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ORIENTATION FIELD RECONSTRUCTION OF ALTERED FINGERPRINT USING ORTHOGONAL WAVELETS

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Abstract

Ridge orientation field is an important feature for fingerprint matching and fingerprint reconstruction. Matching of the altered fingerprint against its unaltered mates can be done by extracting the available features in the altered fingerprint and using it along with approximated ridge orientation. This paper presents a method for approximating ridge orientation field of altered fingerprints. In the proposed method, sine and cosine of doubled orientation of the fingerprint is decomposed using orthogonal wavelets and reconstructed back using only the approximation coefficients. No prior information about the singular points is needed for orientation approximation. The method is found suitable for orientation estimation of low quality fingerprint images also.

Keywords:

Altered Fingerprints, Ridge Orientation, Ridge Texture, Ridge Frequency, Wavelet Transform

1. INTRODUCTION

The main purpose of fingerprint alteration is to defeat the personal identification system by hiding their identity from a watch list of fingerprints. Alteration is one of the major threats to boarder control biometric system [1]. Fingerprint alteration is classified into three types by subjective assessment [1]. They are obliteration, distortion and imitation. Obliteration is created by cutting and abrasion with blades, poring strong chemicals and burning the ridge structure. It is again divided into mutilation and scar. Distortion type is made by removing portions of skin from a fingertip and grafting them back in different positions or replacing them with friction ridge skin from palm or sole. Imitation type is created by plastic surgery in which the entire fingertip transplanted [1].

Different methods have been developed for fingerprint alteration detection by the analysis of ridge orientation field, minutiae distribution, reliability of ridge orientation, and scar and density of singular points [1]-[5]. Soweon Yoon and Anil K. Jain have developed a method for ridge orientation modeling of altered fingerprint in terms of ordinary differential equations which does not require any prior information such as singular points or orientation of a fingerprint [6]. Sherlock and Monro developed an orientation model named zero pole model by considering image plane with the core point as zero and delta point as pole [7]. Vizcaya and Gerhardt improved the zero pole model using a piecewise linear approximation model around singular points [8]. A combinational model for orientation field estimation is presented in [9] which consists of polynomial model for representing entire ridge orientation and lower order phase portrait model is added to represent orientation more accurately [10].

Ram et al. [11] used Legendre polynomial as a basis function for ridge orientation modeling and showed that singular points can be modeled by zero-poles of Legendre polynomial. Wang et al. [12] presented an orientation estimation method using trigonometric polynomials that does not require any prior knowledge of singular points. Huckemann et al. [13] used a quadratic differential model that assumes actual location and type of the singular points of a fingerprint are given.

Proposed method belongs to approximation based method of orientation estimation where orientation field is initially transformed into continuous complex function. The real and imaginary part of the transformed complex function is decomposed using orthogonal wavelet transform. Then the approximation coefficients are reconstructed back to obtain real and imaginary part of complex function. Once the decomposition and reconstruction is complete, orientation field can be found using the reconstructed real and imaginary function.

Rest of the paper is organized as follows. Section 2 gives the theory of approximation. Proposed method is given in section 3. It also explains selection of level of decomposition. Results and discussion is given in section 4. Comparison of different orthogonal wavelets on orientation reconstruction, reconstructed orientation of altered and low quality image and comparison of proposed method with literature is given in Results and discussion. Section 5 gives the conclusion.

2. APPROXIMATION BASED ORIENTATION ESTIMATION

In general, the approximation of a two dimensional function $f(x,y)$ is performed by expanding it using a basis function and finding the coefficients. This is explained by the following equation.

$$f(x, y) = b_1U_1(x,y) + b_2U_2(x,y) + ...+ b_kU_k(x,y) + e(x,y) \quad (1)$$

where, b is the coefficients to be determined, $U(x,y)$ is the basis function and $e(x,y)$ is the error between original and approximated function. In wavelet multiresolution approximation, at a decomposition level of k, $f(x,y)$ can be decomposed as,

$$f(x, y) = d_1 + d_2 + d_3 + ... + d_k + A_k \quad (2)$$

where, d_1, d_2, d_3 and d_k are the detailed coefficients at the corresponding levels and A_k is the approximation coefficients at the level k.

2.1 TRANSFORMATION OF ORIENTATION INTO COMPLEX FUNCTION

Denoting $\theta(x,y)$ as orientation and $U(x,y)$ a transformed function, the mapping can be described as [9],

$$\mathrm{Re}U(x, y) + \mathrm{Im}U(x,y) = cos2\theta + isin2\theta. \quad (3)$$

The orientation angle $\theta(x, y)$ can be easily reconstructed from the values of $\mathrm{Re}U(x,y)$ and $\mathrm{Im}U(x, y)$ using the equation given below,

$$\theta(i, j) = pi/2 + atan2(sin2\theta, cos2\theta)/2 \quad (4)$$

The reasons for taking wavelet as basis for orientation approximation is that orthogonal basis provides good approximations to the two dimensional functions [14], [15]. Wavelet transform also provides provision for multi resolution analysis [16], [17].

2.2 DECOMPOSITION AND RECONSTRUCTION USING WAVELET TRANSFORM

In the 2D wavelet transform, the scaling and wavelet coefficients are computed using a 2D filter bank composed of low pass and high pass filters and decimators. At each scale, the 2D function is decomposed into an approximation image a_j of a low pass band and three detail images d_j^H, d_j^V and d_j^D corresponding to a horizontal high pass band, a vertical high pass and diagonal high pass band respectively as given below,

$$w_\phi(j_0,m,n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y).\phi_{j_0,m,n}(x,y) \quad (5)$$

$$w_\psi^i(j,m,n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y).\psi_{j,m,n}^i(x,y) \quad (6)$$

where, i = {H,V,D}, j_0 is an arbitrary starting scale, $w_\phi(j_0,m,n)$ define the approximation coefficients and $w_\psi^i(j,m,n)$ defines the detailed coefficients in horizontal, vertical and diagonal directions.

Reconstruction is performed according to the Eq.(8) by keeping the detailed coefficients $w_\psi^i(j,m,n)$ at zero in every stage.

$$f_{rec}(x,y) = \frac{1}{\sqrt{MN}} \sum_m\sum_n w_\phi(j_0,m,n)\phi_{j_0,m,n}(x,y) + \frac{1}{\sqrt{MN}} \sum_{i=H,V,D}\sum_{j=j_0}^{\infty}\sum_m\sum_n w_\psi^i(j,m,n)\psi_{j,m,n}^i(x,y) \quad (7)$$

3. PROPOSED METHOD

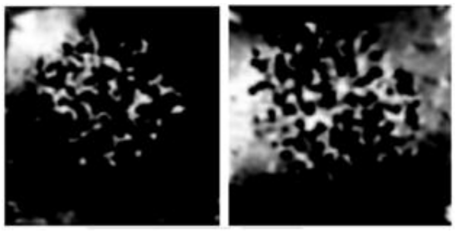
The images of $sin2\theta(x,y)$ and $cos2\theta(x,y)$ of normal and altered FP is shown in Fig.1. Comparison of these images shows that the alteration process introduced more irregularity or discontinuity. These images are decomposed using orthogonal wavelet and energy of the approximation and detailed coefficients are compared. This comparison is made on number of images and the result reveals that the energy of the detailed coefficients of $sin2\theta(x,y)$ and $cos2\theta(x,y)$ of altered FP is higher than that of normal FP while energy of approximation coefficients of $sin2\theta(x,y)$ and $cos2\theta(x,y)$ of altered FP is less than that of normal FP. This suggests that alteration increases high frequency components or irregularity in the real and imaginary part of complex function. Thus the sum of detailed coefficients in Eq.(4) can be taken as error function $e(x,y)$. Accordingly Eq.(4) becomes,

$$f(x,y) = e(x,y) + A_k \quad (8)$$

where, $e(x,y)$ is the sum of detailed coefficients ($e(x,y) = d_1 + d_2 + d_3 + \ldots\ldots + d_k$). The Eq.(8) is similar to Eq.(2).

(a) Normal fingerprint and its altered mate

(b) $sin2\theta(x,y)$ and $cos2\theta(x,y)$ of normal FP



(c) $sin2\theta(x,y)$ and $cos2\theta(x,y)$ of altered FP

Fig.1. $sin2\theta(x,y)$ and $cos2\theta(x,y)$ of normal and altered FP

To make $f(x,y)$ equal to the approximated function, $e(x,y)$ is taken as zero. Thus the real and imaginary part of complex function can be reconstructed from the approximation coefficients by keeping the detailed coefficients to zero at every stage. The proposed method of orientation reconstruction of altered FP is shown in Fig.2.

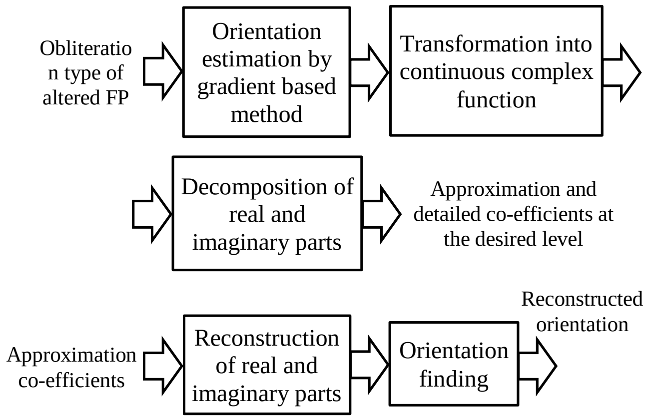
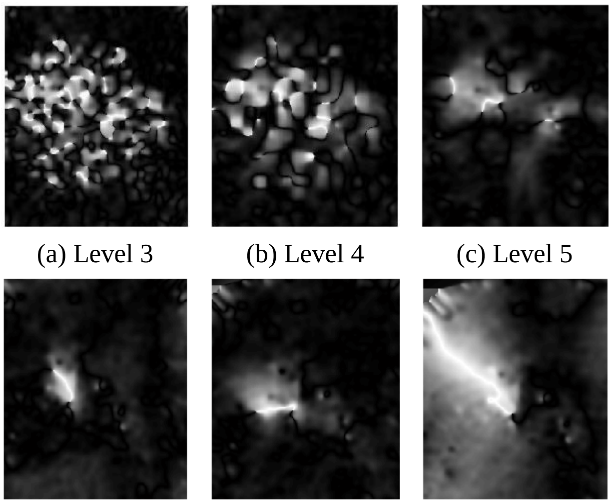


Fig.2. Block diagram of the proposed method

3.1 SELECTION OF LEVEL OF DECOMPOSITION

The selection of level of decomposition depends upon whether the image is smoother or not. If the irregularity present in the image is higher, level of decomposition to decay the detailed coefficients is increased. More smoother the function $f(x,y)$, then faster the decay of detailed coefficients. The comparison of Fig.1(b) and Fig.1(c) shows that the images of real and imaginary part of altered FP contains more irregularity and the level of decomposition also increase. In order to select the correct level of decomposition, ridge orientation difference (R.O.D) is computed.



(a) Level 3 (b) Level 4 (c) Level 5

(d) Level 6 (e) Level 7 (f) Level 8

Fig.3. R.O.D map of FPs reconstructed from different levels of decomposition

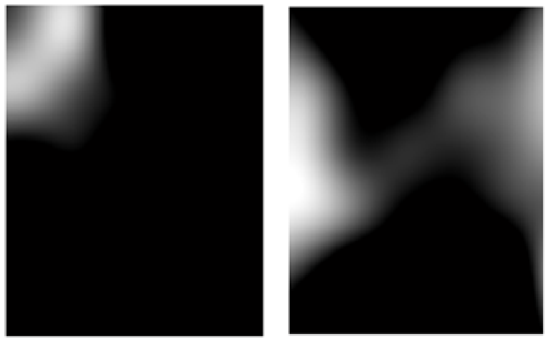
The ridge orientation difference is defined as difference between reconstructed ridge orientation of altered FP and ridge orientation of its unaltered mates and is found using the equation given below.

$$R.O.D = \min\left(\begin{matrix} |\theta_{un}(i,j) - \theta_{rec}(i,j)|, \\ \pi - |\theta_{un}(i,j) - \theta_{rec}(i,j)| \end{matrix}\right) \Big/ \pi/2 \qquad (9)$$

where, $\theta_{un}(i,j)$ is the orientation of unaltered mate and $\theta_{rec}(i,j)$ is the reconstructed orientation.

The ridge orientation difference map has been used as a feature to detect altered fingerprints or to differentiate altered fingerprint from normal ones [2],[5] and [6]. The Fig.3 shows the ridge orientation difference map for different levels of decomposition. From the figure, it is clear that as the levels of decomposition increases R.O.D decreases up to level 6 and then again it increases. At 7th and 8th levels of decomposition, ridge orientation difference is increasing because of the fact that necessary information for reconstruction is lost. Since 6 levels of decomposition produces the minimum R.O.D, it is selected as optimum level of decomposition for this study.

The Fig.4(a) and Fig.4(b) shows the reconstructed $sin2\theta(x,y)$ and $cos2\theta(x,y)$ using 6 levels of decomposition and reconstruction by keeping the detailed coefficients zero at every levels. This is almost same as the $sin2\theta(x,y)$ and $cos2\theta(x,y)$ of unaltered mate shown in Fig.1(b).



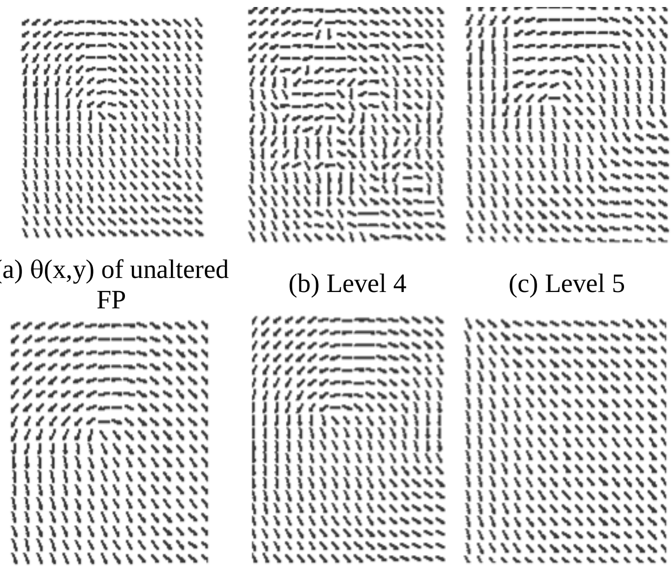
(a) (b)

Fig.4. Reconstructed $sin2\theta(x,y)$ and $cos2\theta(x,y)$

4. RESULTS AND DISCUSSIONS

An altered FP database consisting of real and synthetically altered FPs are used for the experiments. Real altered FP is obtained from NIST SD14 database. Normal fingerprints obtained from FVC 2000 and FVC 2004 database is used for creating synthetically altered fingerprints. Each group in this database consists of 8 impressions of 10 fingers and are captured by optical and capacitive sensors. The resolution of each fingerprint is 500dpi. The normal fingerprints obtained from FVC 2000 and 2004 database are divided into good quality, dry and wet images by subjective assessment. These low quality images are also used for experiments. Synthetically altered obliteration of different area is created by forming scar and scratches in the image.

The Fig.5 shows the reconstructed orientation of altered FP given in Fig.1(b) at different levels of decomposition. The Fig.5(a) shows the orientation of unaltered mate in Fig.1(a). The figure clearly shows that the approximated orientation at level 6 is same as that of its unaltered mate. Daubchies wavelet db5 is used for reconstruction.



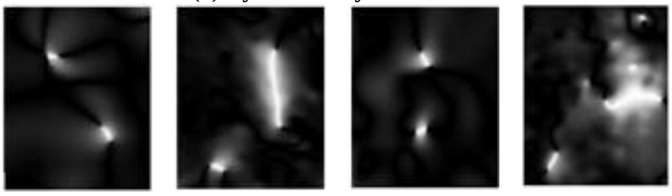
(a) θ(x,y) of unaltered FP (b) Level 4 (c) Level 5

(d) Level 6 (e) Level 7 (f) Level 8

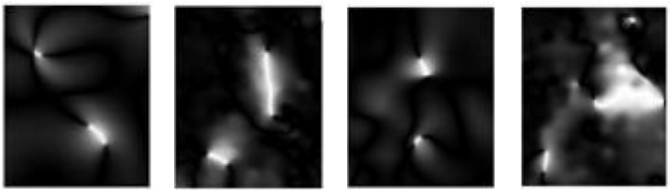
Fig.5. Orientation of unaltered mate and reconstructed orientation of altered FP at different levels of decomposition

4.1 COMPARISON OF ORTHOGONAL WAVELET

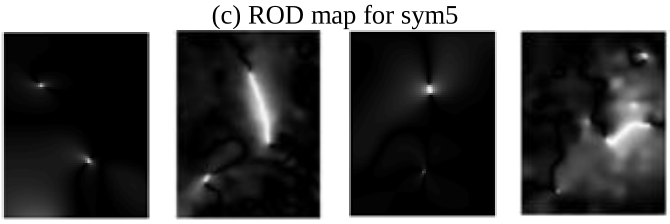
(a) Synthetically altered FP



(b) ROD map for db5



(c) ROD map for sym5



(d) ROD map for coif5

Fig.6. ROD map for different wavelets

Performance of Daubichies (db5), Symlet (sym5) and Coiflet (coif5) wavelets on ridge orientation approximation is compared based on ROD map. Orientation field at the core and delta is irregular or more curved in nature as compared to other regions. It is found from ROD map analysis that Coiflet have better performance at the singular points than Daubichies and Symlet wavelets. This is because coif5 have short duration as compared to other two wavelets. The Fig.6(d) shows the ROD map for Coiflet5 and it is clear that the error present at the singular points especially at delta point is minimum as compared to db5 and sym5. Thus Coiflet5 is chosen for orientation reconstruction of altered FP.

4.2 RECONSTRUCTED ORIENTATION OF ALTERED FP

The Fig.7 and Fig.8 shows the approximated ridge orientation field by the proposed method on both scar and mutilated type of altered fingerprints. Coiflet wavelet with $N = 5$ is used for reconstruction. Performance of the method is good at the altered region.

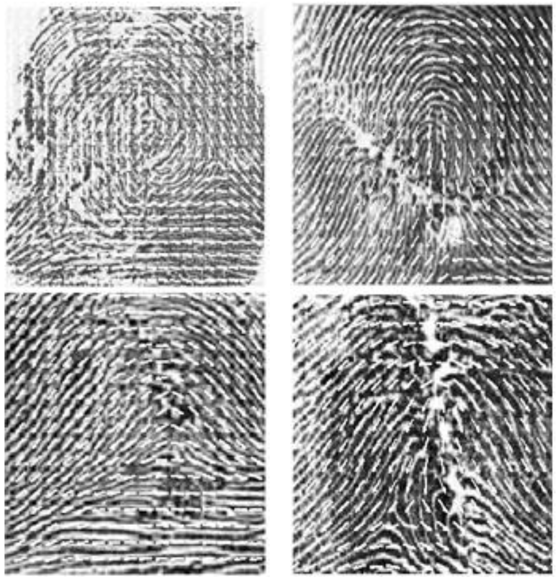


Fig.7. Reconstructed orientation of mutilation scar type of altered FP

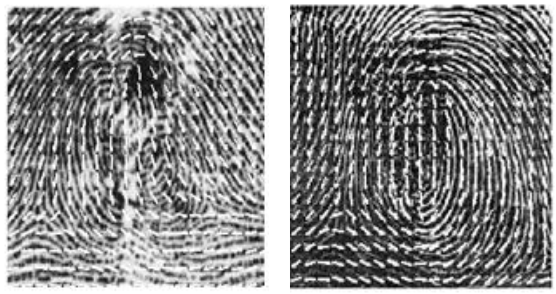


Fig.8. Reconstructed orientation of altered FP

4.3 ORIENTATION OF LOW QUALITY IMAGES

Fingerprint images become low quality due to various reasons such as pressure applied by the individual on the scanner, non-linear distortions, noise, and aging of the people and skin diseases. Orientation estimation with normal gradient based method fails in low quality images. Dry images have absence of ridges and valleys and wet images do not have well separated ridges and valleys. The Fig.9 shows the reconstructed ridge orientation by the proposed method on dry and wet image. These dry and wet images are obtained from FVC2004 database. The Fig.10 and Fig.11 shows the orientation estimated by proposed method in noisy and low quality fingerprint images obtained from FVC2004 DB3 and DB4 database.

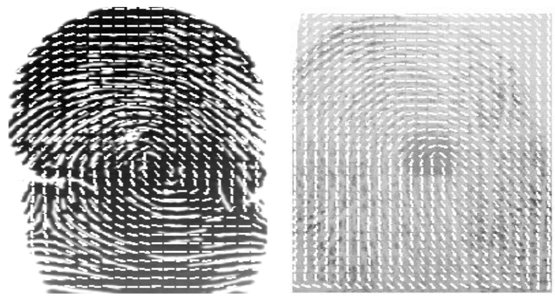


Fig.9. Reconstructed orientation of wet and dry images

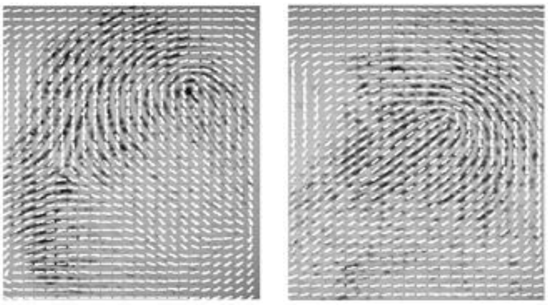


Fig.10. Reconstructed orientation of noisy images

Fig.11. Low quality images

4.4 COMPARISON

Wavelet transform based method is compared with polynomial method proposed by Jain and S. Yoon in [2]. The comparison is done based on matching performance of both the methods on synthetically altered fingerprints created from FVC 2004 and casia database. Matching score based on ridge orientation is computed as follows [18]. Let the reconstructed orientation of altered FP and orientation of its unaltered mates are denoted as A and B respectively. Take 'Ω' as the common area of intersection from two orientation fields and N as the total number of points in Ω. Then matching score between two orientation fields A and B is computed as follows.

$$s(A,B)=\frac{1}{N}\sum_{(i,j)\in\Omega}\delta(i,j) \tag{10}$$

In Eq.(9), $\delta(i,j)$ is the difference between the orientation values at the point, (i,j) in A and B which is given as,

$$\delta(i,j) = \delta_0(i,j), \text{ if } \delta_0(i,j) \leq \pi/2 \tag{11}$$

$$\delta(i,j) = \pi - \delta_0(i,j), \text{ otherwise} \tag{12}$$

and $\delta_0(i,j)$ is defined as,

$$\delta_0(i,j) = |\theta_A(i,j) - \theta_B(i,j)| \tag{13}$$

where, $\theta_A(i,j)$ and $\theta_B(i,j)$ are the direction of point, (i,j) in image A and B. If the matching score $s(A,B)$ is higher than a certain threshold, two orientation fields are said to be matched. Matching is considered as successful one when the score $s(A,B)$ is less than a threshold of 0.22. Receiver Operating Characteristics (ROC) curve is plotted between Genuine Acceptance Rate (GAR) and False Acceptance Rate(FAR) for the matching scores obtained as shown in Fig.12.

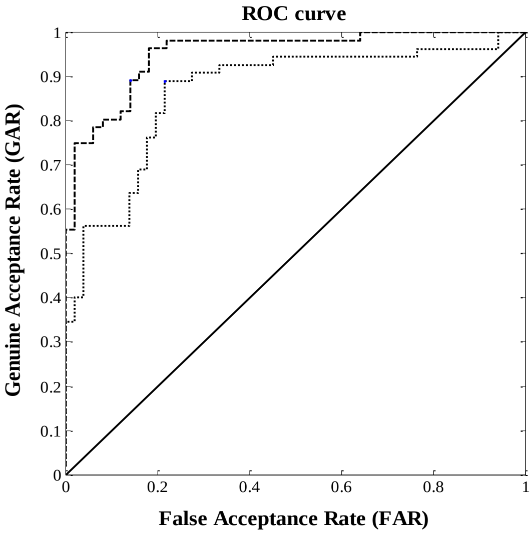


Fig.12. ROC curve of the comparison. Curve on top and bottom in the graph shows proposed method and polynomial method respectively

5. CONCLUSION

This paper presents a method to find ridge orientation field of altered and low quality fingerprint images using wavelet transform. The ridge orientation is transformed into a continuous complex function a real and imaginary parts are decomposed using wavelet transform and reconstructed using approximation coefficients alone. This approximated a real and imaginary part is used to reconstruct the altered FP. The method produced good results on obliteration type of synthetic and real altered fingerprints and low quality FP images. Comparison of the proposed method with polynomial based method is also performed.

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