 pixels) sensor captures only a limited portion of the subject's fingerprint, and (ii) multiple impressions of the same finger (in our database exactly 20), had in some cases very little overlap.

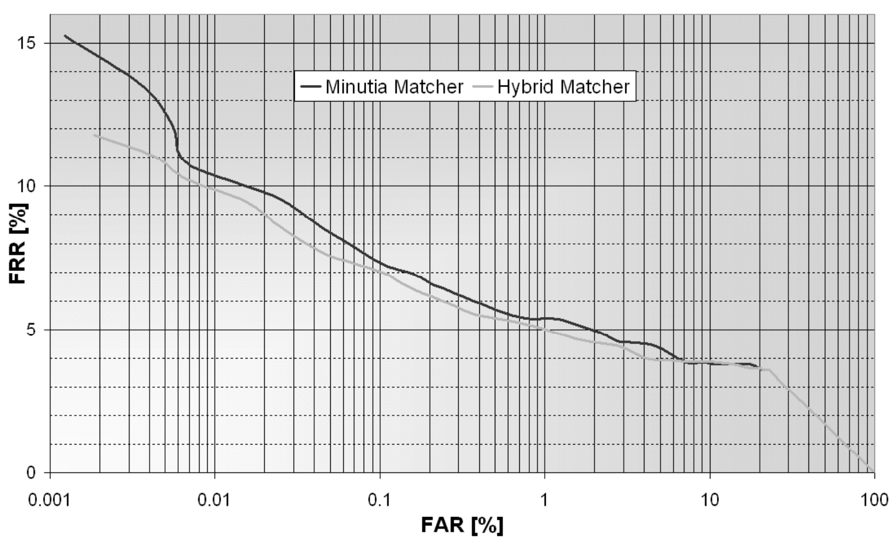

Figure 3. Comparison of the "pure" minutia matcher with the hybrid matcher on the data set with 81 reference and 8100 request fingerprint images

Results are represented as a diagram with a receiver operating characteristic (ROC) curve, where on the one axis is a false acceptance rate (FAR), and on the other axis is a false rejection rate (FRR). Figure 3 shows a significant improvement in the high security area (FAR < 0.01%), which was the purpose of the hybrid matcher. The matcher is designed to work in a smart card based on a 8-bit microprocessor with up to 4 Kb in ROM for code, and less than 700 bytes in RAM for execution, so it can be easily implemented in most smart cards.

5. Summary and future work

We have proposed a fingerprint matching technique that combines minutia information with ridge flow information with the special aspect of matching in memory constrained environments. The minutia information is used to align the reference and the request images, before applying the homogeneity structure of the reference direction image. The homogeneity structure is described and obtained with a quad tree structure. Experiments indicate that the method performs better than a purely minutia-based matcher. We are working on a similar but non-minutia-based method for the classification of fingerprints.

References

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