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Fingerprint Singular Point Detection Based on Modified Poincare Index Method

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Abstract

The use of fingerprint for human identity management has been on the rise lately. Reasons adduced for this include its high level of uniqueness, availability, consistency and universality. The task of human identity management based on fingerprint technology involves a number of processes which include enrolment, enhancement, feature and singular points detection and extraction and pattern matching. Detection and extraction of genuine and reliable feature and singular points are paramount for reliable pattern matching. The limitations of some existing fingerprint singular point detection algorithms include inaccurate detection and failure with some fingerprint pattern and poor quality images. In this paper, a modified Poincare Index fingerprint singular point detection algorithm is proposed for resolving these limitations. The results of the experimental study of the new algorithm on Dataset DB1 of FVC2000 standard fingerprint database show that the new algorithm reliably and adequately detected singular points from fingerprints of all patterns and qualities.

Keywords: *Fingerprint, singular point detection, Poincare index, orientation estimation*

1. Introduction

Fingerprint matching is majorly performed in fingerprint-based human verification and identification systems. It is also performed when the need for establishing the degree of resemblance among different fingerprints arises. Fingerprint matching involves the use of coarse and smooth level characteristics of fingerprint. At the coarse level, fingerprints are classified into six main classes; namely arch, tented arch, right loop, left loop, whorl and twin loop which are shown in Figure 1 [1-7].

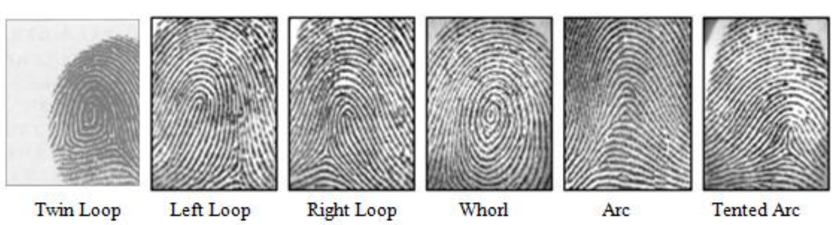

Figure 1. Fingerprint Ridge Patterns

Smooth-level fingerprint matching involves a comparison among the feature (ridge ending, bifurcation and the singular points) sets extracted from fingerprint images. As shown in

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Figure 2(a), the ridge terminates at the ridge ending while it splits into two at a bifurcation point. The singular point is the point where the ridge orientation field experiences discontinuity either through the ridge curvature rising higher than normal or the ridge changes rapidly resulting in a zero gradient. Singular points can be classified into two types; namely core and delta which are shown in Figure 2(b) [8].

At the core point, the pattern exhibits a semi-circular tendency whereas the patterns split into three different sectors at the delta point, and each sector exhibits the hyperbolic tendency [9-10]. Singular points are used for fingerprint indexing, classification, arrangement and orientation field modelling [10-13]. They are also parts of the core components of several fingerprint matching algorithms [11, 14].

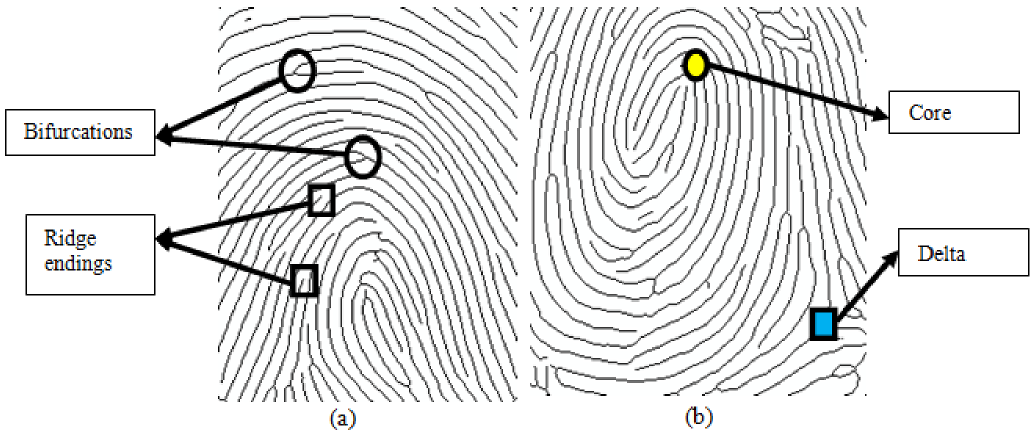

Figure 2. (a) Fingerprint Showing the Bifurcation and Ridge ending (b) Fingerprint Showing the Core and Delta Points

The existing fingerprint singular point detection algorithms include Poincare Index [9, 15-17], Curvature [18], Multi-Resolution [14] and Orientation Field [19-22]. In several cases, the existing techniques for the detection of the singular points do not produce expected or accurate results, especially for noisy images [23-24]. Some of the algorithms are selective in the nature of their performances, others failed with some patterns of fingerprint [1, 25] and some result in many forged detection points. Forged detections are due to inaccurate algorithms and use of only local characteristic of singular points by most post-processing approaches, which is not enough to discriminate true singular points from forged detections caused by creases, scars, blurs, damped prints and so on [8, 26].

Singular points detection methods may also suffer from cropping of the Region of Interest (ROI) thereby containing less information [27]. With a view to addressing the highlighted problems of existing fingerprint singular point detection methods, a modified Poincare index fingerprint singular point detection method is proposed in this research. Synopses of related works on fingerprint singular point detection formed the focus of Section 2 while Section 3 presents the modified Poincare index fingerprint singular point detection method. Sections 4 and 5 present the experimental study of the new algorithm and the conclusion drawn respectively.

2. Précis of Related Works

The précis of some existing works on fingerprint singular point detection is presented in Table 1. The authors in [1, 10, 28-31, 32] presented different techniques based on orientation field estimation for reliable detection of fingerprint singular point. The authors in [33] employed orientation field, localization and type for fingerprint singular points detection while an algorithm which is based on orientation field estimation, coherence and Poincare Index (PI) methods is used for core point detection in [8, 34-35]. The algorithms detect high curvature regions with high accuracy by combining the strengths of the individual methods. Some of the algorithms used optimal combination of singular points to minimize the difference between the original and the model-based orientation field. Core-delta relation is also used as global constraint for the final selection of singular points. The authors in [24] presented an algorithm that uses Multi-Resolution Direction Field (MRDF) and High-Resolution Direction Field (HRDF) to search and locate the positions of fingerprint singular points.

A technique that estimates the positions of the singular points in fingerprint image by processing the global structure of the ridges and extracting a specific set of features is presented in [36]. Computational intelligence classification techniques were used to process the extracted features for the selection of the singular point from the candidate list. The authors in [37] presented a model for determining virtual core point based on changes in gradient at the maxima and minima points while a similar method based on Gaussian processes for the prediction of the locations and orientations of core points for latent fingerprints is proposed in [38]. The method also provides prediction in interpretations of probability rather than binary decision. Direction of Curvature (DC) is used in [26] for the determination of fingerprint core point while Geometry of Region (GR) is used in its tuning. The reference point of a fingerprint is located in [39] based on the rotation-invariant location and Filter-bank-based algorithm. The authors in [40] used a directional masks to detect the neighbourhood of the singular points while Principal Gabor Basis Function (PGBF)-based approach is used in [41] to extract cores, deltas and minutiae from fingerprint images.

Table 1. Summary of Some Existing Works on Fingerprint Singular Point Detection

Research	Methodology	Strength	Weakness
Bo et al. [1]	Poincare Index	Extraction of singular points with high accuracy	Susceptible to forged detection
Kharat and Kodwe [8]	Poincare Index and DORIVAC	Removal of forged detections	Computationally expensive
Anwar et al. [10]	Poincare Index	Detect all the cores and deltas in an image	The operational speed is low due to un-optimized procedures.
Bazen and Gerez [16]	Directional Field	Accurate detection of singular point and orientation	Diminishing performance with low quality images
Zhang and Wang [24]	Multi-Resolution Directional Field	Higher precision and robust to noise	Computationally expensive
Julasayvake and Choomchuay [26]	Region of Interest	Accurate core point detection with less computation load	Susceptible to false detection
Song and Elliot [29]	Orientation and Edge-Map	Singular points detection with high	Medium performance in case

		speed and accuracy	of arch fingerprint type
Khalil et al. [30]	Orientation field/Short Time Fourier Transform Analysis	Consistent and accurate extraction of singular points	Failed with poor quality image
Fei et al. [32]	Orientation Field and Zero Pole models	Consistently extract singular points with high accuracy and speed	Fails in fingerprint with inconsistent orientation field
Mei et al. [33]	Orientation Field Partitioning	Promotion of accurate extraction of singular points	Uncertainty in cases of poor quality images
Kekre and Bharadi [34]	Orientation Field Based on Multiple Features	Core point detection with very high accuracy	Only detect core points for loop images
Weng et al. [35]	Multi-Resolution and Poincare Index	Erasure of noise induced singular points	Fail when image has resolution problem
Basak et al. [37]	Gradient Changes	Detect virtual core points	Result not suitable for fingerprint classification
Chang and Sargur [38]	Gaussian Process	Core point detection for images with or without virtual core points	Only based on probability measure
Sim et al. [39]	Rotation Invariant Reference Point Location	Accurate detection of the core point	Dependent on sectors and filter sizes

3. Modified Poincare Index Technique

The traditional Poincare Index technique, though susceptible to forged detection, is one of the commonly used techniques for fingerprint core and delta point detections [1, 10]. In a fingerprint orientation field, the PI of a core-shaped singular region is 0.5 while that of a delta-shaped singular region is -0.5. For pixel P(i, j), its PI is obtained from [1, 8, 10, 35, 42]:

$$PC(i,j) = \frac{1}{2\pi}\sum_{k=0}^{N_P-1}\Delta(k) \tag{1}$$

$$\Delta(k) = \begin{cases} \delta(k), & if\delta(k) < \frac{\pi}{2} \\ \pi + \delta(k), & if\ \delta(k) \le -\frac{\pi}{2} \\ \pi - \delta(k), & otherwise \end{cases} \tag{2}$$

$$\delta(k) = O'\left(P_x(k'), P_y(k')\right) - O'\left(P_x(k), P_y(k)\right), \tag{3}$$

$$k' = (k+1) mod\ N_P \tag{4}$$

$P_x(k)$ and $P_y(k)$ are the x and y coordinates of the kth point on the closed curve centered at the given point (i, j) and composed of N_P pixels, O' denotes a fingerprint orientation field. To capture the sudden change of orientation, and extract singular points more reliably, the method is improved by modulating the third part of Equation (2) to $\delta(k)-\pi$ which results in [35]

$$\Delta(k)=\begin{cases}\delta(k), & if\delta(k)<\dfrac{\pi}{2}\\ \pi+\delta(k), & if\ \delta(k)\leq-\dfrac{\pi}{2}\\ \delta(k)-\pi, & otherwise\end{cases} \quad (5)$$

Post-processing steps are often used to resolve associated anomalies in the following ways:

a. Both delta and core are eradicated if the distance between them is smaller than 8 pixels
b. In a circular region with a radius of 8 pixels, if there is more than one core (or delta), an average core (or delta) is calculated instead. Given that N cores (or deltas) exist in an area, $\{(u_i, v_i), i=1, 2, 3, \ldots, N\}$ then, the average core (or delta) (u, v) is calculated from:

$$u=\frac{1}{N}\sum_{i=1}^{N}u_i \quad (6)$$

$$V=\frac{1}{N}\sum_{i=1}^{N}v_i \quad (7)$$

The modified Poincare index singular point detection method is in two major steps, namely ridge orientation estimation and singular point detection.

3.1. The Ridge Orientation Estimation

The ridge orientation estimation is in the following phases:

3.1.1. Image Segmentation: A fingerprint image contains the foreground and the background regions. The foreground is the region of interest (ROI) and contains the ridges and valleys while the background is the outside region containing noise and contaminants. The foreground is the region of high variance while the background is the region of low variance [43]. Based on these characteristics, a method which is based on variance levels is used to segment the foreground from the background. The method divides the image into blocks of size W x W and the variance, V(k) for all the pixels in block k is then calculated from:

$$V(k)=\frac{1}{W^2}\sum_{i=1}^{W}\sum_{j=1}^{W}(I(i,j)-M(k))^2 \quad (8)$$

I(i,j) represents the grey-level value for pixel i,j in block k and M(k) is the average grey-level value for block k.

3.1.2. Image Ridge Normalization: Ridge normalization is used to adjust and standardize the fingerprint grey-level values to a range that is suitable for best image contrast and brightness. During normalization, the segmented image is firstly divided into blocks of size S x S and then for each block, a comparison is made between each pixel's grey-level and the average grey-level values. Given that M_0 and V_0 are the desired mean and variance respectively, the normalized grey-level value N(i,j) for pixel I(i,j) belonging to a block of average grey-level value M and variance V is obtained from:

$$N(i,j) = \begin{cases} M_0 + \sqrt{\dfrac{V_0(I(i,j)-M)^2}{V}} & if\ \ I(i,j) > M \\ M_0 - \sqrt{\dfrac{V_0(I(i,j)-M)^2}{V}} & otherwise \end{cases} \quad (9)$$

3.1.3. Orientation Estimation: The orientation at a particular pixel is the direction of the flow of the ridges over it and it is derived based on the following steps [14]:

a. Firstly, blocks of size *S x S* are formed in the normalized image.

b. For each pixel (p,q) in each block, the gradients ∂_x*(p,q)* and ∂_y(p,q), which represent the gradient magnitudes in the *x* and *y* directions, respectively are computed. ∂_x(p,q) and ∂_y(p,q) are computed using any of the gradient operators.

c. V_x, V_y and the least mean square, *Θ* of the local orientation for each block centered at pixel I(i,j) are then computed from:

$$V_x(i,j) = \sum_{p=i-\frac{S}{2}}^{i+\frac{S}{2}} \sum_{q=j-\frac{S}{2}}^{j+\frac{S}{2}} 2\partial_x\,(p,q)\partial_y(p,q) \quad (10)$$

$$V_y(i,j) = \sum_{p=i-\frac{S}{2}}^{i+\frac{S}{2}} \sum_{q=j-\frac{S}{2}}^{j+\frac{S}{2}} \partial_x^2\,(p,) - \partial_y^2(p,q) \quad (11)$$

$$\theta(i,j) = \frac{1}{2}\tan^{-1}\frac{V_y(i,j)}{V_x(i,j)} \quad (12)$$

d. φ_x and φ_y, which are the *x* and *y* components of the vector field of θ, are computed as follows:

$$\varphi_x(i,j) = \cos\big(2\theta(i,j)\big), \quad (13)$$

$$\varphi_y(i,j) = \sin\big(2\theta(i,j)\big), \quad (14)$$

e. The vector field is then smoothened as follows:

$$\varphi_X^{'}(i,j) = \sum_{p=-\frac{s_\varphi}{2}}^{\frac{s_\varphi}{2}} \sum_{q=-\frac{s_\varphi}{2}}^{\frac{s_\varphi}{2}} G(p,q)\varphi_x\,(i-ps, j-qs) \quad (15)$$

$$\varphi_y'(i,j) = \sum_{p=-\frac{s_\varphi}{2}}^{\frac{s_\varphi}{2}} \sum_{q=-\frac{s_\varphi}{2}}^{\frac{s_\varphi}{2}} G(p,q)\varphi_y\,(i-ps, j-qs) \quad (16)$$

G is a Gaussian low-pass filter of size $S_\varphi\ X\ S_\varphi$.

f. $O(i,j)$, which is the smoothened orientation field of the block centered at pixel (i,j) is obtained from:

$$O(i,j) = \frac{1}{2}\tan^{-1}\frac{\varphi_y'(i,j)}{\varphi_x'(i,j)} \quad (17)$$

3.2. Singular Points Detection

The detection of the singular point characteristics for a pixel (i,j) is derived based on a modified Poincare Index method presented as follows:

$$PC(i,j) = \frac{1}{\pi}\sum_{c=1}^{8}\beta_c, \tag{18}$$

$$\beta_c = \begin{cases} p(c)+\pi, & if\ p(c) \le -\frac{\pi}{2} \\ p(c), & if\ p(c) > -\frac{\pi}{2}\ and\ p(c) \le \frac{\pi}{2} \\ p(c)-\pi, & otherwise \end{cases} \tag{19}$$

$$p(c) = |O_{c+1} - O_c|, \quad O_9 = O_1 \tag{20}$$

O_1, O_2,…, O_8 represent the orientations of the 3 x 3 neighbors of pixel (i,j) which are scanned in the direction shown in Figure 3.

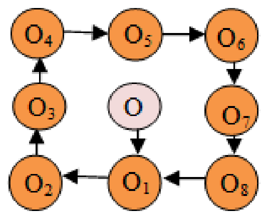

Figure 3. 8 Neighbors of a Candidate Pixel

Based on these characteristics, the core point lies within the range of -1 and -0.5 for PC(i,j) while the delta point is within in the range 0.5 - 1.0. In some fingerprint images, these characteristics produced some false core and delta points which are eliminated by using the post-extraction algorithm as follows:

a. Given that *N* cores (or deltas) defined by (u_i, v_i), i=1, 2, 3, …., N exist in a circular region of radius of 8 pixels, then the coordinate of the average core (or delta) at point (*u*, *v*) is calculated from:

$$u = \aleph(u_1 + u_2 + u_3 \ldots + u_N) \tag{21}$$
$$v = \aleph(v_1 + v_2 + v_3 \ldots + v_N) \tag{22}$$

$\aleph$ is the average operation.

b. Both delta and core points are eliminated if they are within 8 pixels distance.

4. Experimental Study

The experimental study of the modified Poincare index fingerprint singular point detection algorithm was performed using Matlab in an environment characterized by windows 7 Operating System on an Intel (R) 2.50 GHz dual core Pentium IV with 4.0 GByte RAM. Fingerprint images of diverse qualities from dataset DB1 of FVC2000 fingerprint database were used for the study. Each of the images is of size 300 x 300 pixels and captured using optical sensor at resolution of 500 dots per inch (dpi) [44]. The genuineness of the extracted core and delta points based on visual inspections formed the basis for the evaluation. Some of the images in the dataset are presented in Figures 4(a-e) representing right loop (plus arch), right loop, arch, whorl and tented arch patterns respectively.

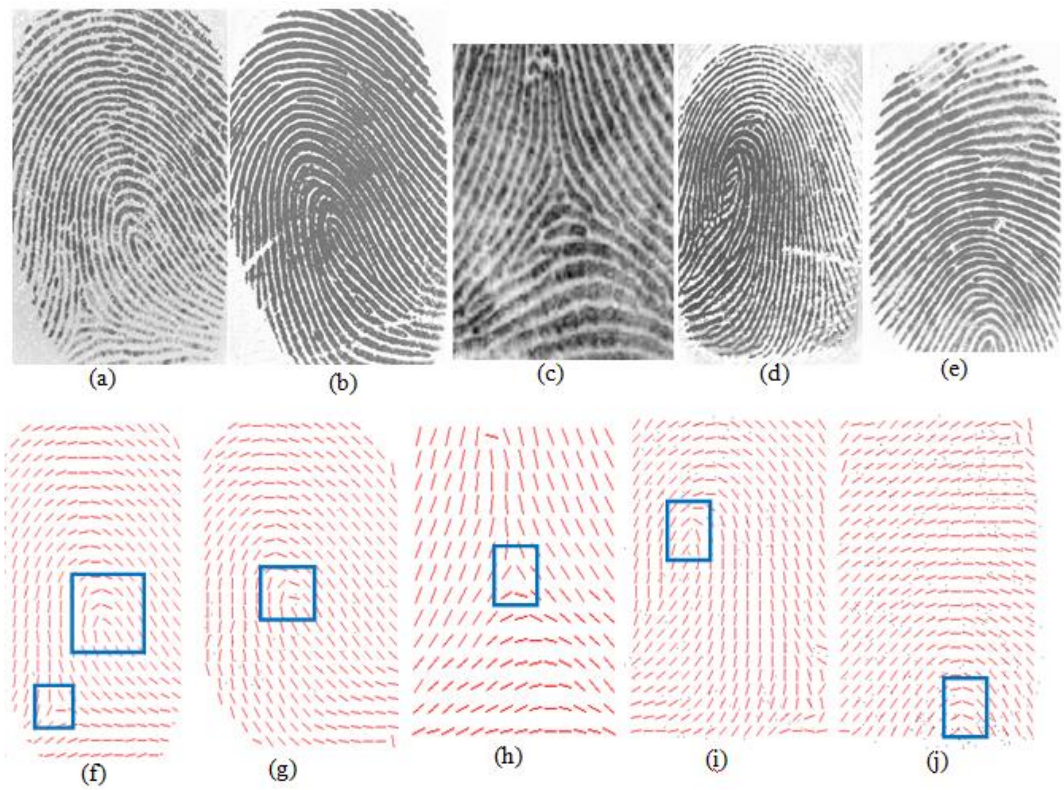

Figure 4. Fingerprints and their Orientation Estimates

Since the modified algorithm is functionally dependent on image ridge orientation, the suitability of the ridge orientation estimation algorithm for effective computation of the ridge orientations was investigated. The results of the investigation (parts of which are presented in Figures 4(f-j) show that irrespective of the fingerprint pattern, there is a very accurate and reliable estimation of the ridge orientations. The suitability of the ridge orientation estimation algorithm is therefore established. In the orientation images, the ROI, which have potential for core or delta point, are annotated with squares.

The results of the extraction of multiple core (in red) and delta (in blue) points from these images are shown in Figures 5(a-e). The thick and overlapping nature of the extractions show combination of several (forged) core or delta points within circular region of 8 or more pixels. Visual inspection of the results of the extractions also shows that some false core and delta points were extracted in several images. The results of the implementation of the post-extraction algorithm on these images are presented in Figures 6(a-e). The post-extraction results show complete elimination of all forged singular points as well as overlapping. The results of Figure 6 also present how the new algorithm appropriately detected and extracted core or delta point from the ROI of images of different patterns.

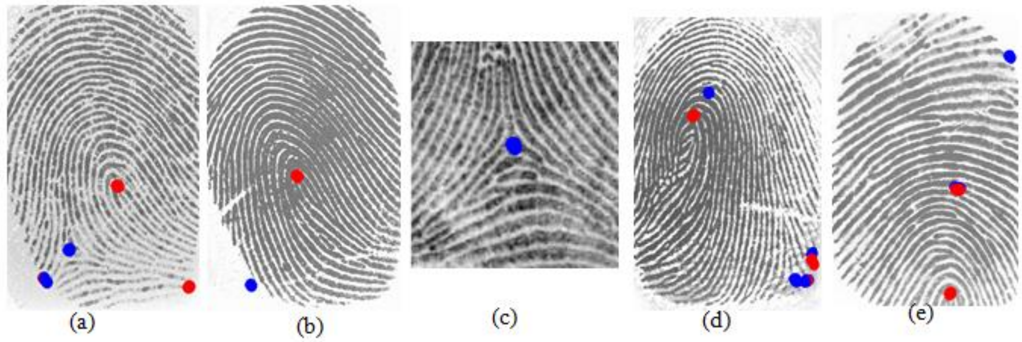

Figure 5. Multiple Singular Points Extractions

Figure 7. Presents Accurate Detection of Singular Points for Medium Quality Images

However, the new algorithm failed with very poor quality images as shown in Figure 8(a-b). The inaccurate extractions are attributed to the misleading forms of the estimated orientation images as shown in Figures 8(c-d). The results presented in Figures 5-8 show clearly that the performance of the new algorithm is significantly dependent on the quality of the image. Accurate and true detection and extraction are attained if the image is of high or medium quality while inaccurate and false detections are recorded for highly degraded images.

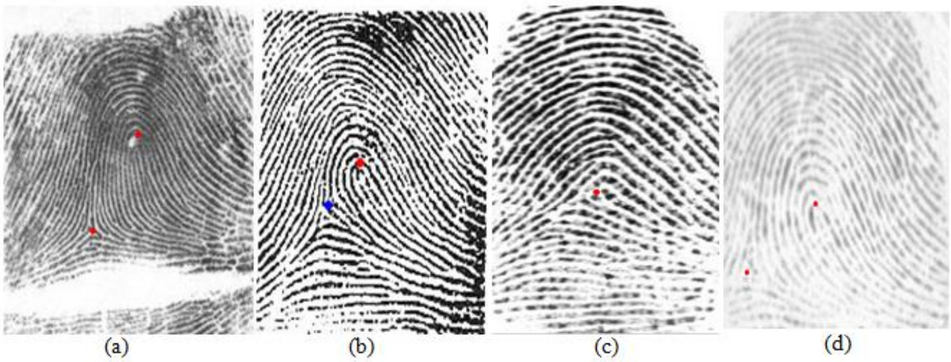

Figure 7. Singular Point Extraction for Poor Quality Images

Some of the results of the implementation of the original Poincare algorithm are presented in Figure 9. Visual inspection and comparison of the extracted singular point with those in Figure 6 shows more accurate results for the new algorithm.

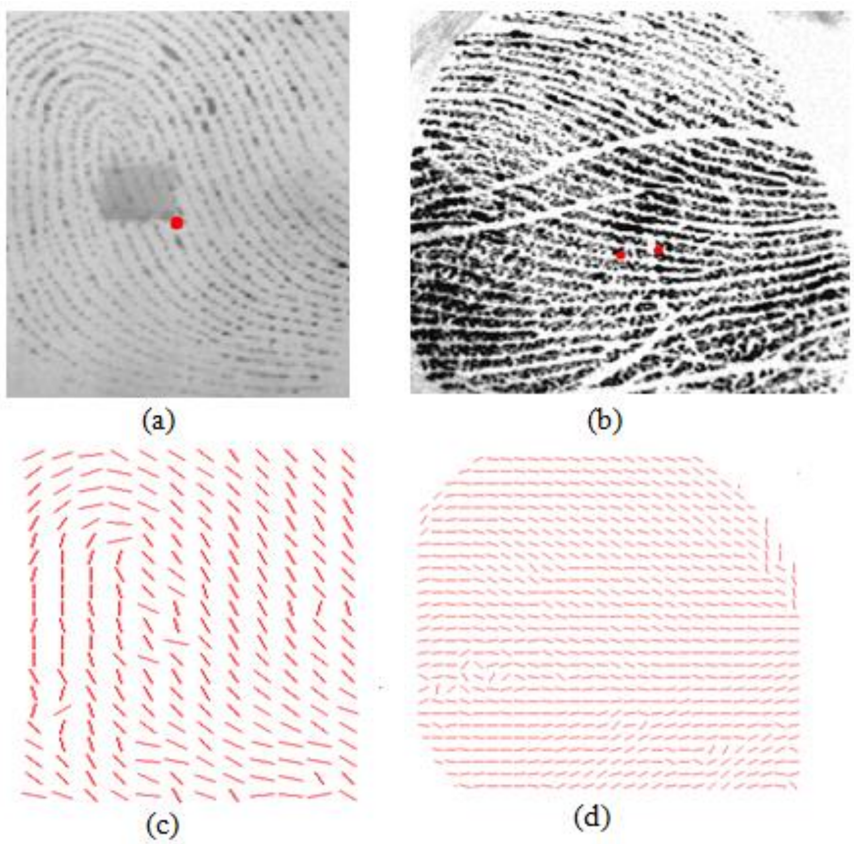

Figure 8. Singular Point Extraction for Poor Quality Images

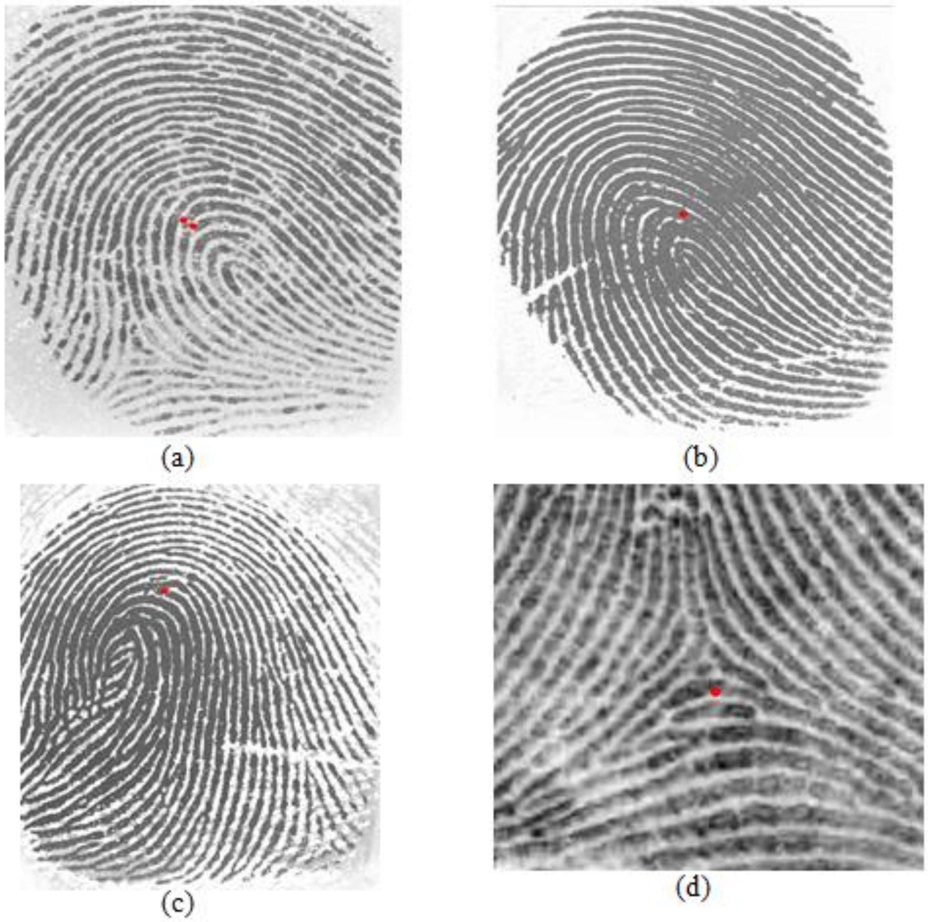

Figure 9. Results for Original Poincare Algorithm

5. Conclusion

This paper presents the experimental study of a modified Poincare Index method for fingerprint singular point detection. Obtained results from the experimental study indicate that the new algorithm improved on some of the existing ones through adequate and superior detection and extraction of singular points from good quality images of different pattern. The major limitation of the Poincare index method, which is forged detection, had been eliminated by the new algorithm. The new algorithm is also suitable for implementation with image of medium quality in which some common algorithms had suffered poor detections and extractions. Future research focuses at improving on the new technique to boost its performance with poor quality images.

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