

Fingerprint Orientation Map Based on Wave Atoms Transform

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Abstract—Most systems of fingerprint identification and/or authentication need a ridge direction map, commonly called the orientation map. In addition, the estimation of orientation field plays an important role in the fingerprint enhancement. In this paper, A novel fingerprint orientation map estimation based on Wave atoms transform is proposed. This paper aims to open a new gateway by proposing a different approach for analyzing fingerprints and try to unify steps of automatic fingerprint identification system (AFIS): classification, compression, quality measure, local orientation and identification. Wave atoms is one of the new geometric multiscale-multidirectional transform, which is more appropriate to represent fingerprint structures. In order to evaluate the performance of the algorithm, FVC2004 database has been considered. The results show that this method has a serious potential in fingerprint orientation evaluation.

Index Terms—fingerprint orientation map, wave atoms transform, multi-directional analysis, orientation field.

I. INTRODUCTION

For security reasons, the reliable identification of persons is become a major necessity. The most practical approach adopted by the fingerprint identification is based on the extraction and matching minutiae. The performances of these methods depend heavily on the correct estimation of local ridge orientation. Currently, the most popular method for local ridge orientation estimation is based on gradients and was introduced by Kass and Witkin [1].

Many other researchers proposed the orientation estimation based on gradients computation [2], [3], [4], [5], and [6].

Mathematically, it represents the direction that is orthogonal to the dominant direction of the Fourier spectrum of the $w \times w$ window. Zhu, Yin, Hu and Zhang [7] estimated fingerprint ridge orientation by a gradient-based method, and then utilize a neural network for the correctness of ridge orientation.

There are some other methods proposed in the literature, Dass [8] used a Markov random field model to compute reliable directional field. Nagaty [9] used neural

networks for computing fingerprints block directional images.

Luping and Zhang [10] proposed a method for estimating four-direction orientation field using pulse coupled neural network (PCNN). They estimated block direction by the minimum projection variance of primary ridge. Liu and Dai [11] divides a fingerprint into certain and uncertain blocks by a rule-based algorithm that can differentiate blocks with parallel ridge flows from those with nonparallel ridge flows and assigns orientations to only certain blocks. Then, the orientations of the uncertain blocks is restored from their neighbor blocks orientations.

Most of these methods can produce good fingerprint orientation extraction, but they require pretreatments and are costly in computing time. In addition, the automatic fingerprint identification system (AFIS) involves a series of image enhancement and minutiae extraction steps: quality measure, local ridge orientation extraction, minutiae extraction, local structure description for classification, compression. For most these steps, we have developed approaches based on Wave atoms transform. Wave atoms is a new transform which is half multi-scale and half multidirectional.

The aim of the present work was to obtain a unique scheme based on Wave atoms transform which takes advantage of the local space-frequency structures particular to fingerprint images. We have already used the Wave atoms in compression [12], [13], [14], quality measure [15] and identification. Fingerprint classification by Wave atoms was proposed in [16]. Then, we try to use this new geometric transform, highlighting the fingerprint particular structures (sinusoidal wave and orientation) for orientation extraction.

In order to test the performance of the adopted measure, we have considered the FVC 2004 database of the Third Fingerprint Verification Competition [17] and compared the obtained results with those of the most simple and very commonly used method which is gradient-based.

The rest of the paper is organized as follows. We first present the proposed fingerprint orientation extraction and we focus on Wave atoms transform. The feature extraction has been detailed in this section. Experimental settings, methodology, results and discussions are represented in section 3. The last section concludes this work and gives some perspectives.

II. THE PROPOSED FINGERPRINT ORIENTATION EXTRACTION

Recently, Several variants of geometric transforms have been proposed: as Curvelets, Ridgelet, Bandelets, Con-tourlets, and the Shearlets. These transforms are trying to represent, at best, the geometrical image in content [18]. Wave atoms transform is one of them, which suits with oscillatory patterns and texture representation. We believe that fingerprint images fall into the category of oscillatory patterns. The proposed method is essentially based on fingerprint oscillatory texture characterization using block Wave atoms transform. This last is one of geometrical transforms emerged recently. It was shown in the work of Demanet [18], [19] and Ying [19] that Wave atoms transform provides high performance in the representation of textures oscillating compared to other transforms. They prove that oscillatory functions or oriented textures (e.g., fingerprint, seismic profile, and engineering surfaces) have a significantly sparser expansion in Wave atoms than in other fixed standard representations like Gabor filters, Wavelets, and Curvelets.

A. Wave Atoms Transform

We present some basic ideas about Wave atoms transform and illustrate the fact that this representation deals with fingerprint oriented structures. The name Wave atoms come from the property to offer a representation in a sparse optimal way of the propagators of the Wave atoms. The main properties of Wave atoms transform are the ability to adapt to arbitrary local directions of a pattern, i.e., warping; and the ability to sparsely represent anisotropic patterns aligned with the axes [19]. The Wave atoms can be implemented by using the strategy of the wrapping in the frequential plan, following the same direction as the Curvelets [20]. In order to understand and situate Wave atoms transform among the other existing transforms, we use two parameters α and β to index a lot of known Wave packets architectures [21]. This description will clarify the connections between various transforms of modern harmonic analysis. The index α indicates whether the decomposition is multiscale ($\alpha = 1$) or not ($\alpha = 0$); and β indicates whether basis elements are localized and poorly directional ($\beta = 1$) or, on the contrary, extended and fully directional ($\beta = 0$). This classification permits to classify, Wavelets to $\alpha = \beta = 1$. Ridgelet transform will correspond to $\alpha = 1, \beta = 0$. For Gabor transform $\alpha = \beta = 0$ and for Curvelet transform $\alpha = 1, \beta = 1/2$. Wave atoms are defined for $\alpha = \beta = 1/2$. Fig.1 illustrates this classification [19].

Wave atoms transform offers a better representation of images containing oscillatory patterns and textures. Mathematically, Wave atoms 2-D family function is defined as a function $\phi_\mu(x)$, with μ a parameter of scale, rotation and translation, $\mu = (j, m, n) = (j, m_1, m_2, n_1, n_2)$. j, m_1, m_2, n_1, n_2 are integer-valued and index a point (x_μ, ω_μ) in phase-space [19] as:

$$x_\mu = 2^{-j} n, \quad \omega_\mu = \pi 2^j m,$$

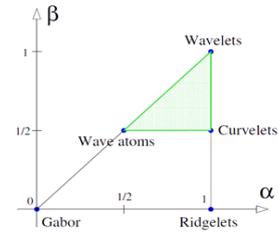


Figure 1. (α, β) diagram.

$$C_1 2^j \leq \max_{i=1,2} |m_i| \leq C_2 2^j \quad (1)$$

where C_1 and C_2 are two positive constants. The index j is a scale parameter and m acts on the orientation angle of oscillation. Fig. 2 represents the Wave atoms tiling of the spatial frequency plane. When the scale j increases by 1, the square size doubles. At a given scale j , squares are indexed by (m_1, m_2) starting from zero near the axis.

Square orientation is estimated by the following equation:

$$\theta_\omega = \tan^{-1}\left(\frac{m_1}{m_2}\right) \quad (2)$$

Thus the number of directions is limited by the possible values of the ratio $\left(\frac{m_1}{m_2}\right)$.

In dimension 2, Wave atoms family is divided into three categories: orthonormal, directional and complex. The Wave atoms orthonormal [19] is a simple extension of the 1-D case. It has the characteristic to oscillate in two mutually perpendicular directions. The product of two 1-D Wave atoms gives rise to four lobes in the frequency domain. The advantage of this transform is that it provides a redundancy rate equal to 1, so it is not redundant. The directional Wave atom [19] is built on a compact support in frequency divided in two symmetric lobes with respect to the origin. This characteristic makes this type of Wave atoms oscillates in one direction instead of two and its directionality is achieved at the expense of a redundancy rate equal to two. The complex Wave atoms [19] is constructed by the isolation of lobes in frequency. The breaking of symmetry between these lobes removes the effect of aliasing. However, the redundancy rate is four. Based on these observations, we can say that the directional Wave atoms highlight the directionality of structures.

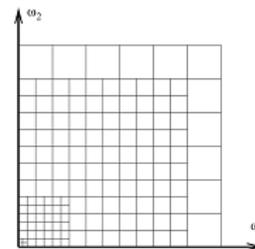


Figure 2. The Wave atoms tiling of the frequency plane.

Finally, we are interested to directional Wave atoms since they emphasize the directionality of fingerprint structures. We used the free toolboxes Wave Atom 1.1 available at the website <http://www.Waveatoms.org/>.

To illustrate the Wave atoms decomposition, one could apply the Wave atoms transform on two fingerprint

blocks with global ridge orientation 45° and 135° , respectively. The Fig. 3 (a, d) depicts the two considered fingerprint blocks. Fig. 3 (b) shows the Wave atoms coefficients associated to the block (a). The coefficients are normalized in each sub-band.

Fig. 3 (c, e) illustrates the no-normalized Wave atoms coefficients corresponding to the considered fingerprints blocks. Herein, one could notice that few coefficients are significant and are localized in specific sub-band. Hence, we should exploit Wave atoms transform by directional location of significant singularities.

B. Feature Extraction

To perform local orientation extraction, the fingerprint image is divided into blocks of size 16×16 pixels. This size is chosen to ensure that the block contains only one minutia and minimize the probability to meet too many distinct characteristics in the same location.

In transformed plan, a fingerprint block presents oscillatory structures along the orthogonal direction of the ridges. This is reflected in the existence of singularities in one specific direction θ_{ω_s} .

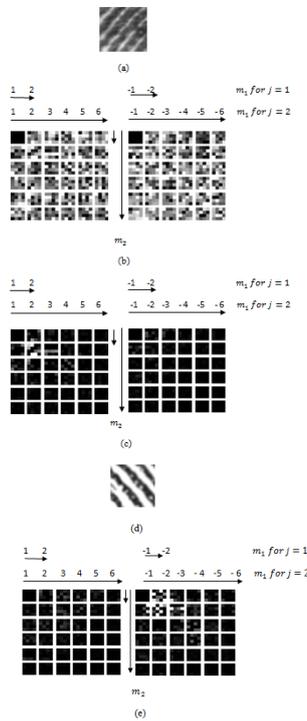


Figure 3. (a, d) Fingerprint image blocks for two ridge structure orientations 45° and 135° respectively, (b) Normalized Wave atoms coefficients distribution for block 45° , and (c, e) no-normalized Wave atoms coefficients of blocks (a) and (d), respectively.

It has been shown that few more significant Wave atoms coefficients are sufficient to accurate fingerprint image reconstruction [13]. A Wave atoms coefficient is considered as significant if it is greater than a fixed threshold. Herein, we consider that 1% of more significant coefficients are sufficient to an accurate reconstruction [13].

Therefore, one could order the Wave atoms coefficients in decreasing order. Each Wave atoms coefficient could be associated to a specific orientation.

Among the 1% selected coefficients, could appear a specific orientation which is associated to a great part of the selected coefficients. We then calculate the occurrence of directions corresponding to the selected Wave atoms coefficients. The orientation which maximizes the probability of occurrence is then considered, and labeled as block orientation.

To analyze the block features, one could perform the further steps:

- 1) Image blocks are decomposed by directional 2D-Wave atoms transform. The cells $c\{j, d\}\{m_1, m_2\}(n_1, n_2)$ with $d = 1, 2$ are the Wave atoms coefficients at scale j , frequency index (m_1, m_2) and spatial index (n_1, n_2) . At each resolution, the partitioning into cells is indexed by m_1 and m_2 . Each cell contains a matrix of Wave atoms coefficients. The cell orientation is estimated by equation
- 2) One could consider only the resolution 2 which represents the maximum of orientations relative to resolution 1 or 3. Each cell is of size 4×4 . The Fig. 4 illustrates the cells of Wave atoms decomposition at resolution 2. At each cell is associated a label i , ($i = 1, \dots, 70$). Wave atoms coefficients are stored according the increasing order of the orientation θ_{ω} . Fig. 4 depicts the scan performed according the cell orientation.

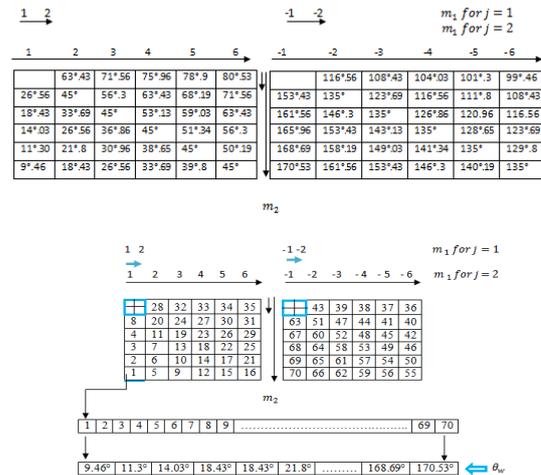


Figure 4. Representation of wave atoms coefficients distribution based on orientation.

The associated Wave atoms coefficients are ordered in relation with increasingly ordered orientation.

Thus, one could plot the Wave atoms projection versus the orientation (Fig. 5. b) for block (Fig. 5. a). Hence, Fig.5.c depicts the Wave atoms coefficients magnitudes reordered in decreasing order. We have considered only the 1% Wave atoms coefficients. The fig.5.d illustrates the orientation associated to the main important Wave atoms projection values. Thus, one could notice that the occurrence of the main orientation is important.

The Proposed method may be summarized by the following algorithm:

- 1) Scan the fingerprint image into blocks of size 16×16 , For each block.

- 2) Calculate the Wave atoms coefficients.
- 3) Store the Wave atoms coefficients in absolute value, from highest to lowest.
- 4) Apply a threshold on the number of coefficients in order to keep only the coefficients (of highest absolute value) that best represent the considered fingerprint block. Herein 1% Wave atoms coefficients are considered which corresponds for block of size 16×16 , to the number of 11 coefficients.
- 5) Store the associated orientations (see fig.4).
- 6) Calculate the occurrences $Occ(\theta_\omega)$ of the selected orientations.
- 7) Assign a block orientation according to the maximum value $Occ(\theta_{\omega S})$ of $Occ(\theta_\omega)$.

In other words, the highest values of Wave atoms coefficients are concentrated in a same cell that corresponds to a dominant ridge orientation.

Fig. 6 shows four blocks of fingerprint image with different orientations, and associated Wave atoms coefficients versus the associated orientations. We note that the peak magnitudes are concentrated on one cell, and then dominant orientation is highlighted.

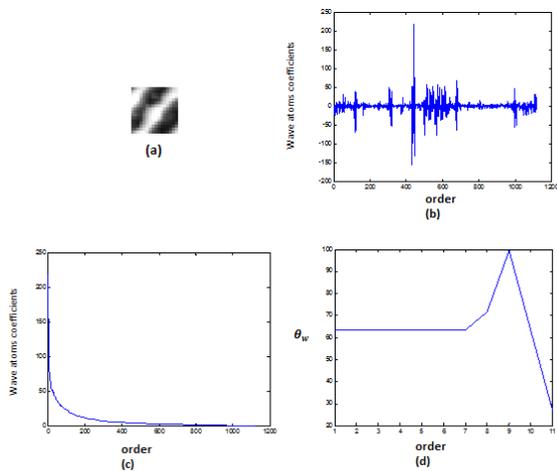


Figure 5. (a) Fingerprint image blocks, (b) Associated wave atoms coefficients, (c) Associated wave atoms coefficients ordered in decreasing order and (d) Associated wave atoms orientation θ_ω to the 1% selected coefficients.

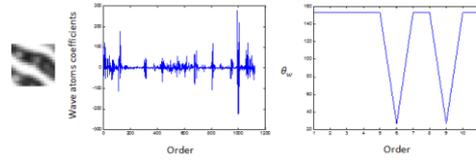
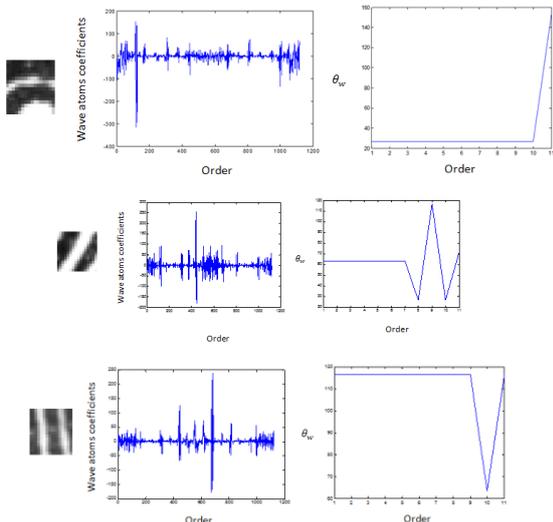


Figure 6. Four fingerprint image blocks for different orientations, associated Wave atoms coefficients and associated orientation θ_ω of 1% decreasingly ordered Wave atoms coefficients.

III. EXPERIMENT RESULTS AND DISCUSSION

In this section, results are presented to illustrate the performance of the proposed fingerprint orientation map extraction. Our methodology has been tested on DB1 database of Fingerprint Verification Competition FVC 2004 [17], which consists of 80 fingerprint images (10 distinct fingers, 8 impressions each). This database is markedly more difficult than the other FVC databases, due to the distortions deliberately introduced. To illustrate the results, it is important to underline that all the orientation values have been quantized in steps of $\frac{\pi}{8}$. The experiments have been conducted in two stages.

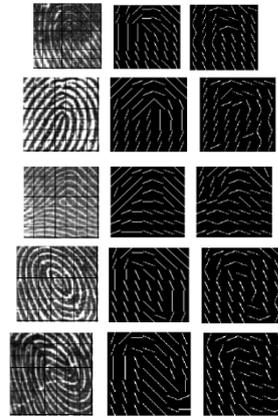


Figure 7. Fingerprint image orientation. Left column: original images, Central column: the results of gradient-based method, Right column: the results of our proposed method.

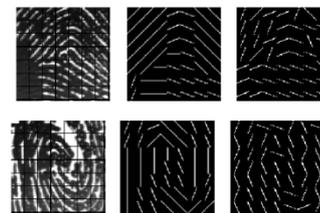


Figure 8. Fingerprint image orientation for poor quality. Left column: original images, Central column: the results of gradient-based method, Right column: the results of our proposed method.

First a set of high quality fingerprints is considered. Fig. 7 shows an example of good quality fingerprints and the associated orientation maps. On this set of fingerprints, it is clearly visible that the both methods are able to produce good results. At a second step, a set of poor quality fingerprints is considered. The Fig. 8 depicts the results obtained by the both methods. One could notice that the orientation estimation by our proposed approach is more efficient than the gradient-based method.

Thus, we believe that wave atoms transform suits with fingerprint image characterization; therefore it can be used as a common tool for different stages of AFIS.

IV. CONCLUSION

In this paper, we propose a new fingerprint orientation map extraction using the Wave atoms transform, which provides very encouraging results.

An important fingerprint local property has been shown by fingerprint block Wave atoms transform study. A particular fingerprint structures (sinusoidal wave and directionality) are highlighted by exploiting Wave atoms multiscale and multi-directional properties. The obtained results for FCV2004 database confirm the effectiveness of this fingerprint orientation map extraction. This measure can be used to improve robustness of AFIS. In addition, a unique scheme based on the same transform could be proposed for compression [14], quality measure [15], fingerprint classification [16] and identification or authentication. As future work, we propose to use the Wave atoms coefficients in fingerprint identification scheme and use the Wave atoms transform for all steps of AFIS to reduce the computing time.

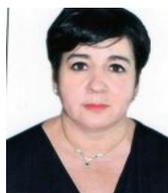
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