Singularity Points Detection in Fingerprint Images

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ABSTRACT
An efficient algorithm for singular points (core and delta) detection in fingerprint images is proposed. The algorithm is based on an efficient maximum variation in local orientation field calculation method. The method was tested with FVC-2000 fingerprint database and the results were compared visually to the results obtained by human experts. The algorithm is capable of detecting singular points with precision and less computational time. The proposed algorithm outperforms existing algorithms in detection accuracy and calculation speed.

Keywords
Fingerprint, orientation field, singularity points.

1. INTRODUCTION
Fingerprints are considered one of the most reliable biological characteristics for personal identification because of its stability and uniqueness. In general, an automatic fingerprint identification system includes five main stages: segmentation, enhancement, feature extraction, classification and matching. The identification of a person requires a comparison of his fingerprint with all the fingerprints in a database. This database may be very large (e.g., several million fingerprints) as in many forensic and civilian applications. In such cases, the identification typically has an unacceptably long response time. The identification process can be speeded up by reducing the number of comparisons that are required to be performed. A common strategy to achieve this is to divide the fingerprint database into a number of classes.

The detection of the singular points (cores and deltas) is an important and difficult task in automatic fingerprint classification and identification. Moreover, fingerprint images often contain noise, which makes the classification task even more difficult. Core points are the points where the innermost ridge loops are at their steepest. Delta points are the points from which three patterns deviate. Qi Yuan[1] utilized core position for direction registration and A K Jain, Prabhakar S et. al [2] utilized it for image adjustment These adjustments reduce the influence of displacement of the fingerprint on the image and increase the accuracy of the recognition system. The number of cores and deltas and the relative position between these points can be used for fingerprint classification and recognition [3, 4, 5, 6, 7, 8, 9, 10, 11, 12] thus improving the robustness of the system in presence of changes introduced by displacement and rotation on the image. The problem of singular points detection in fingerprint images has been addressed before by different authors. Construction of several templates for '$\cap$' lines [12] can find the cores through searching image blocks that match the templates. But, this method works only in cases where no rotation exists on the image. Anil Jain[13, 14] has improved method of single resolution which was proposed by Karu[3]. But the operations for successively smoothing the orientation field to validate the number of singular points take a lot of time for computation, and some core points are missed out because of the smoothing. A coarse classification is derived also the type and position of singular point is conquered from Poincare Index[15]. The problem with Poincare index method is that fingerprints of the arch type do not have any singularity in terms of Poincare Index so structural heuristic is used to locate the core point [16]. Various method for singularity point detection based on singular candidate analysis using an extended relational graph [17] Genetic Algorithms [18] convex orientation consistency that describes orientation curvature and the consistency of the neighborhood with the dominant orientation[19],using bank of discrete Fourier Filters [20] neural network [21, 22] using Poincare index and Gaussian. Hermite moment [23] complex symmetrical filters and model based method [24] using non linear support vector machine followed by multiple scales smoothly in highest resolution and heuristic rules after complex filtering [25] are available in the literature. The time consuming nature of the Poincare index calculations, lead to other techniques to classify the fingerprint images [26, 27, 28, 29, 30, 31, 32].

In this paper a process for detection of singularity points based on maximum variation in local orientation field is introduced. Section II describes the proposed algorithm for detecting core and delta points. Section III displays the results and a brief discussion is carried out based on these results.

2. PROPOSED ALGORITHM
The proposed algorithm computes the core and delta points on the fingerprint image based on the maximum variation of its local orientation as follows :

Divide the input image, into non-overlapping blocks of size 8×8 pixels.

Compute the gradients $\partial_x(i, j)$ and $\partial_y(i, j)$ at each pixel (i, j). Depending on the computational requirement, the gradient operator may vary from the simple Sobel operator to the more complex Marr-Hildreth operator.

Estimate the local orientation of each block centered at pixel (i, j) using

$$o(i,j) = \frac{1}{2}\tan^{-1}\left(\frac{V_y(i,j)}{V_x(i,j)}\right) \quad (1)$$

where,

$$V_x(i,j) = \sum_{u=i-4}^{i+4}\sum_{v=j-4}^{j+4} 2\partial_x(u,v)\partial_y(u,v) \quad (2)$$

$$V_y(i,j) = \sum_{u=i-4}^{i+4}\sum_{v=j-4}^{j+4} \left(\partial_x^2(u,v) - \partial_y^2(u,v)\right)$$

(3)

The value of $o(i, j)$ is least square estimate of the local ridge orientation in the block centered at pixel (i, j). Mathematically, it represents the direction that is orthogonal to the dominant direction of the Fourier spectrum of the 8×8 window.

Convert the orientation field in to range of 0 to 180 degree.

$$o(i,j) = \begin{cases} o(i,j) & if\ o(i,j) < \pi \\ \pi + o(i,j) & if\ o(i,j) \le -\pi/2 \\ o(i,j) - \pi & otherwise \end{cases} \quad (4)$$

Smooth the orientation field in a local neighborhood. In order to perform smoothing (low pass filtering), the orientation image needs to be converted into a continuous vector field, which is defined as

$$\phi_{1x}(i,j) = \cos\left(2\, o(i,j)\right) \quad (5)$$

and

$$\phi_{1y}(i,j) = \sin\left(2\, o(i,j)\right) \quad (6)$$

where, ϕ_{1x} and ϕ_{1y}, are the x and y components of the vector field, respectively. With the resulting vector field, the low pass filtering can be performed as

$$\phi_x(i,j) = \sum_{u=-w/2}^{w/2}\sum_{v=-w/2}^{w/2} W(u,v)\phi_{1x}(i-wu, j-wv) \quad (7)$$

and

$$\phi_y(i,j) = \sum_{u=-w/2}^{w/2}\sum_{v=-w/2}^{w/2} W(u,v)\phi_{1y}(i-wu, j-wv) \quad (8)$$

where $W(.)$ is a two dimensional low pass filter with unit integral and $w\times w$ specifies the filter size. Note that smoothing operation is performed at the block level. For our experimentation we have used a 5×5 mean filter. The smooth orientation field O at (i, j) is computed as

$$O(i,j) = \frac{1}{2}\tan^{-1}\left(\frac{\phi_y(i,j)}{\phi_x(i,j)}\right) \quad (9)$$

Extract the part of image having maximum variation in intensity using mask of size 3×3.

Thin the image.

The singularity detected is referred as delta if the pixel below the singularity point is having angle less than $60°$ in the orientation field, otherwise it is referred as core.

Figure 1 shows the complete process of obtaining the singularity points based on the local field orientation. Figure 1(a) and (b) are obtained by computing the gradient $\partial_x(i, j)$ and gradient $\partial_y(i, j)$ respectively. The local orientation for each block is calculated using (1) to obtain Figure 1(e). The Local orientation field $0° - 360°$ obtained in Figure 1(e) is converted to $0° - 180°$ using (4) as shown in Figure 1(f). The orientation image is converted into a continuous vector field by (5) and (6) to obtain x component of continuous vector field as shown in Figure 1(g) and y component of continuous vector field as shown in Figure 1(h). Smoothing of image is carried out using (9) to obtain Figure 1(i). The part of image having maximum variation of intensities is extracted using mask of size 3×3 to obtain Figure 1(j). This figure is then thinned using thinning algorithm to obtain a line joining the singularity points as shown in Figure 1(k). The detected singularity points can be seen in Figure. 1(l). The proposed algorithm is implemented on various classes of fingerprints.

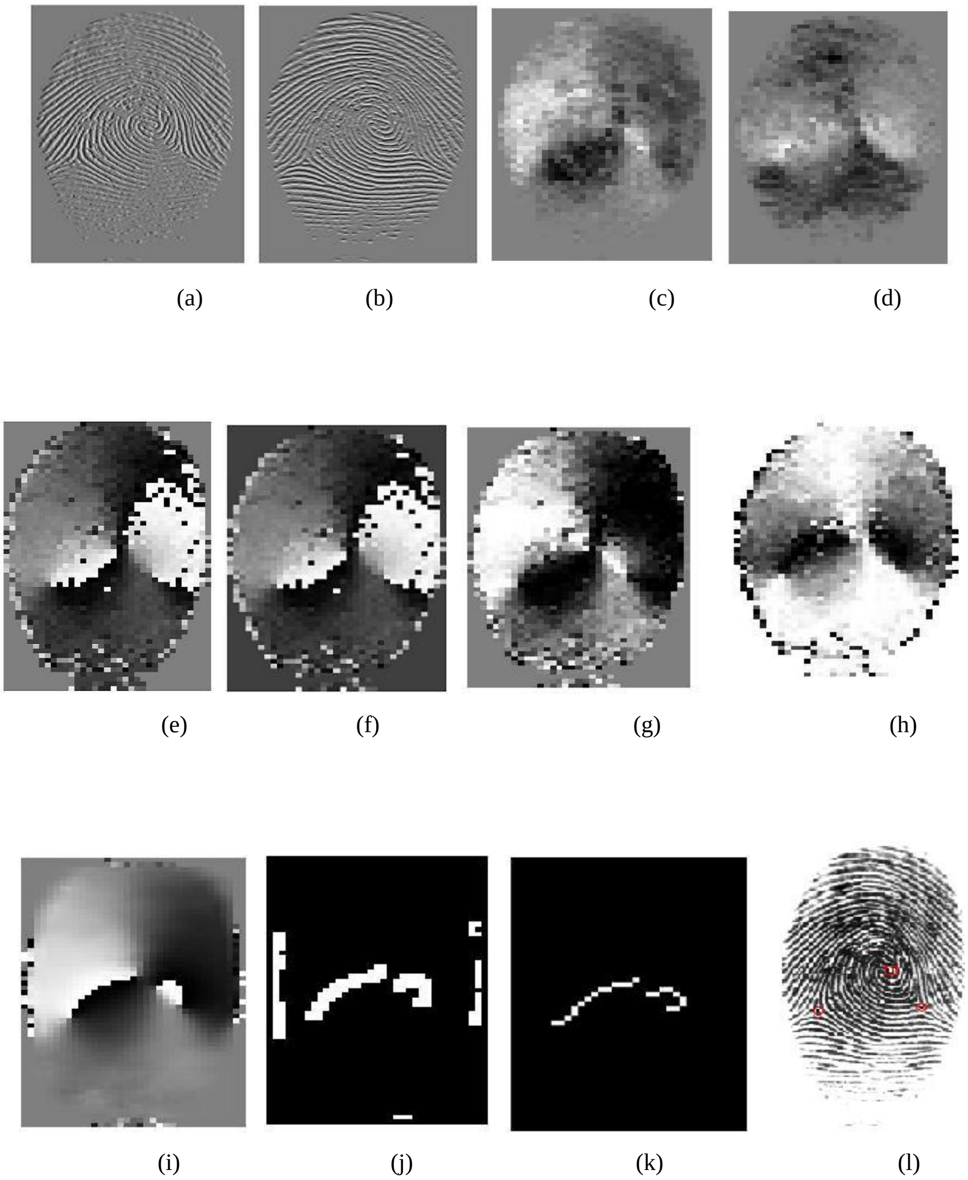


Figure 1 Various steps explaining the proposed algorithm (a) gradient $\partial_x(i, j)$ (b) gradient $\partial_y(i, j)$ (c) $V_x(i, j)$ (d) $V_y(i, j)$ (e) Local orientation field $0° - 360°$ (f) Local orientation field $0° - 180°$ (g) x component of continuous vector field (h) y component of continuous vector field (i) smoothened orientation field (j) extracted area of max variation in local orientation (k) Thinning of maximum variation in local orientation image (l) Detected singularity points shown on the original fingerprint image.

Figure 2 shows each class of fingerprint along with their detected singularity points and the maximum variation in local orientation field

3. RESULTS AND DISCUSSION

The algorithm was executed using MATLAB version 6.3 on a P-IV, 1.2 GHz computer. Randomly selected fingerprint images containing noise, different scale and orientations from the FVC 2000 database is used for detection of singularity points. As per the FVC-2000 specifications the fingerprints were acquired by using a low-cost capacitive sensor. The average time taken for executing the algorithm for detection of singularity points is 2.36 seconds. As the singularity points are being extracted from the orientation field it makes the output highly noise tolerant. Figure 3 displays a set of fingerprints chosen from the FVC-2000 database.

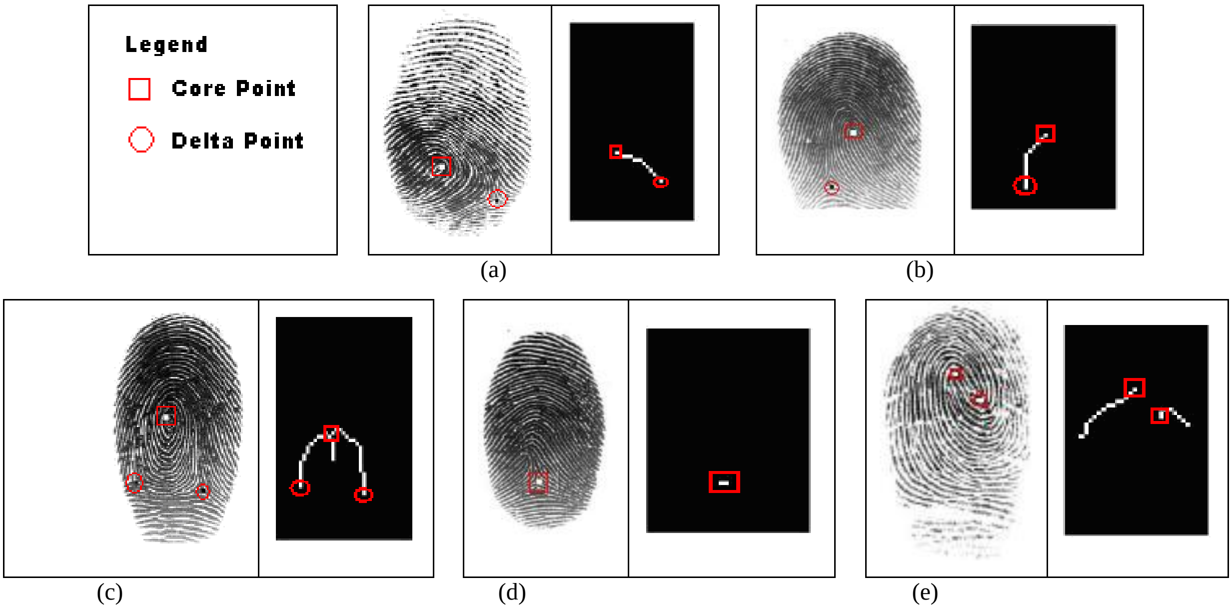
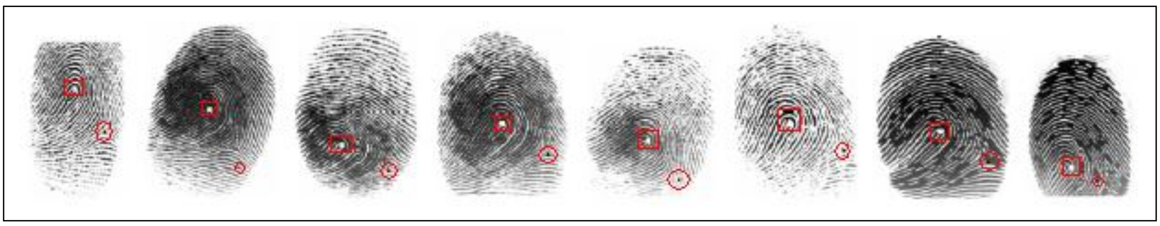


Figure 2 Singularity points for various classes of fingerprints along with the maximum variation of local orientation field image.

Each group of fingerprints consist of eight images of the same class namely Arch, Left loop, Right loop, Whorl and Twin loop. The core and delta points have been distinctively marked. Test results were obtained by comparing the singular points extracted by the proposed algorithm to the singular points detected by human experts. Results were also compared with other singular point detection algorithms. In [26], problems are observed with the whorl type of fingerprints and images with extremely steep ridge curves. Also obtained core points seemed to consistently move away from the actual core points. In the proposed algorithm the points are exactly and consistently found at the precise position. The average calculation time for the algorithm in [3] is 7.8 seconds and for the proposed algorithm is 2.36 seconds under similar conditions. Results show that the detection accuracy is better as compared to the previous algorithms. Consistent results are achieved irrespective of classes of fingerprints, their position, scale, rotation and noise.

(a)



(b)

(c)

(d)

(e)

Figure 3 Singularity points on different classes of fingerprints with different position, scale, rotation and noise.

The performance of the algorithm has been also evaluated using the Receiver Operating Characteristics (ROC). This consists of a measure of false acceptance rate (FAR) and the false rejection rate (FRR) at various thresholds. Alternately the Genuine acceptance rate (1-FRR) and FAR may be measured at different thresholds. A genuine matching score is obtained when two feature vectors of the same individual are compared and an imposter matching score is obtained when feature vectors of two different individuals are compared. A single template per subject has been considered for experimentation. For every possible combination the algorithm has been tested for computation of FAR and FRR as shown in Figure 4.

4. CONCLUSIONS

A novel approach towards singularity points detection based on the maximum variation in local orientation field of fingerprint image has been proposed. Accurate and consistent singularity points detection greatly reduces fingerprint-matching time and computational complexity for a large database. It is a sophisticated and accurate method for detection of core and delta points and is highly noise tolerant. The proposed algorithm produce better results at lower and higher values of FAR as compared to minutiae based algorithms. As the algorithm takes fewer computations it could be implemented using the real time processor.

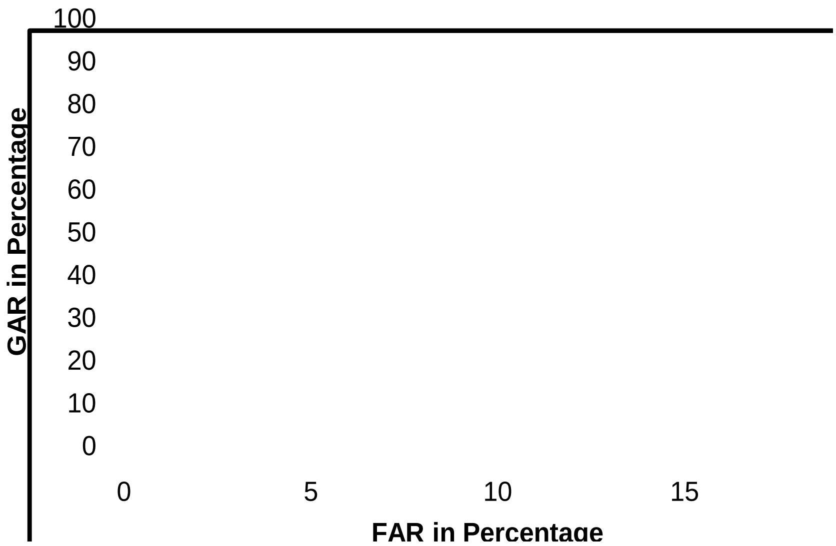


Figure 4 Performance evaluation of the proposed algorithm based on singularity points.

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