New Minutiae Detection Algorithm from Fingerprint Image using the Improved Tracing on Ridge Curve

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Abstract

Among the verification systems using biometric information, the fingerprint-based system is well-known technique as uniqueness and immutability. However, there are some problems in the process of minutiae detection from fingerprint image. In this paper, new minutiae detection algorithm is proposed to solve those problems. New technique called tip tracing is added to trace the exact minutiae point position in the proposed algorithm. From the experiment results, we confirm that the proposed algorithm improves the minutiae extraction accuracy and performance of fingerprint verification.

Keywords: *Fingerprint, biometrics, minutiae detection, pattern recognition, image processing, image enhancement*

1. Introduction

Due to the development of computer and network, and increased usage of internet, leakage of personal information has become a serious social problem. Personal authentication such as token using password or key is changing the way of security to the form of biometric security. Biometric technology preserves a characteristic of permanent, *i.e.*, all people have the universality and time invariant. It has unique features that distinguish one from the other. Therefore, fingerprint is the most widely used biometric features today [1, 2].

Fingerprint identification system processes in three steps. It collects 2D image of fingerprints, and then it extracts specific information from them [3, 4]. Finally, similarity of the certain fingerprint information is measured by comparing it with information already stored in database. However, fingerprint identification system has a critical weakness in which the performance of verification is reduced drastically for a poor fingerprint minutiae.

In this paper, we propose new minutiae detection algorithm that can indicate exact location of minutiae points using the improved preprocessing based on the analysis of the previous research to solve the arising problems. It is also shown that the proposed algorithm can be implemented to robust fingerprint identification system.

2. Minutiae Detection

A Fingerprint is comprised of ridges and valleys. The ridges are dark area of the fingerprint and the valleys are white area that exists between the ridges. Minutiae are the

major features of a fingerprint, so comparisons of one fingerprint with another can be made using them. Maio and Maltoni [M&M] proposed a direct gray-scale minutiae extraction technique [5]. In order to detect the minutiae from the fingerprint image, first the segmentation of the fingerprint image should be done first of all. In M&M algorithm, the segmentation of boundary block between foreground and background are not accurate [6, 7].

In this study, continuous ridges can be traced using sliding window segmentation in pixel basis. Also, normalization process is included to adjust the brightness of the fingerprint image uniformly because there is wrong image information in minutiae detection due to errors. Therefore, the proposed scheme can locally adjust the brightness for faint fingerprint image.

3. Concept of the Proposed Algorithm

We have concentrated our implementation on minutiae based method. In particular we are interested only on row of the most important minutia features i.e. ridge ending and ridge bifurcation.

3.1. Definition

When the curve of the ridge is traced, the radius R of curvature is equal to the distance w of the neighboring ridge. In Figure 1, let P_k is the k-th point for current tracing. The parameters used in ridge tracing for minutiae detection include the orientation ϕ_k of the current ridge point P_k, the angle Φ_k between the current orientation ϕ_k and the next tracing ridge P_kP_{k+1}, and the angle Θ of the current ridge $P_{k-1}P_k$ and the next tracing ridge P_kP_{k+1}. P_{tk} is point as long as the step size according to the orientation of the points P. Angle ϕ_{k+1} is the next ridge orientation Φ_{k+1} and the next ridge P_kP_{k+1}.

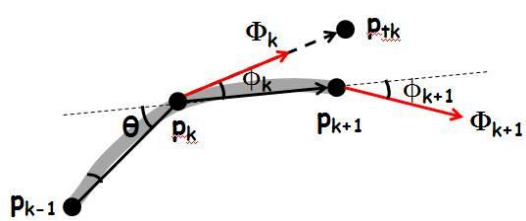

Figure 1. Definition of ridge line

3.2. Continuation

As depicted in the Figure 2, let P_k the k-th point for the current tracing ridge. Because the step size μ of tracing equals to the distance w of the neighboring ridge, we can obtain the angle θ_k as 45 degree from the angles of a triangle. In the Figure 2(a), therefore, the angle ϕ_k and ϕ_{k+1} are derived as 22.5 and -22.5 degree, respectively. If we keep on tracing the same ridge and the radius of curvature R is greater than the distance w of the neighboring ridge, as shown in the Figure 2(b), the angle of curvature A is calculated by *arctan(w/R)*. The angle B is be obtained from the triangle as in the equation 2. Also, angle θ_k is equal to angle A, and ϕ_k and ϕ_{k+1} are derived as angle $A/2$ and angle $-A/2$. Therefore, we can search next tracing position of the ridge within the range of $A/2$.

$$A = \tan^{-1}(w/R) \tag{1}$$

$$B = (\pi - A)/2 \tag{2}$$

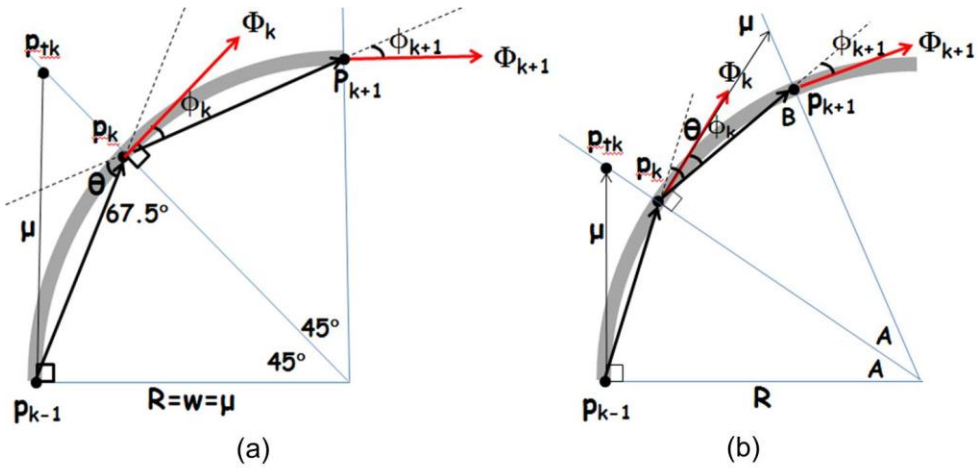

Figure 2. Continue tracing on the curved ridge (P_{k-1}, P_k, P_{k+1})

3.3. Termination

As shown in the Figure 3(a), when the curve of ridge ends with *termination*, the radius of curvature R is equal to the distance w of the ridge. The angle of neighboring ridge θ'_k and the angle of the current ridge Φ'_k becomes 6.1 and -16.4 degree, respectively. Also, the angle of the next ridge Φ'_{k+1} is calculated as -61.4 degree by a triangle. In the Figure 3(b), when the curve of ridge ends with *termination*, the radius of curvature R is greater than the distance w of the neighboring ridge, the angle of curvature A is calculated by *arctan(w/R)*. Angle B is be obtained from the triangle as shown in the equation 3.

$$B = \pi - (\pi / 2 + \phi_k) - A \tag{3}$$

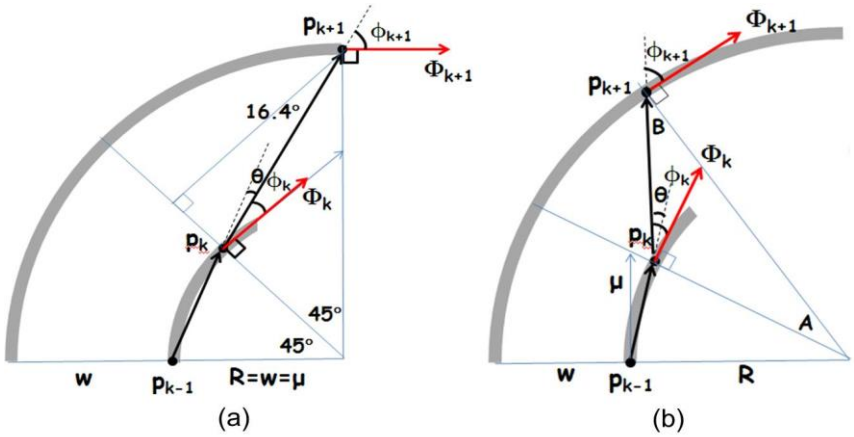

Figure 3. Termination for the curved ridge (P_{k-1}, P_k, P_{k+1})

Also, the angle θ_k is equal to the angle A, and ϕ_k and ϕ_{k+1} are calculated by triangle aspect ratio, resulting in the equations 4, 5 and 6.

$$\frac{\sin(\pi/2+\phi_k)}{R+w}=\frac{\sin B}{R} \tag{4}$$

$$\theta_k=\phi_k-\{\pi/2-(\pi-A)/2\}=\phi_k-\tfrac{1}{2}\tan^{-1}(w/R) \tag{5}$$

$$\phi_{k+1}=\pi/2-B=\phi_k+\tan^{-1}(w/R) \tag{6}$$

According to the conditions in the equation 7, the current ridge is terminated and its minutiae points are recorded by their current positions.

$$\phi_k^{'}=\cos^{-1}\frac{(R+w)w}{\sqrt{(2R^2+2Rw+w^2)(R^2+w^2)-2R^2(R+w)\sqrt{R^2+w^2}}} \tag{7}$$

3.4. Bifurcation

If an inner neighbor ridge is added and the radius R is greater than the distance w of the ridge, the angle A is the calculated as $arctan(w/(R+w))$, reflecting the ratio of the search window size w over the sum of the radius R and w. Also, the angle B between current the ridge and the next joined ridge as in the Figure 4(a) can be obtained as $\pi-(\pi/2-\Phi^{'}_k)+A$ by using a triangle as shown in the equations 8,9,10 and 11.

$$B=\pi-(\pi/2+\phi_k)-A \tag{8}$$

$$\frac{\sin(\pi/2+\phi_k)}{R+w/2}=\frac{\sin B}{R} \tag{9}$$

$$\theta_{ik}=\phi_k+\tfrac{1}{2}\tan^{-1}(w/R) \tag{10}$$

$$\phi_{ik+1}=\phi_k-\tan^{-1}(w/R) \tag{11}$$

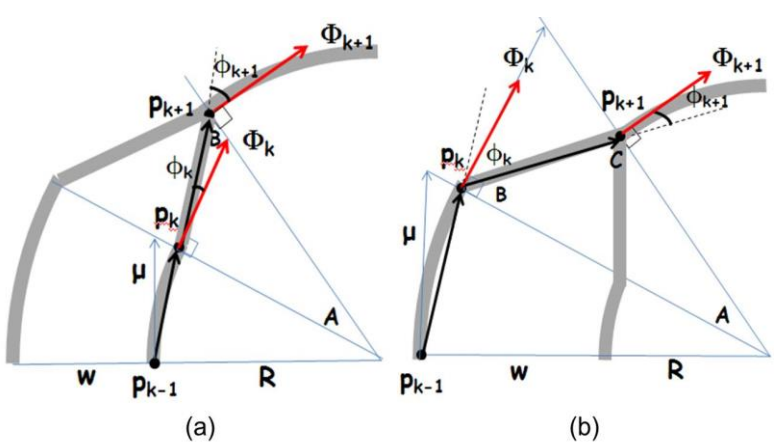

Figure 4. Bifurcation for the curved ridge (P_{k-1}, P_k, P_{k+1})

Therefore, the angle Φ_{ik} can be calculated as shown in the equation 12. In this case, it is called *inner bifurcation*, where the current ridge is bifurcation and the minutiae points are stored by their current positions.

$$\phi_{ik} = \cos^{-1} \frac{(2R+w)w}{\sqrt{(8R^2+4Rw+w^2)(R^2+w^2)-4R^2(2R+w)\sqrt{R^2+w^2}}} \tag{12}$$

In the Figure 4(b), called outer bifurcation, current ridge is bifurcation and register the minutia point. If an outer neighbor ridge is added and the radius R is greater than the distance w of the ridge, the angle A is the calculated as *arctan(w/(R+w))*, reflecting the ratio of the search window size w over the sum of the radius R and w. Also, the angle B between current the ridge and the next joined ridge can be obtained as $\pi/2-\Phi'_k$ using the equations 13, 14, 15 and 16.

$$B = \pi/2 - \phi_k \tag{13}$$

$$\frac{\sin(\pi - A - B)}{R+w} = \frac{\sin B}{R+w/2} \tag{14}$$

$$\theta_{ok} = \phi_k + \tfrac{1}{2}\tan^{-1}(w/R) \tag{15}$$

$$\phi_{ok+1} = \phi_k - \tan^{-1}(w/R) \tag{16}$$

Therefore, the angle Φ_{ok} can be calculated as shown in the equation 17. In this case, it is called *outer bifurcation*, where the current ridge is bifurcation and the minutiae points are stored by their current positions.

$$\phi_{ok} = \cos^{-1} \frac{(2R+w)w}{\sqrt{(8R^2+12Rw+5w\ )(R^2+2Rw+2w^2)-4(R+w)^2(2R+w)\sqrt{R^2+2Rw+2w^2}}} \tag{17}$$

4. Algorithm Description

We examined correlations between the distance ratio w/R and the angles Θ, Φ_k, and Φ_{k+1} by tracing curved ridge as shown in the Figure 5. If the radius of curvature R is greater than one and the angle Θ_{k+1} between the ridge and the next position of the ridge line is less than zero, the absolute value of the angle Φ_{k+1} between the neighboring ridge and the next tracing position is less than 25 degree. If these conditions are satisfied, then the tracing of the current ridge continues. In the same manner, if the radius of curvature R is greater than one and the angle Θ_{k+1} between the current ridge and the next tracing position is greater than zero, the absolute value of the angle Φ_{k+1} between the neighboring ridges and the next tracing position is greater than 45 degree. If the conditions are satisfied, then the current ridge tracing is terminated.

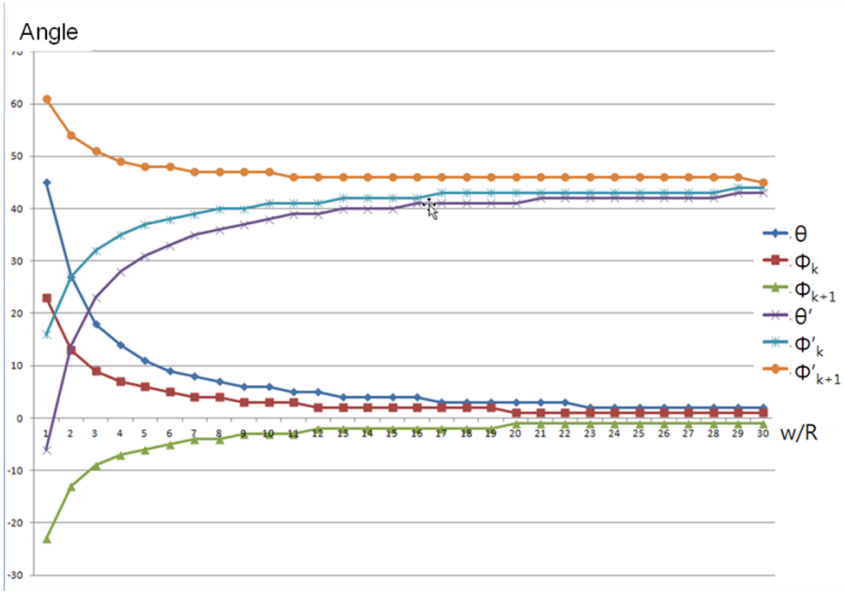

Figure 5. The distance ratio and angles by tracing ridge curve(termination)

In the case that the angle Θ_{k+1} is greater than zero, the absolute value of the angle Θ_{k+1} is greater than that of the angle Φ_{k+1} and the absolute value of the angle Φ_{k+1} is greater than 30 degree as shown in the Figure 6. In this case, the current ridge tracing produces *inner bifurcation*. Similarly, if the angle Θ_{k+1} is greater than zero and the absolute value of the angle Θ_{k+1} is less than that of the angle Φ_{k+1}, then the absolute value of the angle Φ_{k+1} is less than 30 degree. When the given conditions are satisfied, the current ridge tracing produces *outer bifurcation*.

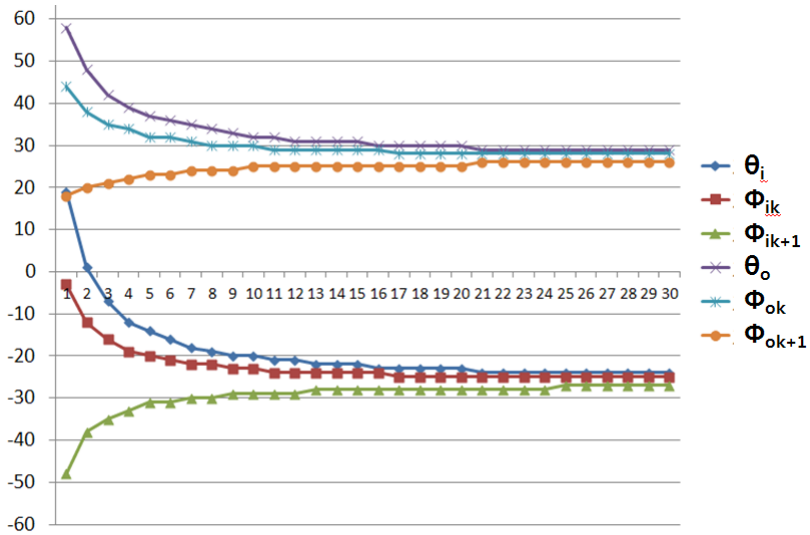

Figure 6. The distance ratio and angles by tracing ridge curve(bifurcation)

The newly proposed minutiae detection algorithm includes termination conditions as for the types of minutia. The pseudo code for next position tracing algorithm is as follows:

```
If (|θ|>60°) terminate
else if(θ k+1<=0 or |θ|<=10°){        // no termination
     if(|Φk+1|<40°) continue;
     else terminate; }
else if (|θ| < |Φk+1| ) {             // outer bifurcation
     if (|Φk+1|<25°) continue;
     else terminate;}
else if(|Φk+1|<15°) continue;         // inner bifurcation
     else termination;
```

If ridge tracing is terminated, register the current ridge position for minutiae point, depicted in the Figure 7. In this case, the current ridge position is recorded rather than the actual end point. And then, the next and more actual end point of the ridge should be traced. Therefore, tip tracing algorithm is added to find the location of the actual end point for minutiae.

(a) termination **(b) continue**

Figure 7. Tracing ridge termination and continuation

In our algorithm, tracing the current ridge is required to find the exact location of minutiae points in the current ridge. The pseudo code for tip tracking algorithm is shown as follows.

```
loop μ = 1 to w-1 do
  if distance (ptk,pk+1) > ϵ then break
end loop
pk = pk + μθ
Perform a step of ridge line tracing at pk, where μ=w
  if termination then record a minutia
  else continue ridge line tracing
```

5. Experiment and Result

In this paper, we performed experiments using the database called FVC2002 DB1. The minutiae detected using the algorithm in the previous research is shown in the Figure 8, in which they are not correct because errors are included in the curvature ridges. The Figure 9 shows the minutiae detection result without using tip tracing proposed in this study. It shows correct result in the curvature ridges, but not accurate at the end point of the ridge curve. Finally, as for the proposed minutiae detection algorithm adopting the tip tracing technique, it shows correct result in the curvature ridges and accurate at end point of the ridge curve as shown in the Figure 10.

Figure 8. Minutiae detection result by M&M algorithm

Figure 9. Minutiae detection result by the proposed algorithm without tip tracing

Figure 10. Minutiae detection result by the proposed algorithm with tip tracing

6. Concluding Remarks

We newly proposed a minutiae detection algorithm and the tip tracing technique from fingerprint image. The proposed algorithm can detect minutiae points with accuracy, even at the curved ridge and the outer area of fingerprint image. Also, it is available in detection process not only with accurate minutiae position but also with minimal error rate. As a

consequence, the proposed algorithm improves the minutiae extraction accuracy and performance of fingerprint verification. Once the fingerprint matching algorithm is added in near future, the fingerprint recognition system can be fully implemented.

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