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Lophoscopy with Thinning Algorithms for inimitable Fingerprint Processing

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Abstract -Biometrics is the automated method of recognizing a person based on their physiological and behavioral characteristics. It is considered to be the new digital key for the tech-savvy digital world. A biometric system operates in two modes, Identification and verification. There is a wide gamut of biometric modalities, of which, the fingerprints are popularly accepted as the unique technology in various fields and industries. This paper deals with three different thinning algorithms. The proposed work establishes the effect of thinning on fingerprints along with minutiae extraction and texture feature analysis. The thinning algorithms such as Zhang-Suens, Halls and Guo-Halls have been implemented to aggrandize the fingerprints for best quality. The thinning algorithms have been compared with respect to extraction of minutiae. The minutiae points obtained have been used to expound the precision rate of fingerprints after processing. The simulations have been carried out and the experimental results have been analyzed.

Keywords - ***Biometric modalities, Fingerprint,* Thinning, Minutiae, Minutiae extraction, Texture features, Precision rate.**

I. INTRODUCTION

There are several human distinguishable traits that fit the definition of biometrics. In order to be used for recognizing a person, the human trait needs to be unique and not subject to change. Fingerprints, for example, have been used for over one hundred years and, therefore, are generally well accepted as an extraordinary recognition technology. Other modalities such as Facial recognition, palm prints, Iris scans, voice recognition, DNA, signature, hand geometry and gait recognition [1] are also employed and used in many fields. Due to the irreproachable comportment of biometrics, it is considered as a desideratum. Fingerprint applications range from forensic departments for criminal investigations [2] to attendance systems and other security systems for various purposes [7]. A fingerprint of an individual can contribute to two aspects: individuality and identification. Enhancing and thinning of a fingerprint plays a vital role in identification, and the minutiae points prove to be riveting and a pivotal factor for fingerprints. Therefore, the need to process a fingerprint in a punctilious manner is of utmost importance to identify the vast number of patterns that are available. The exceptional facet of a fingerprint is its unique pattern which is composed of distinctive features. A fingerprint is composed of motifs of interleaved ridges and valleys [8]. According to Galton's system of classification, curvy lines which tend to form a loop, a whorl, a delta and an arch are called as ridges [3]. Ridges form the black lines and the valleys constitute the white portion seen in between the ridges.

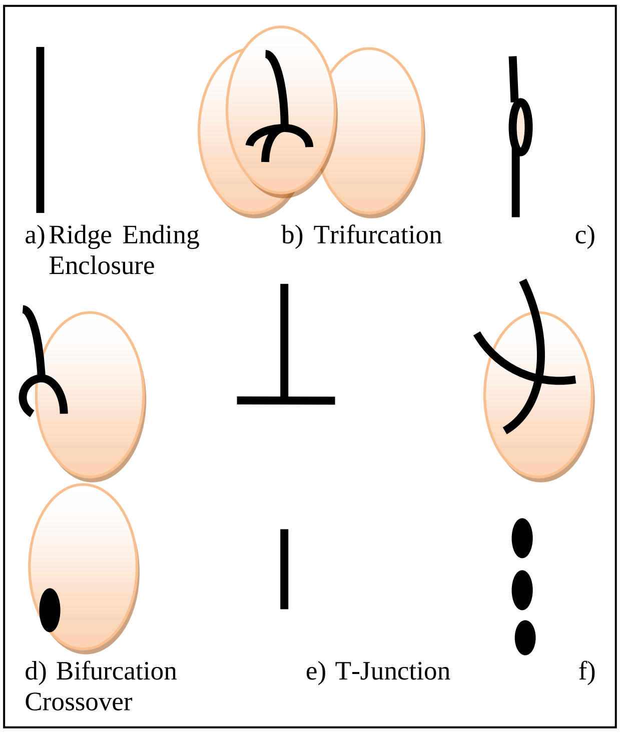

Figure 1. Minutiae

Minutiae are ancillary components of a fingerprint. They are classified as enclosures, crossover, dots [9], amongst many others as shown in Figure 1. But the main focus of this paper is on the terminations (Ridge Endings) and bifurcations (Splits in the ridges).

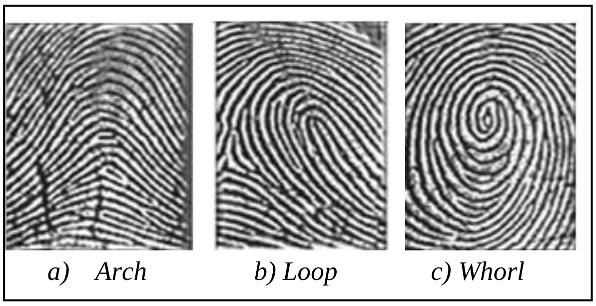

Figure 2. Basic Ridge Patterns

Figure 2 shows the basic ridge patterns that can be formed in a fingerprint. An arch is a pattern when ridges enter from one side, surges up in the center and exits on the other side of the

International Journal of Data Mining Techniques and Applications
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finger. Loops are ridge patterns which enter from one side, makes a rise and egresses on the same side from which it entered. A circular formation of the ridges is called as a Whorl. Recognition of fingerprint is done by various techniques such as minutiae based technique, pattern or ridge based technique and correlation based technique. In the minutiae based technique, the fingerprints are matched based on the minutiae points like the terminations and bifurcations. This technique is widespread and popularly used for the verification and identification of fingerprints. The pattern based technique employs the use of patterns formed by ridges such as the loops, arches and whorls. Correlation based technique compares, matches and identifies fingerprints by computing the correlation of each pixel in a fingerprint. This technique is unlikely to be used due to its computational complexity and excessive time consumption. This paper deploys the minutiae based technique and processes a fingerprint in two stages. Preprocessing is done first, followed by the post-processing stage. Three thinning algorithms have been used in the pre-processing stage to augment the quality of fingerprints. The post-processing stage deals with the extraction of minutiae from the enhanced fingerprint. The paper is organized as follows: Section 2 gives a brief study of image processing, and the algorithms which helps to elucidate the thinning process. Section 3 explains the analysis of texture features which expounds that thinning is an inexorable process for fingerprint processing. Section 4 delineates the extraction of minutiae with respect to the thinning algorithms used. Section 5 shows the various computational results obtained and section 6 concludes the work done with the future work that can be implemented.

II. IMAGE PROCESSING

A high quality, noise free fingerprint image is an exigent task to attain, if preprocessing of the image is not done. All fingerprints consist of relative amount of dirt, scars and noise [10]. Therefore to remove noise and enhance a fingerprint image, preprocessing is mandatory [4]. The preprocessing stage is further divided into three steps. They are loading an image, binarization and thinning. An image before being loaded into a system is checked for its type. An image type can either be RGB or grayscale. A RGB image is that which defines the red, green and blue components of a single pixel in the matrix. The RGB image is otherwise called as a true color image [11]. A grayscale image consists of 256 values. It has values ranging from 1 to 255. A grayscale image is also called as an intensity image due to its values representing intensities within a range [11]. Once the type of the image is checked, it is loaded as a raw image into the system. Binarization is the next process which is executed in the preprocessing stage. This process involves the conversion of the raw image into a binary image consisting of only 0’s and 1’s. Binarizing an image also gives more clarity by removing certain amount of noise from the fingerprint. A grayscale image is converted to a binary image by comparing each pixel value of the former to a threshold value [18]. If the pixel value is lesser than the threshold value then it becomes zero, and if it is higher, it takes the value one.

a) Load Image *b) Raw Image* *c) Binarize*

Figure 3. Loading and Binarization

Figure 3 shows the first two steps of the preprocessing stage. In preprocessing the flow of frequency is obtained by constructing a direction map. The direction map calculates the local flow orientation in each local window with size (block size x block size) [5]. The direction map differs from one fingerprint to the other. The next step in preprocessing which is vital is the thinning process. In a binarized image, the ridges of the fingerprint are usually thick which makes it difficult for plotting of minutiae. Thinning is the process of reducing the width of each ridge to a one pixel value [6]. A minutiae point is better extracted in a perfectly thinned image rather than in a binarized image. Skeletonization is a form of thinning where the pixels on the boundary of the image are removed but the continuity is preserved.

A. Thinning Algorithms

Zhang-Suen’s algorithm [6, 18] is an iterative process executed with many passes over each pixel of the fingerprint. This process is executed till there is no more change on the ridge width of the fingerprints. Zhang-Suen’s algorithm is applied on a block of pixels in a chosen matrix, with a center value 1 and having 8 neighbors. The summation of all the values of the chosen matrix is given by B(p). A(p) is given by 8-neighborhood of the matrix p, containing exactly one 4-connected component of 1’s.

Table 1. Algorithm: Zhang-Suen’s algorithm for thinning

```
While points are deleted do
 for all pixels p(i,j) do
 if (2<= B(p) <=6) & (A(p) == 1)
         Apply one of the following
            a)    (i-1)*(i,j+1)*(i+1,j) = 0 in odd iterations
            b)    (i-1, j)*(i, j+1)*(i, j-1) = 0 in even iterations
          Apply one of the following
            a)    (i,j+1)*(i+1,j)*(i,j-1) = 0 in odd iterations
            b)    (i-1,j)*(i+1,j)*(i,j-1) = 0 in even iterations
        then
            Delete p(i,j)
   end if
 end for
end while
end
```

The Hall’s algorithm [6, 18] is a parallel thinning algorithm that thins the ridges of the fingerprint and at the same time preserves the connectivity of the image. This algorithm is partially serialized by breaking it into two distinct sub-

Volume: 03 Issue: 02 December 2013, Page No.89-94
ISSN: 2278-2419

iterations. Unlike the Zhang-Suen's algorithm, the Hall's algorithm checks for the deletability of the pixel at the initial stage, and then the ridges are thinned pixel by pixel. B(p) and A(p) are the sum of all values and the number of 0 to 1 transitions respectively.

Table 2. Algorithm: Hall's algorithm for thinning

```
While points are deleted do
 for all pixels p(i,j) do
    Determine deletability of pixel
     if (1< B(p) <  7) & (A(p) == 1)
          then  p(i,j) = deletable
       end if
 end for
  for all pixels p(i,j) do
```

The Guo-Hall's algorithm thins the ridges of the fingerprint by using two sub iterations [6]. N(p1) helps to detect the end points in a fingerprint image and also produce thinner ridges. The value for N(p1) is given as the minimum of $N_1(p1)$ and $N_2(p1)$. $N_1(p1)$ is the summation of the logical OR values starting from p9 in the clockwise direction. $N_2(p1)$ is the summation of the logical OR values starting from p2 in the clockwise direction. C(p1) is the number of 1's in the 8-connected neighborhood of the chosen matrix. Three conditions are checked, and if they satisfy, the pixels are deleted.

Table 3. Algorithm: Guo-Hall's algorithm for thinning

While points are deleted do
  for all pixels p(i,j) do
    if (a) C(p1) = 1;
      (b) 2 <= N(p1) <= 3;
      (c)Apply one of the following:
        1. ((i-1,j) V (i-1,j+1) V $\overline{(i+1,j+1)}$) V (i,j+1) = 0 in odd iterations
        2. ((i+1,j) V (i+1,j-1) V $\overline{(i-1,j-1)}$) ^ (i,j-1) = 0 in even iterations
      then
        Delete pixel p(i,j)
    end if
  end for
end while
end

It has been observed that Zhang-Suen's algorithm gave a thinned image, whereas the Hall's algorithm produced a skeletonized image. The ridges were thinned considerably in Guo-Hall's. The minutiae extracted for the three algorithms gave a result where the minutiae points were reduced profusely, thereby helping in fast processing of fingerprints.

III. TEXTURE FEATURE ANALYSIS

Texture features of a fingerprint help in adding relevant and adequate information for a given fingerprint image. Three texture features like the entropy, Correlation coefficient and energy has been computed to show the effect of thinning on fingerprints. Entropy is classified as a statistical measure of randomness that can be used to characterize the texture of an input image [14]. Entropy is defined as [11]

$$-\text{sum } (p.*\log^2 (p)) \qquad (1)$$

In the above equation, p refers to the value obtained after the normalization of the image.

The 2-D Correlation Coefficient is computed in two steps: The first is to remove the noise in an image by applying a 2-D median filter [14]. The second step is to apply the correlation coefficient function to the filtered image. The correlation coefficient for an image is given by [11]

$$r = \frac{\sum_m \sum_n (A_{mn} - \overline{A})(B_{mn} - \overline{B})}{\sqrt{(\sum_m\sum_n(A_{mn} - \overline{A})^2)(\sum_m\sum_n(B_{mn} - \overline{B})^2)}} \qquad (2)$$

Where $\overline{A}$ and $\overline{B}$ are the mean values of A and B.

The retained energy in a given image is computed by using a wavelet toolbox. The input image is subjected to level 5 Daubechies wavelet decomposition [14]. The Shannon entropy is used with a threshold method called Balance Sparsity-norm to compress the image and thereby find the energy retained in the image after decomposition. The values of each texture feature are obtained for images before and after thinning. It has been deduced that the values obtained after the thinning process is better than the values acquired before thinning. When the noise is reduced and the quality of the image is good and consistent throughout, the value of the texture features such as entropy and correlation coefficient is said to reduce, which is inversely proportional to the increase in energy retained in an image. This signifies that thinning is a vital process that revolutionizes a fingerprint quality. The results of the texture features have been shown in table 4 and table 5 in section 5.

IV. MINUTIAE EXTRACTION

The crucial feature found in every fingerprint which helps to match two fingerprints precisely based on their pixel position is termed as minutiae [12]. Minutiae extraction is the process of unsheathing these small points from the fingerprint [13]. In this paper, the terminations and bifurcations are the two types of minutiae which are extracted. The thinning process plays a key role in the accurate plotting of minutiae. The thinned fingerprint image is split into a N X N matrix. The centroid for each chosen matrix is found by using the sliding neighborhood operation [17]. The position of the centroid pixel varies for

International Journal of Data Mining Techniques and Applications
Volume: 03 Issue: 02 December 2013, Page No.89-94
ISSN: 2278-2419

each matrix, depending on whether it is an odd matrix, an even matrix or a customized N X N matrix chosen by the user. Once the centroid is found, its value is checked. If the value of the centroid is one, then the summation of all the pixels in the chosen matrix is done and then subtracted by 1 [17]. But if the value of the centroid pixel is zero, then the matrix is deleted. This process is done for all the pixels in each chosen N X N matrix. Once the values of the respective pixels are found, they are compared to the values in the crossing number technique to check if the pixel is a ridge ending or if the ridge is branched. The simulations were done using a 3 X 3 matrix and the minutiae were extracted by comparing the pixel values with the crossing number method.

A. Crossing Number Technique

The crossing number method [15, 16] is implemented to find the minutiae points in a fingerprint. The algorithm works for all minutiae types by having a number for each of it. For example, the number 0 is given for an isolated point or a dot, number 4 is given for a crossing ridge and so on. Similarly for Terminations the crossing number has a value 1 and for bifurcations the value is 3. Crossing Number is defined as half of the sum of differences between intensity values of two adjacent pixels [15]. It is given by

$$CN=1/2\sum^{8}_{i=1}[|P_i - P_{i+1}|] \quad (3)$$

For any chosen pixel in the matrix, the 8 neighbors of the pixel are scanned in the anticlockwise direction.

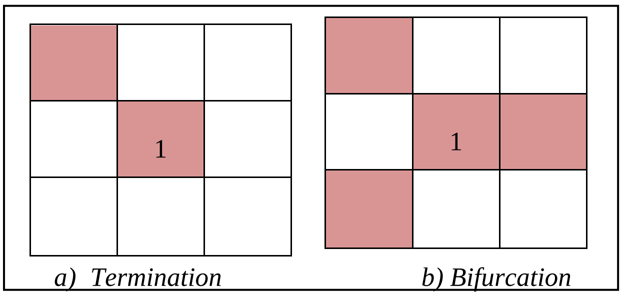

Figure 4. Minutiae Extraction using Crossing Number

Figure 4 shows the centroid pixel with the value 1 and having one neighborhood which is termed as Termination. Bifurcation is given when the center pixel has the value 1 with three neighborhoods.

V. RESULTS

The simulations are carried out using MATLAB and the fingerprint database has been obtained from biometrics.idealtest.org. The implementation of the thinning process is emphasized by computing the texture features of the fingerprint. The minutiae extraction is done in a graphical user interface and the results have been obtained successfully. Three fingerprint images were taken for observation and their computational time is calculated. The precision rates were also obtained to elucidate that thinning is an incumbent process, and to define the accuracy of the three algorithms used in this paper.

Table 4: Texture feature values before thinning

Images	*Before Thinning with Salt and Pepper Noise*		
	En	***CC***	***Er***
Fp1	4.97	0.94	97.36%
Fp2	4.71	0.95	97.14%
Fp3	4.31	0.94	96.67%

The Fingerprints taken for observation were .bmp images. Salt and pepper noise were injected to these raw fingerprint images and processed to find the texture values. Table 4 shows the values obtained for each of these fingerprints before thinning with the salt and pepper noise added to them.

Table 5: Texture feature values after thinning

Images	*After Thinning*		
	En	***CC***	***Er***
Fp1	0.74	0.76	99.99%
Fp2	0.84	0.81	99.97%
Fp3	0.86	0.82	99.92%

The terms En, CC and Er in Table 4 and Table 5, stands for Entropy, Correlation coefficient and Energy respectively. Table 5 shows the thinning applied on the three fingerprint images. The values of the texture features such as Entropy and correlation coefficient decreases with the increase in the quality of the image, whereas the Energy retained in the image increases with the increase in the quality of the image. The results obtained after thinning significantly stipulates that thinning enhances the quality of the image by removing a considerable amount of noise from the image. And thereby helps to attain a high quality image that can aid in the post-processing steps. The sequential steps from loading a fingerprint to obtaining the extracted minutiae points is given in the following set of GUI figures.

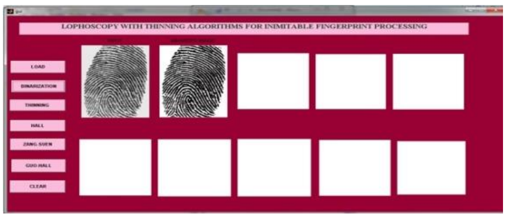

Figure 5. Loading and Binarization

The first step in the processing of a fingerprint is to load an image by applying ink over the finger and scanning it directly on the computer or by using a griaule's fingerprint scanner to obtain the fingerprint image. This raw image is binarized so that it is easily processed. Figure 5 shows the process of loading a fingerprint and converting it into an image of 0's and 1's. The converted binary image is easy to store and manipulate.

Figure 6. Morphological Thinning

The next process shown in figure 6 is the application of the morphological operation ‘thin’ to the binarized fingerprint image. This operation of thinning is done infinitely till there occurs no change in the fingerprint image.

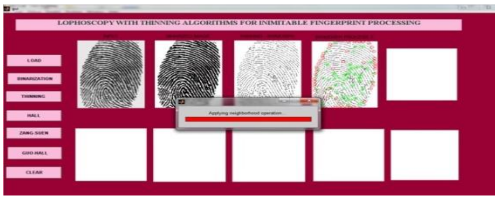

Figure 7. False minutiae removal and Application of Hall’s Algorithm

The minutiae points generated after removing the spurious minutiae from the morphologically thinned image is obtained in figure 7, by the procedure of distance computation.

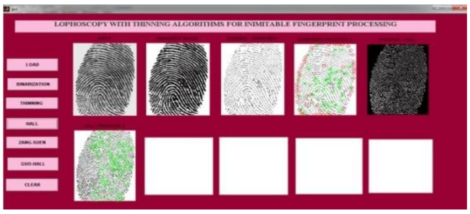

Figure 8. Thinning and Spurious Minutiae removal by Hall’s Algorithm

The neighborhood operation is carried out on the binarized image to effectuate the Hall’s thinning algorithm.

Figure 9. Thinning and false Minutiae removal by Zhang-Suen’s Algorithm

Figure 9 shows the Zhang-Suen’s algorithm applied on the binary image to produce a thinned image. The distance computation method is again used to remove the false minutiae.

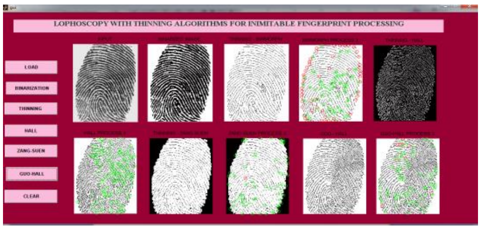

Figure 10. Thinning and Spurious Minutiae removal by Guo-Hall’s Algorithm

The thinning done by Guo-Hall’s algorithm and the respective spurious minutiae removal is shown in Figure 10. It can be deduced that in morphological thinning, a relatively large amount of minutiae appear as compared to Zhang-Suen’s, Hall’s and Guo-Hall’s. The minutiae points were reduced to a large extent after the thinning algorithms were applied. The variation and decrease in the minutiae points can be seen clearly in the results produced. The computational time and the precision rate have been evaluated for three fingerprints. The computational time has been enumerated to show the variations in the timings of the thinning algorithms done, and to establish that thinning is not an exigent process. The computation time is given in seconds for each step of the fingerprint process. Table 6 shows the time taken for each step in the preprocessing and the post-processing stages.

. **Table 6:** Computation Time

Steps	***FP1***	***FP2***	***FP3***
Binarization	0.5	0.4	0.5
Morphological Thinning	0.5	0.7	0.8
Minutiae Extraction For Morphological Thinning	6.0	9.1	12.7
Hall’s Thinning	10.0	10.2	12.7
Minutiae Extraction for Hall’s Thinning	21.0	20.1	23.8
Zhang-Suen’s Thinning	12.4	14.5	15.1
Minutiae Extraction for Zhang-Suen’s Thinning	4.1	4.2	7.3
Guo-Hall’s Thinning	8.9	8.6	8.9
Minutiae Extraction For Guo-Hall’s Thinning	22.1	27.0	30.7
Total	85.5	94.8	112.5

The precision rate is defined to evince the accuracy of computation in each of the thinning algorithms used. And the precision rate is calculated by taking into account the TP and FN for the process. TP and FN stands for True Positive and False Negative. True Positive takes the value of the number of minutiae points extracted properly from the fingerprint. False

Volume: 03 Issue: 02 December 2013, Page No.89-94
ISSN: 2278-2419

Negative is the number of minutiae which are missed being detected from the fingerprint. The precision rate is given by

$$\text{Precision} = \frac{TP}{TP + FN} \times 100 \qquad (4)$$

The following table shows the precision rate for the three thinning algorithms used. The computation has been done and the percentage for each has been given in table 7.

Table 7: Precision Rate

	Thinning Algorithms		
	Zang-Suen's	***Hall's***	***Guo-Hall's***
Fp1	85.91%	84.11%	85.0%
Fp2	80.64%	79.21%	81.61%
Fp3	88.73%	86.23%	88.46%

It can be deduced that Zhang-Suen's Algorithm has the highest precision rate when compared to the other two thinning algorithms.

VI. CONCLUSION

The simulations are performed successfully by binarizing, thinning and after which the minutiae are extracted from the fingerprint image. The success of any fingerprint recognition strongly relies on the precision obtained after the thinning and the minutiae extraction phases of a fingerprint. To ensure unsurpassed thinning, three algorithms were implemented to find the comparisons in the thinning of the ridges. Experimental results showed that Zhang – Suen's algorithm was faster and more efficient. Inorder to obtain more accurate results, an improvement in the image binarization step and minutiae matching algorithm could be introduced with fingerprints with more noise such as scars and cuts. The texture features could be more extensively studied as a future work.

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