Applying Computational Geometry on Fingerprint Recognition

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1 Purpose of research

Automatic fingerprint identification systems (AFIS) provide widely used biometric techniques for personal identification. Fingerprints have the properties of distinctiveness or individuality, and the fingerprints of a particular person remain almost the same (persistence) over time. These properties make fingerprints suitable for biometric uses. AFISs are usually based on minutiae matching. Minutiae, or Galton's characteristics are local discontinuities in terms of terminations and bifurcations of the ridge flow patterns that constitute a fingerprint. These two types of minutiae have been considered by Federal Bureau of Investigation for identification purposes. AFIS based on minutiae matching involves different stages:

1. **fingerprint image acquisition;**
2. **preprocessing of the fingerprint image (binarization, denoising, ridge extraction);**
3. **feature extraction (e.g. minutiae) from the image;**
4. **matching of fingerprint images for identification.**

Existing AFISs face two critical problems. First is the preprocessing phase is known to consume almost 90-95% of the total time of fingerprint identification. That is the reason a considerable amount of research has been focused on this area. Second is the fingerprint distortion change geometric relationship among minutiae. This change makes minutiae matching quite difficult, meanwhile, decreases accurate of AFISs so as to not satisfy some strict applications (e.g. Bank Security System, etc.).

The purpose of this research focuses on reducing preprocessing time and designing a robust matching algorithm with less effect of distortion using computational geometry methods.

2 Progress has been done

The research on reducing preprocessing time has finished. The crucial idea of our methods is Euclidean distance transform. The same feature of Euclidean distance transform can be used for all binarization, denoising and ridge extraction which in real application can save a lot of time. In what follows we describe our new methods in binarization and denoising respectively.

2.1 A Near-Linear Time Algorithm for Binarization of Fingerprint Images using Distance Transform

Up to now, there has been much in the literature with regard to fingerprint binarization. Most of them, however, are heuristics in that they do not start with a definition of an optimal threshold. In contrast, we define a condition for an optimal threshold based on equal widths of ridges and valleys.

The fingerprint images are characterized by almost equal width ridges and valleys. We use this particular characteristic of the fingerprint image for binarization. Measuring the width for arbitrary shapes is a difficult, non-trivial problem. Fortunately, this non-trivial task can be solved by Euclidean distance transform. With analysis on both continuous and discrete domain, we find the total distance transform value (DT) is proportional to the square width of ridge (and valley). This implies that with increase of threshold t, DT of ridges ($DT_{0,1}$) increases and DT of valleys ($DT_{1,0}$) decreases. So, $DT_{1,0}$ and $DT_{0,1}$ can intersect only once and evidently, $DT_{1,0}$ is equal to $DT_{0,1}$ when ridge and valley have same width. That is, the optimal value of threshold is reached when $DT_{0,1} = DT_{1,0}$. Then, we have the following definition:

Definition: *The optimal threshold can be two values t_1 and t_2 such that $t_2 - t_1 = 1$ and the sum total of $DT_{1,0}$ values is greater than the sum total of $DT_{1,0}$ values at t_1 and their relation reverses at t_2.*

With this definition, our method does binary search in gray-scale interval $[0, M]$ and halts at the optimal threshold t_1 (or t_2) which satisfies the above definition. Since we employ a Euclidean distance transform algorithm in optimal $\theta(N^2)$ time here. The total time complexity of the binarization process is $O(N^2 \log M)$. More specifically, due to M being a constant in practice, the algorithm for binarization runs in time that is linear in the number of pixel entries which is $O(N^2)$.

2.2 A Linear Time Algorithm for Binary Fingerprint Image Denoising using Distance Transform

The performance of fingerprint recognition relies heavily on the quality of the input fingerprint image. However, in practice, due to skin conditions (e.g., wet or dry), sensor noise, incorrect finger pressure, and inherently low-quality fingerprints, a significant percentage of fingerprint images contain a lot of noise. Noises in fingerprint images fall into two categories: impulsive noise ("salt and pepper" noise) and useless components. Note that useless components are often mistaken for the terminations that are an essential minutia of a fingerprint. Mathematical Morphology (MM) is a powerful tool in image processing. We propose a linear time algorithm to eliminate impulsive noise and useless components, which employs generalized and ordinary morphological operators based on Euclidean distance transform. There are two contributions. The first is the simple and efficient MM method to eliminate impulsive noise, which can be restricted to a minimum number of pixels. We know the performance of MM is heavily dependent on structuring elements (SEs), but finding an optimal SE is a difficult and nontrivial task. So the second contribution is providing an automatical approach for choosing appropriate SEs to eliminate useless components. We have developed a novel algorithm for the binarization of fingerprint images. The information of distance transform values can be obtained directly from the binarization phase.

To eliminate the impulsive noise, we use generalized morphological operators (GMO) which have more advantages than ordinary morphological operators (OMO). 1. The GMOs have controllable strictness, and thus excessive erosion and dilation can be prevented; 2. The GMOs can adapt itself to the orientation and shape of fingerprint without adopting many directional operators; 3. Using GMOs is that it needn't apply a closing to refill, as happens with the ordinary morphological operation. With these advantages, GMOs still have a problem that it is time consuming for AFISs. The naive GMO is a $O(N^2 \times d^2)$ time algorithm, where d is the radius of structuring element (SE). Euclidean distance transform value can be used to represent a "circular" SE, then we reduce the time complexity of algorithm to $O(l \times d^2)$, where l is the minimum number of pixels processed by GMO. But, this GMO is not a linear time algorithm yet owning to the strictness. Integral image can easily solve this problem. Note that, it is a very fast linear time complexity algorithm. Thus, with new representation of binary fingerprint image by Euclidean distance transform and integral image, GMOs can eliminate impulsive noise in $O(N^2)$ time.

Some fingerprint images contain useless components, which are often mistaken for the terminations. Thus, AFISs recognize the fingerprint with useless components as a distinct print. In order to eliminate useless components, a good SE is necessary. There are several methods to find the optimal or adaptive SEs. None of them, however, start with a definition of appropriate SEs. With analysis on both continuous and discrete domain, we find the average distance transform value is less than but approximates to one-forth the widths of the ridges. Following this observation, we have the following lemma:

Lemma: *When an isotropic SE satisfies the following condition:* $max(w_{useless}) \leq 2d \leq mean(w_{ridge})$*, the useless components can be eliminated, but some eroded ridges of the fingerprint shall remain.*

Our strategy is to take information from the original image I with useless components and the eroded image I_e by using the SE that satisfies Lemma, in which useless components are eliminated completely but fingerprints can not totally be deleted although they are affected to some degree. Then, we integrate fingerprint images I and I_e to restore the expected image I_r without useless components. Eroding image using OMO represented by Euclidean distance transform takes $O(l)$ time. Integrating two images is $O(N^2)$ time. So, this phase also is linear time.

3 Present work

The evident effect of fingerprint distortion is the local compression, stretching or rotation of the fingerprint ridges and valleys. The most existing AFISs are based on geometric minutiae matching. However, distortions change the geometric relationship among minutiae. This makes matching phase of AFISs very difficult. Our research focuses on the invariable information of fingerprint. Topology of fingerprint is independent on distortion. But, how to design an efficient topology matching algorithm is still open. We are using sweeping-line to construct a more condensed graph of fingerprint topology. And then check if there exists a isomorphic graph in DB. This step guarantees the two fingerprints have same topology. Our method will combine graph and geometric matching to improve the accuracy of AFISs.

4 Publication

1. X.F.Liang, A. Bishnu, T.Asano. "A Near-Linear Time Algorithm for Binarization of Fingerprint Images using Distance Transforms". *Proc The 10th IWCIA*, pp. 197-208, 2004.

2. X.F.Liang and T.Asano, "A Fast Denoising Method for Binary Fingerprint Image", *Proc The 4th IASTED international conference on VIIP*, pp. 309-313, 2004.

3. X.F.Liang, K.Kotani and T.Asano, "Automatically Choosing Appropriately-Sized Structuring Elements to Eliminate Useless Components in Fingerprint Image", *Proc The VCIP*, 2005.

5 Programs

1. Program for binarization of fingerprint image based on Euclidean distance transform. (C++)
2. program for denoising of binary fingerprint image (impulsive noise and useless component respectively). (C++)