lip trace, lip print, cheiloscopy,
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LIP TRACES RECOGNITION BASED ON LINES PATTERN

This paper presents a method for automatic lip traces recognition based on lip furrows arrangement. First, lip trace is scanned and subjected to image processing and feature extraction. Then, identification is performed by comparing lip trace characteristics with a collection of comparative lip prints characteristics stored in a database. The proposed solution gives a satisfactory level of identification accuracy. After further improvement, it can be used as part of a system performing analysis of traces recovered from crime scenes.

1. INTRODUCTION

Lips model in the embryonic period of human individual development along with evolution of face. During this period basis of a future lip pattern, present on human lips for a lifetime, is also formed.

Surface of lips is covered by numerous depressions (furrows), which reflect as a line pattern. They are arranged in various shapes and drawings, which are individual for each person. There are no two people with identical lip furrows arrangement [7]. The study of furrows systems occurring on human lips is called cheiloscopy.

Although, cheiloscopy is a relatively young field of forensic science, it gained large popularity around the world. In many countries, the results of lip traces analysis are considered as evidence in lawsuits [6]. Personal identification based on lip traces is possible due to the fact that lip pattern, similar to fingerprint pattern, has three properties: permanence, indestructibility and uniqueness [1-5].

In Polish criminological practice, lip traces are successfully used to identify crime perpetrators. However, lip traces recognition is performed completely manually. Due to this fact, comparison of traces found at a crime scene with a comparative lip prints collected from suspects is a long process. In case of poor lip trace quality and large number of comparative lip prints, it can reach up to several months.

There is a strong demand for software that assists in an identification of traces recovered from crime scenes, including lip traces. The solution proposed in this article can be part of such a system.

2. DATABASE

There are no lip prints databases available publicly. Therefore, one of tasks in implementing the lip traces recognition system was to create a digital database of lip prints.

For this purpose, a cheiloscopic tool kit was used. The same toolkit is used by forensic experts to collect comparative lip prints from suspects. It consists of the following elements:

- cheiloscopic roller,
- white sheets,
- black magnetic powder,
- magnetic applicator.

The database created for the purposes of this research includes two types of lip prints:

- comparative lip prints - imprints of an entire lips surface for comparative purposes (similar to comparative material collected from suspects),
- lip traces - imprints of fragments of lips used as test samples (similar to traces recovered from crime scenes).

Fig. 1 shows a sample collection of lip prints stored in the database.

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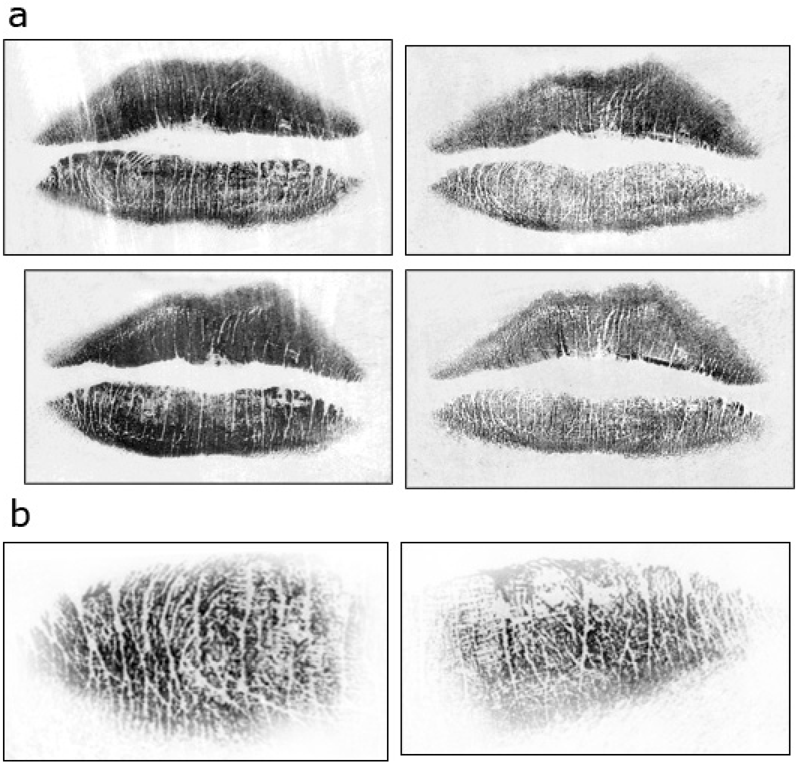

Fig. 1. A sample collection of lip prints stored in the database: a) comparative lip prints, b) lip traces.

In order to create the database, lip prints were collected from ten individuals. For each person, two lip traces and four comparative lip prints are stored. The way of collecting both types of lip imprints was very similar to the procedure of collecting comparative lip prints used in present forensic laboratories:

1. Person applies a little bit of moisturizing cream to the red area of lips.
2. After about two minutes, cheiloscopic roller with white sheet attached is pressed gently against person's lips.
3. Then the trace left on white sheet is disclosed using black magnetic powder and magnetic applicator.
4. The final step is to attach white sheet with lip print to a cheiloscopic card containing all lip prints taken from a person and some additional information.

After all the lip imprints had been collected, digitization process took place. Cheiloscopic cards were scanned at 600 dpi. Then, using image processing software individual lip imprints were extracted and saved as bitmaps in a resolution of 300 dpi.

3. IMAGE PROCESSING

Lip imprint image processing is used for extracting a set o characteristics for both lip traces and comparative lip prints. The set of characteristics is a collection of segments, which approximates a lip pattern present on the analyzed lip trace. Image processing procedure used in the proposed system consists of four stages (the stages are presented in detail in article [8]):

- background detection, where the image is converted to a monochrome (greyscale) and lip print area is separated from the background;
- binarization, where the image is converted to a black-white version. After this process the lip pattern is mapped in black color;
- Hough transformation, where straight lines occurring in the lip pattern are detected;
- segments detection, which are a substitute of lip furrows.

Background detection is the first stage of the image pre-processing. The aim of this procedure is to separate lip print area from the background. This way it is possible to use different types of image processing for these two areas of the image. Each pixel of an original greyscale lip imprint image I_{ORG}

(Fig. 2a) is checked whether it belongs to background or lip print area. Pixel $I_{ORG}(x, y)$ belongs to the image background, if the average brightness of pixels in its surroundings $d(x, y)$ is greater than the background detection threshold γ:

$$I_{BG}(x,y) = \begin{cases} 0 \text{ if } d(x,y) > \gamma \\ I_{ORG}(x,y) \text{ if } d(x,y) \le \gamma \end{cases}, \quad (1)$$

where:

$x = 1, 2, ..., w$,

$y = 1, 2, ..., h$,

w – width of image I_{ORG},

h – height of image I_{ORG}.

Parameters $d(x, y)$ and γ are defined by the following formulas:

$$\gamma = 255 - 0.75\left(255 - \frac{\sum_{y=1}^{h}\sum_{x=1}^{w} I_{ORG}(x,y)}{wh}\right), \quad (2)$$

where:

$x = 1, 2, ..., w$,

$y = 1, 2, ..., h$.

$$d(x,y) = \frac{\sum_{j=y-1}^{y+1}\sum_{i=x-3}^{x+3} I_{ORG}(i,j)}{21}, \quad (3)$$

where:

$x = 4, 5, ..., w-3$,

$y = 2, 3, ..., h-1$.

Fig. 2b shows the image I_{BG} resulted from the background detection procedure (background detected in the image is marked in black).

The second stage of the image pre-processing is binarization. The main goal of the binarization procedure is to remove image artifacts and emphasize lip pattern for further processing. Binarization is carried out for every pixel of image I_{BG}. If a pixel is part of the background, it takes the value of 0 (white). Otherwise its value is determined as follows:

$$I_{BIN}(x,y) = \begin{cases} 1 \text{ if } I_{BG}(x,y) > b(x,y) \\ 0 \text{ if } I_{BG}(x,y) \le b(x,y) \end{cases}, \quad (4)$$

where:

$x = 1, 2, ..., w$,

$y = 1, 2, ..., h$.

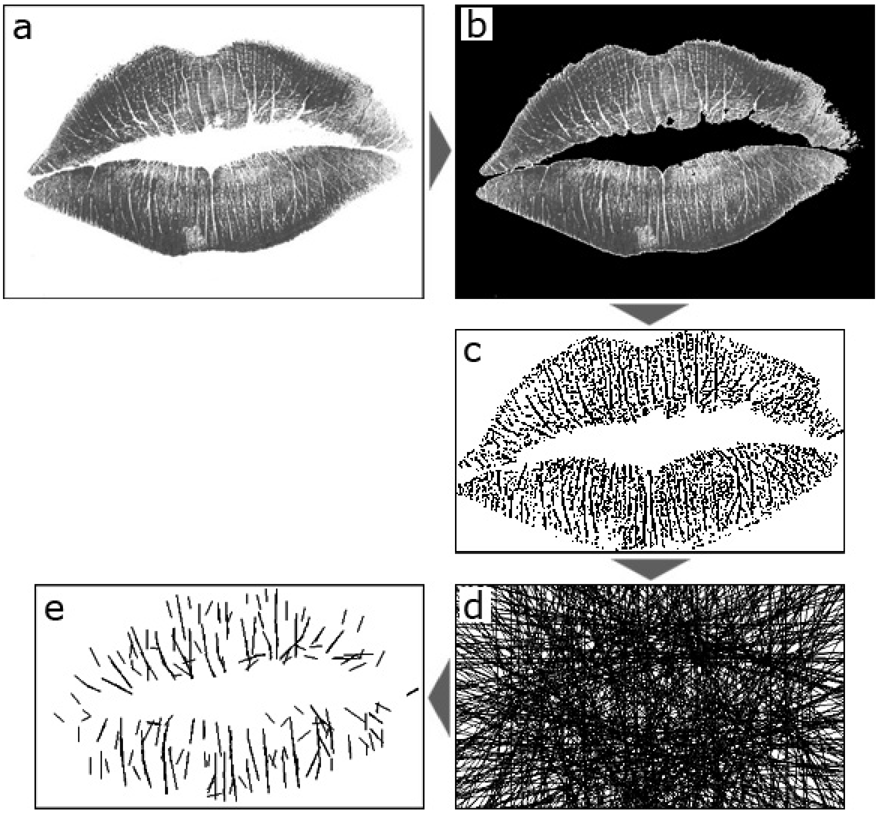

Fig. 2. Graphical representation of lip imprint analysis stages: a) original lip imprint image, b) result of background detection, c) image resulted from binarization procedure, d) set of straight lines resulted from the Hough transform, e) final set of segments approximating lip pattern.

Parameter $b(x,y)$ is defined by the following formula:

$$b(x,y)=1.1\left(\frac{\sum_{j=y-4}^{y+4}\sum_{i=x-4}^{x+4} I_{BG}(i,j)}{81}\right), \tag{5}$$

where:

$x=5,6,...,w-4$,

$y=5,6,...,h-4$.

The final result of binarization and cropping is presented in Fig. 2c.

After the pre-processing, image feature extraction is conducted. First stage of the feature extraction is Hough transform. This method is used to detect straight lines in the lip imprint image. In the first step pixels of image I_{BIN} belonging to lip pattern area (marked black in Fig. 2c) are transferred to polar coordinate system. On the basis of $I_{BIN}(x,y)$ coordinates, length of vector r for each value of angle θ is determined:

$$r = x\cos\theta + y\sin\theta\,, \tag{6}$$

where:

$\theta \in \left\{0, \frac{\pi}{128}, \frac{2\pi}{128}, ..., \pi\right\}$.

Obtained pair of polar coordinates allocates an address of cell in a so-called accumulator array. Value in the allocated cell is then incremented. This way pixels belonging to lip print pattern are reproduced in the accumulator array as curves.

In the second step, intersections of curves in the accumulator array are identified. Coordinates of the intersection points determine the parameters of straight lines existing in the lip pattern. Analysis is conducted to all cells in the accumulator array. Coordinates of cells that form the local maxima define the (r,θ) parameters used to determine straight lines equations according to formula 6. Fig. 2d presents a graphical representation of straight lines detected using Hough transformation.

The final stage of lip print analysis is segments detection. The aim of this procedure is approximation of lip pattern by a corresponding collection of segments, which form a set of characteristics of a lip print. Segments detection is based on lip pattern (Fig. 2c) and a set of straight lines resulted from Hough transformation (Fig. 2d).

In the first step, straight lines resulted from Hough transformation are transferred to Cartesian coordinate system:

$$\theta \in [0,\frac{\pi}{4}) \cup (\frac{3}{4}\pi,\pi] \Rightarrow \begin{cases} y = round\left(r - xctg\theta\right) \\ x \in \{1, 2..w\} \end{cases} , \tag{7}$$

$$\theta \in [\frac{\pi}{4},\frac{3}{4}\pi] \Rightarrow \begin{cases} x = round\left(r - yctg\theta\right) \\ y \in \{1, 2..h\} \end{cases} . \tag{8}$$

Next, points which form a straight line and overlap the lip pattern are examined. For every straight line so-called segment detection array is created. If a point (x, y) of the straight line lies in the lip pattern area, then value of the corresponding coordinate in the segment detection array is set to 1.

In the last step, parameters of segments corresponding to lip pattern are determined. Analysis of the segment detection array for each of the straight lines is conducted. Beginning and end of each sequence of ones determines beginning and end coordinates of the corresponding segment, while number of consecutive ones defines its length. Graphical interpretation of a set of segments resulted from the segment detection procedure is presented of Fig. 2e.

4. LIP TRACE RECOGNITION

Recognition of a lip trace is a complex procedure. First, image of a lip trace is analyzed to determine its set of characteristics. The set of characteristics is a collection of segments, which approximates a lip pattern present on the analyzed lip trace. Then a comparison between lip trace and comparative lip prints stored in the database takes place. Each record of the database refers to an individual person and contains four comparative lip prints belonging to that person. The comparison is conducted for each of the four comparative set of characteristics. The highest value obtained defines a similarity coefficient between lip trace and comparative lip print of a person.

After all records of the database were analyzed, the highest similarity coefficient value is selected. If the value is greater than or equal to the estimated similarity threshold, then the process of lip trace identification is successfully completed. A diagram of lip trace identification process is shown in Fig. 3.

Set of segments obtained during the lip print analysis is represented as a list, where each element is defined by three parameters: center coordinates, length and angle of the segment. To determine similarity between two sets of segments, all of the above parameters are used.

Similarity between lip trace (set T of segments) and comparative lip print (set C of segments) is determined as follows. In the first step, the longest segment t_L in set T is found. Then, in set C segments $c_{S,i}$ similar to the selected segment are found (length and angle do not differ by more than 50%). Next, segments in set T are transferred to the space of set C in such a way that angle and center coordinates of t_L match the same parameters of $c_{S,i}$ (segments in set T are shifted and rotated [9]).

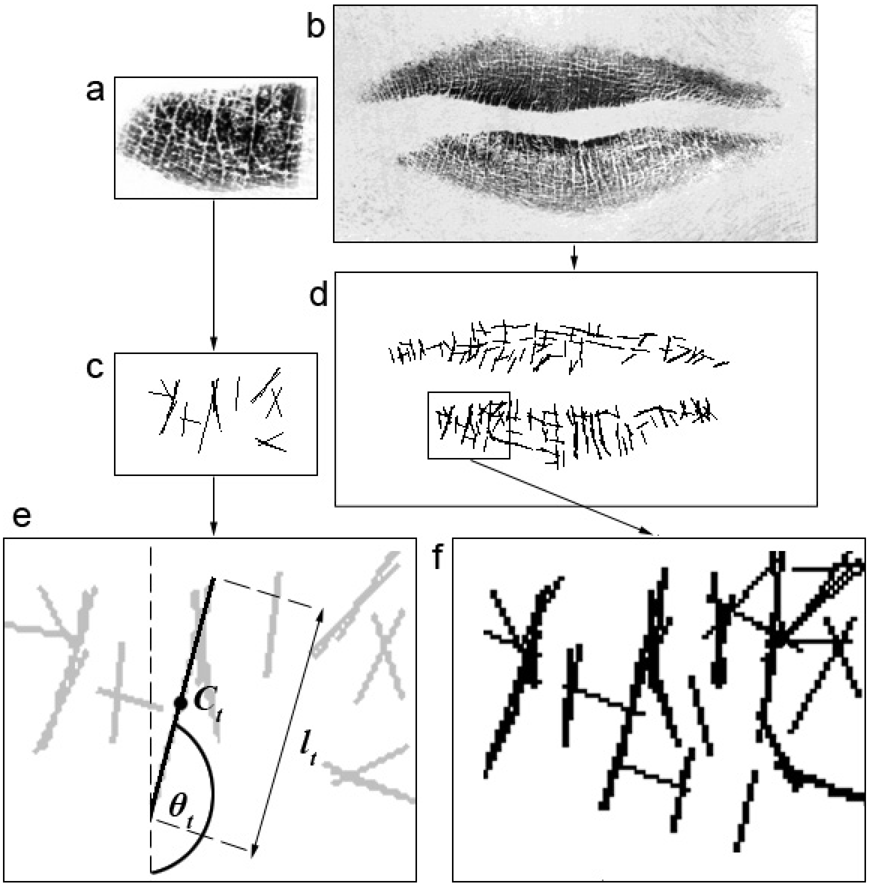

Fig. 3. A diagram of lip trace recognition process: a) lip trace image, b) comparative lip print image, c) set of characteristics T of lip trace, d) set of characteristics C of comparative lip print, e) features describing a sample segment t in set T, f) fragment of the set C most similar to set T.

In the last step, similarity between T and C sets is determined. Every segment t in set T is compared with the most similar segment c in set C. Similarity coefficient δ is calculated on basis of similarity sub-values for each segment t according to the following formula:

$$\delta = \frac{\sum_{t \in T} \left(\frac{\delta_{t(C)} + \delta_{t(l)} + \delta_{t(\theta)}}{3} \right)}{card(T)} . \tag{9}$$

The similarity sub-values $\delta_{t(C)}$, $\delta_{t(l)}$, $\delta_{t(\theta)}$ define respectively similarity between center coordinates, length and angle of t and c segments. The above values are defined by the following formulas:

$$\delta_{t(C)} = 1 - \frac{\Delta C}{0.25\sqrt{w_t^2 + h_t^2}} , \tag{10}$$

where:

ΔC - Euclidean distance between center coordinates of segments t and c,

$\sqrt{w_t^2 + h_t^2}$ - diagonal of lip trace image I_{ORG}.

$$\delta_{t(l)} = 1 - \frac{|l_t - l_c|}{0.25\sqrt{w_t^2 + h_t^2}}, \quad (11)$$

where:

$|l_t - l_c|$ - absolute value of the difference between t and c segment lengths,

$\sqrt{w_t^2 + h_t^2}$ - diagonal of lip trace image I_{ORG}.

$$\delta_{t(\theta)} = 1 - \frac{|\theta_t - \theta_c|}{0.25\pi}, \quad (12)$$

where:

$|\theta_t - \theta_c|$ - absolute value of the difference between t and c segment angles.

Similarity coefficient δ ranges from 0 to 1, where 0 - no similarity, 1 - full similarity. After analyzing the entire database, a record for which δ coefficient has the highest value is selected. If this value is higher or equal to the similarity threshold of 0.75, then the identification process ends successfully. Analyzed lip trace match the comparative lip prints belonging to the person corresponding with the selected record.

5. RESULTS

Present study evaluated the usefulness of the proposed method in the lip traces identification procedure. In comparative tests FAR and FRR rates were used. The study was conducted on a collection of 20 lip traces and 40 comparative lip prints coming from ten individuals (two lip traces and four comparative lip prints for each person). Every lip trace was compared with four comparative lip prints of each person.

The highest system effectiveness (percentage of correctly classified lip traces) was obtained for similarity threshold of 0.75. The test results are presented in Table 1:

Table 1. Test results.

	FAR	FRR	Effectiveness
Identification	35%	10%	55%

For 20 test lip traces, 11 were correctly classified, 7 were incorrectly approved and 2 were incorrectly rejected. These results define the effectiveness of the system at 55% and the error rates FAR = 35% and FRR = 10%.

6. CONCLUSIONS

Human lips, in contrast to fingertips, are very ductile. Due to this fact, lip prints of the same person vary in shape. They also vary in size, visibility and arrangement of furrows forming the lip pattern. Therefore, automatic identification of lip traces is a very difficult task. This area of image recognition is still insufficiently investigated and there are no solutions performing lip trace recognition available publicly. Results obtained by the proposed system are average, but encouraging enough to allow further research in this direction. Proposed algorithms are still improved and have high potential. Further research will include lip imprint image shape manipulation simulating natural ductility of human lips and recognition of more complex shapes existing in a lip pattern.

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