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FINGERPRINT IDENTIFICATION BASED ON DERMATOLOGICAL FEATURES

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Abstract. One of the long-standing problems of practice is the personal identification, namely ascertaining personal identification. Several methods have been adapted for solving this problem during history, from seal ring, through signature to photo. Fingerprint, as a possibility for identification is widely known from the last century. From the sixties when computers became widely used, the possibility of computerizing of identification was brought up.

In this paper we explain a fingerprint identifying system used in automatic personal identifying systems. The identification is based on dermatological characteristics, namely the unique pattern of ridges of fingers. Usually two levels of pattern are distinguished, global and local patterns

In this system we improved both the global and the local characteristics using a identification. We use the direction matrix representing orientation of ridges as global characteristics and the method of identification of bifurcations as local characteristics.

1. Introduction

One of the long-standing problems of practical life is personal identification, namely ascertaining personal identification. Several methods have been adopted for solving this problem during history, from seal ring, through signature to photo.

It is well known, that fingerprint, as a possibility for identification, has already been used in the ancient China for signing trade contracts. From the 19th century its criminal application has become widespread. From the sixties of the 20th century when computers became widely used, the possibility of computerizing identification was brought up.

Concerning the automatic finger-print identification — mainly by the spreading of the modern scanning equipment, which besides by taking fingerprints control the temperature and circulation of the finger — at the present technological level forging is almost impossible. It is worth mentioning that the main goal of criminal identification and automatic personal identifying systems is different. In criminal identification the main task is to compare the fingerprint found on a scene of a crime to all fingerprints of the archives and to choose the one (if exists) which is identical. In case of automatic personal identifying systems the identifiable person in some way — by using password or identification card — determines the ethanol with which the sample taken from him has to be compared. It can be presumable the person cooperates with the system, and this conduct and the well thought-out construction of the sensor gets rid of the errors coming from the translation and/or rotation of the finger.

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2. Principles of Dermatology

The biological basis for finger print identification (*dactyloscopy*) is the pattern of epidermal ridges. These epidermal ridges (*tori dactyles*) are slightly elevated ribbings of the epidermis, formed by the papillae of the dermis found in the connective tissue, and separated by narrow grooves.

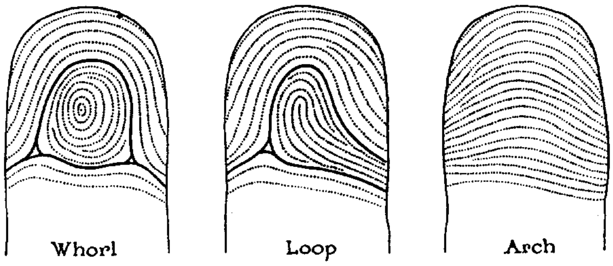


Figure 1. Three basic types of finger prints distinguished by Galton [1]

In dactyloscopy the positive print of epidermal ridges are simply called ridges, while the cavities between them are called sulci.

Usually, two levels of patterns are distinguished, the *global* or *macro patterns* and the *local* or *micro patterns*. The patterns formed only by a few (max. 3–5) ridges are the local patterns, the global ones contain much more patterns.

Since dermatological patterns consist of epidermal ridges which have linear structure, one of the most important features of the patterns is the *direction* of the ridges. Since, — viewing locally — the ridges run parallel to each other on most part of the surface, it is worth taking into consideration the direction of certain points of the surface.

The other important feature of the global patterns is the characteristic of the ridge-systems developed by connections, ramifications, and ceasing of ridges.

The main aim of the traditional dermatology is to recognize and describe the patterns of the ridges, the directions of them were considered only as secondary features. On the basis of this, such terms as *arches*, *loops*, and *whorls* are used in the traditional dermatology for describing finger prints (see in Figure 1). The acurrence of the pattern arch on thumb is seldom (see in [1]). Several subtypes of these patterns can be distinguished in order to give more detailed descriptions. According to an other terminology, the centre parts of a pattern, characterized only by the fact that the direction of the ridges are different than of the neighbouring ones, are called *minors*.

Using these classifications in computerized identification looks to be rather difficult. On the one hand, these types can only be described by features and hardly be extracted from the input image with the help of computer image processing methods, e.g. they are topologically equivalent, and on the other hand, the methods based on these features are extremely error sensitive, even the case of one ridge might make the sample unrecognizable for the computer.

Application of the local patterns, so-called *minutiae*, which are irregularities of direction, in the dactiloscopy seems to be easier. The most important types of the minutiae are the triradii, bifurcations or forks, breakings and terminations (see in

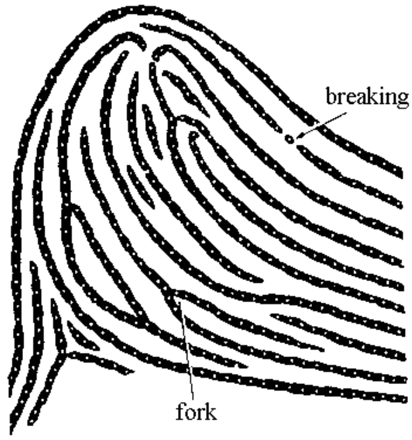


FIGURE 2. The main types of local patterns

Figure 2). Let us note, as it is mentioned in the paper of Hung [4] as well, that there is a duality among the minutiae. For example where you find bifurcation in the foreground, there is a termination in the background, and a breaking of a ridge in the front results in a bifurcation in the back. The *triradii* are formed by the consolidation of ridges in triangular formation lying at the conjunction of three ridge systems of opposed courses. The appearance of the triradii can be different depending on whether the ridges actually meet, or on the location of the ridges. The smallest types of patterns proved to be useful in the identification are the *forks*, also known as *bifurcations*, where a ridge branches into two lines. We can determine the direction of the fork as well, which means the direction of the "handle".

For identification with forks we also have to determine the notion of *fork-groups*. It is known from experience if several forks with the same direction, the so-called fork-groups can be found in a small area, than these hold more information for identification than the individual forks. A fork-group can be characterized by the number of forks found in the group and their common direction.

On the basis of the experience of practical dactiloscopy it can be stated that besides the global patterns, the forks bearing the most useful information about the finger print. That is the reason for paying special attention to these features in the system developed by us.

The third additional method for identification is the so-called ridge-counting. Ridges are counted along a line which connects two indicated points, e.g., the centres of two minutiae, or a triradial point with a point of core, and this number is regarded as one of the identification marks of the ridge system.

3. The general outline of the computerized identification process

We developed and implemented the identification method which is shown on the scheme of Figure 3.

The first step is *making prints*. Nowadays on the basis of three basic methods the following types of sensors are used for making prints: optical, laser and electromechanical. Papers on the typical construction of sensors can be found, in e.g., [7, 8].

The physical scanning and the digitalization of the obtained image can be regarded as the input of the identification process.

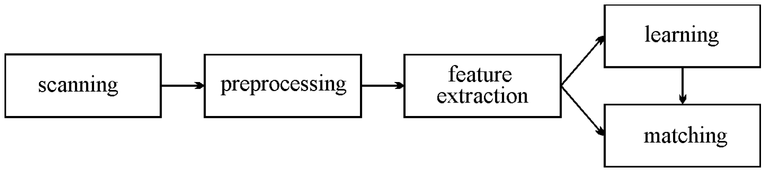


FIGURE 3. The general scheme of identification method

For the method applied it is important to characterize the noises to compare the original source and input. The most typical noises are the smoothing, over- or underfulness, the non-linear geometrical distortion, translation, and rotation.

The above mentioned noises, except the over- or underfulness and the non-linear geometrical distortion can be eliminated by improving the hardware. The correction of the over- or underfulness can be done for example by using the algorithm introduced in [4].

As a result of the first step we usually obtain a grey-scaled image. This image has to be modified for extracting the features. In order, the image has to be thresholded with the help of an adaptive algorithm, which determines the thresholds on such part-images, called cells, where the ridge-fullness are same. It is worth applying a filter on this binary image to eliminate the salt-pepper noise. The skeletonization to find the local features is very useful, since it is easier to find the local pattern on the skeleton. In our system we use the thinning algorithm introduced in [2].

In some respect the third step is one of the most interesting parts of the process, since in this phase takes place, the *extraction of the dermatological characteristics* needed for identification. Details will be given on this in Sections 4 and 5. The extraction of the features has two purposes. The extracted features can be used for making ethanol, that is, for determining those feature groups which will compared to the newer samples. This ethanol has to be made only once and it will be stored. This will be discussed in detail in Section 6. During further application of the system the extraction of the features also serves for comparing the new samples to the old ones.

The last step of the actual identification process is the *decision making process* when we compare the characteristics obtained from the ethanol to the characteristics of the new sample, and on this basis we make either a positive or negative decision. One can read on the decision making model in Section 7. The result of the experiments can be found in Section 8.

4. EXTRACTION OF THE GLOBAL DIRECTION FEATURES

In order, to analyse the global patterns we need to determine the direction of different parts of the sample.

In [4, 6, 3, 5] the idea of adding a direction to every pixel is already introduced, and the vector-field obtained describes the image. This characterization, however, is rather redundant. The direction assigned to a point is always determined by the analysis of its environment, which means that the information content of the direction data assigned to different image points is much less than the amount of data stored.

In order, to eliminate this redundancy in our system the information concerning the direction is stored in condensed form in a so-called direction matrix. In the direction matrix, stores the characteristic direction of one part usually one cell, of the original finger print. If the size of the original matrix is $n \times m$, and the size of the cells is $k \times l$, than the size of the direction matrix will be $\lfloor n/k \rfloor \times \lfloor m/l \rfloor$.

In our system, we determine the direction matrix used for global characterization of the finger print with chain-coding. We are going to introduce this method in the following.

4.1. **Chain-coding.** In the method of chain-coding we extract from the thinned image, which is the skeleton of the ridge-system. This algorithm is different from classical algorithms known in the literature, where the codes assigned to the skeleton points may be direction codes and other special ones, such as branching or termination.

Chain-coding provides useful information more than the determination of direction matrix, it gives the opportunity of correcting such errors of skeletonization as breaking or false branching. It is also possible to use the characteristics of local patterns, the locations and the type of minutiae.

After coding we have to make two basic corrections: remove the breaking and the so-called false branches. While *correcting the breaking* we can try to correct errors such as abrupt stop in the course of a ridge during either sampling or processing. Our criterion to recognize these errors is really simple: two terminations with the same directions cannot be closer to each other than a given limit which depends on the mean ridge-width of the sample. According to out experience if this criterion holds the ridge really breaks, has to be corrected by connecting the two end points.

The other correction which can be done on the basis of the skeleton includes the *removing of the false branches.* This correction deletes those false skeleton-branches which came from the previous noises/errors of the skeletonization. Suppose that the ridges are long, then the removing of false branches depends on a simple criterion: if one of the branches terminates earlier than a given limit of the pixel-number, then it turns out to be false and it has to be deleted.

4.2. **Determination of direction matrices on the basis of a skeleton chain-coding.** When the chain-coding of the skeleton and its corrections are finished and the information is available, the direction matrix can be determined. In order, to determine one element of the direction matrix we have to count the skeleton points found in the adequate cells, then from these frequencies the main direction-feature can be calculated. In comparison with other determinations of direction matrices it is new that we do not assign direction to the adequate cell of the sample. So, it is possible to indicate explicite by for the further processing that the given area can not be unambiguously characterized by a direction because of some reasons, so it is not expedient to take it into consideration later in the decision making process.

Let n_0, n_1, n_2, n_3 be the number of the skeleton points with codes $0°$, $45°$, $90°$, $135°$, respectively, and n the number of all skeleton points in the given cell. If n is smaller than a given limit, or bigger than another one we do not assign any direction to the given cell. The element which should be stored in the direction matrix can be determined as follows:

(1) If $n_0 = 0$ and $n_1 = n_3$, then the direction of the cell is $90°$.
(2) Calculate the direction number Γ in the following way:

$$\Gamma = \begin{cases} \dfrac{n_1 + n_2 + n_3}{n_0 + n_1 - n_3}, & \text{if} n_1 \geq n_3, \\ -\dfrac{n_1 + n_2 + n_3}{n_0 - n_1 + n_3}, & \text{otherwise.} \end{cases}$$

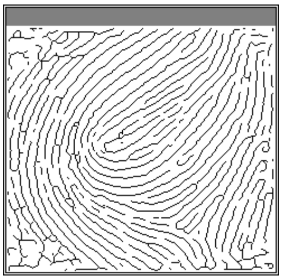
(3) If $|\Gamma| < 0.2$, then the direction assigned to the cell is $0°$.
(4) If $|\Gamma| \geq 2.5$, then the direction assigned to the cell is $90°$.
(5) If $\Gamma > 0$, then the direction is $45°$, otherwise it is $135°$.

If any of the conditions holds, that one determines the direction, otherwise we have to examine the criteria in the given order.

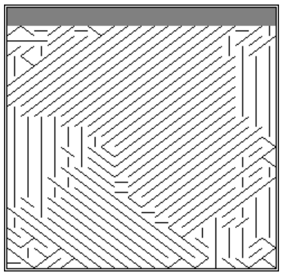
(a) Grey-scaled image

(b) Thresholded image

(c) Filtered image



(d) Thinned image



(e) Direction matrix

Figure 4. The results of the pre-processing

5. Recognition of the local minutiae

The dermatological bifurcations play important role in identification (see in [1]).

Forks (bifurcations) are such local patterns, from the centre of which one branch runs into one direction and two other branches, parallel to each other run to the opposite direction. Forks can be identified either by their locations or by the direction of their lonely branch (the so-called "handle"). On the basis of observations the direction of the fork is always parallel to the direction of the local ridges.

The first, natural idea is to find the forks consist in the chain-coded skeleton. Where a fork can be found on the sample, there a point should be located with a ramification code of the chain-coded skeleton, and the branches of the fork should run out in the appropriate directions from this point. However, errors might occur, so while searching for forks we should use the thresholded and filtered images as well, in the following way.

- Indicate (for example on the basis of the chain-coded skeleton) the centre of the supposed fork.
- Fit a rectangle around the centre with a size, which surely comprise the fork, and in such a way that the shorter side of the rectangle would face to the direction of the handle of the fork.
- Tight the rectangle in all direction, in order to make the following two conditions held:
  - the top of the rectangle should touch at least one ridge;
  - the bottom of the rectangle should touch at least two ridges.

- If we can tight the rectangle to smaller than a given threshold while these conditions are held, then it will contain the centre of a fork with the suitable direction.

As we already mentioned, the fork-groups possess special importance from the point of view of dactyloscopy. According to our experience groups formed by several forks with the same direction are more important in identification than a lonely fork. That is the reason for paying special attention to the recognition of fork-groups in our system. See Chapter 7.3.

6. The process of ethanol-making

The process of ethanol-making consists of, on the one hand, to the mark the characteristics, and on the other hand, the control built into the process of definition. However, we designed the systems in such a way that the definition of the ethanol needs manual work, so we built control points into the system wherever possible for the sake of safety.

The definition of ethanol actually starts by creating the pre-processed image.

The first elements of the ethanol are the minors. These are the rectangle shaped territories of the cells in the direction matrix. They contain, on the basis of directions, easily identifiable parts of the global pattern.

In our system, we have to mark exactly three minors for making the ethanol. The reason for this, on the one hand, is that at least much characteristics have to be on the finger print. On the other hand, the minors help us to determine the geometrical distortions.

With respect to the minors, the manual method assures that the number of ridges between minors is a good characteristic in the global structure of finger prints and in the ethanol a part can be designated to every minor pair. The locations of the parts, and the number of ridges cut by these parts belong to the ethanol, too. The co-ordinates of the end points of the parts are calculated in a relative way by comparing them to the adequate minor. This makes certain the elimination of the effects of geometrical distortions.

Forks can be characterized by their locations and directions and they are sufficient to store them, as well. It is worth storing the co-ordinates of the centre of forks relatively to the nearest minor, in order to prevent the problem of geometrical distortion. The optimum is it one determines three forks by ethanols.

In case of fork-groups, besides storing the forks we have to store the data of the rectangle framed them.

7. The decision-making model

The decision-making model can be determined, e.g., by a multidimensional interval. The decision-making process is a multistep one which means that the single decision dimensions are not examined parallel to each other, first we examine whether they fall into the projection of the give interval, and if this does not hold then we refuse the sample without additional calculations. It means the decision is the calculation of the distance between the projections of two vectors (one of them is the ethanol, other is the extracted feature vector).

To list these components of the feature vector the easiest way is to look over the identification steps applied by us. We want to determine those quantities which describe the bonity of fittings by giving a basis to make a decision.

7.1. **Fitting of minors.** The first step is to search the minors stored in the ethanol on the sample. It is important to make this step first, because to determine the locations of minors one can correct the errors like *displacement* during the identification.

First, we determine a window, in which we search the minor. This window will be the extension of the location of the minor in the ethanol with a given size. This means in practice, that even if we allow some displacements at sampling, we also limit the extent of it by the given parameter.

The determination of the location of the minor means that within the given window by fitting the minor obtained from the ethanol to the direction matrix of the sample we look for the minimum distance between the minors which overlap each other, with the help of the searched window. This position is considered to be the location of the minor in the sample. We perform this for all three minors of the ethanol.

In order, to determine the difference between two minors we apply a measure, which is based on the distance among the cells. The distance between two cells is zero, if their directions are the same; it equals 1, if the deviation of their direction is 45°; and it equals to 2, if the deviation is 90°. If one of the cells has not direction, then the distance is not interpreted.

The first measure in determination of the distance between the ethanol and the sample is the value of the minimum distance of them. The number introduced to measure the failure of fitting is the *maximum distance of minors*, which contains the biggest one from the minimized distances of the three minors.

The next step is the investigation of the relative locations of the minors, and the comparison with the relative locations in the ethanol.

As a consequence, the next measure for determination the difference between the ethanol and the sample is the distance of the relative positions of the minors in the ethanol and the sample. We define this in the following way.

Let (x_1, y_1), (x_2, y_2), (x_3, y_3) indicate the upper left corner of the minors in the direction matrix in the ethanol. In the sample we have (x'_1, y'_1), (x'_2, y'_2), (x'_3, y'_3). We create the vectors

$$(x_2 - x_1, y_2 - y_1, x_3 - x_1, y_3 - y_1, x_3 - x_2, y_3 - y_2),$$

$$(x'_2 - x'_1, y'_2 - y'_1, x'_3 - x'_1, y'_3 - y'_1, x'_3 - x'_2, y'_3 - y'_2)$$

they should be identical if geometrical distortion does not exist. The distortion can be characterized by the difference of the two vectors. The two measures introduced by us are the *maximum minor difference*, which shows the biggest one among the differences of the co-ordinates of the two vectors, and the *total minor difference* which means the sum of the absolute values of all differences.

7.2. **Ridge-counting.** The next step is to determine the number of ridges cut by the sections laid between points of the ridges. In order, we determine the points relatively to the positions of minors already found. Since we marked three ridge point pairs we are going to get three values.

By comparing these values with values of the ethanol we can define two additional values: the *maximum ridge-count difference* for the biggest difference, and the *total ridge-count difference* for the sum of the absolute values of the differences.

With these measures defined now and those determined at minor-fitting we can actually describe the sameness/diversity of the global pattern of finger prints comparing to the ethanol. The other group of parameters in decision-making are the local features.

7.3. **Searching for forks and fork-groups.** To search for forks we use the fork-detection algorithm introduced earlier. The probable location of the minor in the sample serves as the reference point for the position of searching. The result of the detection of a given fork is binary: we either find it or not. In the point of view of decision-making we found only one number to be important: the *ratio of forks found*, that is, how many percentage of forks defined in the ethanol have been found.

We applied two measures for the success of detection of forks. The first one is the *ratio of the whole fork-groups* found, which expresses that how many fork-groups exist among those all forks of which we have found.

We mentioned that the fork-groups play an important role in identification, that is why we considered that the "almost whole" fork-groups should be included into the decision-making. Since breaking of ridges during sampling because of any reason might result in the elimination of a fork from the investigated sample.

On the basis of this the algorithm of the identification uses the number of the complete and the *incomple te fork-groups* as well, in which only one fork is missing comparing to the number set in the ethanol, for decision-making.

8. Experiments

To examine the reliability of our finger print identification system we have carried out the following experiments. First, we formed a group of 14 people who had no previous information on the methods of finger print taking. We have recorded the finger prints of the thumb, the forefinger and the middle finger of both the left and right hands of the participants directly by an optical recording instruments. The number of prints taken from one person varied between 20 and 300. The recorded images are recorded in 64 grey levels with sizes 256×256. For each person the ethanol had been taken manually. From the experiments we can conclude the following. The system has never made any error of the first kind, i.e., it has never declared two prints to be the same if they were not. It made several times a error of the second kind, i.e., it refused a print in such cases when it should have been accepted. In order, to check the error of the second kind we have divided the prints into two groups. The first group contained those prints which were taken when the participants had no previous knowledge on the proper use of the recording instrument (adaptation period). This means approximately the first 10 prints in case of each person. The second group consist of the prints taken after the adaptation period. The extent of the error of the second kind was about 20-25% in the average during the adaptation period, while in the main period the extent of it decreased to 5–8%. The standard deviation of the error of the second kind was quite high due to the persons. We should also note, that among the finger tips examined the thumb has been proved as the most useful for identification since its "rich" ridge pattern collection (see in [1]). However, beside the finger, the success of the identification seems to depend on the choose of the hands. The left hand (in case of the right-handed persons) is more useful, since its epithelium is less made use of.

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