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Touchless Fingerprint Biometrics: a Survey on 2D and 3D Technologies

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Abstract

Traditional fingerprint recognition systems require that the users touch a sensor to perform biometric acquisitions. In order to increase the usability, acceptability, and accuracy of fingerprint recognition technologies, touchless systems have recently been studied. With respect to touch-based biometric techniques, these systems present important differences in most of the steps of the recognition process. Studies in the literature can be classified into technologies based on two-dimensional and three-dimensional methods. These studies also present important differences in terms of accuracy and required level of user cooperation.

This paper presents a brief survey on touchless recognition technologies, proposing a classification of two-dimensional and three-dimensional biometric recognition techniques.

Keywords: Biometrics, Fingerprint, Touchless, 3D, Survey

1 Introduction

Most of the current fingerprint recognition systems perform biometric acquisitions using touch-based devices, such as optical and solid state sensors. Touch-based techniques, however, suffer from intrinsic problems:

- fingerprint images present non-linear distortions due to elastic deformations of the friction skin;
- local regions of fingerprint images can present contrast differences, due to factors as inconstant pressure of the finger, dryness of the skin, skin diseases, sweat, dirt, and humidity in the air;
- for each biometric acquisition, a latent fingerprint is left on the sensor platen, introducing a security lack.

Recent studies aim to overcome these problems by designing touchless-recognition methods.

Touchless systems, in fact, do not introduce deformations of the finger skin, are more robust to dirt and environmental factors, and do not present problems related to latent fingerprints.

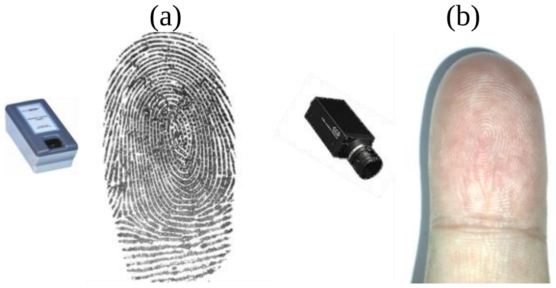

Fig.1. Examples of fingerprint acquisitions performed using different technologies: (a) touch-based image captured with a CrossMatch V300 sensor; (b) touchless image obtained using a Sony XCD-SX90CR digital camera. Touchless fingerprint images present different non-idealities with respect to touch-based images.

Touchless systems can also increase the acceptability of fingerprint biometrics, overcoming limitations due to cultural factors and fears related to the transmission of skin diseases. Moreover, less-constrained touchless acquisitions can reduce the efforts necessary for training the users, and can decrease the number of Failures to Acquire (FTA).

The acquisition technologies used by touchless recognition systems can be based on one or more digital cameras. The obtained images present important differences with respect to the ones obtained by touch-based sensors. Examples of touch-based and touchless acquisitions are shown in Fig. 1. It is possible to observe that touchless fingerprint images present more noise, reflections, and a more complex background with respect to touch-based images. Moreover, the skin can be considered as part of the background. Other non-idealities are related to inconstant resolution of the images and perspective distortions.

In order to overcome these problems, recent studies proposed different hardware and software solutions.

All the recognition methods in the literature, anyway, can be divided into common steps: acquisition, computation of a touch-equivalent image, feature extraction and matching. The schema of the biometric recognition process is shown in Fig. 2.

Considering the used acquisition strategy, systems in the literature can be classified in methods based on two-dimensional and three-dimensional data.

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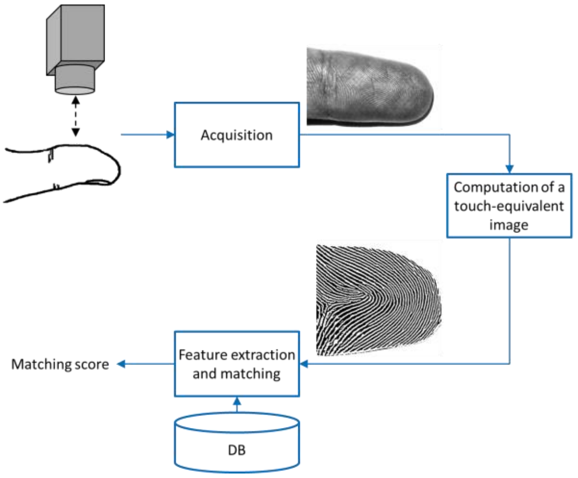

Fig.2. Schema of the recognition process in biometric systems based on touchless fingerprint acquisitions.

Two-dimensional acquisition setups are usually based on a single digital camera. Three-dimensional acquisition methods can be based on multiple-view setups, structured lights techniques, or photometric stereo strategies.

The computation of a touch-equivalent image aims to obtain enhanced fingerprint images describing the ridge pattern with constant resolution. Two-dimensional and three-dimensional systems perform this step using different strategies.

The feature extraction and matching steps are usually performed applying algorithms designed for touch-based images.

The paper is structured as follows. Section II presents a literature review on two-dimensional systems. Then, Section III analyzes three-dimensional systems. Finally, Section IV summarizes the work.

2 Two-dimensional systems

Touchless recognition systems based on two-dimensional samples present important differences. In the literature, there are technologies based on unconstrained acquisition setups and designed to be integrated in mobile devices, and there are systems that use more complex and constrained acquisition setups in order to obtain higher accuracy. In both of these cases, touchless systems capture one or more images using digital cameras, then compute a touch-equivalent fingerprint image with algorithms designed according to the used acquisition setup, and usually perform the feature extraction and matching steps with methods designed for touch-based recognition systems. In order to overcome non-idealities of the samples due to perspective deformations and inconstant resolution, there are also studies on dedicated feature extraction and matching techniques.

2.1 Acquisition

The simplest acquisition setup consists in the use of a single camera in uncontrolled light conditions. A study on biometric recognition techniques based images captured using a webcam in natural light conditions is presented in [1], and methods based on mobile phone cameras are described in [2, 3, 4].

The images captured with these acquisition setups, however, present low contrast between ridges and valleys. For this reason, illumination techniques are usually adopted to obtain better quality samples. Some studies are based on simple illumination systems based on a single point light source [5, 6, 7, 8, 9, 10]. Other studies adopt diffused light sources in order to obtain more uniform contrast in different regions of the finger [11]. There are also studies based on specifically designed ring illuminators [12], which permit to obtain light rays perpendicular to all the finger surface.

Studies have also been performed for searching the best wavelength for touchless fingerprint acquisitions [13, 14, 15, 16]. They report that long wavelength rays, like white light and infrared, tend to penetrate the skin, and to be absorbed by the epidermis. On the contrary, blue light with wavelength of 500 nm obtains the lower hemoglobin absorption and permits to enhance the visibility of the ridge pattern.

The acquisition system described in [17] uses a red light source placed on the fingerprint side to focus the light transmitted through the finger onto a CCD sensor. This technique permits to obtain images more robust to skin diseases and aging, but require constrained acquisition setups.

Another aspect of acquisition systems is the distance between the finger and the cameras. Most of the systems perform acquisitions at a distance of less than 100 mm from the sensor. Only some methods capture images at a distance of more than 200 mm [8, 9, 10, 11].

In order to avoid motion blur problems and to obtain images with known resolution, most of the systems in the literature use finger placement guides placed at a known distance from the acquisition device. There are also studies on unconstrained setups [16, 9].

Due to the curved finger shape, the images captured from a single camera present inconstant resolution in the different local regions. In order to reduce this problem, some systems use multiple cameras placed around the finger [18, 16].

In the literature, there are also systems based on multiple fingers [19] and systems able to capture both fingerprint samples and images of the vein pattern [16, 20].

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2.2 Computation of touch-equivalent images

Most of the touchless fingerprint recognition systems in the literature perform the feature extraction and matching steps using methods designed for touch-based images in order to obtain results compatible with touch-based systems and AFIS (Automated Fingerprint Identification Systems).

Feature extraction and matching algorithms designed for touch-based fingerprint samples, in fact, usually obtain poor results if directly applied on touchless images. As proved in [3], commercial fingerprint recognition software can obtain sufficient results only on touchless samples with very high quality.

In order to obtain images compatible with touch-based systems, touch-equivalent images are therefore computed. This step aims to obtain images representing only the ridge pattern with constant resolution. An example of touch-equivalent image is shown in Fig. 3.

In systems based on a single image, the computation of touch-equivalent images can be divided into two tasks: enhancement and resolution normalization.

In the literature, there are different enhancement methods designed for touchless fingerprint images.

The ones proposed in [8, 9, 10, 11, 21] first perform a background subtraction and then apply contextual filtering algorithms [22]. Other techniques use morphological enhancement algorithms before applying contextual filtering methods [5, 6, 7]. There are also methods based on background subtraction techniques and frequency filters [1], and specific contextual filtering algorithms [23].

Since most of the fingerprint recognition systems are based on identity comparison techniques that require fixed resolution images (e.g. minutiae matching algorithms) a resolution normalization step is usually performed. In most of touchless recognition systems, this task is performed by using a constant resizing factor estimated by analyzing the distance between the cameras and the finger placement support. In less-constrained systems, this factor can only be estimated from the captured images [1].

Two-dimensional acquisition methods, however, cannot obtain fingerprint images with constant resolution in each region of the finger and suffer from perspective deformations. Some methods in the literature reduce this problem by computing touch-equivalent images from the mosaicking of acquisitions performed from different cameras [18, 24]. A different approach computes touch-equivalent images from frame sequences describing a finger moving in a ring mirror [25].

A software approach for the compensation of perspective distortions due to finger rotations is described in [11].

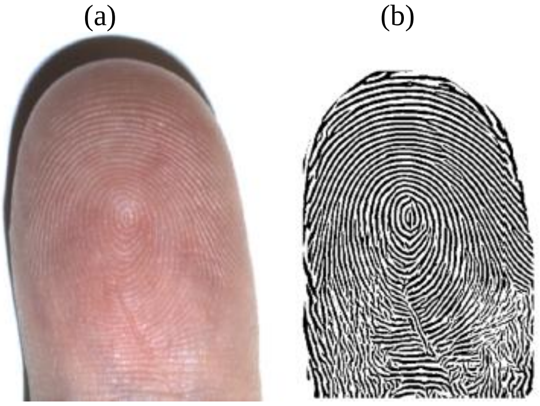

Fig.3. Example of touch-equivalent image obtained from a touchless sample: (a) touchless image; (b) touch-equivalent image.

2.3 Feature extraction and matching

Most of the touchless fingerprint recognition systems in the literature are based on algorithms designed for the analysis of minutiae in touch-based images.

In systems based on unconstrained acquisition setups, however, traditional minutiae-based techniques can obtain poor results due to the presence of perspective distortions and inconstant resolution in the samples. Feature extraction and matching methods designed to overcome these non-idealities have therefore been studied. The method described in [10] permits to extract Level 1 features [22] by using Neural Network classifiers. A minutiae matching technique based on Neural Networks is proposed in [8]. The system described in [26] performs identity comparisons using Support Vector Machines and features similar to the template Fingercode [27].

3 Three-dimensional systems

With respect to two-dimensional systems, technologies based on three-dimensional data can use more information and less-distorted samples. The obtained samples, in fact, represent metric reconstructions of the finger skin. Three-dimensional systems, however, are usually based on more complex and expensive acquisition setups.

The acquisition process can be based on different three-dimensional reconstruction strategies, as multiple-view methods, structured light techniques, or photometric stereo methods. Also the obtained samples present important differences.

Most of the systems in the literature compute touch-equivalent images in order to obtain data compatible with the existing AFIS. The feature extraction and matching steps are then performed using algorithms designed for touch-based samples.

There are also preliminary studies on three-dimensional feature extraction and matching strategies.

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3.1 Acquisition

Three-dimensional acquisition techniques used by touchless fingerprint recognition systems present important differences.

Systems based on multiple-view techniques can only obtain samples composed by the finger volume with a superimposed image representing the ridge pattern. Systems based on structured light techniques and photometric stereo strategies can also estimate three-dimensional models of ridges and valleys. However, these systems require more user cooperation since they need that user stays still during the time needed to acquire the frame sequences necessary for the computation of three-dimensional models.

Fig. 4 shows an example of finger volume with superimposed ridge pattern and a sample representing the three-dimensional shape of ridges and valleys.

An acquisition device based on a multiple view technique is presented in [25, 28, 29]. The setup is composed by five cameras located on a semicircle and pointing to its center, where the finger has to be placed during the biometric acquisition. It also uses a set of five LED lights placed around the finger. The used three-dimensional reconstruction method first perform a rough volume estimation using a shape from silhouette technique and then refines the three-dimensional model by triangulating pairs of corresponding points obtained using a correlation-based algorithm.

The acquisition technique described in [30] is based on an acquisition setup composed by three cameras and four LED lights placed around the finger. The adopted three-dimensional reconstruction strategy is based on the triangulation of corresponding points extracted considering minutiae, ridges, and SIFT features [31]. The finger shape is finally refined using prior estimated mathematical models.

The system presented in [21] uses a setup based on two cameras and a static projected pattern in order to perform fast three-dimensional reconstructions with a less-constrained acquisition setup.

A system based on a structured light technique is presented in [32, 33]. This system permits to estimate both the three-dimensional shape of ridges and valleys and a texture of the ridge pattern obtained from the visual aspect of the finger. The three-dimensional reconstruction of the ridge pattern is obtained by projecting a sine-wave pattern shifted several times. The texture of the ridge pattern is computed as the albedo image [34].

An acquisition system based on a photometric stereo strategy is described in [35]. It estimates the three-dimensional shape of the ridges from frame sequences captured by a single camera. Seven symmetrically distributed LED illuminators are used. The used three-dimensional reconstruction algorithm is based on the Lambertian reflectance based shape from shading technique [34].

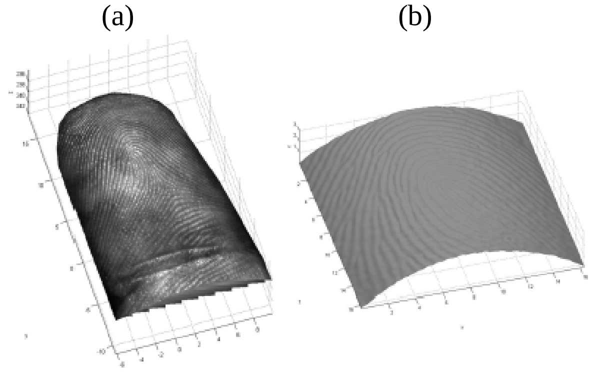

Fig.4. Example of three-dimensional samples obtained using different techniques: (a) finger volume and the texture of the ridge pattern; (b) portion of a three-dimensional model of ridges and valleys.

3.2 Computation of touch-equivalent images

This step aims to obtain images of the ridge pattern compatible with the existing biometric databases and AFIS.

An example of touch-equivalent image obtained from a three-dimensional sample is shown in Fig.5.

The three-dimensional samples are mapped into the two-dimensional space using algorithms that permit to preserve the distances between discriminative points of the ridge pattern. This task is usually called “unwrapping” or “unrolling”. The final task consists in the enhancement of the ridge texture, and is based on the same strategies used for two-dimensional touchless images.

Unwrapping algorithms in the literature can be divided into parametric methods (techniques that use previously defined geometrical models to approximate the finger shape) and non-parametric methods (techniques that do not perform assumptions on the finger shape).

A simple unwrapping algorithm based on a parametric strategy is proposed in [3] and it is based on the conversion of the three-dimensional finger model in cylindrical coordinates. The obtained images, however, present important distortions along the x axis.

The method described in [32] approximates the finger shape using as a set of rings and then convert every ring in Polar coordinates.

Another parametric method is described in [36]. It first approximate the finger model to a sphere and then refines the obtained results using a non-linear mapping strategy.

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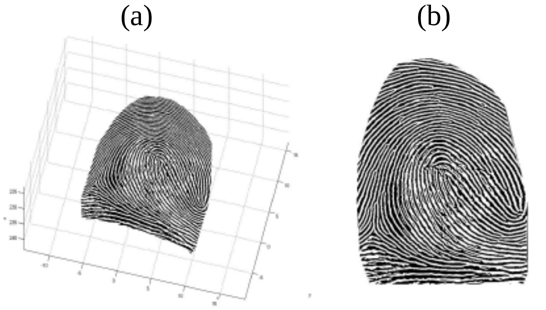

Fig.5. Example of touch-equivalent fingerprint image obtained from a three-dimensional model: (a) finger volume and texture of the ridge pattern; (b) touch-equivalent image.

The non-parametric strategy proposed in [3] aims to preserve the inter-point surface distances and scale to a maximum degree. First, it divides the fingerprint model into slices along the vertical direction, and then it unfold every slice by a resampling algorithm that tries to preserve the distances between the points pertaining to the slice.

Another non-parametric method is presented in [37]. It computes the fitting plane for each local region of the fingerprint model and then unwraps the points for each fitted plane by minimizing a cost function that describes the movement exerted between each point and its neighbors.

In order to increase the compatibility between touch-equivalent images and touch-based databases, the method presented in [38] includes a simulation of the finger pressure on a touch-based sensor.

In the literature, there are also quality assessment methods for touch-equivalent images obtained by the unwrapping of three-dimensional models [39].

3.3 Feature extraction and matching

Most of the methods in the literature adopt identity comparison techniques designed for touch-based images.

Preliminary studies on Level 1 features extracted from three-dimensional samples and three-dimensional minutiae matching techniques are reported in [35].

In order to reduce the efforts needed to collect data necessary for the design and evaluation of feature extraction and matching algorithms, methods for the simulation of synthetic three-dimensional samples have also been studied [40, 41].

4 Conclusion

With respect to traditional fingerprint recognition systems, which require the contact of the finger with the sensor, touchless biometric technologies present important advantages in terms of quality of the acquired samples, usability, acceptability, and robustness to environmental conditions.

In most of these systems, the recognition process can be divided into these steps: acquisition, computation of a touch-equivalent image, feature extraction and matching. The first step is based on one or more digital cameras. The acquired images are then processed to obtain touch-equivalent images representing only the ridge pattern with constant resolution. Feature extraction and matching are usually performed using algorithms designed for touch-based images.

Touchless recognition systems can be divided into technologies based on two-dimensional data and three-dimensional models.

Most of the two-dimensional systems are based on a single camera, and compute touch-equivalent images using enhancement and resolution normalization algorithms. Usually, these systems are less-expensive with respect to three-dimensional technologies, but present problems due to perspective deformations and non-constant resolution of the samples.

Three-dimensional systems can be based on different acquisition techniques: multiple-view setups, structured lights methods, or photometric stereo strategies. The obtained three-dimensional models can present different levels of detail. In these systems, the computation of touch-equivalent images is based on “unwrapping” algorithms, which map the tree-dimensional samples in the two-dimensional space. These methods can be based on assumptions on the finger shape (parametric algorithms) or on the analysis of local characteristics of the fingerprint (non-parametric algorithms).

In the literature, there are also studies on feature extraction and matching strategies specific for touchless samples.

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