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RESEARCH ARTICLE

Fingerprint Recognition System Using Specific Point Method

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ABSTRACT

Fingerprint recognition is the most developed to the date biometric method of personal identification. As each person has a unique papillary pattern of fingerprints, so identification is possible. Typically, algorithms use characteristic points on fingerprints: the end of the pattern line, branching lines, single points. In addition, information about the morphological structure of the fingerprint is attracted: the relative position of the closed lines of the papillary pattern, "arched" and spiral lines. Peculiarities of papillary patterns are converted to some unique codes, which preserves the information content of the fingerprint image. And it is "fingerprint codes" that are stored in the database used for searching and comparing. Currently, fingerprint recognition systems occupy more than half of the biometric market. A lot of companies are engaged in the production of access control systems based on the method of fingerprinting identification. Due to the fact that this direction is one of the oldest, it has become the most widespread and is currently the most developed.

INTRODUCTION

Biometrics has gained the most widespread adoption among data protection techniques to date. In order to carry out human identification processes, fingerprints are used as the most frequently employed biometric feature. Recently, human identification by fingerprint has attracted attention as a biometric technology that is likely to be most widely used in the future. Its advantages include ease of use, convenience, and reliability. The relevance of using fingerprint-based identification stems from its broad range of applications. These include banking systems, access control management systems (ACMS), personal identity verification systems, etc. Currently, there exist ready-made examples of specific implementations for employee access restriction systems at enterprises, computing devices, and mobile telecommunication equipment. In order to create accurate recognition systems, it is necessary to conduct high-quality testing. For this purpose, databases containing sets of fingerprint models are required. The process of forming such an information base is highly labor-intensive, costly and complex. Therefore, algorithms for generating artificial fingerprints have recently become popular. Such fingerprint models can be used in the process of creating new databases that will allow testing the operation of an automatic fingerprint identification system.

Currently, three main classes of fingerprint comparison algorithms are distinguished:

Based on special points;

Using correlation functions;

by pattern matching.

The purpose of this article is to develop a fingerprint recognition system based on the special points comparison method.

Fingerprint Recognition Methods

The papillary pattern located on the surface of the finger is compose the fingerprint. The uniqueness of each fingerprint can be determined by the pattern that the protrusions and grooves form, as well as by other details such as the wavelength between the papillary lines, phase shift, etc. Thus, two types of features are distinguished - global and local.

Global features are features which can be seen with the naked eye [1-3]:

Papillary pattern is a unique pattern formed by a combination of depressions, protrusions, and whorls.

Depression (groove) is a groove between protrusions.

Protrusion is a line of a fingerprint that rises, thus forming a protrusion.

Center (core) is the point of greatest curvature of a protrusion, a point localized in the middle of a fingerprint or some highlighted area.

Delta is the zone where a protrusion branches into three lines, then converges at one point.

Region of interest is a selected fragment of a fingerprint in which all features are localized (usually the central area of a fingerprint).

In traditional dactyloscopy, finger patterns are classified into three primary categories: loops (65%), whorls (30%), and arches (about 5% of all fingerprints). Each category is further subdivided into more detailed classes. This study adopts a five-class classification scheme: left loop (A), right loop (B), whorl (C), arch (D), and hemisphere (E) [4-5]. Figure 1 shows some examples of fingerprints that fall into the main classes mentioned above.

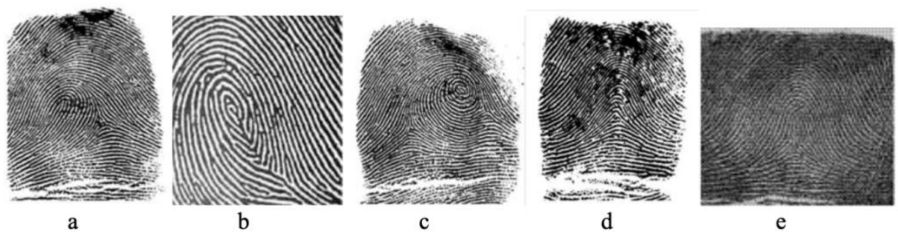


Figure 1 – Some examples of fingerprints: a) left loop, b) right loop, c) whorl, d) arch, e) hemisphere

Local features are details unique to each individual fingerprint. They determine the points of change in the structure of the papillary lines (termination, bifurcation, breakage, etc.), the orientation of the papillary lines and the coordinates at these points [6].

The following main details are distinguished in the fingerprint image:

End points (ends of protrusions) – points where the protrusions “distinctly” end;

Branching points – points where the lines of the protrusion diverge.

In this paper, we consider these details as minutiae points. A single human fingerprint may contain up to 70 such points.

Figure 2 shows an example that clearly shows what end points and branching points are.

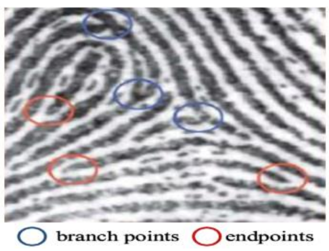


Figure 2 - Endpoints and Branch Points

Practice shows that fingerprints of different people can have the same global features, but it is absolutely impossible to have the same local features. Therefore, global features are used at the authentication stage. At the second stage of recognition (unique identification), local features are used [7].

Obtaining an electronic representation of fingerprints with a clearly distinguishable papillary pattern is a rather difficult task. Since the fingerprint is too small to obtain a high-quality image. Modern methods for obtaining an electronic image of a fingerprint are scanning.

The proposed method of fingerprint recognition

It is believed that the probability of identical fingerprints of two different people is approximately 1:64,000,000,000. Dactyloscopic BSCDs captures the papillary pattern from one or more fingers using a special fingerprint scanner and compare it against a registered standard. The information stored in the standard is only a certain preparation of the original papillary pattern, which can be used to identify a person, but insufficient to restore the full fingerprint pattern. According to their physical characteristics, there are three types scanners used in fingerprint access control systems:

Optical;

Ultrasonic;

Silicon.

Standards used for dactyloscopy of fingerprints include:

The fingerprint image must have a minimum resolution of 500 dpi;

The fingerprint image must be a grayscale with 256 brightness levels;

The maximum angle of rotation of the fingerprint from the vertical must not exceed 15 degrees;

Each fingerprint image is presented in uncompressed TIF format;

Minutiae types - endpoints and branching points.

Comparison of fingerprints by local features takes place in the following five stages:

1. In order to improve the quality of the original fingerprint image, it is necessary to increase the sharpness of the papillary line boundaries [8-11].

2. Calculation of the orientation field of the fingerprint papillary lines. It is necessary to divide the input image into square blocks with a side greater than 4 pixels. After that, the orientation angle of the papillary lines for a fingerprint fragment is calculated using brightness gradients (Figure 3).

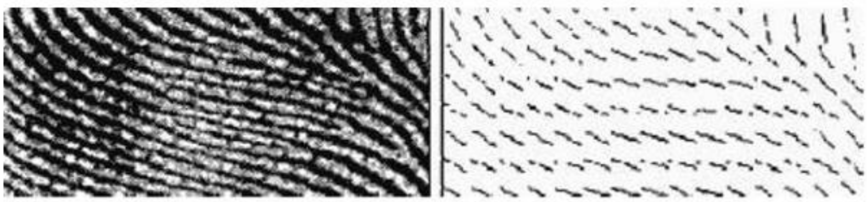


Figure 3 – Calculations of the Orientation Field of the Papillary Lines of the Imprint

3. Binarization of the fingerprint image. Reduction (1 bit) to a black and white image by threshold processing.

4. Thinning of the fingerprint image lines. As shown in Figure 4, thinning is performed until the thickness of the papillary line is equal to 1 pixel.

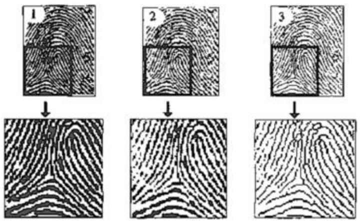


Figure 4 – Refinement of the Lines of the Print Image

5. Matching of minutiae. In real conditions, two fingerprints of the same finger will almost always differ from each other in the area of contact, rotation, displacement, and change in scale depending on how the user placed their finger on the scanner. Therefore, it is impossible to say with 100% certainty whether a fingerprint belongs to this person or not based only on their simple comparison (the vectors of the standard and the current fingerprint may differ in length, contain incompatible minutiae, etc.). Therefore, the matching process must be implemented separately for each minutia. Examples of matching minutiae are shown in Figure 5.

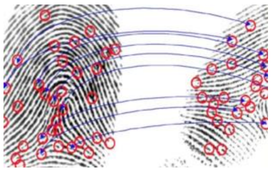


Figure 5 – Minution comparison

A method of comparing fingerprints based on global features. Global features (kernel, delta) are detected. The number of these features and their mutual arrangement can be used to classify the type of this pattern. The final recognition is based on local features (the number of comparisons is several orders of magnitude higher for a large number of fingerprints).

Building a Fingerprint Recognition Algorithm

The fingerprint identification system using the keypoint method includes modules for pre-processing fingerprint images, keypoint extraction, and matching current fingerprints with database template fingerprints.

Let's look at the methods underlying these modules. Image pre-processing. When processing fingerprints to extract keypoints, the image undergoes the following transformations (Figure 6).

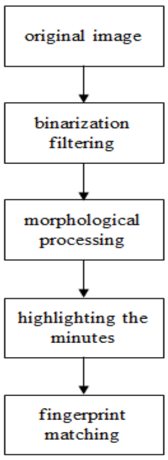


Figure 6 – Identification System Modules

Filtering is applied to images to reduce the amount of noise in them. Binarization of the image. After filtering the image, it is converted to black and white. Binarization begins after the quality of the images has been improved and all directions of the existing papillary lines have been calculated [12,13]. An image is defined as an image if each pixel takes one of two possible values

- zero and one. One corresponds to a protrusion on the fingerprint, zero - to a depression, the calculation is calculated according to formula (1):

$$R_{(i,j)} = \begin{cases} 1, if\ (i,j) \rangle B_0 \\ 0, or \end{cases} \quad (1)$$

where B_0 – masking threshold, $G(i,j)$ – image pixel intensity.

Morphological processing is the third step. After binarization of the filtered image, homogeneous areas are selected with further morphological processing of the image. It consists of noise removal (i.e. removal of small areas of black and white) [8].

Images with structural redundancy consist of a large number of lines and details. If the lines of the read image are fuzzy and it is necessary to determine their contour, then it will be effective to apply morphological operations for fingerprinting. Skeletonization is effective for removing small objects and noise, "refines" ("compresses") the binary image using a structure-forming element.

For sets X and S from the space Z^2, the erosion of X by S ($X\Theta S$) is determined in accordance with formula (2) [13]:

$$X\Theta S = \{\varsigma | (S)_\varsigma \subseteq X\}. \quad (2)$$

In other words, erosion is the set of all points ζ, when shifted to which the set S is completely contained in X [8]. Here S is the structure-forming set, X is the image.

When the value of 1 of the structure-forming element coincides with the value of 1 of the binary image, the logical addition of the corresponding pixels is performed. If the objects are smaller than the structure-forming element, they are discarded.

Dilation, the dilation operation "builds up" or "thickens" objects in binary images. For sets X and S from the space Z^2, the dilation X by S ($X \oplus S$) is defined according to formula (3) [13]:

$$X \oplus S = \{\varsigma | (S)_\varsigma \cap X \neq \varnothing\}. \quad (3)$$

After this, the number of black (non-zero) pixels around the center is counted. The pixel in the center is considered a minutia. If it is non-zero and there is one neighboring non-zero pixel, the minutia is an "end" or three pixels, the minutia is a "bifurcation". This can be seen clearly in Figure 7.

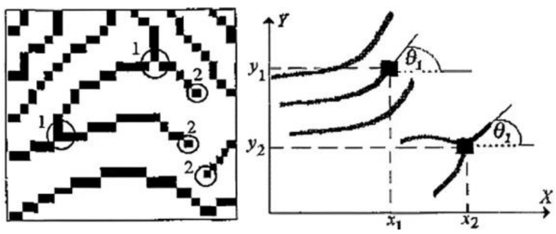
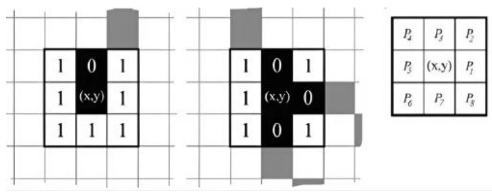


Figure 7 – Selection of Minutiae

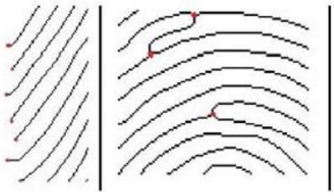
The calculation of the number of black pixels around the selected pixel is based on the analysis of the eight-connected region of adjacent pixels. An example of this can be seen in Figure 8.



a) b) c)

Figure 8 – 8-Connected Region of Adjacent Pixels A) End, B) Bifurcations, C) 3 × 3 Blocks

The coordinates of the detected minutiae and their orientation angles are written into a vector: $W(p) = [(x_1, y_1, t_1), (x_2, y_2, t_2)...(x_p, y_p, t_p)]$ (p is the number of minutiae) [14]. An example of what these points look like can be seen in Figure 9.



a) b)

Figure 9 – Selection of Minutiae: A – Ending, B – Bifurcation

Fingerprint matching is calculated by matching two fingerprints. Fingerprints of the same finger should be maximally matched, and minimally matched if the fingers are different.

Let T and Q be a function of vectors representing the checkpoints, the shape of the fingerprint template, and the query, respectively.

Each element of these characteristic vectors is a minutia point, which can be described by various attributes such as location, orientation, type, quality of the region's neighborhood, etc. The most general representation of minutia is a triplet x, y, θ where x, y are the coordinates of the position θ is the angle of the minutia. Let the number of minutiae in T and Q be m and n, respectively, formulas (4, 5):

$$T = m_1, m_2, ..., m_m, m_i, = x_i, y_i, \theta_i, i = 1...m, \quad (4)$$

$$Q = m'_1, m'_2, ..., m'_m, m'_i, = x'_i, y'_i, \theta'_j, j = 1...n, \quad (5)$$

In minutia $m\ i$ in T and $m\ j'$ in Q are considered to coincide if the conditions of formula (6, 7) are satisfied:

$$sd\left(m'_j, m_i\right) = \sqrt{\left(x'_j - x_i\right)^2} + \left(y'_j - y_i\right)^2 \le r_0. \quad (6)$$

$$dd\left(m'_j, m_i\right) = \min\left(\left|\theta'_j - \theta_i\right| 360 - \left|\theta'_j - \theta_i\right|\right) \le 0. \quad (7)$$

where r and θ are the parameters of the tolerance window, which is required to compensate for errors in the extraction function and distortions due to skin plasticity [15-17].

Once matching minutiae pairs have been found, the similarity of the fingerprints can be calculated. The similarity metric should accurately describe how similar two fingerprints are, taking into account all the information obtained from the previous step, such as the number of matching minutiae pairs and the degree of similarity of the pairs. According to the method chosen for implementation in this paper, the general algorithm for identifying a person by fingerprints is presented in the diagram in Figure 10.

The algorithm includes three stages, each stage is divided into separate procedures. At the first step of the algorithm, the original image is obtained, after which stage 1 of pre-processing begins, which is required to reduce the amount of noise in the original image I. At stage 2, special points are extracted from the image I^*, and a feature vector is obtained, which is necessary for stage 3 of comparison with the database template recorded for fingerprint recognition. This stage returns the index S of the fingerprint match, which is compared with the threshold value T. As a result, if the comparison result is positive, then the fingerprint match is recorded and the procedure ends with the identification of the person, otherwise no match is found and it is determined that this person does not exist in the database.

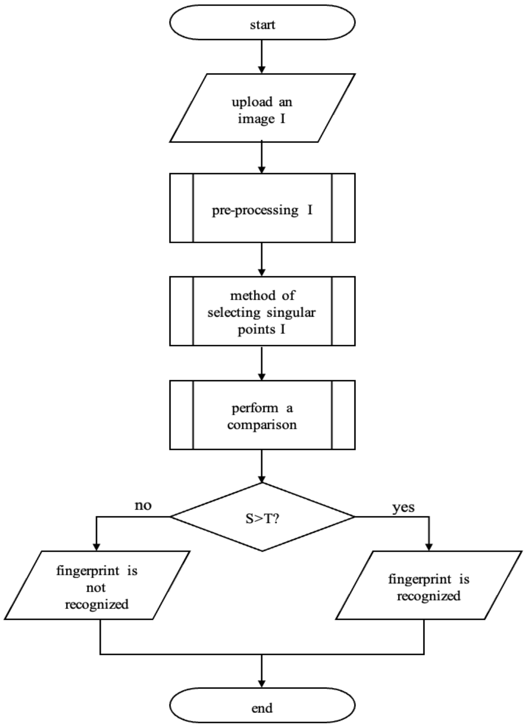


Figure 10 – Diagram of the General Fingerprint Identification Algorithm

In accordance with the general scheme of the algorithm (Figure 10), the following sections describe the procedures that implement the blocks of the scheme. Pre-processing algorithm. Such processing, as was said earlier, is required to reduce the amount of noise in the image. The original image I is fed to the input of the pre-processing procedure, and the input image is improved within the procedure, for which binarization, filtering, etc. are used. A detailed algorithm of the process is presented in Figure 11.

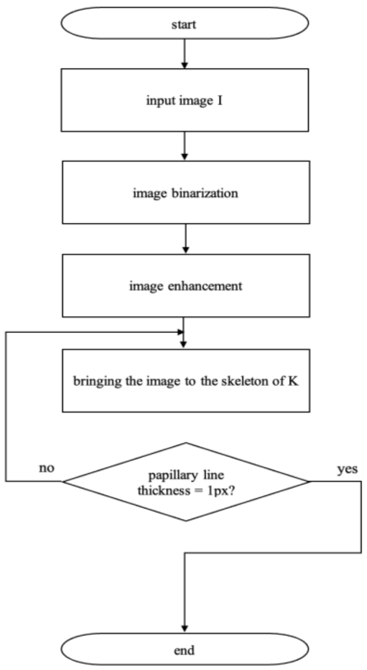


Figure 11 – Diagram of the Preprocessing Stage Algorithm

Binarization of the image *I* converts each pixel with an intensity value corresponding to a shade of gray into a binary intensity value - black (0) or white (1). The simplest approach is to apply a global threshold.

Feature Point Extraction. Binarization combined with morphological thinning provides a simple basis for minutia extraction. The following figure shows a flow chart of the process.

In the first step, to find a minutia, it is necessary to refine the skeleton of the image K, the width of the skeleton should be exactly one pixel. However, this is not always true, there are some places where the skeleton is two pixels wide, usually at some erroneous pixel locations. Erroneous pixels are defined as one with more than two connected neighbors. The presence of erroneous pixels can, for example, change the type of minutia.

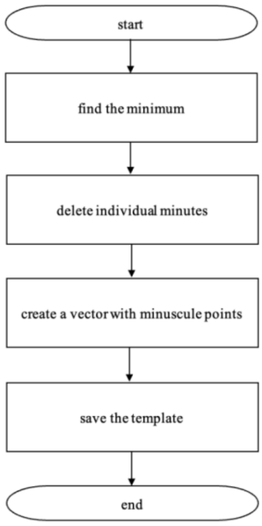


Figure 12 – Diagram of the Algorithm for Selecting Singular Points

Therefore, before obtaining minutiae, it is necessary to eliminate erroneous pixels while maintaining the connectivity of the skeleton in the bifurcation regions. To do this, the image skeleton is scanned along the line from the upper left corner of the image to the lower right, then it is checked whether the pixel has a value of 1, and the sum of its four connected neighbors is calculated. If the sum is greater than two, it is marked as an erroneous pixel. Then this erroneous pixel is deleted. Thus, after scanning the entire image, all erroneous pixels will be deleted.

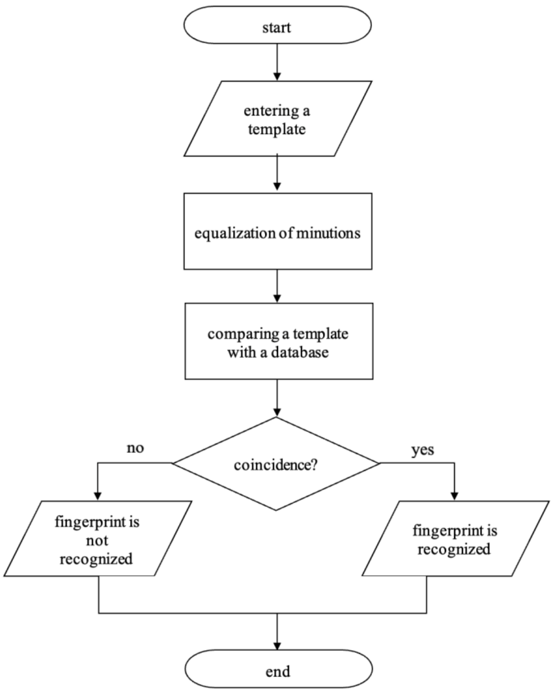


FIGURE 13 – DIAGRAM of the COMPARISON ALGORITHM with the REFERENCE

Given two sets of minutiae for two fingerprint images, the comparison algorithm determines whether the sets of minutiae correspond (same finger) or not (different fingers). The fingerprint comparison algorithm used in this work partially follows from [14]. It includes two consecutive procedures:

Alignments.

Matches.

5. Experiment Results

Two fingerprints from the same finger will differ from each other by rotation, offset, scale or contact area depending on how the user places the finger on the scanner. Therefore, it is impossible to say whether a fingerprint belongs to a person or not based on a simple comparison (the vectors of the reference and the current fingerprint may differ in length, contain inconsistent minutiae, etc.). Because of this, the matching process must be implemented for each minutia separately.

Figure 14 shows a negative result of comparing two fingerprints.

Figure 14 – Negative Example of Comparing Two Fingerprints

Figure 15 shows an example of a positive comparison of two fingerprints.

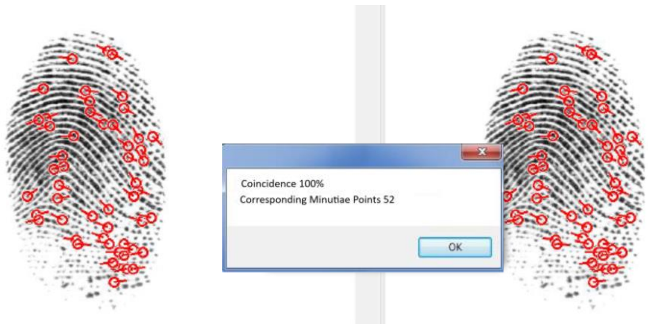


Figure 15 – Positive Example of Comparing Two Prints

When comparing, the percentage of fingerprint matches and how many points of the munitions correspond to the searched one are displayed.

When registering, the parameters of affine transformations (rotation angle, scale and shift) are determined, at which some minutia from one vector corresponds to some minutia from the second. When searching for each minutia, it is necessary to sort through up to 30 rotation values (from -15 degrees to +15), 500 shift values (from -250 px to +250 px) and 10 scale values (from 0.5 to 1.5 with a step of 0.1). In total, up to 150,000 steps for each of the 70 possible minutia. The assessment of fingerprint matches is performed using formula (8):

$$K = \frac{D^2}{pq} \times 100\% \quad (8)$$

where D is the number of matching minutiae, p is the number of minutiae of the standard, q is the number of minutiae of the identified imprint.

If the result exceeds the passing threshold, the fingerprints are considered identical.

The following fingerprint matching algorithms were selected for the experiments (Table 1). The total number of images for the experiments was 234.

MJY is the multiple alignment algorithm proposed by Medina-Pérez [18];

M3gl is an optimized fingerprint verification algorithm using m-triplets proposed by Medina-Pérez [19];

MQYW is the algorithm proposed by Medina-Pérez with an improvement in the multiple alignment strategy [20];

Table 1 – Summary Table of Experiments

Method	Criterion \ Experiment	1	2	3	4	5
PP	Similarity, %	81	97	79	91	89
	Minutiae matches	55	69	51	63	59
MJY	Similarity, %	71	93	69	82	78
	Minutiae matches	46	65	42	51	50
M3gl	Similarity, %	72	92	68	78	75
	Minutiae matches	45	64	41	49	47
MQYW	Similarity, %	73	92	69	80	80
	Minutiae matches	46	63	42	48	48

The integral assessment of the identification quality was calculated based on the average similarity coefficient based on the experimental results for each algorithm.

6. CONCLUSION

A fingerprint recognition system has been developed using the feature point method. The method has proven its operability under the following conditions:

fingerprint images are obtained under identical conditions (uniform lighting, identical shooting parameters);

image resolution should be sufficient to preserve significant fragments (details) of the pattern;

MJY, M3gl and MQYW algorithms have shown good results, but the proposed algorithm is superior to these algorithms.

The results of this study can be used to create a human fingerprint identification system.

7. Acknowledgements

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