

Discarding low quality Minutia Cylinder-Code pairs for improved fingerprint comparison

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Abstract: Local minutiae descriptors such as Minutia Cylinder-Code (MCC) are becoming increasingly popular in modern fingerprint verification systems. The verification performance depends on the fingerprint image quality in global and local levels. Discarding part of the lowest quality samples based on quality measures is a universal approach being widely used for improving the performance of biometric recognition systems. In this work, we evaluate several different discarding methods to filter out low quality pairs of MCC descriptors using minutiae qualities, with the final aim of improving global comparison accuracy. Moreover, we propose an efficient MCC based fingerprint comparison method based on discarding the low quality elements from local similarity matrix. Our extensive experiments on three different databases (FVC2002.DB2, FVC2002.DB3 and FVC2004.DB3) show that 1) the proper discarding of low quality MCC pairs from local similarity matrix either independently or using pairwise measures can improve the MCC based comparison performance, 2) for the proposed discarding method, the quality of central minutiae is more efficient as cylinder quality measure than the average minutiae qualities in each descriptor.

1 Introduction

Fingerprint verification systems are widely used every day for security purposes. The most common method in these systems is minutiae based fingerprint comparison, whose performance depends a lot on the fingerprint image quality. Low quality regions in fingerprint images may harm the verification systems by the extraction of false minutiae. One common solution to this problem is to filter out the false minutiae using minutiae quality [MMJP09, CCM07]. Apart from the false minutiae removal, minutiae quality have been already utilized via other approaches such as quality-based weighting [CDJ05].

Minutia quality is usually computed either using local quality assessment of underlying fingerprint in the minutia neighborhood or based on the correlation with a set of previously selected high quality minutia images [CCM07]. Several methods have been investigated in [CCM07] for embedding minutia quality scores in fingerprint comparison. However, since the reliability of the existing minutiae quality assessment algorithms in discriminating genuine and false minutiae is far from optimal, only certain carefully designed combination of minutiae quality and fingerprint comparison strategies could achieve improvement in

verification performance [CCM07].

Discarding a portion of low quality samples based on quality measures is a universal approach being widely used for improving the performance of many biometric recognition systems. For fingerprint comparison, such a discarding approach have been used in global setting, e.g., in the NIST Fingerprint Image Quality (NFIQ) developments [TWW04, OTMB13], as baseline algorithm for comparing global quality measures [AFFOG⁺07].

Modern fingerprint comparison algorithms are more and more exploiting local minutiae descriptors [CFM12]. Local minutiae descriptors generally encode the relationships between each minutia and its neighboring minutiae within the fingerprint image in terms of some invariant measures. Minutia Cylinder-Code (MCC) [CFM10] is one of the most efficient local minutiae descriptors, which is known for being rotation and translation invariant, robust to skin distortions, and computationally fast. Moreover, it has shown a high performance comparing to other minutiae descriptors [PGT⁺15].

Similar to minutiae qualities, cylinder quality measures have been introduced in [IMD12] as local quality measures for minutiae descriptors, together with some methods to embed such quality measures into the MCC based comparison. These methods are generally based on: 1) quality based weighting scheme [IMD12] or 2) quality based modification of local similarity scores using a training data set of synthetic fingerprints [ID15].

In this paper, we focus mainly on another widely recognized approach, which is discarding of the low quality elements, for improved MCC based fingerprint verification. We evaluate several discarding scenarios for MCC based fingerprint comparison using minutiae qualities. Then, we propose an efficient method based on discarding a portion of low quality elements from local similarity matrix using only the central minutia quality in each cylinder.

The rest of this paper is organized as follows: In Section 2, we briefly introduce the MCC based fingerprint comparison procedure, then in Section 3, we discuss several discarding scenarios for MCC based comparison and propose a novel and efficient discarding method for it. In Section 4, we present the results of our evaluations on three different FVC databases followed by a short discussion. Finally, in Section 5, conclusions are summarized together with some directions for future work.

2 MCC based fingerprint comparison

The MCC is a fixed-length descriptor computed for each minutia, encoding its relationships with the neighboring minutiae in a fixed-radius circular area around it. In addition to distance, the angular difference is taken into account using an additional dimension, finally creating a discrete 3D cylinder-shaped structure for each minutia, whose base and height are related to the spatial and directional information, respectively. This 3D structure is then linearized into a vector, whose entries can be binarized into bits by simply setting a threshold. For an MCC pair, a local similarity score can then be computed rather fast using simple bit-based operations, comparing the underlying binary vectors.

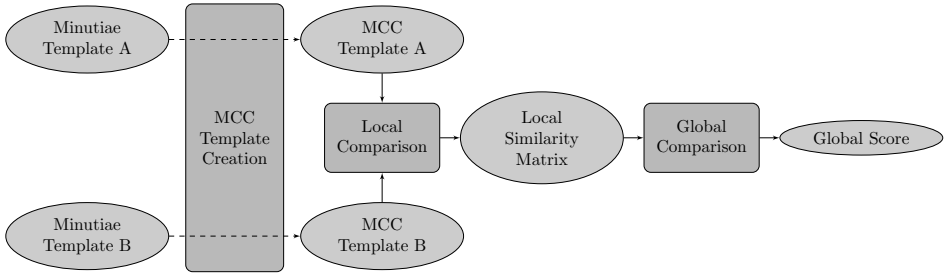


Figure 1: MCC based fingerprint comparison.

Given two MCC templates, say $A = \{a_1, a_2, \dots, a_{n_A}\}$ and $B = \{b_1, b_2, \dots, b_{n_B}\}$, we assume that $\Gamma(a_r, b_c)$ is the local similarity score between two cylinders a_r and b_c from the templates A and B respectively. r and c denote the cylinder indices in the templates A and B respectively ($1 \leq r \leq n_A$, $1 \leq c \leq n_B$). Hence, there are $n_A \times n_B$ MCC pairs in total. Local similarity scores can be also represented in the form of a matrix Γ , called local similarity matrix, with n_A rows and n_B columns. In the next step, usually a set of candidate pairs is pre-selected from the $n_A \times n_B$ pairs available in Γ . The local similarity score of these pre-selected pairs can be relaxed in an iterative process using second-order compatibility measures, taking into account their global relationship with other pairs. Finally, a small number of pairs (usually between 3 to 12) is selected depending on the minimum number of minutiae in the two templates. The global score is then computed by averaging the similarity scores of the final pairs. These steps are illustrated in Figure 1.

It is worth mentioning that if no relaxation procedure is used for comparison, the final selection will be merged into the pre-selection step, meaning the final pairs will be selected from the matrix Γ to contribute directly into the global score. This is usually the case when there is no information about position and direction of minutiae available in the templates, such as in Noninvertible P-MCC templates [FMC12].

3 Discarding approach for MCC based fingerprint comparison

In this work, we focus on discarding approach as a widely recognized methodology for embedding quality measures into biometric recognition systems. This approach is based on the fact that a part of biometric data (samples, regions, ...) with lowest quality can be considered as unreliable data, and discarding them may improve the comparison accuracy in general. There are thresholds needed to be set for discarding criteria. It can be for example an absolute threshold on the value of corresponding quality measures, or the percentage of low quality data to be discarded. Difficulty in setting universal discarding thresholds makes this approach challenging as an embedding technique. Another important application of this approach is to evaluate and compare different quality measures in terms of their ability in discriminating between unreliable and reliable data.

Quality based rejection is usually applied early during the minutiae extraction process in any minutiae based comparison technique. But in this work, we focus on the rejection approach after minutiae extraction process within the MCC based comparison framework. Almost at any stage of MCC based comparison, shown in Figure 1, a discarding method can be applied. For example:

1. Some low-quality or unreliable minutiae can be discarded from minutiae templates.
2. Some unreliable cells can be considered as invalid inside each descriptor.
3. Some low-quality or unreliable descriptors can be discarded from MCC templates before local comparison.
4. Some low-quality or unreliable MCC pairs can be discarded from local similarity matrix before global comparison.

Other discarding scenarios can be considered depending on the global comparison method being used. From the possible approaches listed above, the first one is usually performed during minutiae extraction. The second and third ones are already considered in original MCC algorithm by introducing some cell and cylinder validity criteria for descriptors. Here in this paper, we consider mainly the fourth approach, where low-quality MCC pairs are discarded from local similarity matrix based on quality measures. Other than performance improvement, we also aim at designing a baseline algorithm for evaluating local quality measures within the framework of MCC based comparison.

Assuming a local similarity matrix Γ of size $n_A \times n_B$, and a given percentage $(100 \cdot \alpha)$ of the MCC pairs to be discarded from Γ , we can consider the following discarding scenarios:

1. *Discarding independently:* We discard $\text{round}(n_A \times \sqrt{\alpha})$ rows and $\text{round}(n_B \times \sqrt{\alpha})$ columns entirely from the matrix Γ . These rows and columns are corresponding to the descriptors having the lowest quality in each template independent of the other one. $\text{round}(x)$ is a rounding operator which returns the nearest integer to x .
2. *Discarding based on pairwise quality measures:* We discard the $\text{round}(n_A \times n_B \times \alpha)$ elements from the matrix Γ , corresponding to those MCC pairs having the lowest pairwise quality based on some pairwise function such as square root or minimum.

Discarding elements from local similarity matrix means to replace them with zero. In other words, the local similarity matrix will be multiplied element-wise with a $n_A \times n_B$ binary mask which is zero where the elements are going to be discarded, and one elsewhere.

4 Experiments and Results

4.1 Experimental setting

Databases: For our evaluations, we have chosen three FVC databases which are captured by different types of sensors: FVC2002.DB2 (optical sensor), FVC2002.DB3 (capacitive

sensor) and FVC2004.DB3 (thermal sweeping sensor). Each database contains 800 fingerprint images, including 100 different fingers and 8 samples for each finger. Each sample is compared against the remaining samples of the same finger, creating 2800 genuine pairs, and the first sample of each finger is compared to the first sample of the remaining fingers, providing 4950 impostor pairs for each database.

Minutiae extraction: The open source minutiae extractor FingerJetFX OSE is used to extract minutiae for all fingerprints. This extractor also provides a quality value for each minutia using a correlation-based method and keeps by default only those minutiae having quality above 40 (out of 100) up to maximum 68 minutiae for each fingerprint.

MCC parameters: All parameters for MCC template creation and comparison have been set according to the last published version in [CFMT10].

MCC template creation and comparison: The publicly available MCC SDK Version 1.4 has been used to create the bit-based MCC descriptors (MCC16b). The Local Greedy Similarity (LGS) method [CFMT10] is applied for global comparison using the SDK in all cases. Therefore, the global score is directly computed from the local similarity matrix, without any iterative relaxation in between.

4.2 Cylinder quality: average vs. central minutiae quality

In [IMD12], the cylinder quality measures have been proposed based on a weighted average of minutiae qualities inside cylinders, with much bigger weights given to the minutiae close to the center. Here we consider two extreme cases of such cylinder quality measures: 1) a simple average of minutiae qualities inside each descriptor, 2) only the quality of central minutia in each descriptor. The Equal Error Rate (EER) has been evaluated on all three databases for different percentages of MCC pairs discarded independently. The results are shown in Figure 2. One can interpret from this figure that the central minutia quality is usually more efficient than the average minutiae quality to be used in the proposed approach, especially for higher discarding percentages. This could be due to the overlap between the cylinder areas within the fingerprint image.

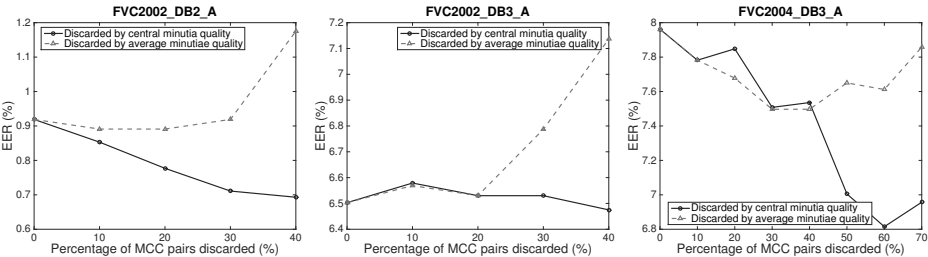


Figure 2: EER vs. percentage of MCC pairs discarded based on central minutia quality (solid line) and based on average minutiae quality (dashed line).

4.3 Evaluation of the proposed methods

Following the results presented in Section 4.2, central minutia quality is assumed here to be the cylinder quality measure. Given two MCC descriptors with cylinder quality measures Q_a and Q_b , we consider two common pairwise measures for our experiments: $\sqrt{Q_a \times Q_b}$ and $\min(Q_a, Q_b)$. The Equal Error Rate (EER) has been evaluated on each database for different percentages of MCC pairs discarded from local similarity matrix via the methods proposed in Section 3, i.e., (1) discarding MCC pairs independently (independent discarding of rows and columns from local similarity matrix), (2) discarding of MCC pairs based on the pairwise quality $\sqrt{Q_a \times Q_b}$, and (3) discarding of MCC pairs based on the pairwise quality $\min(Q_a, Q_b)$. The results given in Figure 3 show that all the methods improve the global verification performance to some extent after discarding a proper portion of low-quality MCC pairs. The performance improvement differs for different methods depending on the database and the percentage of discarding. The independent discarding of MCC pairs performs equally well or even better in some cases than the pairwise methods, with \min function outperforming the $\sqrt{}$ function most of the times.

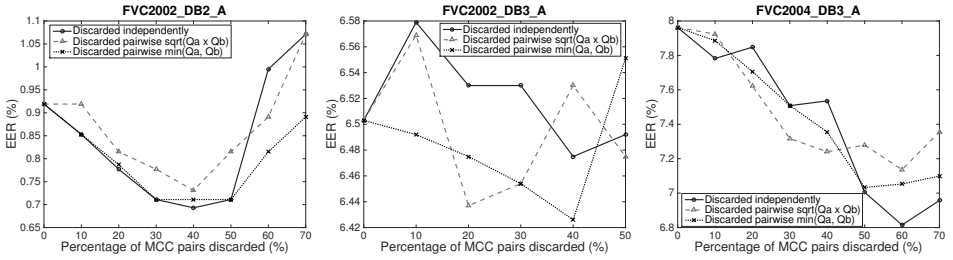


Figure 3: EER vs. percentage of MCC pairs discarded independently (solid line), discarded using pairwise quality-square root (dashed line) and discarded using pairwise quality-minimum (dotted line).

4.4 Discussion

In Figure 3, one can see that the proposed discarding method performs much better for FVC2004.DB3 than FVC2002.DB3 for example. This could be due to the fact that the average number of minutiae extracted for each fingerprint in FVC2004.DB3 is much higher (almost double), as seen in Table 1. On the other hand, there are several fingerprints in FVC2002.DB3 with only a few minutiae, while there is no fingerprint with less than 19 minutiae in the FVC 2004.DB3. Another interesting difference among these databases is the distribution of minutiae qualities, shown in Figure 4. The distribution looks closer to normal for the FVC2004.DB3, with only a small percentage of minutiae having very low quality. On the other hand, the minutiae qualities have a rather different distribution in the FVC2002.DB3 with relatively a high percentage of low quality minutiae.

Table 1: Some statistics on the number of extracted minutiae per fingerprint.

Database	Mean	Min	Max	Std
FVC2002_DB2_A	50.8	9	68	14.0
FVC2002_DB3_A	31.2	6	68	11.5
FVC2004_DB3_A	64.1	19	68	8.7

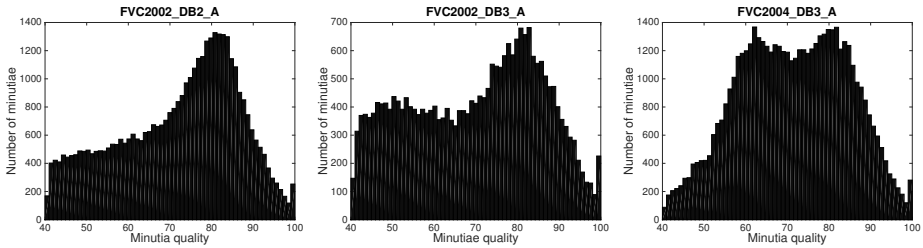


Figure 4: Distribution of minutiae qualities extracted by FingerJetFX.

5 Conclusions and future works

In this paper, we focused on the quality based discarding approach for improving the MCC based fingerprint comparison. We evaluated several different discarding scenarios in this context, and proposed an efficient discarding method based on discarding the low quality elements from the local similarity matrix. These elements could be discarded independently or by using some pairwise quality measures. Our experiments on three different FVC databases show that proper discarding of low quality MCC pairs either independently or pairwise can improve the comparison performance. On the other hand, the quality of central minutiae was shown to be more efficient for this discarding method than the average minutiae qualities in each descriptor. As a future step, we aim at using a similar discarding approach to evaluate different local quality measures in the context of minutiae based fingerprint comparison. The adaptation to other comparison methods involving relaxation and other applications such as palm print comparison will be considered as well. Setting a threshold on the minimum number of minutiae per fingerprint might be also helpful to be combined with this approach.

6 Acknowledgment

This work was supported in part by the Swiss National Science Foundation (SNSF) through the grant 200020-146826.

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