Fingerprint Minutiae Extraction

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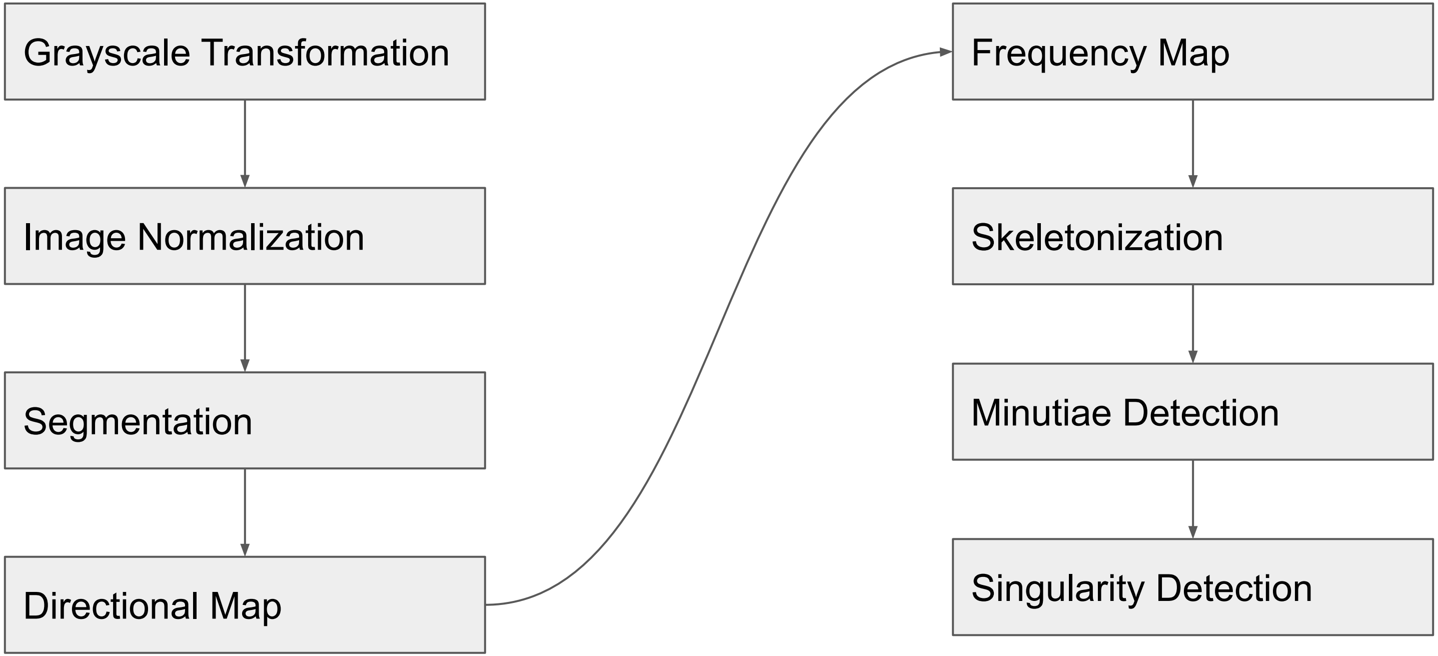
Introduction

- A fingerprint-based biometric system is essentially a pattern recognition system that recognizes a person by determining the authenticity of their fingerprint.
- A fingerprint-based biometric system can be called a:
  - **Verification System** which authenticates a person's identity by comparing the captured fingerprints with their own template fingerprint stored in the system.
  - **Identification System** which recognises an individual by searching the entire template database for a match.
- Our project subjects to a unique fingerprint matching algorithm based on the minutiae extraction technique, which consists of two essential parts, preprocessing of the fingerprint image to improve its quality and extraction of the signature.

Introduction continued

- The performance of minutiae extraction algorithms and other fingerprint recognition techniques relies heavily on the quality of the fingerprint images, and thus, pre-processing is a very important step.

Stages in Minutiae Extraction



Grayscale Transformation

- A fingerprint sensor usually returns a color image of the fingerprint, but for this algorithm, the color planes are not required for processing.
- So, each pixel will be represented on 8 bits (gray levels) instead of 24 bits for the color image (RGB levels).
- This step makes it possible to optimize on the general appearance of the image and facilitates biometric processing.

Image Normalization

- The main goal of normalization is to reduce the variance of the gray level value along the ridges to facilitate subsequent processing steps.
- Normalization is performed locally on each block according the following steps:
    - Averaging

$$M = \frac{1}{n \times m} \sum_{i=0}^{n-1} \sum_{j=0}^{m-1} I(i, j)$$

    - Variance Calculation

$$V = \frac{1}{n \times m} \sum_{i=0}^{n-1} \sum_{j=0}^{m-1} (I(i, j) - M)^2$$

Image Normalization continued

- Calculating the normalized gray level for each pixel

$$N_i(x, y) = \begin{cases} M_0 + \sqrt{\dfrac{V_0 \times (I(x, y) - M_i)^2}{V_i}} & I(x, y) > M_i \\ M_0 - \sqrt{\dfrac{V_0 \times (I(x, y) - M_i)^2}{V_i}} & otherwise \end{cases}$$

Segmentation

- Segmentation is necessary in order to eliminate the edges of the image and areas that are too noisy.
- It is based on the calculation of the variance of gray level in previous step for each block of size $W \times W$.
- The root of the variance of each block is then compared with a threshold T, which then decides whether the block is to be considered as the background of the image and excluded from subsequent processing, if the value is less than the threshold.
- This step makes it possible to reduce the size of the useful part of the image and subsequently optimize the minutiae extraction phase.

Directional Map

- The directional map defines the local orientation of the striates in the fingerprint impression.
- The estimation of orientation is a fundamental step in the process of image enhancement based on Gabor's filtering.
- Sobel filters are used to compute the gradients $G_x(i,\ j)$ and $G_y(i,\ j)$ according to the formulas:

$$G_x = V(x,\ y) \times \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad G_y = V(x,\ y) \times \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

Directional Map continued

- Thus, the local direction in the vicinity V, in the horizontal Vx(i, j) and vertical Vy(i, j) directions can be estimated as:

$$V_x(i,\ j)\ =\ \sum_{u=i-\frac{W}{2}}^{i+\frac{W}{2}}\ \sum_{v=j-\frac{W}{2}}^{j+\frac{W}{2}} 2\cdot G_x(u,\ v)\cdot G_y(u,\ v)$$

$$V_y(i,\ j)\ =\ \sum_{u=i-\frac{W}{2}}^{i+\frac{W}{2}}\ \sum_{v=j-\frac{W}{2}}^{j+\frac{W}{2}} \left((G_x(u,\ v))^2\ -\ (G_y(u,\ v))^2\right)$$

Directional Map continued

- The estimation of the local orientation in the neighbourhood V is $\theta(i, j)$ such that:

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

Frequency Map

- In addition to the directional map, we must have the local estimation of the frequency map to be able to construct the Gabor's filter.
- The frequency map is an image of the same size as the fingerprint image and represents the local frequency of the streaks.
- The frequency is calculated by the ratio $1 / T$ where T represents the period calculated between two successive extrema i.e. the set of successive maxima and minima.
- The maxima and minima are centers of the streaks and valleys respectively.
- The maxima Mi and minima mi are determined by detecting the zero crossing of the derivative of the vector V.
- If the difference between a maxima Mi and minima mi is less than a threshold T, then we consider that Mi corresponds to noise is eliminated.

Gabor Filter

- Gabor filters have both frequency-selective and orientation-selective properties and have an optimal joint resolution in both spatial and frequency domains.
- The filter used here is the Gabor filter with even symmetry and oriented at 0 degrees.

$$h_b(x_\theta,\ y_\theta;\ \theta,\ f) = e^{-\frac{1}{2}\left(\frac{x_\theta^2}{\sigma_x^2} + \frac{y_\theta^2}{\sigma_y^2}\right)} \cdot \cos\left(2\pi f x_\theta\right)$$

- To obtain other orientations, it’s sufficient to carry out a rotation of the coordinate axes.

Gabor Filter continued

- The resulting image will be the spatial convolution of the original normalized image and one of the base filters in the direction and local frequency from the two-directional and frequency maps.

Skeletonization

- The process involves using morphological erosion operations to remove redundant pixels from the ridges, leaving only one-pixel wide ridges.
- The resulting skeleton can be used to extract the minutiae points of the fingerprint for identification purposes.

Minutiae Detection

- There are two types of minutiae points in a fingerprint: ridge endings and bifurcations.
- In this project, we use cross number method for detecting minutiae points.
- The method involves analyzing 3 x 3 pixel blocks and calculating the crossing number based on the following formula:

P_1	P_2	P_3
P_8	P	P_4
P_7	P_6	P_6

$$CN(P) = \frac{1}{2}\sum_{i=1}^{8}|P_i - P_{i-1}|$$

$$with\, P_0 = P_8 \; and \; P_i \, \epsilon \, \{0, 1\}$$

Minutiae Detection continued

- If a pixel on the boundary of the block crosses the ridge once, a ridge ending is detected.
- If a pixel on the boundary crosses the ridge three times, a ridge bifurcation is detected.
- There are alternative techniques for minutiae extraction that work directly on gray-scale images without the need for binarization and thinning.
- These methods can preserve more information from the original image and may be more efficient in terms of time.

Singularity Detection

- The Poincaré index method is used to detect singularities in fingerprints.
- The method involves computing the orientation field (G) and position ([i,j]) of elements in the fingerprint.
- A closed path (C) is defined as an ordered sequence of elements with [i,j] as an internal point.
- The Poincaré index assumes discrete values of 0°, ±180°, and ±360° on closed curves.
- 0° is not part of any singular region, while 360° is part of a whorl type and 180° is part of a loop type singular region.
- -180° belongs to a delta type singular region.

Works Cited

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