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Automatic Fingerprint Recognition System Using Fast Fourier Transform and Gabor Filters

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1. Abstract

Fingerprint recognition is one of the most popular methods used for identification with greater degree of success. The fingerprint has unique characteristics called minutiae, which are points where a curve track finishes, intersect or branches off. Identification systems using fingerprints biometric patterns are called AFIS (Automatic Fingerprint Identification System). In this work a novel method for Fingerprint recognition is considered using a combination of Fast Fourier Transform (FFT) and Gabor Filters to enhancement the image.

Key words: Fingerprint, Gabor filter, FFT, Minutae, AFIS.

2. Resumen (Reconocimiento de huellas dactilares usando la transformada de Fourier y filtros de Gabor)

El reconocimiento de huellas dactilares es uno de los métodos de identificación más populares debido a su precisión. La huella dactilar se caracteriza de forma única debido a ciertos rasgos característicos llamados minucias, las cuales son puntos de intersección entre dos curvas, puntos en los cuales las curvas se bifurcan o terminan. Este artículo presenta un nuevo método para reconocimiento de huellas usando una combinación de la transformada de Fourier y los filtros de Gabor.

Palabras clave: huellas dactilares, filtros de Gabor, FFT, minucias, AFIS.

3. Introduction

The biometry or biometrics refers to the automatic identification (or verification) of an individual (or a claimed identity) by using certain physiological or behavioral traits associated with the person. Traditionally, passwords (knowledge-based security) and ID cards (token-based security) have been used to moderate access to restricted systems. However, security can be easily breached in these systems when a password is divulged to an unauthorized user or an impostor steals a card. Furthermore, simple passwords are easy to guess (by an impostor) and difficult passwords may be hard to recall (by a legitimate user).

Fingerprints are fully formed at about seven months of fetus development and finger ridge configurations do not change throughout the life of an individual except due to accidents such as bruises and cuts on the fingertips (Babler, 1991). This property makes fingerprints a very attractive biometric identifier.

Fingerprint recognition represents the oldest method of biometric identification. Its history is going back as far as at least 2200 BC. Since 1897, dactyloscopy (synonym for non-computer-based fingerprint identification) has been used for criminal identification. A fingerprint consists of ridges (lines across fingerprints) and valleys (spaces between ridges). The pattern of the ridges and valleys is unique for each individual. Here the probability of finding two fingerprints similar is of 1.9×10^{15}.

There are two major methods of fingerprint matching: Local Features and global pattern matching. The first approach analyses

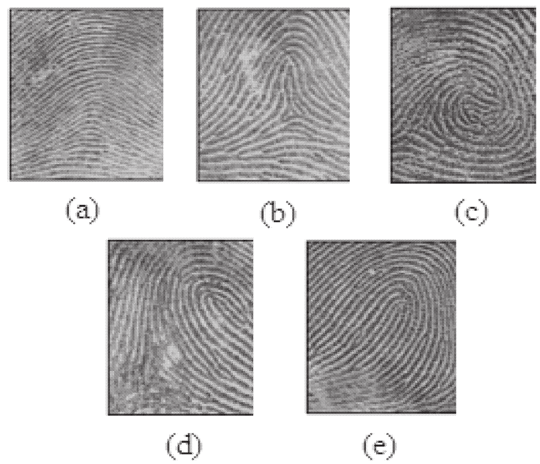

Fig. 1. Fingerprint classification: (a) arch, (b) tended arch, (c) whorl, (d) right loop, (e) left loop.

ridge bifurcations and endings, the second method represents a more macroscopic approach. The last approach considers the flow of ridges in terms of, for example, arches, loops and whorls. As the equal-error-rate is low, therefore fingerprint recognition is very accurate. Another important characteristic is to take into account the type from used reader, one of capacitive surface or of optical surface; we used of optical surface for this work. In an image between greater is the quality, lesser is the probability of finding a false minutia. A false minutia is created by a bad quality of the image. Figure 1 shows some typical fingerprints types.

4. Proposed system

The proposed system in this paper consists of a combination of two algorithms, the Fast Fourier Transform and Gabor Filters to enhancement and reconstructs the image's information. The

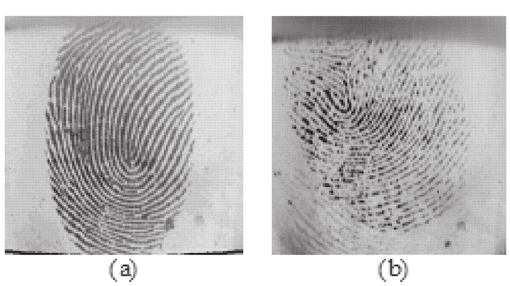

Fig. 2. Fingerprint: a) with sufficient information, b) with poor information.

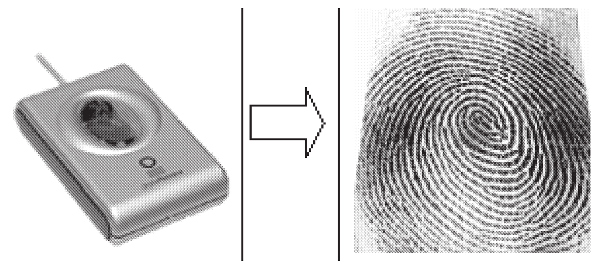

Fig. 3. Scanner and captured fingerprint.

system consists of eight steps: Acquisition, Noise Reduction, Enhancement with Gabor Filters, Enhancement with Fast Fourier Transform, Binarization, Thinning, Minutiae Detection and Recognition. Each one of these steps was evaluated with different fingerprints, ones with less noise in which it was easier to work and others with information almost null, even so, our system made a good recognition. See figure 2.

4.1. Acquisition stage

The acquisition of the fingerprint was made from a biometric device UareU 4000 of Digital Persona Inc. with interface USB 2.0. The images were captured with a resolution of 512 DPI and a size of 340 x 340 pixels in gray scale (fig. 2). For this work a data base with 500 images of fingerprints was created that correspond to 50 different people, this is, 10 images by each person.

4.2. Preprocessing

Most fingerprint images displays noise in the zones near the ends of the image, this noise can be caused by different factors such as the movement of the finger at the moment of the capture or the little pressure in the lateral areas from scanner. This noise must be eliminated to assure that only useful information will be processed at the time of minutiaes extraction. In case that were not eliminated these noises, the algorithm could detect false minutiae due to the noise. Therefore the image was cut in a 10% in each one of its sides taking into account that did not eliminate own information of the fingerprint. This is shown in figure 4.

4.3. Fingerprint enhancement

The performance of minutiae extraction algorithms and other fingerprint recognition techniques relies heavily on the quality of the input fingerprint images. In an ideal fingerprint image, ridges and valleys alternate and flow in a locally constant direction. In such situations, the ridges can be easily detected

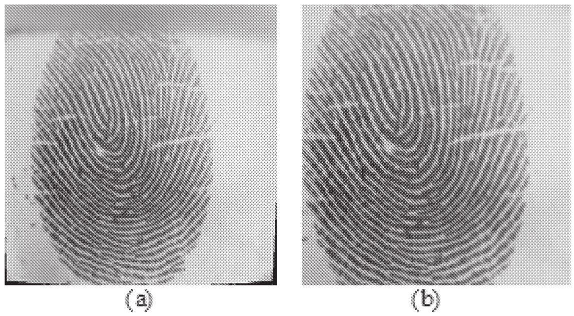

Fig. 4. (a) Original image, (b) preprocessed image.

Fig. 5. Fingerprint image enhanced using Gabor filter.

and minutiae can be precisely located in the image. However, in practice, due to skin conditions (*e.g.*, wet or dry, cuts, and bruises), sensor noise, incorrect finger pressure, and inherently low-quality fingers (*e.g.*, elderly people, manual workers), a significant percentage of fingerprint images are of poor quality. The goal of an enhancement algorithm is to improve the clarity of the ridge structures in the recoverable regions and mark the unrecoverable regions as too noisy for further processing. The majority of the existing techniques are based on the use of contextual filters whose parameters depend on the local ridge frequency and orientation. The context information includes: Ridge continuity and Regularity. Due to the regularity and continuity properties of the fingerprint image occluded and corrupted regions can be recovered using the contextual information from the surrounding neighborhood. Hong *et al*. [1] label such regions as 'recoverable' regions. The efficiency of an automated enhancement algorithm depends on the extent to which they utilize contextual information. The filters themselves may be defined in spatial or in the Fourier domain. In this work a combination of filters in the two dominions is used, spatial and Fourier for a better enhancement.

4.3.1. Spatial domain filtering

O'Gorman *et al*. [2] proposed the use of contextual filters for fingerprint image enhancement for the first time. They use an anisotropic smoothening kernel whose major axis is oriented parallel to the ridges. For efficiency, they recomputed the filter in 16 directions. The filter increases contrast in a direction perpendicular to the ridges while performing smoothening in the direction of the ridges. Recently, Greenberg *et al*. [3] proposed the use of an anisotropic filter that is based on structure adaptive filtering by Yang *et al*. [4]. Gabor filters have important signal properties such as optimal joint space frequency resolution [5]. Gabor elementary functions form a very intuitive representation of fingerprint images since they capture the periodic, yet non-stationary nature of the fingerprint regions. The even symmetric Gabor has the following general form:

$$G(x,y)= \exp\{-\frac{1}{2}\,[\frac{x^2}{\delta_x^2}+\frac{y^2}{\delta_y^2}]\}\cos\,(2\pi f x) \qquad (1)$$

where f represents the ridge frequency and the choice of δ_x^2 and δ_y^2 determines the shape of the filter envelope and also the trade of between enhancement and spurious artifacts. This is by far, the most popular approach for fingerprint enhancement. Figure 5 shows a fingerprint enhanced using Gabor filtering.

4.3.2. Frequency domain filtering

Sherlock and Monro [6] perform contextual filtering completely in the Fourier domain. Each image is convolved with precomputed filters of the same size as the image.

Fig. 6. Fingerprint image enhanced using FFT-based filtering.

However, the algorithm assumes that the ridge frequency is constant through out the image in order to prevent having a large number of precomputed filters. Therefore the algorithm does not use the full contextual information provided by the fingerprint image. Watson *et al*. [7] proposed another approach for performing enhancement completely in the Fourier domain. This is based on 'root filtering' technique. In this approach the image is divided into overlapping block and in each block, the enhanced image is obtained by

$$I_{enh}(x,y) = FFT^{-1}\{F(u,v)\,|F(u,v)|^{k}\} \quad (2)$$

$$F(u,v) = FFT\,(I(x,y)) \quad (3)$$

Another advantage of this approach is that it does not require the computation of intrinsic images for its operation. This has the effect of increasing the dominant spectral components while attenuating the weak components. However, in order to preserve the phase, the enhancement also retains the original spectrum $F(u,v)$.

4.3.3. Proposed fingerprint enhancement approach

From the previous subsections is clear that both approaches present desirable features that can be combined to obtain better image enhancement results. Thus this paper proposes to use a combination of Fourier transform and Gabor filtering to carry out the image enhancement task. In figure 12 the final image with minutiaes detected in each stage is observed. Since we have the two enhanced images an algebraic sum is made and only the resulting pixel will be white, if in the two images the pixel is white too. Figure 7 shows the proposed method.

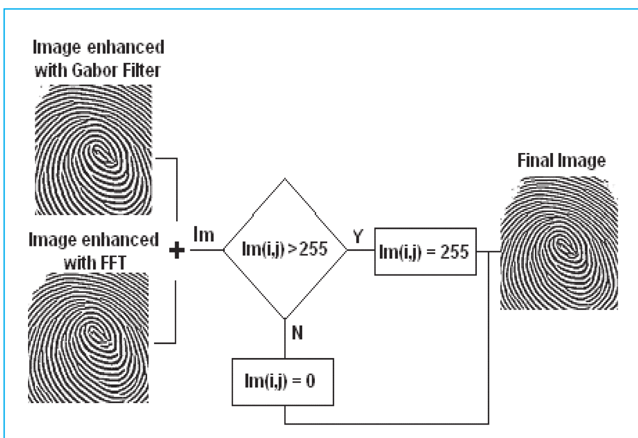

Fig. 7. Block diagram of proposed fingerprint enhancement method.

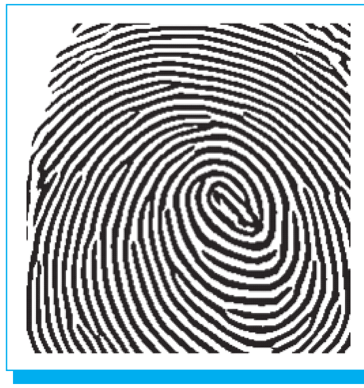

Fig. 8. Binarization and enhancement using the proposed method based on a combination of FFT-based and Gabor filtering.

4.4 Binarization

The image segmented with the crests and valleys better defined, now will be binarized, this is, the black pixels will have a value of 0 and the white pixels a value of 1. The results of the binary image with the combination of both previous filters are observed in figure 8.

4.5. Thinning

Before the stage of extraction of minutiaes, a thinning process is applied, this is an algorithm where the result is an image with lines of the minimum possible thickness. In order to understand better the algorithm it is necessary to know some definitions. Let us remember that after the binarization process the image is made up only of 1 and 0, where a 1 means a white pixel and a 0 black pixel. A pixel 0 (x,y) is internal, if its four neighbors $(x+1,y)$, $(x-1,y)$, $(x,y+1)$ and $(x,y-1)$ are 0 (black pixel). The limit is defined using its 8 connections. A pixel is a pixel limit if this isn't an internal pixel and at least one of its 8 neighbors is a 1. A pixel is of connection if it is eliminated in a matrix of 3 x 3 and its neighbors are disconnected.

Basically, the algorithm consists in finding internal pixels in our image and later to eliminate the pixel limit. This process is carried out until it is not possible to find more internal. Next, it is explained with greater detail.

The first step of this algorithm consists in finding the total internal pixels that exist in our image. Later, all the pixels that are a limit are eliminate, having taken care of that this isn't a connection pixel. This first step is shown in figure 9. This algorithm is repeated until not finding more internal pixels.

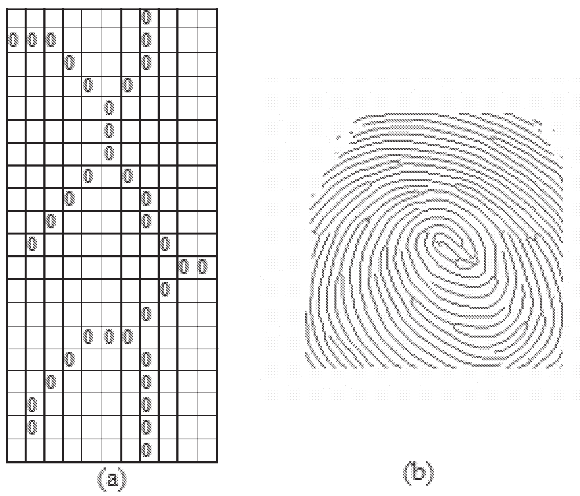

Fig. 10. Fingerprint image after thinning process, a) example and b) original fingerprint.

After thinning the image and not finding more internal pixels, the algorithm is applied again but in this occasion with a small change. This change consists in finding internal pixels only with 3 neighbor pixels and later to eliminate the limits pixels. The elimination of internal pixels is possible when the elimination of some limit pixel is not possible but exist an internal pixel.

The last step is again the repetition of the algorithm but in this occasion finding internal pixels with two neighbors only. Considering the elimination of an internal pixel if isn't possible to eliminate some neighbor pixel. The final result after the *N* necessary repetitions is shown in figure 10.

4.6 Minutae detection

After the thinning process the image is ready so that the algorithm of detection of minutiae is applied. The algorithm consists in to calculate the number of pixels that cross to Pixel center (Pc) and it is calculated with the following equation:

$$Pc = \sum_{i=1}^{8} p(i) \qquad (4)$$

where if $Pc = 7$ there is a a block with a termination minutae, if $Pc = 6$ there is a block without minutae and if $Pc \leq 5$ there is a block with a bifurcation minutae; here P_1 to P_8 is an ordered sequence of pixels, that define the block of 8 neighbors of a given pixel as shown in Fig. 11.

In the figure 11a is observed the configuration of the used window to locate bifurcations and ending. Figures 11b, 11c and 11d are the possible configurations that we can find. A Pc = 7 means that we are on a window with a ending. A Pc = 6

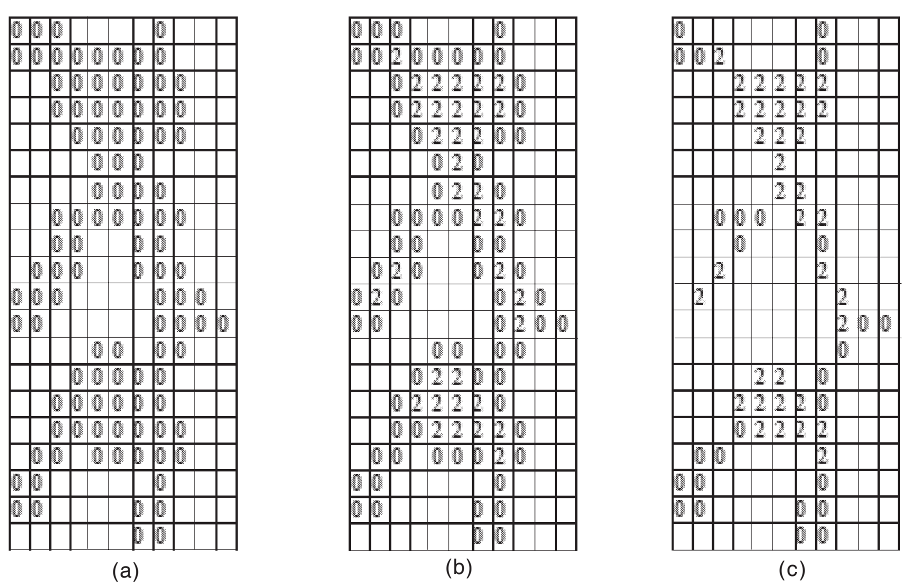

Fig. 9. Process of thinning (a) Original Image, (b) Image with internal pixels, (c) Image after the elimination of pixels limit.

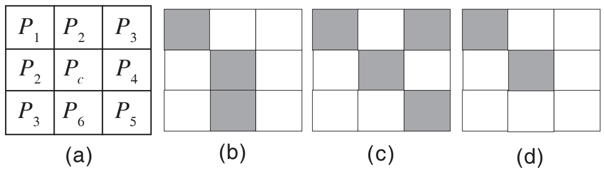

Fig. 11. (a) Window of 3 x 3 used to find minutiaes; (b) block without minutiaes; (c) block with bifurcation; (d) block with ending.

means that not exist bifurcation or ending. A $Pc \leq 5$ means that we have found a bifurcation. This process is made on all the binary image applying windows of 3 x 3. In this paper we did not use the windows 11d (Block with ending) because we have considered that a bifurcation gives greater information than an ending in a recognition system. The result of this process is a vector with the characteristic points that later will be used in the recognition or verification. Figure 12 is the result of this process with each stage.

4.7. Recognition process

The recognition was made with three important characteristics: coordinates, distance and angles between each minutia. The reason of to use three characteristics is to have a smaller percentage of error in the recognition.

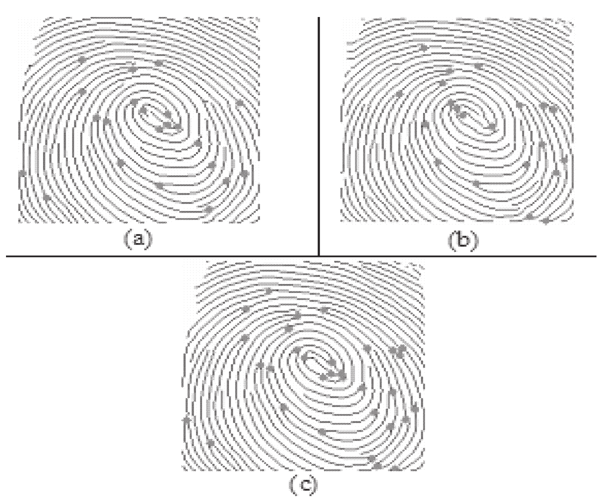

Fig. 12. (a) Final image with Gabor Filters, (b) final image with Fast Fourier Transform and (c) Final Image with combination and used for our system.

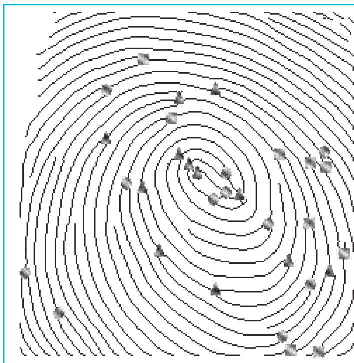

Fig. 13. Minutaes extracted from fingerprint images enhanced using: (a) ● Gabor filters, (b) ■ FFT-based filters, (c) ▲ proposed method.

Therefore, the information of the stored fingerprint consists of a size matrix 4 x 500. The matrix is compound of four vectors that consist of the two coordinates of the minutiae, the distance to following minutiae and the angle that form with respect to the *y*-axis. The total size of our stored matrix is of 1000 x 500. The recognition is made of the following form: The input image becomes in a matrix of 4 x 500 and this matrix is compared with each matrix of our data base. First, equal distances are located and are taken only the same angle. Later, are eliminated the coordinates very different and this way we can assure a better recognition. After several tests it was decided that the coordinates can vary in a radius of 10 pixels. Figure 14 shows the method to form a vector. After several tests we considered that a greater threshold of 15 gives a good recognition, this is that the recognition exists only when the input image contains more than 15 equal values to the stored in our data base.

Figure 15 shows the process of recognition. The input image is transformed to a matrix of 4 x 500 and later it is compared with each one of the stored matrices. If in a stored matrix

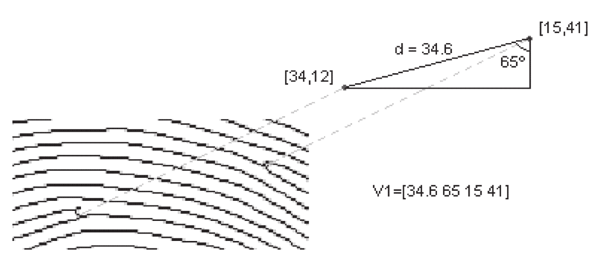

Fig. 14. Resulting vector of one minutiae.

Table 1. Recognition performance using three different enhancement methods.

Enhancement Method	Recognition rate	False acceptance	False rejection
Gabor-based	94.1%	3.7%	2.2%
FFT-based	93.7%	2.7%	3.6%
Proposed	97.7%	0.5%	1.8%

exist more than 15 equal vectors to the input, the image is recognized.

5. Evaluation results

The tests consisted of the recognition of 51 people, 50 people with stored fingerprint and one without storing. Each person made five tests and the results are the following. The table 1 shown the results of the tests made with the first stage of enhancement. The acceptance threshold was of 15, in other words, we needed minimum 15 equal values for to say that the image is true.

The table 1 shows the results of the evaluation tests made with the three methods used for fingerprint enhancement.

Later, we made some modifications to the threshold. Table 2 shows the results of the two combined stages with acceptance

Table 2. Recognition performance of proposed method using two different acceptance thresholds.

Acceptance threshold	Recognition rate	False acceptance	False rejection
10	96.1%	3.1%	0.8%
20	92.2%	0.0%	7.8%

thresholds of 10 and 20, in other words, we needed minimum 10 equal values for to say that the image is true in first case and 20 in the second case.

6. Conclusions

We presented a new fingerprint image enhancement algorithm based in a filter's combination in the Fourier and spatial domain. One of the best algorithms for the enhancement of fingerprints is Gabor Filter whose main characteristic is that it has an optimal joint directional and frequency resolution but does not handle high curvature regions well due to block wise approach. Angular and radial bandwidths are constant. The reason of to use a second method of enhancement is for eliminating the problem of handle high curvature regions, since the enhancement by means of FFT presents a very robust even near regions of high curvature but marked by large storage requirements. Frequency of ridges is assumed to be constant. Once the fingerprint is enhanced and processed an algorithm of recognition based on minutiaes was developed obtaining good results. The results show an elevated percentage of recognition for an application of regular size. The implementation of a system with these characteristics is very acceptable because presents a high percentage of recognition and only 0.5% of false acceptance, 1.8% of false rejection is not problem since the user only will have to put his fingerprint again.

A possible solution to reduce the percentage of false rejection is to make greater the base stored of fingerprints. We proposed as work to future a base of fingerprints with 10 stored images and to make the recognition again. In the recognition system that we have proposed here only bifurcations were used, therefore, also we proposed as work to future a system that uses bifurcations and ending for the recognition.

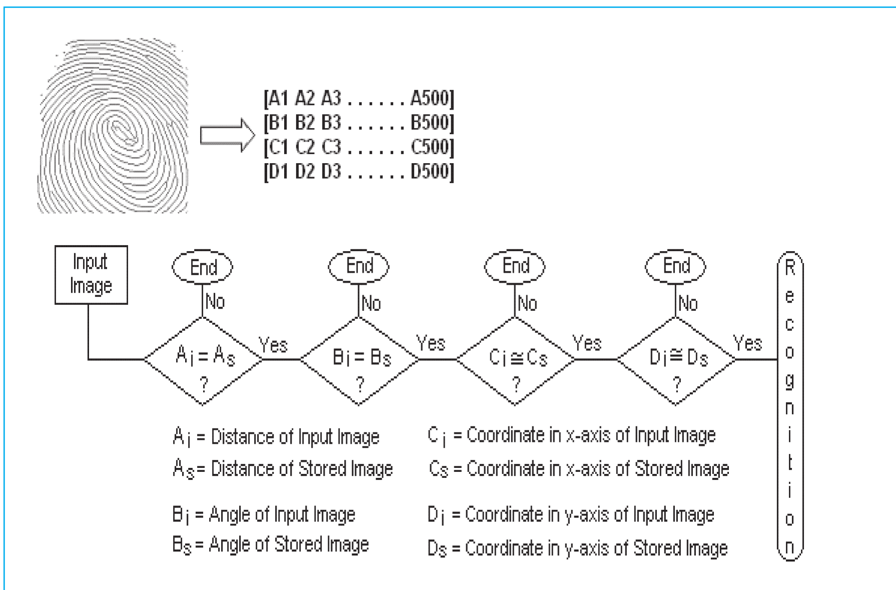

Fig. 15. Recognition process, where *A* is the Distance between minutiaes, *B* denotes the angles between minutiaes, *C* are the coordinate in *x*-axis and *D* coordinate in *y*-axis.

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