Touchless Fingerprint Matching Using FingerCodes in Comparison to Minutia-based Approach

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***Abstract*— This paper proposes FingerCodes as a touchless fingerprint matcher and compares it with the traditional minutia-based approach. First, the input images are processed with a touchless-to-touch algorithm in order to generate touchbased equivalents used in the minutia-based matching evaluation. Ragarding FingerCodes, each touchbased equivalent is used to estimate a reference point and a region of interest is defined. Pixels belonging to the original touchless image that fall within this region are divided into sub-blocks, normalized, filtered with a bank of Gabor filters, and FingerCodes are finally extracted. In our experiments, 400 touchless fingerprints are used. Matchings are performed using bootstrapping and the observed average equal error rates are 9.32% and 4.29% for FingerCodes and for minutia-based matching, respectively.**

***Keywords*— Touchless fingerprints, Touchless-to-touch transformation, FingerCodes, Matching.**

I. Introduction

Fingerprints stand out among the various types of biometrics and are considered one of the most employed ones [1]. However, despite the maturity of fingerprinting technologies, betterments are constantly being proposed. The evolution of biometric systems can be achieved through improvements either in acquisition hardware or in discriminant features extraction algorithms. Nevertheless, it is important to note that the quality of acquired images is a limitation, no matter how competent these algorithms are.

Most of today's fingerprinting technology is touchbased, demanding users to press their fingers against the surface of a scanning device. Major problems with this technology are the uncontrollable distortions, inconsistencies between captures and non-ideal contact.

Touchless fingerprinting solutions have been proposed over the past ten years [2], [3], [4], [5] as an effort to overcome the intrinsic problems of touchbased systems. Touchless devices do not require the users to press their fingers on a flat, transparent and backlit surface, thus attacking the image quality problem at its fundamental level.

The photographic images captured by touchless devices are very different from those captured by touchbased ones. Consequently, matching algorithms used to process touchbased fingerprints may not perform well with touchless fingerprints. This paper compares two matching approaches, one based on FingerCodes [6] and the other based on minutia [7], both originally designed to work with touchbased images, but here adapted to work with touchless fingerprints.

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II. Fingerprint Acquisition Paradigms

Biometric authentication can be defined as the automatic recognition of an individual using behavioral or physiological characteristics [8]. In general, a biometric trait is evaluated with respect to the following parameters [9]: universality, distinctiveness, permanence, collectability, acceptability and circumvention. The evaluation of a biometric trait according to these six parameters determines its performance. Fingerprints present high levels of distinctiveness and medium levels of universality, collectability, acceptability and circumvention, which results in a high-performance and widely used biometric trait [1], [9]. Next, the two fingerprinting paradigms addressed in this paper are briefly presented.

A. Touchbased Acquisition

The quality of acquired fingerprints clearly affects the overall performance of a fingerprint recognition system. Touchbased scanners require the contact between the users' fingers and the acquisition device. Consequently, distortions and inconsistencies between acquisitions may be introduced due to skin elasticity. Fingerprint quality may be also seriously influenced by non-ideal contact caused by dirt, sweat, moisture, excessive dryness, air humidity, temperature and latent fingerprints [10]. In some scenarios, the previously-mentioned drawbacks demand several attempts per finger, in order to ensure a high-quality template, and the enrollment process may become very time-consuming if the number of users to be registered raises. In the Brazilian Electoral System, for instance, there are 144,088,912 voters whose fingerprints need to be acquired. Nevertheless, from 2008 until 2016 only 32.13% of voters had their biometric traits enrolled[1].

Although over the past few years many algorithms have been proposed to compensate for the limitations of touchbased technology, this sensing paradigm may represent a bottleneck for further improvement of fingerprint image quality. Instead of generating a representation of the finger that tries to mimic ink-based acquisitions, one can use a more faithful high definition photographic image.

B. Touchless acquisitions

Touchless devices do not compel users to press their fingers on a platen and rely on photographic acquisitions. Among the proposed touchless solutions, some devices combine reflection-based imaging with a three-camera multiview system [2]. One main camera is positioned to capture the

[1] http://www.tse.jus.br/eleicoes/biometria/biometria

portion of the finger where normally the core and deltas are located, and taking this central camera as a reference, the other two are displaced by 45 degrees clockwise and counter-clockwise. Hence, a touchless fingerprinting device is able to deliver high quality photographic images of the fingers.

Considering the two paradigms previously discussed, we now may suggest a more general definition of fingerprint. It is not only the ridge-valley structure captured by a device when a finger is pressed against its acquisition surface, but rather the complete set of anatomical characteristics of a finger, including the ridge-valley structure, captured by any kind of sensor, as long as adequate levels of universality, distinctiveness, permanence, collectability, acceptability and circumvention are delivered.

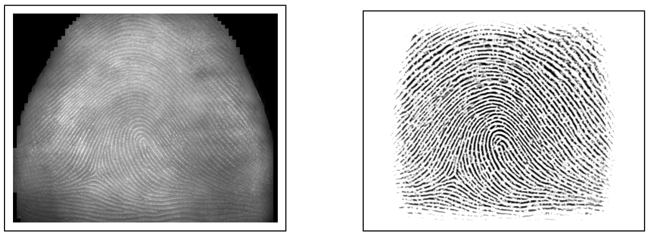
III. Proposed Methodology

The evaluation of the minutia-based matching approach depends on the touchbased equivalent fingerprints generated by the touchless-to-touch processing algorithm described in the next subsection. The resulting touchbased equivalents are also required as inputs in the evaluation of the adapted FingerCodes matching solution. The need to adapt traditional FingerCodes resides on the fact that this technique is meant to operate only on touchbased fingerprints rather than on touchless ones. From this point forward the adapted version of FingerCodes will be referred to as Touchless FingerCodes, which can be divided into three main steps: (a) touchless-to-touch processing; (b) reference point location; and (c) feature vector extraction and matching. Next, each step is described in more detail.

A. Touchless-to-touch Processing

Touchbased biometric systems have a long history of use, maturation and validation. Many processing algorithms for fingerprints captured using the touchbased paradigm have already been proposed. Thus, when convenient, such algorithms can be used to process touchless fingerprints as well. But given the diverse nature of the images captured by touchless devices compared to those captured by touchbased device, sometimes it is necessary to use a touchless-to-touch compatibility processing procedure [11].

Although touchless FingerCodes matching is performed on original touchless images, an intermediate step depends on fingerprint images that have the general aspect of touchbased ones. Therefore, a touchless-to-touch compatibility algorithm is used. The initial step consists of block-based histogram equalizations, followed by a gamma transformation. Then, Gaussian filtering with three different standard deviations and kernel sizes, defined as their full width at half maximum, is performed. Each filtered image is thresholded, and the binary results are averaged. A geometrical interpolation is performed, synthetic texture is added and, finally, a fading effect is applied to the fingerprint borders. A typical result is shown in Figure 1. As stated before, the touchbased equivalent images are used to evaluate the minutia-based matching approach and also as inputs to the reference point location algorithm of the touchless FingerCodes method.



(a) (b)

Fig. 1. Touchless-to-touch conversion: (a) input touchless fingerprint; and (b) output touchbased fingerprint.

B. Reference Point Location

Reference points are those defined by a region of maximum concave curvature. In our work, it is important to find the coordinates $(x_c,\ y_c)$ of the center of touchless fingerprints, which is a reference point. The reason is that FingerCodes are generated in the neighborhood of $(x_c,\ y_c)$.

To find the reference points, the method proposed by Salil is used [12]. Considering that the input to the algorithm is a touchbased equivalent fingerprint image $I_{M\times N}$, the orientation field of $I(i,j)$ is defined as $O_{P\times Q}$, where $O(i,\ j)$ represents a local orientation at $(i,\ j)$. Since orientation is normally block-wise computed, the image I is divided into non-overlapping blocks of $w \times w$ pixels. In our experiments, w is set to 16, and the resulting number of blocks depends on M and N, which may vary between acquisitions. In order to estimate the orientation field, a least mean square estimation is used [13]. In summary, this algorithm is divided in three steps: (1) divide I into $w \times w$-pixels non-overlapping blocks; (2) compute the $\partial_x(i,\ j)$ and $\partial_y(i,\ j)$ gradients in the x and y directions, respectively; and (3) compute the local orientation for each block centered at pixel $(i,\ j)$ using Equations 1 to 3,

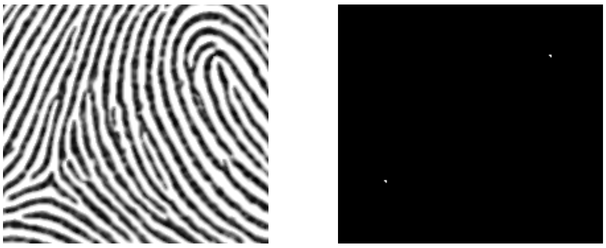
$$\mathcal{V}_x(i,\ j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{j+\frac{w}{2}} 2\partial_x(u,\ v)\partial_y(u,\ v) \quad (1)$$

$$\mathcal{V}_y(i,\ j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{j+\frac{w}{2}} \partial_x^2(u,\ v) - \partial_y^2(u,\ v) \quad (2)$$

$$\mathcal{O}(i,\ j) = \frac{1}{2}tan^{-1}\left(\frac{\mathcal{V}_y(i,\ j)}{\mathcal{V}_x(i,\ j)}\right) \quad (3)$$

Once the orientation field $O(i,j)$ is estimated, the next step consists in generating $O'(i,j)$, which is a smoothed version of $O(i,j)$.

Figure 2(a) shows a zoomed part of a typical touchbased equivalent image $I(i,j)$. Once that $O'(i,j)$ is obtained, an image $E(i,j) = sin(O'(i,j))$ is calculated. Next, the gradient of E is calculated using the Sobel filter. Finally, a binarization procedure generates the image B, shown in Figure 2(b). In this image, the candidate points are defined and the top most is chosen as the reference point location $(x_c,\ y_c)$.



(a) (b)

Fig. 2. Reference point location: (a) zoomed part of the touchbased equivalent image $I(i,j)$; (b) $B(i,j)$ (reference point candidates).

C. *Feature Vectors Extraction and Matching*

FingerCodes are vectors composed by local descriptors that try to assure the uniqueness between fingerprints. In this paper, a modified version of FingerCodes is employed. The first step consists in processing the touchless input image, as described in Section III-A, in order to generate its touchbased equivalent. A typical result is shown in Figure 3(a). Then, the algorithm uses the touchbased image to locate the reference point, as discussed in Section III-B. Next, a region of interest (ROI) is selected around the reference point using the original touchless image as input. Here a 320×320-pixels region is used. The ROI is further divided into 400 non-overlapping sub-sectors of 16×16 pixels and a local normalization procedure is applied, as illustrated in Figure 3(b).

After the normalization, a bank of 8 Gabor filters, with 8 different directions (from $0°$ to $157.5°$, with increments of $22.5°$), is applied to each sub-sector of the enhanced region, generating 8 filtered images, shown in Figures 3(c). Finally, the FingerCodes are extracted also according to [12]. Figures 3(d) illustrates typical outputs. The matching procedure is performed by comparing an input FingerCode with a template FingerCode, as depicted in Figure 3(e).

The most relevant difference between the algorithm proposed by Salil [12] and the algorithm presented in this section is that FingerCodes are evaluated on touchless images, which was not investigated until now.

IV. Experimental Results

A database containing 400 touchless fingerprints (80 individuals, 5 samples per individual) is used. The performance of the proposed method was determined using bootstrapping, according to the following steps:

1) Let F denote the set containing all samples of $20 \times p$ individuals, with $p = 1, 2, 3$ or 4. The experiments begin with $p = 4$.
2) If $F = \emptyset$, the fingerprint samples of all 80 individuals are reinserted into F. In other words, p is reset to 4.
3) All fingerprint samples of 20 randomly chosen individuals are removed without replacement from the remaining samples in F and included in the k-th test set D_k. The variable p is decremented by one.
4) Let f_{ij} denote the j-th fingerprint sample of individual i in D_k.
5) Each $\{f_{ij}\}_{i=n,j=m}$ (m is set to any fixed row value between 1 and 5) is matched against all $\{f_{ij}\}_{i>n,j=m}$ (for n from 1 to 19). This is the horizontal matching procedure depicted in Figure 4, which results in the combinations of 20 fingerprints taken 2 at a time (190 matchings).
6) Each $\{f_{ij}\}_{i=n,j=m}$ (for n from 1 to 20) is matched against all $\{f_{ij}\}_{i=n,j>m}$ (for m from 1 to 4). This is the vertical matching procedure shown in Figure 4, which results in the combinations of 5 fingerprints taken 2 at a time multiplied by 20 individuals (200 matchings).
7) Calculate equal error rate (EER) by varying the matching threshold in steps 5 and 6.
8) Step 5 is repeated independently for each possible row of samples (m is successively set to a fixed row index from 1 to 5, as illustrated in Figure 4), and new EERs are calculated using the false rejection rates already computed in step 6.
9) Steps 2 to 8 are repeated for k = 1 to 400.

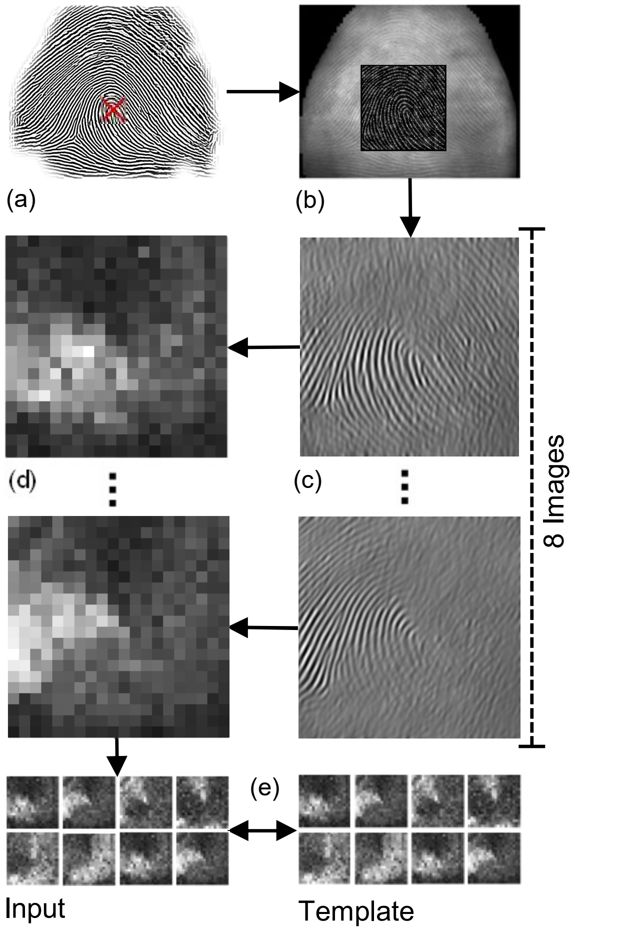


Fig. 3. Feature vectors extraction and matching: (a) reference point location; (b) ROI selection, sub-sectors definition and local normalization; (c) Gabor filtering using; (d) FingerCodes extraction; and (e) matching.

Bootstrapping is performed by repeating the whole procedure using 400 randomly sampled test sets. Considering that each test set is used to compute 5 EERs (5 different rows/subsets are selected in step 5), the total number of evaluations is 2000. It is important to emphasize that 4 experiments containing 20 randomly chosen individuals are performed without replacement before all 80 individuals are reinserted into the original set F. The performance is given by

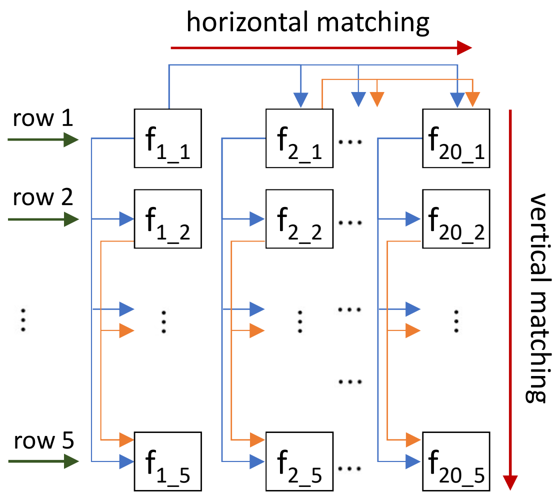
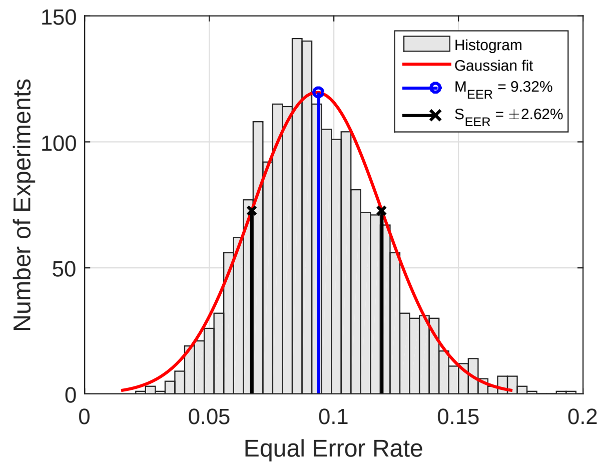


Fig. 4. Matching scheme. False acceptance and false rejection rates are calculated using horizontal and vertical matchings respectively.

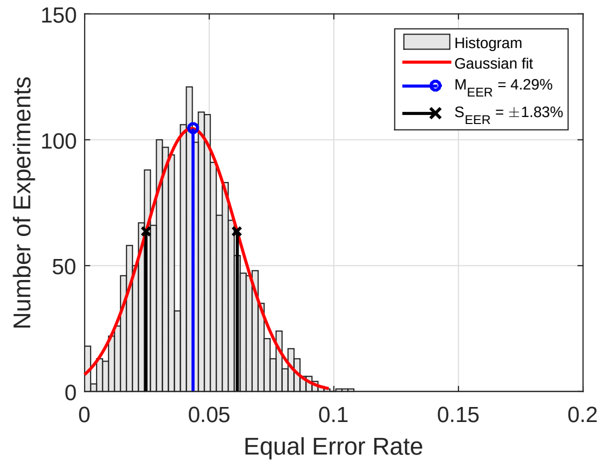
the average EER (M_{EER}) and the correspondent standard deviation (S_{EER}). Figure 5 summarizes the experimental results. It shows the distribution of the EERs for all 2000 experiments, as well as the values of M_{EER} and S_{EER} for FingerCodes and the *bozorth3* minutia-based matching implementation [7].

V. Conclusions

This paper compares the performance of the FingerCodes and minutia-based matching algorithms adapted and applied to touchless fingerprints. The performance of these two approaches was evaluated using 400 touchless fingerprints. Bootstrapping with 2000 evaluations is applied. Results show an average equal error rates of 9.32% with a standard deviation of 2.62% for the FingerCodes and 4.29% with a standard deviation of 1.83% for the minutia-based approach. One may conclude that although FingerCodes could benefit from the richness of photographic textures present in touchless images, the minutia-based approach combined with the touchless-to-touch transformation algorithm is still the best option. Future work may investigate the combination of both methods in order to achieve better performance.



(a)



(b)

Fig. 5. Histogram of EERs considering all 2000 experiments: (a) FingerCodes matching; and (b) minutia-based matching.

References

[1] Arun Ross and Anil K. Jain, "Human recognition using biometrics: an overview," *Annales Des Télécommunications*, vol. 62, no. 1, pp. 11–35, 2007.

[2] G. Parziale, "Touchless fingerprinting technology," in *Advances in Biometrics: Sensors, Algorithms and Systems*, Nalini K. Ratha and Venu Govindaraju, Eds., chapter 2. Springer, London, 2008.

[3] A. Genovese, E. Muñoz, V. Piuri, F. Scotti, and G. Sforza, "Towards touchless pore fingerprint biometrics: A neural approach," in *2016 IEEE Congress on Evolutionary Computation (CEC)*, July 2016, pp. 4265–4272.

[4] R. Donida Labati, A. Genovese, V. Piuri, and F. Scotti, "Toward unconstrained fingerprint recognition: A fully touchless 3-d system based on two views on the move," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 46, no. 2, pp. 202–219, Feb. 2016.

[5] V. Piuri and F. Scotti, "Fingerprint biometrics via low-cost sensors and webcams," 2008.

[6] A. K. Jain, S. Prabhakar, Lin Hong, and S. Pankanti, "Fingercode: a filterbank for fingerprint representation and matching," in *Proceedings. 1999 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (Cat. No PR00149)*, 1999, vol. 2, p. 193 Vol. 2.

[7] NIST, "NIST biometric image software: bozorth3," 2018, https://goo.gl/CBaLjw.

[8] J. Wayman, "A definition of biometrics," in *National Biometric Test Center Colected Works 1997-2000*. San Jose State University, 2000.

[9] A. K. Jain, A. Ross, and S. Prabhakar, "An introduction to biometric recognition," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 14, no. 1, pp. 4–20, Jan 2004.

[10] A. K. Jain and S. Pankanti, "Automated fingerprint identification and imaging systems," in *Advances in Fingerprint Technology*, H. C. Lee and R. E. Gaensslen, Eds., chapter 8. CRC Press, Boca Raton, 2nd edition, 2001.

[11] Pedro Salum, Daniel Sandoval, Alexandre Zaghett, Bruno Macchiavello, and CauÃª Zaghetto, "Touchless-to-touch fingerprint systems compatibility method," in *Proceedings. 2017 IEEE International Conference on Image Processing*, Sept 2017.

[12] Salil Prabhakar, *Fingerprint Classification and Matching Using a Filterbank*, Ph.D. thesis, Michigan State University, 2001, Computer Science and Engineering.

[13] Lin Hong, Yifei Wan, and Anil Jain, "Fingerprint image enhancement: Algorithm and performance evaluation," *IEEE transactions on pattern analysis and machine intelligence*, vol. 20, no. 8, pp. 777–789, 1998.