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A new fingerprint ridges frequency determination method

Piotr Porwik[a] **and Łukasz Więcław**[b]

Institute of Informatics, University of Silesia

41–200 Sosnowiec ul. Będzińska 39, Poland

a) *piotr.porwik@us.edu.pl*

b) *lukasz.wieclaw@us.edu.pl*

Abstract: In many cases the average fingerprint ridge frequency in the whole fingerprint image should be determined. This parameter is, among other things, very important in procedures, where so-called fingerprint reference point has to be located. Unfortunately, as far, ridges frequency has been determined *a priori*, on the basis of anthropological measurements of the human population. This parameter is established as 10 pixels, regardless of captured fingerprint image resolution. Until now it is assumed, that this resolution is equal to 500 dpi. In practice, scanners obviously work with different resolution. This point of view has been revised and a new method of fingerprint ridge frequency measurement was introduced. This method allows to precisely calculate fingerprint ridges frequency – individually for any fingerprint image. The new approach allows determining more precisely, among other things, so–called fingerprint reference point, which is an important element of fingerprint recognition procedures.

Keywords: fingerprint recognition, ridges frequency

Classification: Science and engineering for electronics

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1 Introduction

Biometry is a study of the person recognition through its physiological characteristics (for instance face, retina, fingerprint) or behavioural (voice, smell, signature). Only biometric identification can provide a really precise control of the people, with a high level of certainty recognition. In the midst of many biometric methods, the most popular is biometry based on fingerprint characteristics of a person and this method is used to achieve a good recognition of humans [4]. It is obvious that fingerprint images have often very low quality because are mostly gathered in crime places. For this reason quality of these images, if it is possible, should be improved first. It is well known that only good quality fingerprint images can be processed by *AFIS* (Automated Fingerprint Identification System) procedures. Computer programs of *AFIS* search for individual (unique) features of fingerprint such as layout of ridges and valleys, minutiae structure, etc. Effectiveness of *AFIS* depends on quality of fingerprint [1, 2, 5]. The differences between ridges characterize human fingerprints. These differences between ridges frequencies can be notably observed if fingerprints are captured by means of differently working devices (scanners) – images can have various qualities. In many works [1, 2, 6], fingerprint identification and recognition methods are applied for laboratory conditions or for preconditions with many restrictions. One of these restrictions is the determination of average difference between fingerprint ridges. This distance is also called as ridges frequency [4]. In addition, this parameter is an element of many fingerprint image quality enhancement methods [1, 4, 6]. For this reason, an automatic method of a given fingerprint ridges frequency recognition will be considered and its measurement will be described in the paper.

2 Estimation of local ridges orientation

An orientation field θ represents local orientation of fingerprint ridges, which occurs on fingerprint surface. To estimate the local ridge orientation, we use the modified least mean square orientation algorithm [1].

Let $N \times M$ fingerprint image be defined as $I(x, y)$, where $x = 1, \dots, N$ and $y = 1, \dots, M$ are pixel coordinates of the image. In the first step, fingerprint image I is divided into blocks. Each block η of dimension $W \times W$ is centered at the pixel (u, v), then for all $u, v \in I, \eta$ we have:

$$V_x(u, v) = \sum_{i=-W+u}^{W+u} \sum_{j=-W+v}^{W+v} 2G_x(i, j)G_y(i, j),$$

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$$V_y(u,v) = \sum_{i=-W+u}^{W+u} \sum_{j=-W+v}^{W+v} \left(G_x^2(i,j) G_y^2(i,j) \right),$$

$$\theta(u,v) = \frac{1}{2} \tan^{-1} \left(\frac{V_x(u,v)}{V_y(u,v)} \right) \tag{1}$$

In our case $W = 3$, and G_x, G_y are gradient magnitudes towards x and y direction, respectively estimated on the basis of the formulas:

$$\begin{aligned} G_x(i,j) &= \frac{(I(i,j) - I(i-1,j))}{2} - \frac{(I(i,j) - I(i+1,j))}{2}, \\ G_y(i,j) &= \frac{(I(i,j) - I(i,j-1))}{2} - \frac{(I(i,j) - I(i,j+1))}{2} \end{aligned} \tag{2}$$

The value $\theta\,(u,v)$ determines the local orientation of the fingerprint ridge at the image point (u,v). The gradient G can also be displayed in the form of the image [2].

$$G(u,v) = \sum_{i=-W+u}^{W+u} \sum_{j=-W+v}^{W+v} \sqrt{G_x^2(i,j) + G_y^2(i,j)}, \tag{3}$$

$$I_{avr}(u,v) = \left(\sum_{i=-W+u}^{W+u} \sum_{j=-W+v}^{W+v} I(u,v) \right) \Big/ W^2 \tag{4}$$

3 Choice of the appropriate fingerprint area

In the first step of ridges frequency estimation, on the orientation fingerprint field θ, the horizontal line of pixels,$L_{hor \in \{1,2,\ldots,N\}}$ and the vertical line of pixels $L_{ver \in \{1,2,\ldots,M\}}$ are searched (Fig. 1). These lines are located in places where appropriate column (row) of fingerprint image contains the longest sequence of the pixels, with appropriate features. This pixels sequence should fulfill the following restrictions:

$$\begin{aligned} &\text{for } L_{ver} \text{ pixels seq.:} \quad \left(\theta(x,y) > \pi - \frac{\pi}{\sigma}\right) \wedge \left(\theta(x,y) < \frac{\pi}{\sigma}\right) \wedge (G(x,y) > 1), \\ &\text{for } L_{hor} \text{ pixels seq.:} \quad \left(\theta(x,y) > \frac{\pi}{2} - \frac{\pi}{\sigma}\right) \wedge \left(\theta(x,y) < \frac{\pi}{2} + \frac{\pi}{\sigma}\right) \wedge (G(x,y) > 1) \end{aligned} \tag{5}$$

where constant $\sigma = 18$ was experimentally matched.

In another stage, for the lines L_{hor} andL_{ver} range (5), the pixel sequences is browsed once more with changed parameter $\sigma = 12$ (Fig. 1). It allows

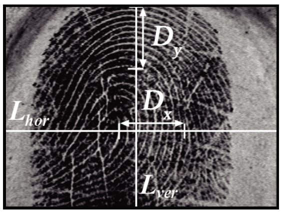

Fig. 1. Fingerprint with plotted L_{hor}, L_{ver} lines, where appropriate set of the pixels (the sequences D_x or D_y) will be searched.

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selecting the appropriate pixels match more precisely. The appropriate ranges of sequences, which lie on the straight lines L_{hor} and L_{ver}, are indicated in the Fig. 1 by the symbols D_x and D_y respectively.

In the average image I_{avr} (4) in the range $D \in \{D_x, D_y\}$ sequence, there are searched pixels which determine local minimum and maximum points. The local minimum points B_r, $r = 1, 2, \ldots, \kappa$ – correspond to fingerprint ridges, and local maximum points T_v, $v = 1, 2, \ldots, \gamma$ – correspond to valleys between fingerprint ridges. For this assumption, κ determines the number of fingerprint ridges in sequence, and γ the number of valleys inside the area of interest. Because the origin fingerprint image I and the average image I_{avr} have similar appearance, all symbols were depicted only on image I and image I_{avr} is not presented here.

The waveform of a given fingerprint ridges presents Fig. 2. In many cases the average ridges frequency in the whole fingerprint image should be determined. This parameter is very important in procedures, where so-called fingerprint reference point has to be located [3, 5]. Unfortunately, ridges frequency was determined until now *a priori*, on the basis of type of used scanner [2, 4]. In the proposed approach, fingerprint ridges frequency determination is based on measurement of distance between appropriate points (Fig. 2). For this reason, the ridge frequency can be determined more precisely – individually for any fingerprint image. The measurement procedure is performed two times, separately for L_{hor} and L_{ver} lines. In other words, pixel sequences D_x or D_y are considered. For each sequence two distances are computed:

$$
\begin{aligned}
V_r &= T_r - T_{r+1}, \ r = 1, 2, \ldots, \kappa - 1, \\
R_v &= B_v - B_{v+1}, \ v = 1, 2, \ldots, \gamma - 1
\end{aligned}
\tag{6}
$$

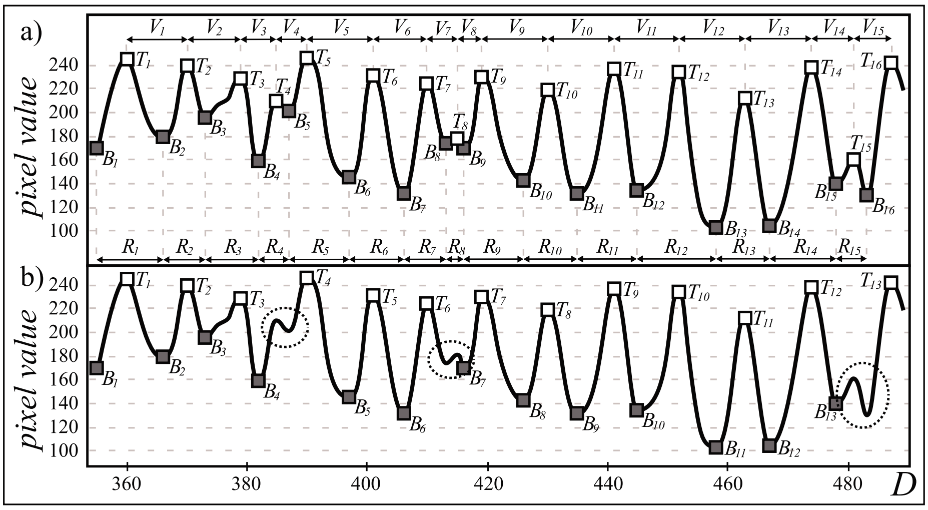

Fig. 2. Fingerprint ridges as waveform (B_r, $r = 1, 2, \ldots,$ κ – gray points) and valleys (T_v, $v = 1, 2, \ldots, \gamma$ – white points). a) waveform with artifacts, b) waveform without noise (repaired places indicate dot-circles)

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For these assumptions, the pixels sequence $D \in \{D_x, D_y\}$, which was determined by means of the equation (5), is searched and some elements of this sequence can be modified. In this modification several points T_i and B_i (see Fig. 2b) are removed.

4 Determination of fingerprint ridges frequency

Taking mentioned considerations into account, fingerprint ridges frequency can be determined independently of the type of used scanners, what was so far bottleneck in many procedures of *AFIS*. Let $\varepsilon(j) = \sum_{i=1}^{p-1}(x_j - x_i)$, where $x_l = V_l$ or $x_l = R_l$ is the pixel value in the selected sequence D, then elements (T_r, B_v pixels) of the sequence D are appropriately ordered by means of the procedure:

$$\underset{j=1}{\overset{p-1}{\forall}} |\varepsilon(j)| > |\varepsilon(j) + x_{j+1}| = \begin{cases} then & x_j = x_j + x_{j+1} \ and \ x_{j+1} \ is \ removed \\ otherwise & j = j+1 \end{cases} \tag{7}$$

where substitution $p = \kappa$ or $p = \gamma$ depends on sequence D.

The average fingerprint ridge frequency can be directly estimated inside of the sequences D_x and D_y by means of the formula:

$$F = \frac{\sum_{r=1}^{\kappa} R_r + \sum_{v=1}^{\gamma} V_v}{\kappa + \gamma - 2} \tag{8}$$

The measurement can be unfortunately noised, because in measurement areas minutiae can occur. For this reason, in neighborhood of L_{hor} and L_{ver} the additional sequences are determined. These sequences are located on lines $L_{hor\pm5}$ and $L_{hver\pm5}$. In other words, the new lines are shifted ± 5 pixels with relation to line L. Hence, three sequences D, laying along the lines L, are formed: $D_{x1} \in L_{hor}$, $D_{x2} \in L_{hor+5}$ and $D_{x3} \in L_{hor-5}$. The sequences D_{y1}, D_{y2}, D_{y3} are found similarly. For every D sequence the values F_i^{ver}, F_i^{hor}, $i = 1, 2, 3$ can be computed. Finally, global fingerprint ridge frequency is calculated from the formula:

$$Q^j = \frac{\sum_{i=1}^{3} D_{y_i} F_i^{ver} + \sum_{i=1}^{3} D_{x_i} F_i^{hor}}{\sum_{i=1}^{3} D_{y_i} + \sum_{i=1}^{3} D_{x_i}} \tag{9}$$

where the index j determines number of image from database.

5 Experimental results

Investigations were carried out for the database, which included 992 fingerprint images [7]. This database includes images in resolution of 500 dpi and 300 dpi. In most cases one finger was represented by eight different fingerprint images (samples). In the first investigation, average difference of fingerprint ridge frequency has been determined. From this examination follows, that difference between police expert indication and proposed solution is equal

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of $Dist_{single} = 0,40$ pixels. For fingerprint represented by 8 samples, mentioned difference is computed as average value and is equal of $Dist_{group} = 0,22$ pixels. It was depicted at Fig. 3a, where values located on the OX axis represent the number of fingerprints group, which consists of 8 samples from database. Fingerprint groups are sorted in increasing order of differentiation. In addition, for analyzed group of eight fingerprint images, average absolute deviation of ridge frequency has been calculated:

$$DIFF_{avr} = \frac{1}{124}\sum_{j=1}^{124}\left(\frac{1}{64}\sum_{g=1}^{8}\sum_{i=1}^{8}(Q_g^j - Q_i^j)\right) \tag{10}$$

From investigation follows, that this value is equal of $DIFF_{avr} = 0,53$ pixels. This value indicates average repeatability of the measurement results. These investigations have been presented in Fig. 3b. The absolute deviation of fingerprint ridges frequency $DIFF$, for eight different samples per one fingerprint, was also determined. The $DIFF$ value was computed directly from part of eq. (10) as expression in parenthesis.

The Fig. 3c presents differences of reference point location (this point

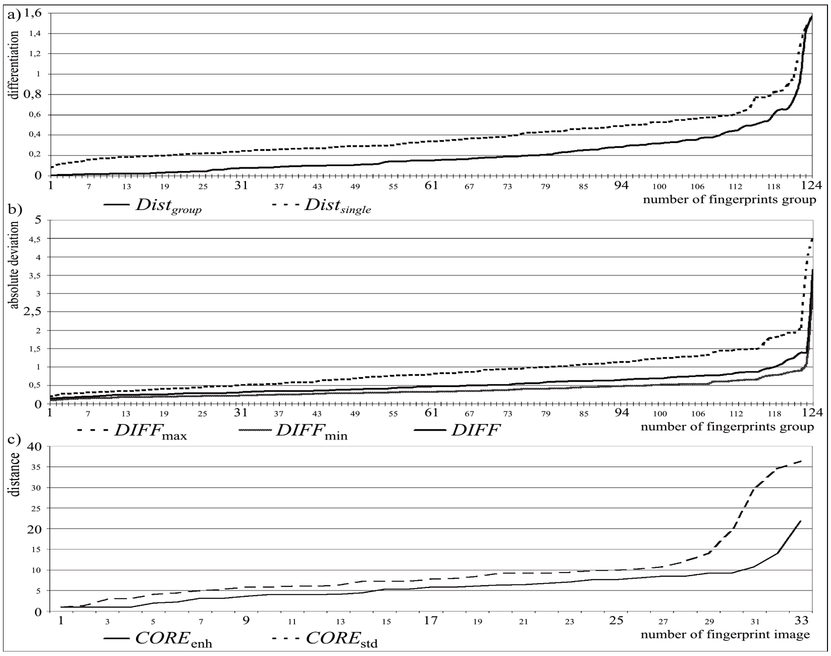

Fig. 3. a) Ridge frequency differences between police expert indication and proposed procedure: $Dist_{single}$ – for single fingerprint image, $Dist_{group}$ – for group of eight images of one fingerprint, b) $DIFF$ – Absolute average deviation of fingerprint ridges frequency (for eight images of one fingerprint), $DIFF_{min}$ – a minimal value indicated by algorithm, $DIFF_{max}$ – a maximal value, c) differences between $CORE$ point localization: $CORE_{std}$ – obtained from standard fingerprint ridges frequency measurement, $CORE_{enh}$ – obtained after applied described in the paper method.

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should indicate so-called fingerprint core point). The difference was determined by means of simple Euclidean distance formula. The dashed line presents differences between results of police experts and methods, where ridge frequency was computed on the basis of the constant frequency. The continuous line depicts differences between police expert indications and proposed method, where fingerprint frequency was determined individually for each image.

6 Conclusions

In this paper, we have presented a solution of fingerprint ridge frequency determination problem. To evaluate the effectiveness of the proposed method, the 33 randomly selected images were selected, and core point was determined. The proposed approach gives the better results of the core point location compared to methods, where fingerprint ridge frequency were globally determined as constant value [2, 4]. Proposed method is very simple, compared to method [6], where ridges frequency by means of the Fourier Transform and the radial distribution functions are computed. It was shown that our results of fingerprint ridge frequency estimation are also consistent with police expert's findings.

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