Fingerprint reference point detection for image retrieval based on symmetry and variation

Article *in* Pattern Recognition · September 2012
DOI: 10.1016/j.patcog.2012.02.017

2 authors:

Thai Hoang Le
VNU-HCM University of Science
65 PUBLICATIONS **397** CITATIONS

Thien Hoang Van
Ho Chi Minh City University of Technology (HUTECH)
14 PUBLICATIONS **89** CITATIONS

XML-IS

Our reference: PR 4412 P-authorquery-vx

AUTHOR QUERY FORM

ELSEVIER	**Journal: PR** **Article Number: 4412**	**Please e-mail or fax your responses and any corrections to:** **E-mail: corrections.eseo@elsevier.macipd.com** **Fax: +44 1392 285878**

Dear Author,

Please check your proof carefully and mark all corrections at the appropriate place in the proof (e.g., by using on-screen annotation in the PDF file) or compile them in a separate list. Note: if you opt to annotate the file with software other than Adobe Reader then please also highlight the appropriate place in the PDF file. To ensure fast publication of your paper please return your corrections within 48 hours.

For correction or revision of any artwork, please consult http://www.elsevier.com/artworkinstructions.

Any queries or remarks that have arisen during the processing of your manuscript are listed below and highlighted by flags in the proof. Click on the Q link to go to the location in the proof.

Location in article	**Query / Remark: click on the Q link to go** **Please insert your reply or correction at the corresponding line in the proof**
Q1	Please confirm that given names and surnames have been identified correctly.
Q2	References given here were noted in the reference list but are missing from the text – please position each reference in the text or delete it from the list.
Q3	Please note that Figs. 2 and 11 were not cited in the text. Please check that the citations suggested by the copyeditor are in the appropriate place, and correct if necessary.
Q4	Please check whether the designated corresponding author is correct, and amend if necessary.

Thank you for your assistance.

Pattern Recognition ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at SciVerse ScienceDirect

Pattern Recognition

journal homepage: www.elsevier.com/locate/pr

Highlights

Pattern Recognition ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Fingerprint reference point detection for image retrieval based on symmetry and variation

Q1 Thai Hoang Le [a], Hoang Thien Van [b]

[a] Department of Computer Science, Ho Chi Minh City University of Natural Science, Ho Chi Minh City, Vietnam
[b] Department of Computer Science, Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam

► A novel reference point detection algorithm is proposed for fingerprint retrieval. ► A semi-radial symmetry filter can detect rotational symmetries of core points. ► VORIV describes the vertical orientation variation of neighborhood blocks. ► VORIV provides more discriminating features of convex core points. ► The Variation and Symmetry Combined Energy of the reference point is global maximum.

doi:10.1016/j.patcog.2012.02.017

Pattern Recognition ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at SciVerse ScienceDirect

Pattern Recognition

journal homepage: www.elsevier.com/locate/pr

Fingerprint reference point detection for image retrieval based on symmetry and variation

Thai Hoang Le [a,*], Hoang Thien Van [b]

[a] Department of Computer Science, Ho Chi Minh City University of Natural Science, Ho Chi Minh City, Vietnam
[b] Department of Computer Science, Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam

A R T I C L E I N F O

Article history:
Received 31 August 2011
Received in revised form
29 December 2011
Accepted 21 February 2012

Keywords:
Fingerprint recognition
Reference point
Orientation consistency
Rotational symmetry

A B S T R A C T

Reference point plays an important role in fingerprint identification systems. The reference point is widely used for the fingerprint retrieval in large-scale databases. This paper proposes a novel algorithm for detecting a convex core point as a unique reference point consistently and accurately for all types of fingerprints. In order to detect robust core point candidates, a modified complex filter, called semi-radial symmetry filter, is proposed to detect correctly rotational symmetries of core points. Moreover, a vertical orientation variation feature, called VORIV feature, is proposed to remove spurious core points and concave core points. Therefore, the proposed technique computes the Variation and Symmetry Combined Energy (VSCOME). Then, the reference point is located by searching the global VSCOME maximum. The experimental results on the public database (FVC2004 DB1 set A) show that the proposed technique exhibits a very high robustness and gets the best performance in comparing with other approaches in literature.

1. Introduction

Fingerprint is increasingly being used for personal recognition in commercial, civilian and financial domains because of its uniqueness and immutability. Generally, there are two kinds of features for fingerprint recognition: global features like the special ridge flow pattern and local features like minutiae. At global level, there are unique landmarks of fingerprints, where the ridge curvature is higher than other areas and the orientation changes rapidly. They are commonly known as singular points. Typically, there are two types of singular points: core points (concave core points and convex core points) and delta points (see Fig. 1(a)). A core point locating on the convex curving ridge (see Fig. 1(c)) is called convex core point, or locates on the concave curving ridge (see Fig. 1(d)) is called concave core point. We can identify easily these points because of its special symmetry properties. They are used to align between the reference and the unknown fingerprint. In fingerprint identification systems, these points have played important roles in most fingerprint classification algorithms [1–5] and fingerprint matching algorithms [7–9,24,25]. In order to extract fingerprint features for fingerprint retrieval in large-scale databases, a reference point is widely used. The reference point is commonly located based on the singular points. The quality of the acquired fingerprint is poor. Moreover, the number of core and delta points differs in different types of fingerprints [1,10]. Therefore, how to efficiently detect a unique reference point consistently for all types of fingerprints is a great challenge. Many approaches of singular point extraction and reference point detection found in the literatures have been reviewed for optimization, such as Poincaré index based technique, Sine-map-based technique, Orientation-consistency-based technique, Complex filter technique and others. Most of them operate on the fingerprint block-orientation field.

The Poincaré Index (PI) based method is one of the conventional singular point detection methods [1,5,7,14,28]. This method calculates the total rotation of a vector along a closed curve in orientation field to judge whether it exists a singular point. This method is efficient, but it is sensitive to noise as the orientation deviation caused by noise will affect the computation of PI, especially when the direction change is near $\pi/2$ or $-\pi/2$ [10,14,17]. This method can locate core and delta points [28]; however, it cannot distinguish between convex core and concave core points. Jain et al. [7] proposed the Poincaré Index based method to locate the core point as reference point. This technique is still not overcome the limitation of the computation of PI.

Sine-map-based technique was proposed by Jain et al. [8] for detecting the reference point. This approach locates a convex core points as a reference point based on multiple resolution analysis of the differences of sine component integration between two

* Corresponding author. Tel.: +84 83 8497225; fax: +84 8 8301 334.
E-mail addresses: lhthai@fit.hcmus.edu.vn (T.H. Le), vthoang@hcmhutech.edu.vn (H.T. Van).

0031-3203/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.patcog.2012.02.017

Please cite this article as: T.H. Le, H.T. Van, Fingerprint reference point detection for image retrieval based on symmetry and variation, Pattern Recognition (2012), doi:10.1016/j.patcog.2012.02.017

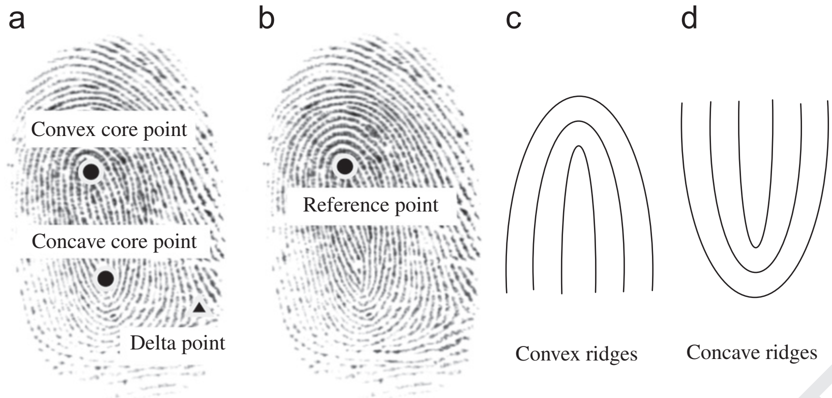

Fig. 1. (a) Core point and Delta point. (b) Reference point with maximum curvature on the convex ridge. (c) Convex ridges. (d) Concave ridges.

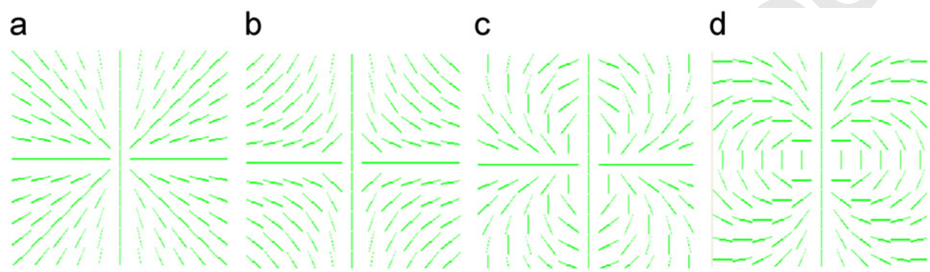

Fig. 2. The orientation field image of model: (a) $z(1)$, (b) $z(-1)$, (c) $z(-2)$, and (d) our model $z(m,k)=\exp\{im\phi^k\}$ with $z(-2,-1)$.

defined regions of the orientation field. This method is robust to against noise; however the pre-defined semicircular mask makes it difficult to detect the reference points near the image border and accurately locate the reference points of the rotated fingerprint images.

Liu et al. [10] proposed an orientation consistency-based method, in which the reference point localization is based on multi-scale analysis of the orientation consistency to search the local minimum. This method is very efficient for delta point and core point detection by applying orientation consistency analysis. However, the performance of this method severely depends on the orientation field estimation. In addition, its limitation is the way to filter delta point based on analysis of curvature direction. Van and Le [18] proposed the improved version for detecting reference point based on computing the convex orientation consistency. All the methods [10,18] used the curvature based technique [13] to remove delta points and concave core points. However, the computed curvature can be unreliable measure in some cases.

In complex filter methods, symmetry properties have been used for singular point detection [13,15]. In this method, two complex filters are suggested that detect rotational symmetries for core points and delta points. The filtering was applied to complex images associated with the orientation tensor field [18] in different scales. This method has the advantage of being able to extract the position of core point and delta point. However, there are two disadvantages: (1) that the core-type filter cannot detect correctly the core point in plain arch fingerprints, and (2) that the singular points to be used as reference points cannot be located in fingerprint images without enough strong filter responses, especially the double-core fingerprint images.

Other approaches utilize various techniques such as orientation curvature [13,16,17], template model matching [29], and pixel-wised orientation field based-approaches [11,12]. The performance of these approaches degrades when the fingerprint quality worsens.

This paper proposes the novel algorithm to locate a unique reference point based on computing the Variation and Symmetry Combined Energy (VSCOME) which describes both the vertical orientation variation features and rotational symmetry features. The reference point is defined as the point with maximum VSCOME value, which is the convex core point located in the central area of fingerprint (see Fig. 1(b) and (c)). The main contributions of this paper consist of the following aspects: (1) A new complex filter is proposed for core point detection which tends to be more reliable than the parabolic symmetry filter; (2) A Vertical ORIentation Variation (VORIV) measure is proposed for detecting the convex core point and removing concave core points and spurious detections which can be robust to noise. The performance of our approach on the public database FVC2004 DB1 set A shows that our proposed method is accurate and robust for a wide variety of fingerprint types in comparing with other approaches in literature.

In the following sections, our proposed algorithms of reference point detection are presented in detail. In Section 2, the proposed semi-radial symmetry filter for core point detection is presented. Section 3 describes the VORIV feature for detecting the convex core points. Section 4 discusses how to select the unique core point as reference point. The experimental results are presented in Section 5. Finally, our conclusion work and future work are drawn in Section 6.

2. Semi-radial symmetry filter for core point detection

The complex filter [15] is very efficient in detecting singular points. Complex filters, of order m, for detection of patterns with radial symmetries are modeled by $z(m)=\exp\{im\phi\}$ [15,19]. A polynomial approximation of these fields in Gaussian windows yields $(x+iy)^m g(x,y)$ where g is a Gaussian defined as the formula:

$$g(x,y,\sigma)=\exp\left\{-\frac{x^2+y^2}{2\sigma^2}\right\}, \tag{1}$$

Please cite this article as: T.H. Le, H.T. Van, Fingerprint reference point detection for image retrieval based on symmetry and variation, Pattern Recognition (2012), doi:10.1016/j.patcog.2012.02.017

These filters are applied to the complex valued orientation tensor field image $f(x,y)=(f_x+if_y)^2$. Here, f_x is the derivative of the original image in the x-direction and f_y is the derivative in the
Q3 y-direction (Fig. 2).

For fingerprint, the orientation of each pixel is the double angle of the gradient vector, in order to avoid an ambiguity of deciding the orientation as either θ or $\theta+\pi$. The squared gradient can be expressed in complex number by

$$f=(G_x+iG_y)^2=(G_x^2-G_y^2)+i(2G_xG_y), \tag{2}$$

$$\bar{f}=\cos(2\theta)+i\sin(2\theta) \tag{3}$$

where $i=\sqrt{-1}$; G_x and G_y denote the gradients of the original fingerprint image in the x and y direction, respectively; f is called the complex image; $\bar{f}$ is the normalized complex image.

In order to detect the core point, the filter of parabolic symmetry [15] are used as

$$h_1(x,y)=z(1)g(x,y)=(x+iy)g(x,y). \tag{4}$$

The filter is implemented by compute the 2-D scalar product for each image point of complex image $\bar{f}$. In order to robust to again noise, the block-orientations are used to replace the pixel-orientations. The radial symmetry of each block image (u,v) is computed as the following formulas:

$$\mathrm{sym}_1(u,v)=\frac{1}{M}\sqrt{F_x(u,v)^2+F_y(u,v)^2}, \tag{5}$$

$$F_x(u,v)=\sum_{x=-(w_{s1}/2)}^{w_{s1}/2}\sum_{y=-(w_{s1}/2)}^{w_{s1}/2} g(x,y,\sigma_c)(\bar{x}\cos(2\theta(u+y,v+x)) -\bar{y}\sin(2\theta(u+y,v+x))), \tag{6}$$

$$F_y(u,v)=\sum_{x=-(w_{s1}/2)}^{w_{s1}/2}\sum_{y=-(w_{s1}/2)}^{w_{s1}/2} g(x,y,\sigma_c)(\bar{y}\cos(2\theta(u+y,v+x)) +\bar{x}\sin(2\theta(u+y,v+x))), \tag{7}$$

$$\bar{x}=\frac{x}{\sqrt{x^2+y^2}},\quad \bar{y}=\frac{y}{\sqrt{x^2+y^2}}, \tag{8}$$

where M is the number of the block orientations using in the filter, and w_{s1} specifies the size of the filter h_1. Fig. 3 presents the results of the parabolic filter. The range of the symmetry values is [0,1] ([0,0.6] in our experiments). This symmetry value can isolate the core point in the fingerprint image.

When we analysis the topological properties of fingerprint orientation field structures, the orientation pattern of core point or delta-point is similar to the orientation pattern of $z(1)$ or $z(-1)$, respectively. However, the orientation pattern of the plain arch fingerprint image is similar to $z(1)$ with positive plane ($x>0$, $y>0$) and is similar to $z(-1)$ with negative plane ($x<0$, $y<0$), so the values of filter with $z(1)$ or $z(-1)$ in core point areas are small and are nearly equal to in other areas. Moreover, the orientation pattern of $z(1)$ with positive plane is nearly similar to these of core point areas. Fig. 4 illustrates all these cases.

Therefore, a novel symmetry model $z(m,k)=\exp\{im\phi^k\}$ is used to capture the new type of orientation field structure. The complex filter $z(-2,-1)g(x,y)$ with negative plane ($x<0$, $y<0$), called semi-radial symmetry filter, is proposed to locate more correctly core points of all fingerprint types (see Fig. 5). The filter is denoted in Eq. (7).

$$h_2(x,y)=z(-2,-1)g(x,y)=(2xy+i(x^2-y^2))g(x,y),\quad x<0,y<0, \tag{9}$$

The semi-radial symmetry value of each block image (u,v) is computed as follows:

$$\mathrm{sym}_2(u,v)=\frac{1}{m}\sqrt{F_x(u,v)^2+F_y(u,v)^2}, \tag{10}$$

$$F_x(u,v)=\sum_{x=-(w_{s2}/2)}^{w_{s2}/2}\sum_{y=-(w_{s2}/2)}^{w_{s2}/2} g(x,y,\sigma_c)(\bar{x}\cos(2\theta(u+y,v+x)) -\bar{y}\sin(2\theta(u+y,v+x))), \tag{11}$$

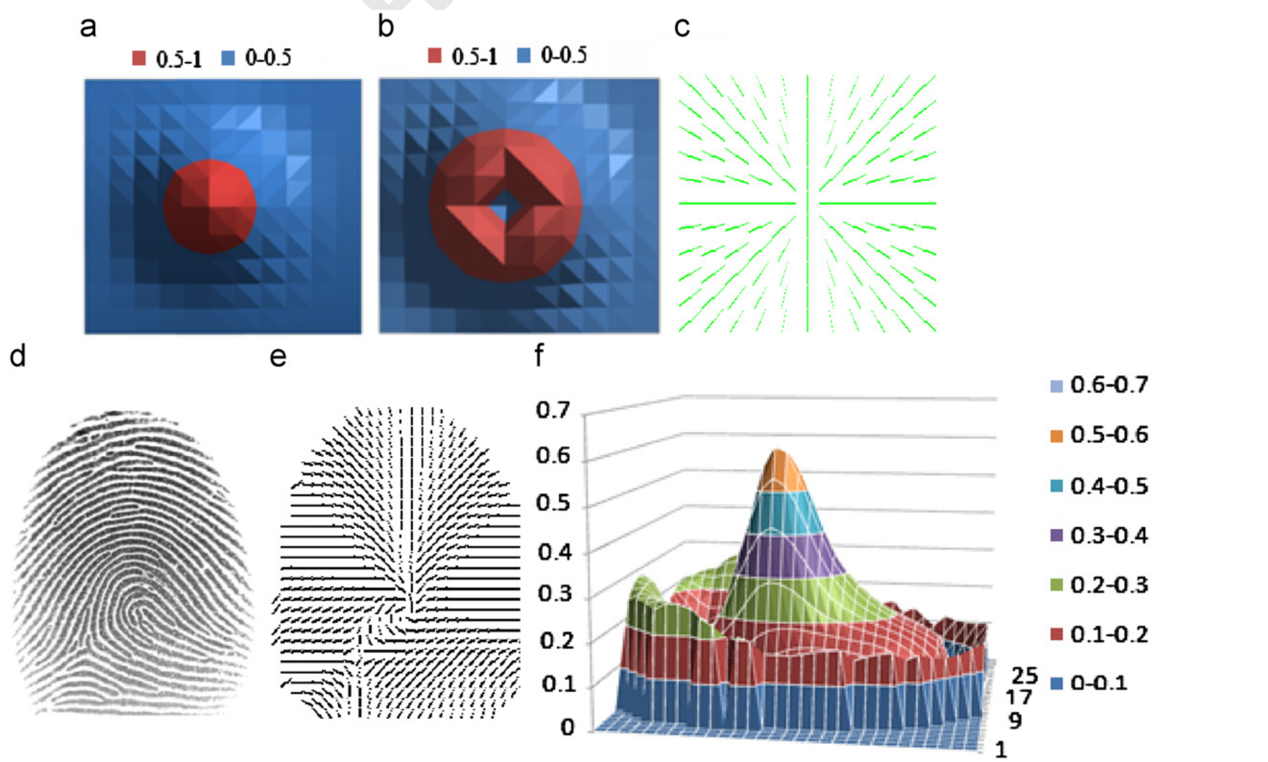

Fig. 3. (a) Magnitude image of Gaussian filter, (b) magnitude image of filter h_1, (c) the orientation field image of filter h_1, (d) the squared orientation field image, and (e) the symmetry value image.

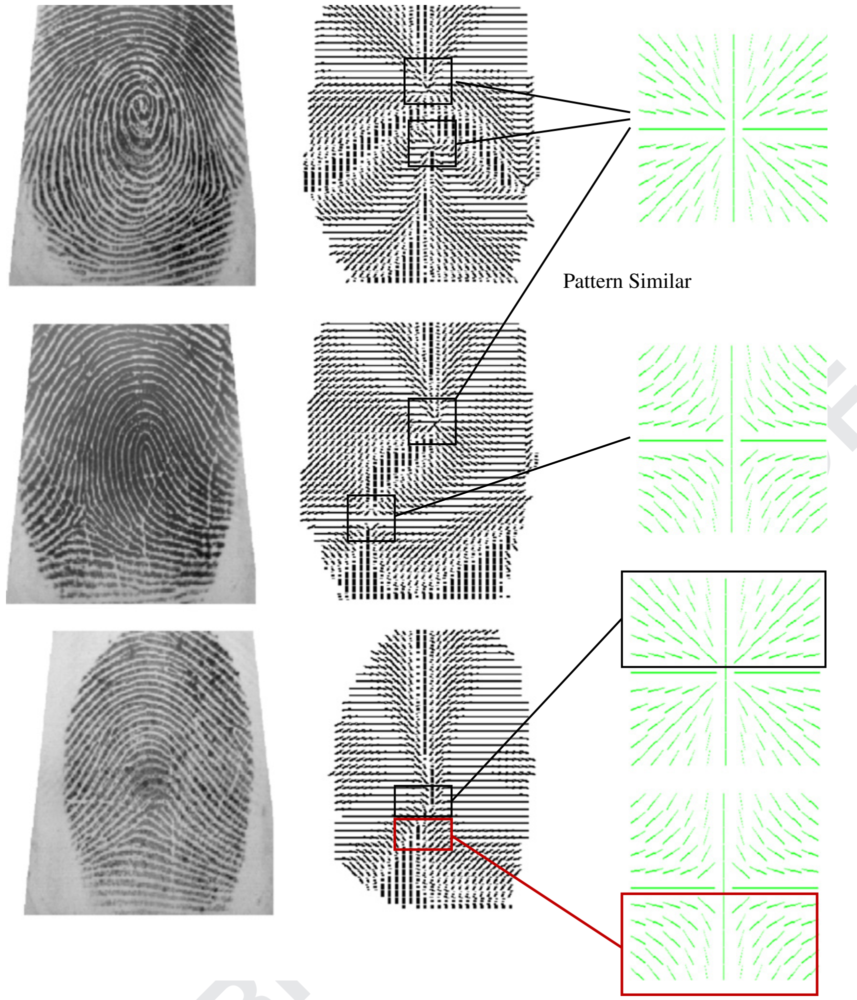

Fig. 4. The similar of orientation pattern between $z(1)$ and core point areas or between $z(-1)$ and delta-point areas.

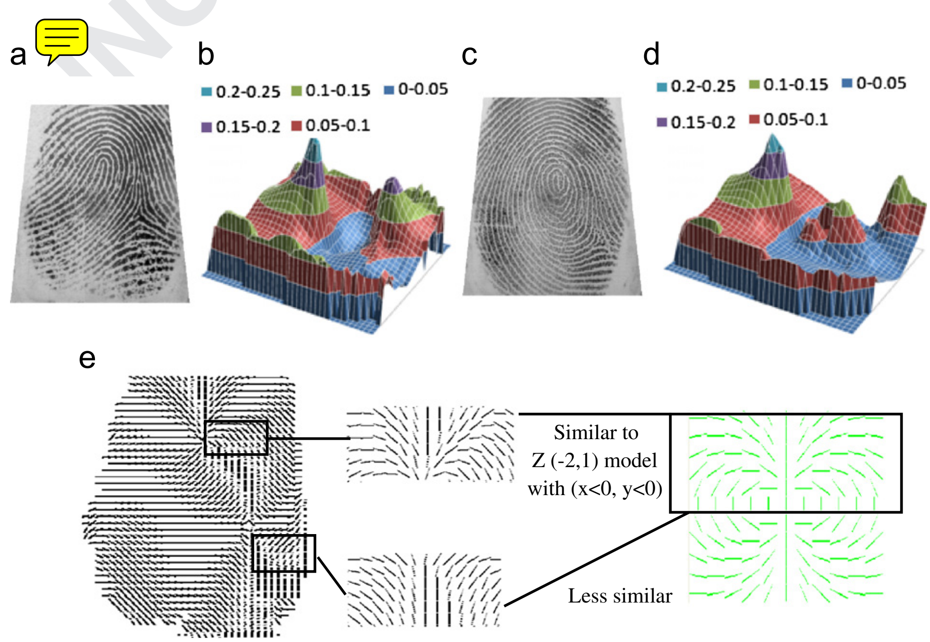

Fig. 5. The results of filter h_2: (a), (c) original fingerprint images and (b), (d) the symmetry value images of (a) and (d), respectively. (e) The comparison of the similar between convex core point and $z(-2,-1)$ with the similar between delta point and $z(-2,-1)$.

$$F_y(u,v)=\sum_{x=-(w_{s2}/2)}^{w_{s2}/2}\sum_{y=-(w_{s2}/2)}^{w_{s2}/2} g(x,y,\sigma_c)(\bar{y}\cos(2\theta(u+y,v+x)) +\bar{x}\sin(2\theta(u+y,v+x))), \tag{12}$$

$$\bar{x}=\frac{2xy}{\sqrt{x^2+y^2}},\quad \bar{y}=\frac{x^2-y^2}{\sqrt{x^2+y^2}},\quad x<0,y<0, \tag{13}$$

where m is the number of the block orientations using in the filter, and w_{s2} specifies the size of the filter h_2. The range of the semi-radial symmetry (SRS) values is [0,1]. The SRS values of core point areas are always higher than that of others.

If the fingerprint images have both core points and delta points, all the SRS values of core points are higher than all that of delta points because all the orientation pattern of core point areas is always more similar to $z(-2,-1)$ model than all that of delta point areas (see Fig. 5(b), (d) and (e)). Moreover, Fig. 6 points out that the filter h_2 is more robust than the parabolic filter h_1 in plain-arch fingerprint images. In our experiments, the range of the SRS values of these core points is (0.2,0.3] and the range of the SRS values of these delta points is [0.1,0.2); the SRS of core points in a fingerprint image are always greater than 0.05 that of delta points in the same fingerprint image. Therefore, the filter h_2 can detect core points in all types of fingerprint images.

3. VORIV feature for removing spurious core points

The Poincaré Index based method is one of the conventional singular point detection methods [1,5,7,14,28]. The PI method can represent the topological structure of singular points and is robust to against noise. In this section, we propose a novel feature extended from the Poincare' Index which describes the vertical

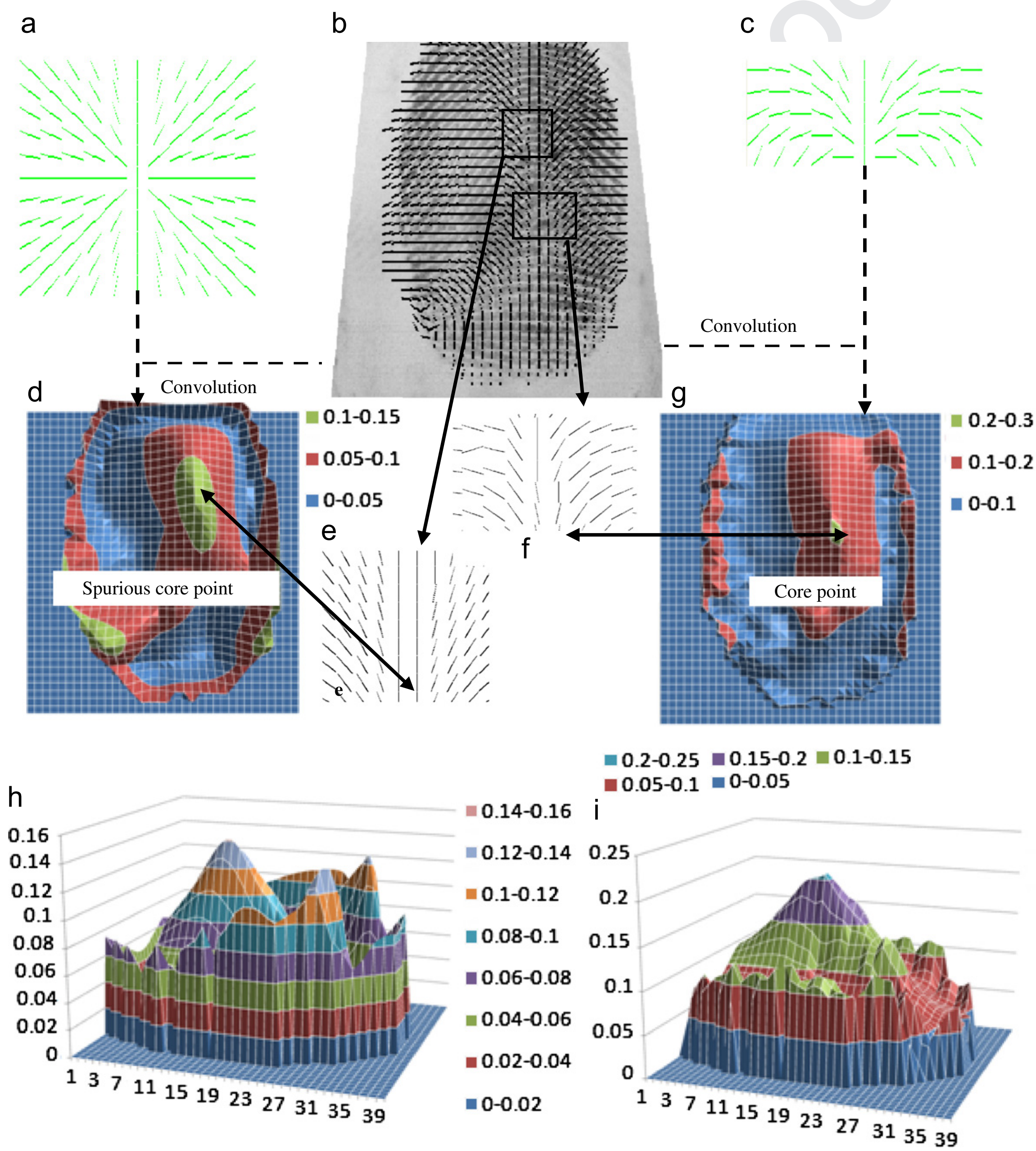

Fig. 6. The comparative results of core point location between h_1 and h_2: (a) the parabolic filter h_1; (b) the original image with the squared orientation field; (c) the proposed filter h_2; the symmetry value images (d), (h) with h_1, and (g), (i) with h_2, respectively; The orientation patterns are the same with the patterns of (e) the filter h_1, (f) the filter h_2, respectively.

Please cite this article as: T.H. Le, H.T. Van, Fingerprint reference point detection for image retrieval based on symmetry and variation, Pattern Recognition (2012), doi:10.1016/j.patcog.2012.02.017

orientation variation of neighborhood blocks and provides more discriminating features of convex core points to removing the concave core points and spurious core points.

3.1. Poincare' index background

Definition 1. [28] Let $V(x,y)=p(x,y)+i\cdot q(x,y)$ be a continuous 2D vector field. Then, Poincare' Index of $V(x,y)$ along an arbitrary simple closed path γ is defined as

$$I(\gamma)=\frac{1}{2\pi}\int_{(x,y)\in\gamma} \mathrm{d}\phi(x,y), \tag{14}$$

where $\phi(x,y)=\arg V(x,y)$ is the angle at point (x,y) and $\phi\in[0,2\pi)$. The integration is taken counterclockwise along γ.

The Poincare' Index is always an integer. By computing I along a simple closed circle around a point P, one can find whether P is a singular point ($I\neq 0$) or a common point ($I=0$).

3.2. VORIV feature

With the structure properties of singular points and the Poincare' Index, a Vertical ORIentation Variation feature, called VORIV feature, is proposed to measure the variation properties of singular point types.

Definition 2. The VORIV feature is the sum of the orientation differences of the set of sampled points belonged to the vertical line and picked from up to down (see Fig. 7(a)). For a given point P, let $\theta=\{\theta_1,\ldots,\theta_{N-1}\}$ be the orientation set of sample points belonged to the vertical line l. The VORIV value of point P with the line l is computed as follows:

$$\mathrm{VORIV}_P(l)=\frac{1}{\pi}\sum_{i=1}^{N-1} f(\theta_{i+1}-\theta_i) \tag{15}$$

where function f is defined as

$$f(x)=\begin{cases} x, & |x|\le \frac{\pi}{2} \\ \pi-x, & x>\frac{\pi}{2} \\ \pi+x, & x<-\frac{\pi}{2} \end{cases} \tag{16}$$

The VORIV feature has the following properties:

Property 1. VORIV value of line l is positive if $\theta_1<\theta_2<\ldots<\theta_N$.

Property 2. VORIV value of line l is negative if $\theta_1>\theta_2>\ldots>\theta_N$.

Because of the same properties of the neighborhood columns in singular areas, VORIV values are computed with many lines. In

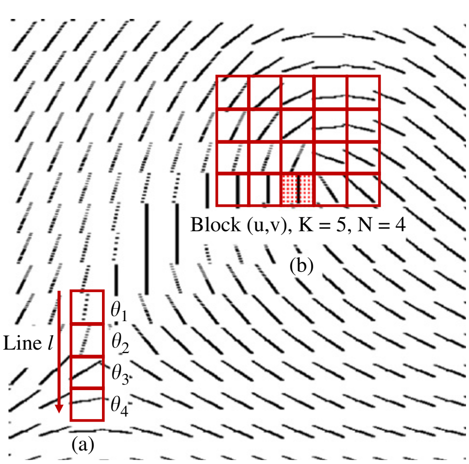

Fig. 7. (a) The set of sampled points belonged the vertical line l. (b) The K neighborhood columns of block (u,v).

Fig. 7(b), the set of K lines ($L=\{l_1,\ldots,l_{K-1}\}$) are the K neighborhood columns of block (u,v). Then, the VORIV value of block (u,v) is defined as

$$\mathrm{VORIV}(u,v)=\frac{1}{\pi}\sum_{k=-K/2}^{K/2}\sum_{i=0}^{N-1} f(\theta(u-i,v+k)-\theta(u-i-1,v+k)) \tag{17}$$

From Property 1, the VORIV values of convex core point areas are positive and are much higher than that of others in fingerprints (see Fig. 8(b), (f), and (j)). From Property 2, the VORIV values of the concave core point and delta-point areas are negative and very small in fingerprints (see Fig. 8(b) and (j)). With Property 1 and Property 2, VORIV feature is utilized to classify the convex core point, concave core point and delta point.

4. Reference point detection

There are many singular points in fingerprint images. Therefore, the Variation and Symmetry Combined Energy (VSCOME) is proposed for detecting unique a core point as a reference point. VSCOME value is defined as follows:

$$\mathrm{VSCOME}=\frac{1}{2}(\mathrm{VORIV}+\mathrm{Sym}_2) \tag{18}$$

VSCOME values are high in the convex core point areas and are small in other areas. Fig. 8(c), (g), and (k) illustrate that the VSCOME-value images remove the concave core points and delta-points of semi-redial symmetry images (see Fig. 8(a), (e) and (i)), and isolate the unique points as the reference points (see Fig. 8(d), (h) and (l)) which have the highest VSCOME value in each VSCOME images. The processing steps of the proposed algorithm for detecting reference point are summarized as follows:

1. Compute symmetry value $\mathrm{Sym}_2(i,j)$ of each block (i,j) by using formulas (1), (10)–(13).
2. Compute the value $\mathrm{VORIV}(i,j)$ of each block (i,j) with formulas (15) and (16).
3. Compute the convex curvature symmetry $\mathrm{VSCOME}(i,j)$ of each block (i,j) by applying Eq. (18).
4. Locate the block (ir,jr) with global maximum $\mathrm{VSCOME}(ir,jr)$ as the unique reference point.

5. Experimental results

The proposed algorithm has been tested on the low-quality fingerprint databases DB1 of the FVC2004, for comparison with the previous reference point detection approaches [10,15]. The FVC2004 were collected to provide a more challenging benchmark for state-of-the-art recognition systems than previous fingerprint verification competitions [26,27]. The databases were acquired using different sensor types and each of them contains eight impressions 100 fingers. The characteristics of the database are shown in Table 1. This fingerprint database contains many poor-quality fingerprints such as the partial images with the reference point left outside and the images with heavy noise like scars, ridge breaks, too wet or dry fingerprints, and so forth.

5.1. Orientation estimation

Orientation fields play important role in our reference point detection algorithm. In our method, the orientation fields of fingerprint images are first estimated by using the state-of-the-art method [21] with the flowchart described in Fig. 9. This method is robust against noise. In this method, the first level orientation fields are estimated with the block size 6×6, 12×12,

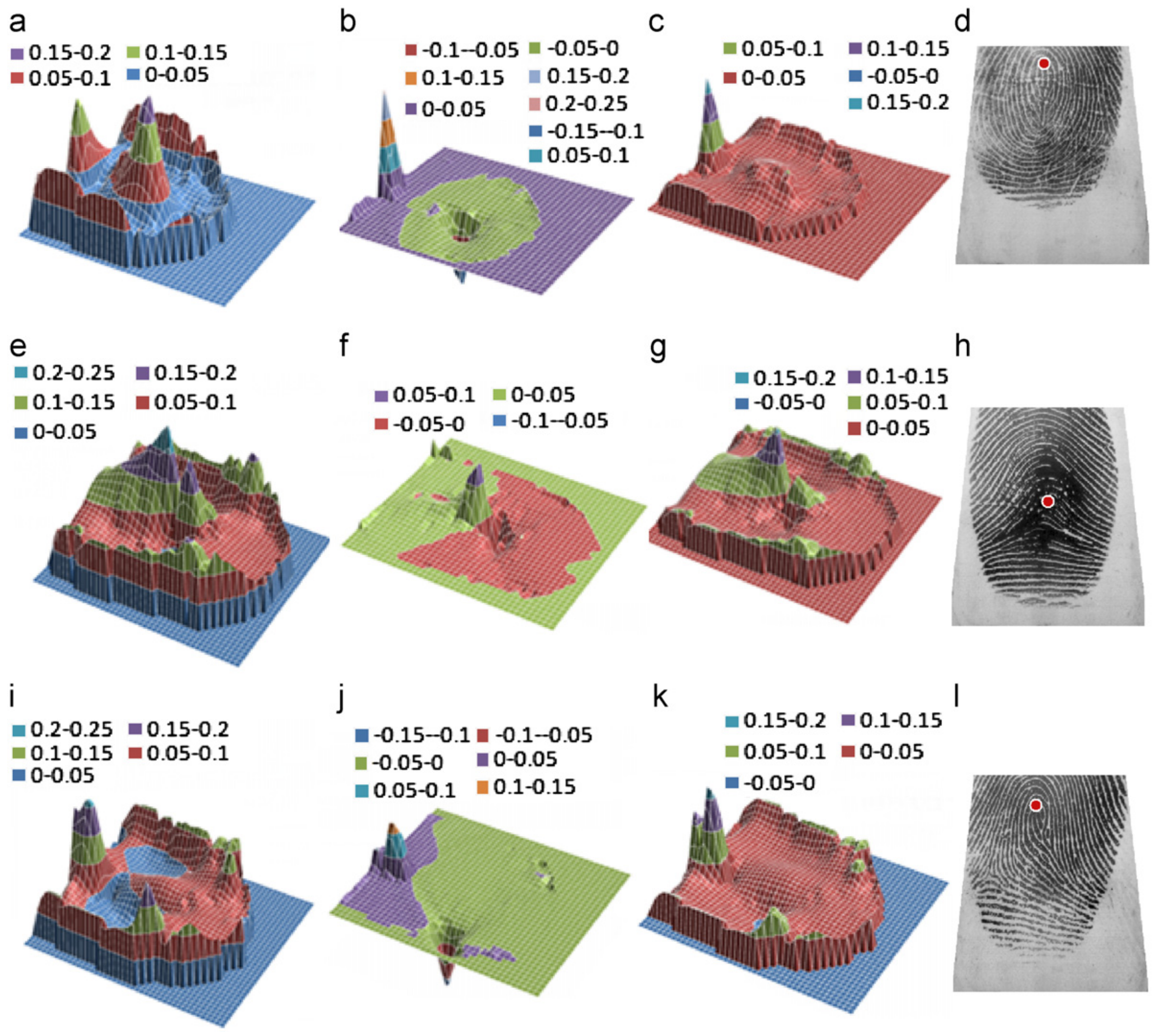

Fig. 8. The results of our proposed method: (a), (e) and (i) the semi-radial symmetry images; (b), (f) and (j) VORIV images; (c), (g), and (k) VSCOME images; (d), (h) and (l) the results of our reference point detection.

Table 1
The characteristics of database FVC 2004, DB1 set A.

Sensor type	Image resolution (dpi)	Image size	No. of images
Optical sensor "V300"	500	640 × 480	800
Arch	**Left loop**	**Right loop**	**Whorl**
120	240	248	192

18 × 18. The variance threshold for distinguihsing "smooth area" and "non-smooth areas" are 0.25 for 6 × 6 block, 0.18 for 12 × 12 block, and 0.12 for 18 × 18 block. The final orientation field with block size 6 × 6 is computed by selecting the reliable orientations of these three orientation fields based on the variance threshold. Fig. 10 shows that the orientation field is smoothed in large noise areas without destroying essential singular areas.

5.2. *Position of reference points*

Like Liu's experiments [10], the performance of our proposed method for detecting reference point is evaluated by the accuracy and consistency. First, the coordinate of each singular point was manually assigned by fingerprint experts. Then, our algorithm is used with the parameters (listed in Table 2) to locate the blocks of the reference points. The position of the reference point is the center pixel of the finally located block. Then, the accuracy and consistency are computed automatically by comparing the results with the defined reference points. The Euclidean distance between the manually located position and position detected by our algorithm is computed as distance error of reference point location. If the distance error is not larger than 10 pixels (about 1 interridge), the localization is considered to be accurate as the error that may be caused by human vision. If the distance error is between 10 pixels and 20 pixels, it is considered as small error which may be caused by both human vision and algorithm. If the distance error is between 20 pixels and 40 pixels, it is considered as significant error which may have negative effect on the subsequent processing steps. If the distance error is larger than 40 pixels, most likely a spurious or false reference point is detected that cannot be used for subsequent processing steps (Fig. 11).

In order to demonstrate the effectiveness of our proposed method, we compare the performance of the proposed method and that of Orientation-consistency-based method [10] and complex filter method [15]. The performance comparisons are shown in Figs. 12–16. The accuracy of our method reaches 91.67% (arch-fingerprints), 97.9% (whorl-fingerprints), 98.75% (left-loop-fingerprints), 95.56% (right-loop fingerprints) and 96.63% (all of DB1)

Please cite this article as: T.H. Le, H.T. Van, Fingerprint reference point detection for image retrieval based on symmetry and variation, Pattern Recognition (2012), doi:10.1016/j.patcog.2012.02.017

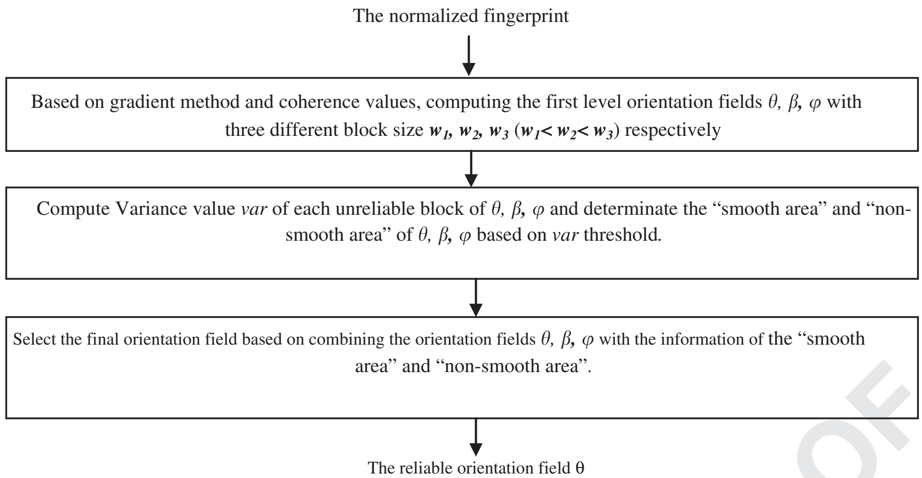

Fig. 9. The flowchart of reliable orientation field estimation.

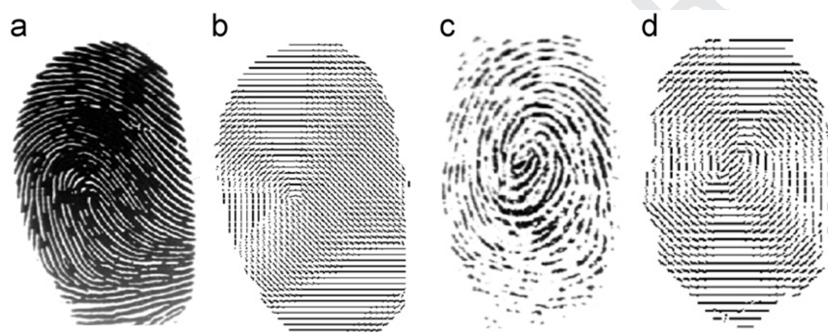

Fig. 10. Some orientation field results of DB1.

Table 2
Parameters of fingerprint reference point detection in our experiments

Parameters	Value	Parameters	Value
w_{s2}	7	σ_c	1.5
K	5	N	4

if small distance errors can be tolerated in the subsequent processing steps.

From formulas (8) to (16) and our algorithm for detecting fingerprint reference point, the average number of statements for detecting reference point is about $n(40w_{s2}^2+7KN+7)$ with $5 \le w_{s2}$, $K,N \le 11$ $(n(40w_{s2}^2+7KN+7) < 168n)$, where n is the number of blocks in a fingerprint image. The computational complexity of our proposed method is $O(n)$. The proposed methods are implemented on a PC with CPU Intel Core2Duo 1.8 GHz RAM 1 GB by Java language. The average time of reference point detection is less than 112 ms. Table 3 shows the average runtime comparison of three reference point detection methods over entire DB1. Same as our method, the orientation consistency based method [10] and the complex filter based method [21] are all coded with java language by the authors. The runtime of our method is longer than the orientation consistency based method, but it is shorter than the complex filter-based method. Moreover, the average time of all steps for detecting fingerprint reference point is less than 700 ms. It is worth to be applied into real-time fingerprint recognition.

5.3. Fingerprint retrieval

How to efficiently search the large fingerprint database is a great challenge [9]. The fingerprint retrieval technique as the coarse level matching is often used to reduce the searching space of the time-consuming fine matching and alleviate the accuracy deterioration of identification [9,30]. We use FingerCode features [8] to demonstrate the effectiveness of our method. In order to extract local invariant features from the original images, a series of Gabor filters with various scales and orientations (called Gabor filter bank) are used. 2D-Gabor has the following general form:

$$G(x,y,\theta,u,\sigma) = \frac{1}{2\pi\sigma^2}\exp\left\{-\frac{x^2+y^2}{2\sigma^2}\right\} \times \exp\{2\pi i(ux\cos\theta + uy\sin\theta)\}, \tag{19}$$

where $i=\sqrt{-1}$, u is the frequency of the sinusoidal wave, θ controls the orientation of the function and σ is the standard deviation of the Gaussian envelope. In order to extract the FingerCode feature with rotation invariance, the orientation of reference point is used to align rotated fingerprint images. In our experiments, we use Liu's method for detecting reference direction [10]. This work defines 16 radial directions from the reference point with $\pi/8$ interval (Fig. 17(a)). The local ridge orientation, which is most parallel to the corresponding radial direction, is defined as the unique reference orientation of the reference point (Fig. 17(b)). For the plain arch fingerprint, there exist two different such local ridge orientations, the average of which is defined as the unique reference orientation (Fig. 17(c)).

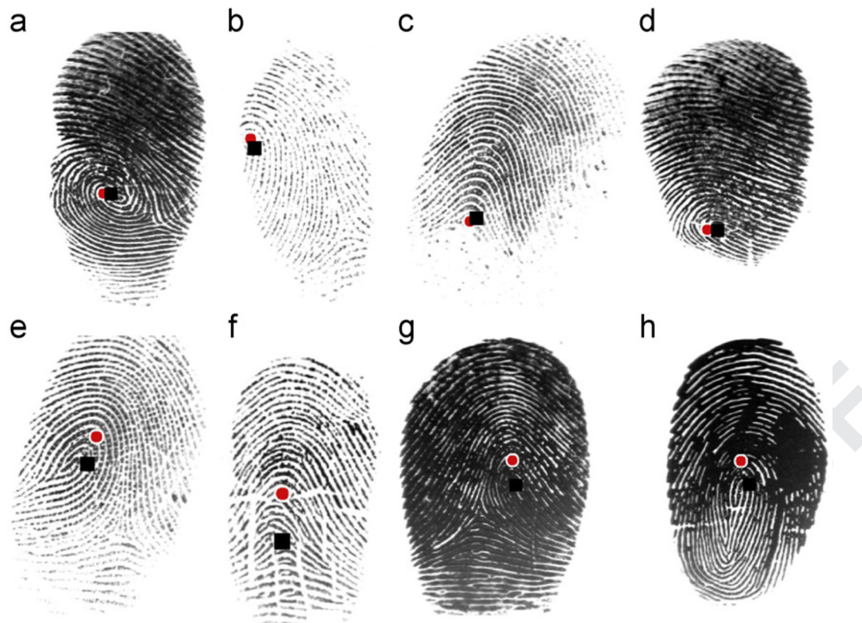

Fig. 11. (a)–(d) the accepted cases: distance error < 20, and (e)–(h) false cases: distance error > 20 ("■" and "●" denote the reference points detected by human experts, and our proposed approach, respectively).

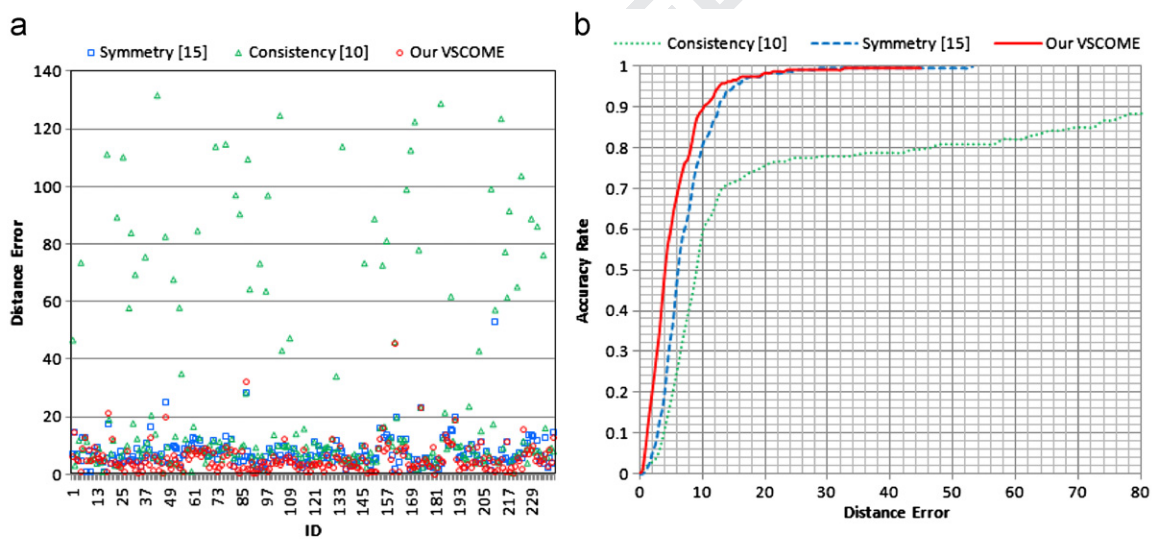

Fig. 12. The experimental results of the set of left-loop fingerprints: (a) distance error, and (b) the accuracy rate.

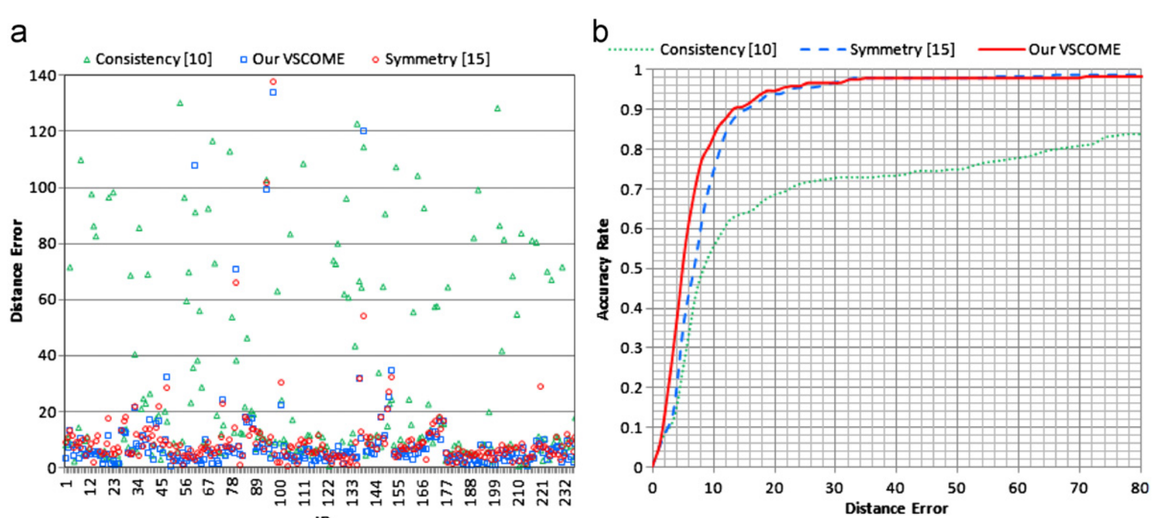

Fig. 13. The experimental results of the set of right-loop fingerprints: (a) distance error, and (b) the accuracy rate.

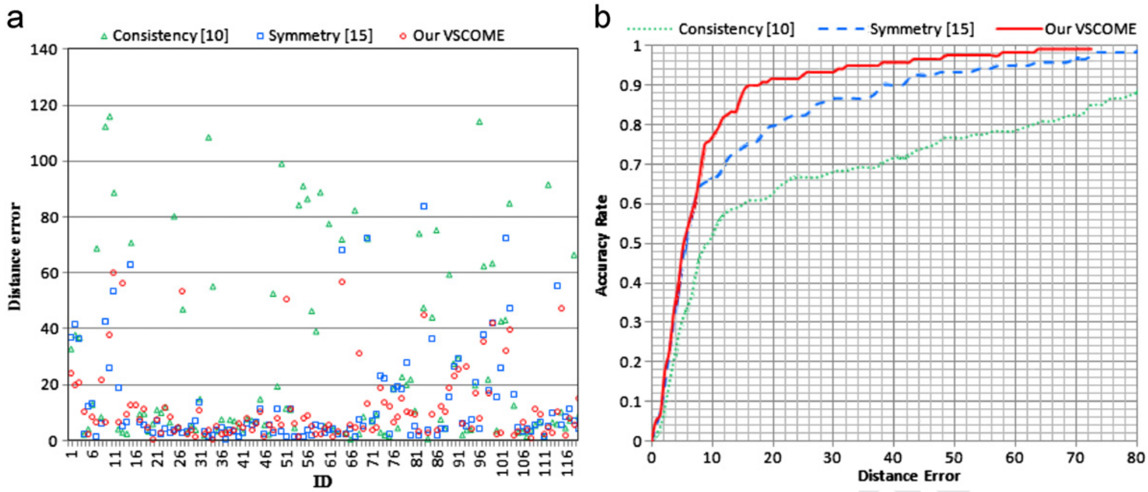

Fig. 14. The experimental results of the set of arch fingerprints: (a) distance error, and (b) the accuracy rate.

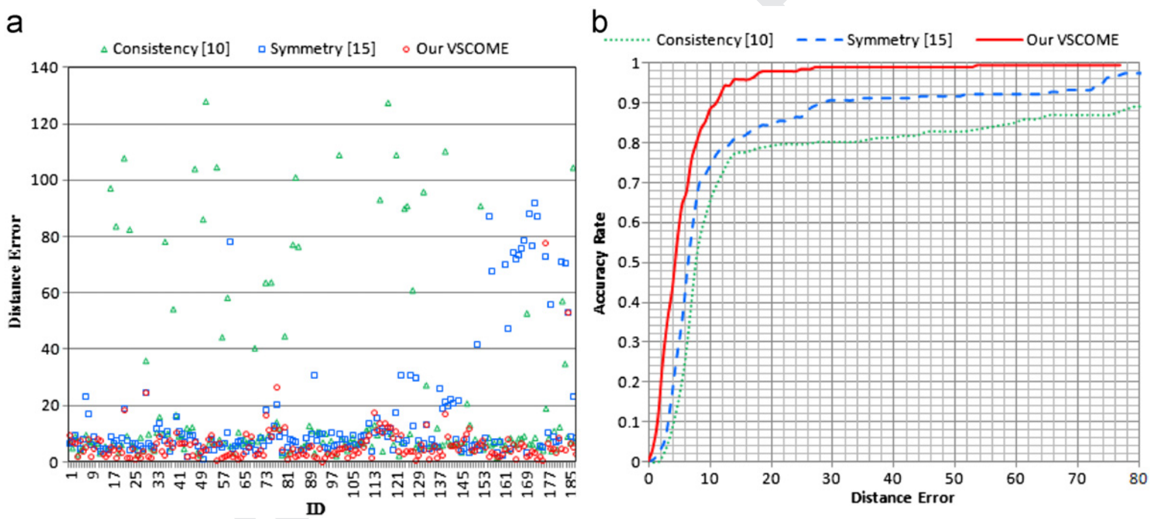

Fig. 15. The experimental results of the set of whorl fingerprints: (a) distance error, and (b) the accuracy rate.

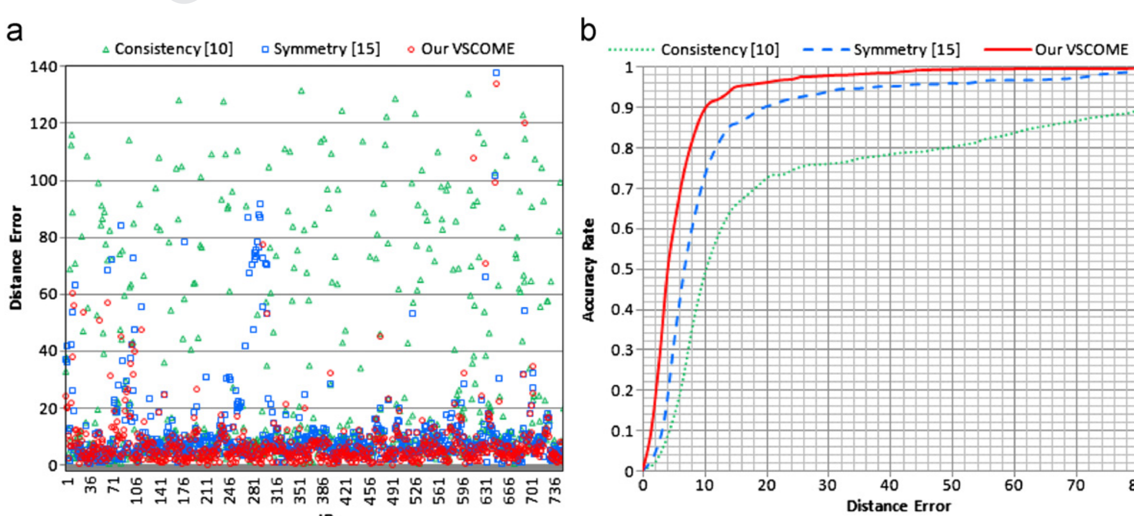

Fig. 16. The experimental results of DB1 database: (a) distance error, and (b) the accuracy rate.

In order to extract the FingerCode with rotation invariance, fingerprint images were rotated by the orientation of the reference point. Then, we apply Gabor-filter banks for these rotated images. And then, the region of interest (RI) defined as the collection of all the sectors (Fig. 18(a)) is computed for extracting the FingerCode. Let $GI(x,y)$ be the gray value at pixel (x,y) of the gabor-filtered fingerprint image of size $M \times N$. The RI is composed of sectors determined by the radius r from (x_r,y_r) and the rotation angle φ. The sector ith is computed as

$$\begin{aligned} &S_i = \{(x,y) \mid b(T_i+1) \le r < b(T_i+2), \quad \varphi_i \le \varphi < \varphi_{i+1}, \\ &1 \le x \le N, \quad 1 \le y \le M\}, \\ &T_i = i \text{ div } k, \\ &\varphi_i = (i \text{ mod} k) \times (2\pi/k) \\ &r = \sqrt{(x-x_r)^2 + (y-y_r)^2}, \\ &\varphi = \tan^{-1}((y-y_r)/(x-x_r)), \end{aligned} \tag{20}$$

where b is the band width of each band, k is the number of sectors considered in each band, and $i=0\ldots(B \times k-1)$, where B is the number of concentric bands considered around the reference point for feature extraction. The parameters φ_j, b, E, F are determined empirically to obtain the best performance of fingerprint retrieval over database DB1. In our experiments, $k=16$, $b=20$ pixels, $B=10$. If the sector S_i is foreground, the FingerCode value v_i of sector S_i is the average absolute deviation from the

Table 3
Average time comparison for reference point detection over DB1.

Our method	Runtime (ms)
The Orientation consistency [10]	50
The complex symmetry [15]	160
Our method	112

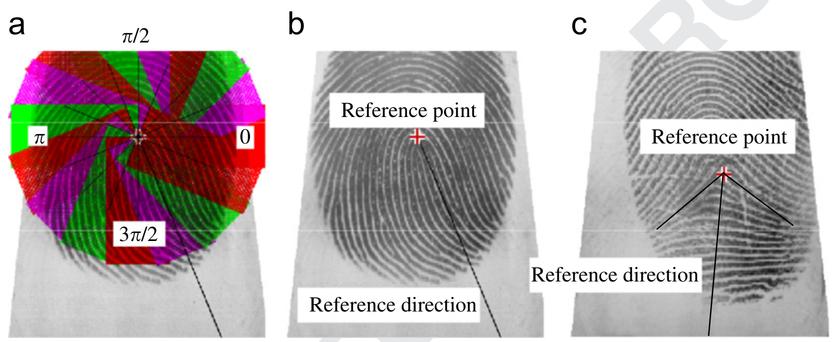

Fig. 17. (a) The 16 radial directions from the reference point. (b) The reference orientation for the core point. (c) The reference orientation for the plain arch fingerprint.

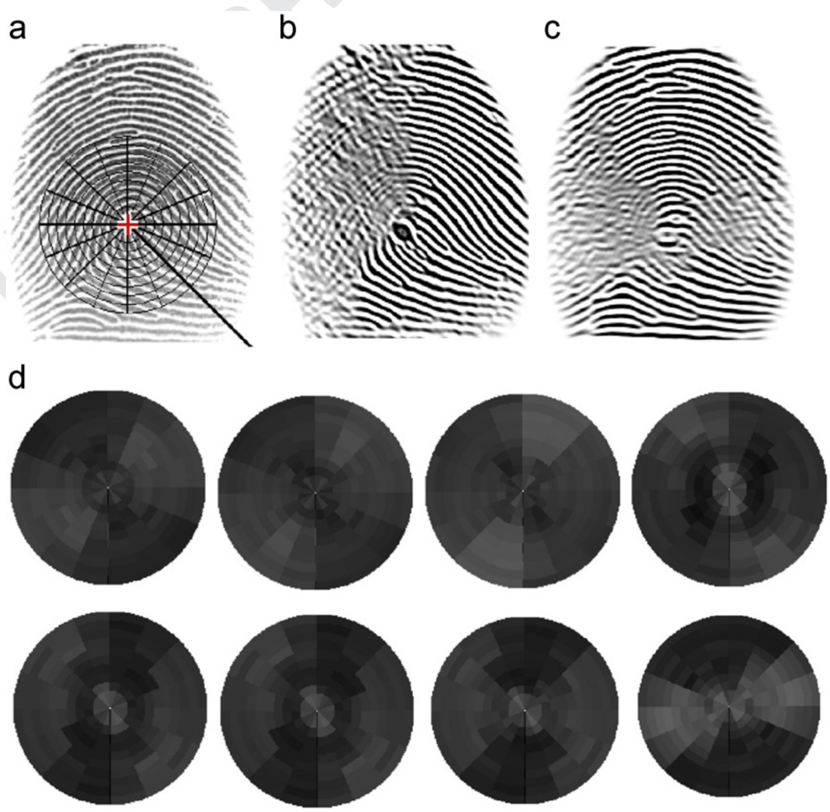

Fig. 18. (a) The circular tessellation of fingerprint aligned by the reference point and direction (the bold line). The $-45°$, $35.325°$ filtered images (b), (c), respectively. (d) FingerCode.

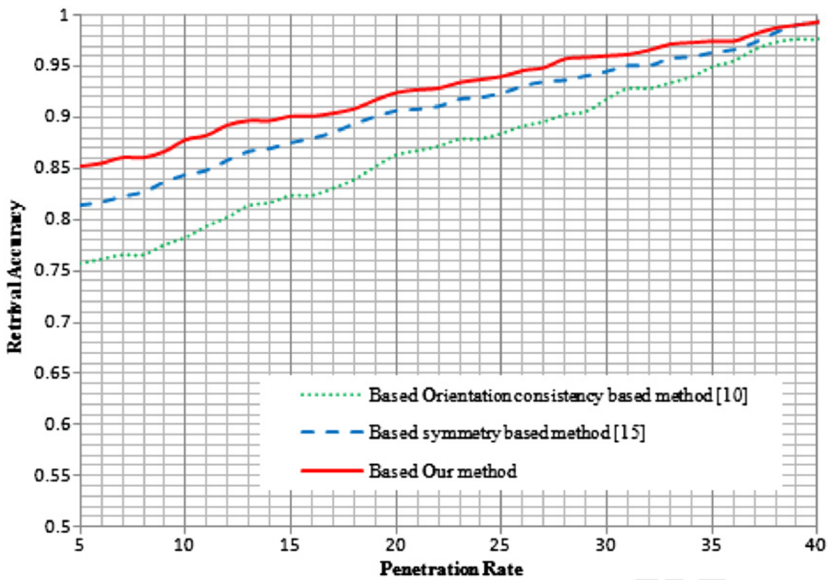

Fig. 19. The results of fingerprint retrieval with the Fingercode features extracted based on our reference point location method, orientation consistency based method [10] and symmetry based method [15].

Table 4
Average time all steps of FingerCode Feature extraction for fingerprint retrieval over DB1.

Steps	Runtime (s)
Normalize	0.2
Orientation field estimation	0.37
Reference point detection	0.112
Reference direction	0.19
FingerCode extraction	0.21
All steps	1.082

mean defined as [8]:

$$v_i = \frac{1}{|S_i|}\left(\sum_{(x,y)\in S_i} |GI(x,y) - P(S_i)|\right) \tag{21}$$

where $|S_i|$ is the number of pixels in S_i and $P(S_i)$ is the mean of pixel values of in sector S_i. If the sector S_i is background, $v_i = 0$. The average absolute deviation of each sector in each of the eight filtered images defines the components of our feature vector (Fig. 18(b)). The FingerCode vector $Vq = [v_{q,1}, v_{q,2}, \ldots, v_{q,M}]$ $(M = 8 \times E \times F)$ is constructed. The distance error between the FingerCode p and q is computed as

$$d(V_p, V_q) = \frac{1}{\sum_{i=1}^{M} x_i}\sqrt{\sum_{i=1}^{M} x_i (v_{p,i} - v_{q,i})^2}, \tag{22}$$

where $x_i \in \{0,1\}$ and $x_i = 1$ means that element is valid for both fingerprint p $(v_{p,k} \neq 0)$ and q $(v_{q,k} \neq 0)$.

The performance of fingerprint search is evaluated by the penetration rate and retrieval accuracy [9]. The penetration rate is the average portion of database retrieved over all query fingerprint. It indicates how much the fingerprint search can narrow down the database. For a query fingerprint, the search is successful if one of the retrieved candidates is from the same finger as the query. It is more likely to retrieve the correct one if more templates are retrieved from the database. The retrieval accuracy is thus computed at various different penetration rates. Fig. 19 presents the comparison of the performance of fingerprint search based on FingerCode extraction method with our reference point location method and that with the reference point location method [10] on DB1 fingerprint database. These experiments illustrate the effectiveness of our fingerprint reference point detection method. Fig. 19(b) and Table 4 show that our method is worth to be applied into real-time fingerprint recognition.

6. Conclusion and future work

In this paper, a new algorithm is proposed to consistently locate a unique reference point with high accuracy for fingerprint identification systems. In the method, the new symmetry filter, called semi-radial symmetry, is applied to detect the correct position of core points in all types of fingerprints, especially, plain arch fingerprints. In order to remove the concave core points and delta points, the new measurement extended from the Poincare' Index, called VORIV, is proposed. It describes the vertical orientation variation of neighborhood blocks. Finally, the combination of the semi-radial symmetry filter and the VORIV feature is used to isolate the unique reference point which has global maximum VSCOME value. Experimental results show that the proposed approach is better than other approaches.

Fingerprint identification has been a great challenge because of its complexity search of large database. There are many interesting works [6,7,9,30] to overcome this challenge. The singular point features (such as: orientation structure, their position comparative with the reference point) and the reference orientation is very important feature for aligning and classifying the fingerprint images. In future work, we are going to develop the fingerprint retrieval method in which the feature vector of fingerprint image is extracted based on combining all the global fingerprint features: the orientation field (as elements of feature vector), orientation structure energy (as structure-contribution factor of singular points), the reference point, and the orientation of reference point (as alignment).

Uncited references Q2

[20,22,23].

Please cite this article as: T.H. Le, H.T. Van, Fingerprint reference point detection for image retrieval based on symmetry and variation, Pattern Recognition (2012), doi:10.1016/j.patcog.2012.02.017

References

[1] K. Karu, A. Jain, Fingerprint classification, Pattern Recognition 17 (3) (1996) 389–404.

[2] R. Cappelli, A Lumini, D. Maio, D. Maltoni, Fingerprint classification by directional image partitioning, IEEE Transactions on Pattern Analysis and Machine Intelligence 21 (5) (1999) 402–421.

[3] Q. Zhang, H. Yan, Fingerprint classification based on extraction and analysis of singularities and pseudo ridges, Pattern Recognition 37 (11) (2004) 2233–2243.

[4] J. Li, W.-Y. Yau, H. Wang, Combining singular points and orientation image information for fingerprint classification, Pattern Recognition 41 (1) (2008) 353–366.

[5] L. Wang, M. Dai, Application of a new type of singular points in fingerprint classification, Pattern Recognition Letters 28 (13) (2007) 1640–1650.

[6] M. Liu, Fingerprint classification based on Adaboost learning from singularity features, Pattern Recognition 43 (3) (2010) 1062–1070.

[7] A.K. Jain, S. Prabhakar, L. Hong, A multichannel approach to fingerprint classification, IEEE Transactions on Pattern Analysis and Machine Intelligence 21 (4) (1999) 348–359.

[8] A.K. Jain, S. Prabhakar, L. Hong, S. Pankanti, Filterbank-based fingerprint matching, IEEE Transactions on Image Processing 9 (5) (2000) 846–859.

[9] M. Liu, X.D. Jiang, A.C. Kot, Efficient fingerprint search based on database clustering, Pattern Recognition 40 (6) (2007) 1793–1803.

[10] M. Liu, X.D. Jiang, A.C. Kot, Fingerprint reference point detection, EURASIP Journal on Applied Signal Processing 2005 (2005) 498–509.

[11] C.Y. Huang, L.M. Liu, D.C.Douglas Hung, Fingerprint analysis and singular point detection, Pattern Recognition Letters 28 (15) (2007) 1937–1945.

[12] C. Jin, H. Kim, Pixel-level singular point detection from multi-scale Gaussian filtered orientation field, Pattern Recognition 43 (11) (2010) 3879–3890.

[13] S. Chikkerur, N. Ratha, Impact of singular point detection on fingerprint matching performance, presented at Fourth IEEE Workshop on Automatic Identification Advanced Technologies (2005) 207–212.

[14] A.M. Bazen, S.H. Gerez, Systematic methods for the computation of the directional fields and singular points of fingerprints, IEEE Transactions on Pattern Analysis and Machine Intelligence 24 (7) (2002) 905–919.

[15] K. Nilsson, J. Bigun, Localization of corresponding points in fingerprints by complex filtering, Pattern Recognition Letters 24 (13) (2003) 2135–2144.

[16] C.H. Parka, J.J. Lee, M.J.T. Smith, K.H. Park, Singular point detection by shape analysis of directional fields in fingerprints, Pattern Recognition 39 (5) (2006) 839–855.

[17] X. Wang, J. Li, Y. Niu, Definition and extraction of stable points from fingerprint images, Pattern Recognition 40 (6) (2007) 1804–1815.

[18] T.H. Van, H.T. Le, An efficient algorithm for fingerprint reference-point detection, in: Proceedings of the International Conference on Computing and Communication Technologies (RIVF'09), pp. 1–7, 2009.

[19] J. Bigun, T. Bigun, K. Nilsson, Recognition by symmetry derivatives and the generalized structure tensor, IEEE Transactions on Pattern Analysis and Machine Intelligence 26 (12) (2004) 1590–1605.

[20] L. Hong, Y. Wan, A.K. Jain, Fingerprint image enhancement: algorithm and performance evaluation, IEEE Transactions on Pattern Analysis and Machine Intelligence 20 (8) (1998) 777–789.

[21] Y. Mei, H. Sun, D. Xia, A gradient-based combined method for the computation of fingerprints' orientation field, Image and Vision Computing 27 (2009) 1169–1177. no..

[22] Y. Wang, J. Hu, F. Han, Enhanced gradient-based algorithm for the estimation of fingerprint orientation fields, Applied Mathematics and Computation 185 (2007) 823–833.

[23] J. Gu, J. Zhou, D. Zhang, A combination model for orientation field of fingerprints, Pattern Recognition 37 (3) (2004) 543–553.

[24] J.V. Kulkarni, B.D. Patil, R.S. Holambe, Orientation feature for fingerprint matching, Pattern Recognition 39 (8) (2006) 1551–1554.

[25] T.H. Le, H.T. Van, Combining global features and local minutiae descriptors in genetic algorithms for fingerprint matching, in: Proceedings of the 2010 Symposium on Information and Communication Technology (SoICT'10), pp. 100–107, 2010.

[26] D. Maio, D. Maltoni, R. Cappelli, J.L. Wayman, A.K. Jain, FVC2004: third fingerprint verification competition, Lecture Notes in Computer Science 3072 (2005) 1–5.

[27] R. Cappelli, D. Maio, D. Maltoni, J.L. Wayman, A.K. Jain, Performance evaluation of fingerprint verification systems, IEEE Transactions on Pattern Analysis and Machine Intelligence 28 (1) (2006) 3–18.

[28] J. Zhou, F. Chen, J. Gu, A novel algorithm for detecting singular points from fingerprint images, IEEE Transactions on Pattern Analysis and Machine Intelligence 31 (7) (2009) 1239–1250.

[29] Y. Wang, J. Hu, D. Phillips, A fingerprint orientation model based on 2D Fourier expansion and its application to singular-point detection and fingerprint indexing, IEEE Transactions on Pattern Analysis and Machine Intelligence 29 (4) (2007) 573–585.

[30] X.D. Jiang, M. Liu, A.C. Kot, Fingerprint retrieval for identification, IEEE Transactions on Information Forensics and Security 1 (4) (2006).

Thai Le received the B.S. and M.S. degrees from Hanoi University of Science and Technology, Vietnam in 1995 and 1997, respectively, and Ph.D. degrees from the University of Science Ho Chi Minh city, Vietnam in 2004. He is currently a professor in the University of Science Ho Chi Minh city, Vietnam. His research interests include soft computing, pattern recognition, image processing, Biometrics, and their applications.

Hoang Van received the B.S. degree from Qui Nhon University, Vietnam in 2005 and the M.S. degrees from the University of science Ho Chi Minh city, Vietnam, in 2009. He is currently pursuing the Ph.D. degree in the same school. His research interests include biometrics, pattern analysis, pattern recognition, image processing and machine learning, and their applications.

Please cite this article as: T.H. Le, H.T. Van, Fingerprint reference point detection for image retrieval based on symmetry and variation, Pattern Recognition (2012), doi:10.1016/j.patcog.2012.02.017