The Surround Imager™: A Multi-camera Touchless Device to Acquire 3D Rolled-Equivalent Fingerprints

Geppy Parziale, Eva Diaz-Santana, and Rudolf Hauke

TBS North America Inc. 12801,
Worldgate Drive, Herndon, VA 20170, USA
{geppy.parziale, eva.diaz-santana, rudolf.hauke}@tbsinc.com

Abstract. The Surround Imager™, an innovative multi-camera touchless device able to capture rolled-equivalent fingerprints, is here presented for the first time. Due to the lack of contact between the elastic skin of the finger and any rigid surface, the acquired images present no deformation. The multi-camera system acquires different finger views that are combined together to provide a 3D representation of the fingerprint. This new representation leads to a new definition of minutiae bringing new challenges in the field of fingerprint recognition.

1 Introduction

The current fingerprinting technologies rely upon either applying ink (or other substances) to the finger tip skin and then pressing or rolling the finger onto a paper surface or touching or rolling the finger onto a glass (silicon, polymer, proprietary) surface (platen) of a special device. In both cases, the finger is placed on a hard or semi-hard surface, introducing distortions and inconsistencies on the images [1, 2].

Touchless Biometric Systems[1], formally TBS, has developed the Surround Imager™, an innovative live-scan device able to capture a rolled-equivalent (nail-to-nail) fingerprint without the need of touching any surface. The intrinsic problems of the touch-based technology, also known as *inconsistent, non-uniform* and *irreproducible contacts* [2], are definitively overcome with this new device.

The paper describes this new acquisition technology that, besides the above mentioned advantages, introduces also a novel representation of fingerprints. In fact, the multi-camera system acquires different finger views that are combines to generate a 3D representation of the fingerprint. This implies the design and development of new algorithms that are able to manage the 3D information provided by the new device and bring new challenges in the field of fingerprtin recognition.

The paper is organized as follows. In the next Section 2, the main functionalities of the Surround Imager™ are reported. Section 3 provides an overview of the image processing algorithms involved with the 3D reconstruction. The new representation and a new definition of minutiae is provided in Section 4. In the same Section, the problem of matching the new fingerprint against *traditional* representation and a possible approach to match minutiae in 3D are discusses. Finally, concluding remarks and future activities are presented in Section 5.

[1] http://www.tbsinc.com

D. Zhang and A.K. Jain (Eds.): ICB 2006, LNCS 3832, pp. 244–250, 2005.

2 The Surround Imager™

The left-hand side of Fig. 1 highlights a schematic view of the Surround Imager™. The device is a cluster of 5 cameras[2] located on a semicircle and pointing to its center, where the finger has to be placed during the acquisition. The size of the acquired images is 640×480 pixels.

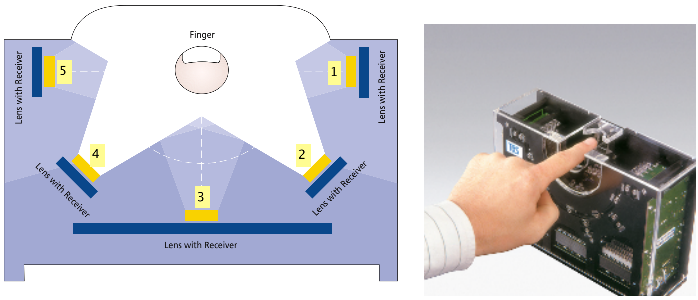

Fig. 1. The Surround Imager™ (on the right-hand side) and its schematic view (left-hand side)

The Surround Imager™ has currently the size of $15\ cm \times 24\ cm \times 10\ cm$. This size (large compared with other fingerprint devices) is mainly due to our choice of a reasonable quality-price ratio. Since the finger has to be far away from the 5 sensors with a distance depending on the sensor size and dot-pitch, the lens system and the required optical resolution, we chose the best solution in term of image quality, resolution and final costs of the device. The chosen distance has been fixed to $50\ mm$. Moreover, the device contains a set of 16 green LED arrays and the large size has also been chosen to dissipate the heat generated by the light system.

The LED intensities can be individually controlled during each acquisition. In previous experiments, we demonstrated that the green light produces a better contrast on the fingerprint structure than the red and the blue lights. The advantage of the use of a green light is illustrated in Fig. 2. The touchless approach combined with the green LEDs allows the acquisition of fingerprints with a very dry or a very wet skin. These kinds of fingers are very difficult to acquire by touch-based devices.

Due to the large distance between the camera and the object (with respect to their size), the image resolution is not constant within the image and decreases from the center to the image extremities. The optical system has been designed to ensure a resolution of $700\ dpi$ in the center and a minimum of $500\ dpi$ on the image borders.

During a capture, the finger is placed on a special support (right-hand side of Fig. 1) to avoid trembling that could create motion blur. The portion of the finger that has to be captured does not touch any surface. Moreover, the finger has to be placed in a correct position so that it is completely contained in the field-of-views of the 5 cameras at the same time. A realtime algorithm helps the user during the finger placement. Once

[2] Since the Surround Imager™ is a modular device, versions with 1 or more (up to five) cameras are also available on request.

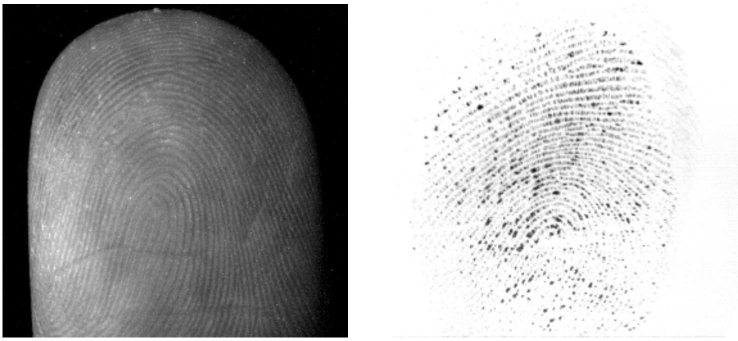

Fig. 2. The same fingerprint acquired with the Surround Imager ™ (on the left-hand side) and a touch-based optical device (on the right-hand side). The finger skin is very dry and thus, has a very low contrast on the touch-based device

the finger is in the correct position, the user receive a *'Don't move'* request from the device and the capture can start automatically. During an acquisition, each LED array is set to a specific light intensity and the 5 cameras capture synchronously a picture of the finger. This procedure is repeated 16 times in only 120 ms, ensuring that eventual finger movements are negligible for the following computation steps.

Each camera captures 16 times the same portion of the finger skin with different light conditions. Since the following 3D reconstruction steps are very complex and computationally expensive, the different illuminations are used to help these algorithms in extracting special image features.

In Fig. 3, a comparison of the same fingerprint acquired by the touchless device (on the left-hand side) and a touch-based optical sensor (on the right-hand side) is highlighted. Observing the two images, one can immediately notice that the Surround Imager™ provides a *negative polarity* representation of the fingerprint, i.e. the ridges appears to be brighter than the valleys. Besides, the image obtained by the TBS device contains also the structure of the valleys. This information is completely inexistent in other technologies where the valleys belong to the image background.

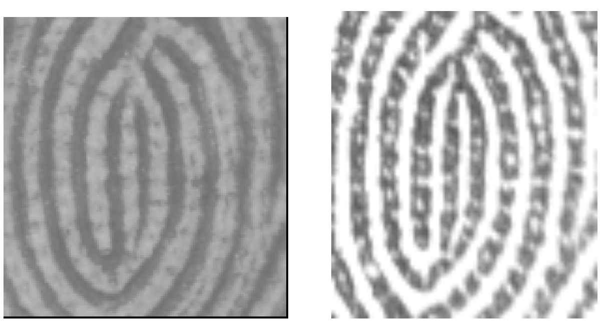

Fig. 3. The same portion of a fingerprint skin acquired with the Surround Imager ™ (on the left-hand side) and a touch-based optical device (on the right-hand side)

3 3D Reconstruction Algorithm

A detailed description of the used 3D reconstruction algorithms goes beyond the scope of this paper, but an overview of them is here reported for completeness.

The Surround Imager™ has been designed to provide a precise deformation-free representation of the fingerprint skin. The 3D reconstruction procedure is based on stereovision and photogrammetry algorithms. Thus, the exact position and orientation of each camera (*camera calibration*) with respect to a given reference system are needed for the following processing steps [5, 6]. The calibration is done off-line, using a 3D target on which points with known positions are marked.

The position of the middle camera (camera 3 in Fig. 1) has been chosen so that it could capture the central portion of the fingerprint, where the *core* and the *delta* are usually located. Then, the other cameras have been placed so that their field-of-views partially overlap. In this way, the images contain a common set of pixels (homologous pixels) representing the same portion of the skin. To compute the position of each pixel in the 3D space (3D reconstruction), the correspondences between two image pixels must be solved (*image matching*). This is done computing the cross-correlation between each adjacent image pair. Before that, the distortions generated by the mapping of a 3D object (the finger) onto the 2D image plane have to be minimized. This reduces errors and inconsistencies in finding the correspondences between the two neighbor image pair. Using shape-from-silhouette algorithms, it is possible to estimate the finger volume. Then, each image is unwrapped from the 3D model to a 2D plane obtaining the corresponding *ortho-images*.

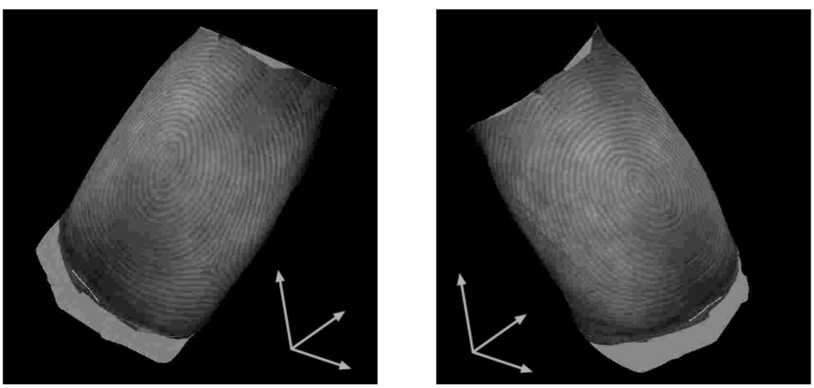

Fig. 4. Two views of a fingerprint reconstructed with the approach described in Section 3

The unwrapped images are used to search for homologous pixels in the image acquired by each adjacent camera pair. To improve the image matching, a multiresolution approach [4] has been chosen and an image pyramid is generated from each image [7]. Then, starting from the lower resolution level, a set of features is extracted for every pixel, obtaining a feature vector that is used to search the homologous pixel in the other image. When this is completed, the search is refined in the higher levels, until the original image resolution is reached. Once the pixel correspondences have been resolved, the third dimension of every image pixel is obtained using the camera geometry [6]. In Fig. 4, an example of the 3D reconstruction is highlighted.

4 A New Representation of Fingerprints

The image processing shortly described in Section 3 provides a new representation model for fingerprints. Since each image pixel can be described in a 3D space, a new representation of minutiae has to be adopted.

In the 2D image domain, a minutia may be described by a number of attributes, including its location in the fingerprint image, orientation, type (e.g. ridge termination or ridge bifurcation), a weight based on the quality of the fingerprint image in the minutia neighborhood, and so on [2, 3, 8]. The most used representation considers each minutia as a triplet $\{x, y, \theta\}$ that indicates the (x,y) minutia location coordinates and the minutia orientation θ. Considering this simple representation and adapting it to the 3D case (Fig. 5), a minutia point M_i may be represented by the t-upla $\{x, y, z, \theta, \phi\}$ that indicates the x, y and z coordinates and the two angles θ and ϕ representing the orientation of the ridge in 3D space.

Besides the coarse 3D representation of the fingerprint shape, the Surround Imager™ provides also a more fine 3D description of the ridge-valley structure. Since during the acquisition the finger does not touch any surface, the ridges are free of deformation. Besides, as shown in Section 2, this technology is also able to capture the information related to the fingerprint valleys. Thus, the entire 3D ridge-valley structure captured with a specific illumination can be well represented by the image gray-levels, mapping each image pixel into a 3D space $\{x, y, I(x, y)\}$, where $I(x, y)$ represents the value of the gray-level of the fingerprint image I at position (x, y). An example of this mapping is illustrated in Fig. 6, where the fingerprint portion of Fig. 3 is reported using a 3D representation.The fingerprint obtained by the Surround Imager™ would be useless if it was not possible to match it against fingerprints acquired with *traditional*

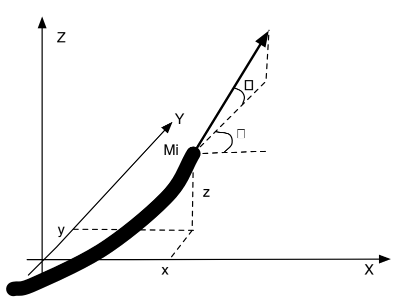

Fig. 5. 3D representation of a minutia M_i (ridge ending). The feature point is uniquely represented by the t-upla $\{x, y, z, \theta, \phi\}$.

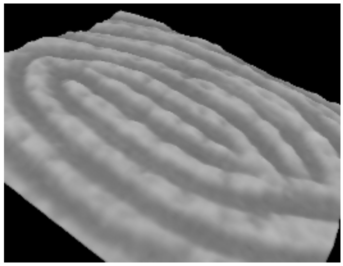

Fig. 6. A detail of the 3D ridge-valley structure

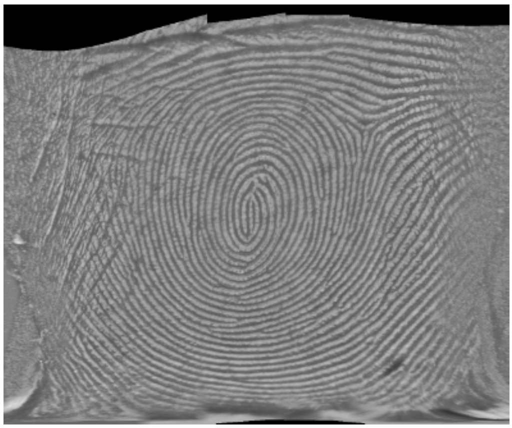

Fig. 7. A detail of the 3D ridge-valley structure

technologies. Besides, since large fingerprint databases are already available, it is inconvenient or/and impossible to build them up again using this new device. Thus, to facilitate the integration of the Surround Imager™ into existing systems, a 2D version of the reconstructed fingerprint is also provided after the reconstruction. The computed 3D finger geometry can be used to *virtually roll* the fingerprint onto a plane, obtaining a complete rolled-equivalent fingerprint of the the acquired finger (Fig. 7).

The presented 3D representation brings new challenges in field of fingerprint recognition and new algorithms to match fingerprints directly in the 3D space have been designed. This has many advantages with respect to the 2D matching. In fact, since fingerprints acquired by the Surround Imager™ do not present any skin deformation, the relative position of the minutia points is always maintained[3] during each acquisition. In this case, the minutiae matching problem can be considered as a rigid 3D point-matching problem [2].

[3] In reality, a small change in the water content of the skin can modify the relative distance among minutiae. These small variations can be corrected directly on the 3D reconstructed model.

The approach used to matching fingerprints in the 3D space is a generalization to the 3D case of the algorithm presented in [3]. Once the minutiae have been localized on the fingerprint skeleton, a 3D Delaunay triangulation is applied to the point clouds. From each triangle, many features are computed (length of the triangle sides, internal angles, angles between the minutia orientation and the triangle side, and so on) and then used to match the triangles in the other fingerprint.

5 Conclusion and Further Work

A novel device to acquire fingerprints has been here presented. The Surround Imager™ is a touchless device using 5 calibrated cameras that provide a 3D representation of the captured fingerprints. This novel representation leads also to a new definition of minutiae in 3D space, here given for the first time.

Because the different nature of the finger image with respect to the traditional approaches new methods for image quality check, analysis, enhancement and protection can be implemented to provide additional flexibility for specific applications. Besides, new forensic and pattern-based identification can also be developed and exploited to surpass the existing fingerprint methods. Also, due to this flexibility, the provided finger images are compatible with existing Automated Fingerprint Identification System (AFIS) and other fingerprint matching algorithms, including the ability to be matched against legacy fingerprint images.

References

1. D. R. Ashbaugh: Quantitative-Qualitative Friction Ridge Analysis. An Introduction to Basic and Advanced Ridgeology, CRC Press LLC, USA, 1999.
2. D. Maltoni, D. Maio, A. K. Jain, S. Prabhakar: Handbook of Fingerprint Recognition, Springer Verlag, June 2003.
3. G. Parziale, A. Niel: A Fingerprint Matching Using Minutiae Triangulation, on Proc. of International Conference on Biometric Authentication (ICBA), LNCS vol. 3072, pp. 241-248, Hong Kong, 15-17 July 2004.
4. M. del Pilar Caballo-Perucha, Development and analysis of algorithms for the optimisation of automatic image correlation, Master of Advanced Studies of the Post-graduate University Course Space Sciences, University of Graz, Austria, Dec. 2003.
5. M. Sonka, V. Hlavac, R. Boyle: Image Processing, Analysis, and Machine Vision, Second Edition, Brooks/Cole Publishing, USA, 1999.
6. R. Hartley, A. Zisserman: Multiple View Geometry in Computer Vision, Cambridge University Press, UK, 2003.
7. R. C. Gonzalez, R. E. Woods: Digital Image Processing, Prentice Hall, New Jersey, USA, 2002.
8. A. K. Jain, L. Hong, R. Bolle: On-Line Fingerprint Verification, PAMI, Vol. 19, No. 4, pp. 302-313, 1997.