Enhancement Techniques in fingerprints as a tool in Dactyloscopy

Moler, E. , Blotta, E. , Pastore, J., Meschino, G. , Ballarin, V.

Laboratorio de Procesos y Medición de Señales.
Universidad Nacional de Mar del Plata, J.B.Justo 4302
egmoler@fi.mdp.edu.ar

ABSTRACT

In this work an application of image enhancement techniques in fingerprints is presented. Digital Image-processing technology was applied to restored fingerprints with non-uniform contrast. These fingerprints corresponded to unidentified persons who were murdered by Military Forces in 1976.

In 1997, after a court decision, Human Right Organisations acceded to the microfilms of the Computer Records Division of the Province of Buenos Aires Police, which contained fingerprints and complementary information from these missing people. Unfortunately most of the fingerprints were taken with a reduction ratio of 41x, they were blurred and their spatial definition was not clear. These features made their classification and comparison very difficult.

In this paper a combination of spatial, frequency and morphological enhancement techniques used to restore the fingerprints is presented. Filters had to be combined because the results obtained by applying conventional enhancement techniques were not satisfactory.

The resulting images show prominent features in fingerprints that cannot be extracted by other enhancement techniques.

Keywords: Dactyloscopy, Forensic Sciences, digital image, fingerprints, enhancement.

1. INTRODUCTION

From 1976 to 1983 Argentina was under military dictatorship which was responsible for the disappearances of 30,000 people [1]. Since Argentina restored its democracy, different human rights organisations have been looking for missing people, and nowadays they are still working to achieve this goal. However victim's identification is very difficult to complete.

The Argentine Forensic Anthropology Team (Equipo Argentino de Antropología Forense, EAAF) is a group advocated to identification of missing people. In some cases, the bodies of missing people were buried as "NN" ("no name") in public cemeteries across the country [2]. Government agencies, including the police and the National Register of Persons (Registro Nacional de las Personas, RNP) created a number of bureaucratic records concerning these bodies. They frequently followed the normal procedures established in any routine case involving an unidentified corpse. These procedures included writing a description of the found, taking photographs, fingerprinting the corpse, conducting an autopsy or external examination of the body, writing a death certificate, making an entry in the local civil register, issuing a death certificate and making an entry in the cemetery records. Through these procedures, the mentioned institutions created a number of documents containing important information about the disappeared persons.

In 1997, after a court decision, EAAF gained access to the so-called "Cadavers File" microfilms kept in the microfilm section of the Computer Records Division of the Province of Buenos Aires Police (Provincia de Buenos Aires, PPBA). A total of 889 microfilms were copied and classified constituting the "Cadavers File" in the PPBA's Division of Fingerprinting, which contained fingerprints and complementary information. They attempted to match the historical data described in the police files with the information about NNs contained in the RNP records. They also cross-referenced the fingerprints of unidentified persons from the "Cadavers File" microfilms with those of disappeared persons obtained by EAAF from the RNP.

The main problem was that most of the fingerprints were taken with a reduction ratio of 41x, they were blurred and their spatial definition was not clear. These features made their classification and comparison almost impossible.

A fingerprint is the pattern of ridges and valleys on the surface of a fingertip. Each individual has unique fingerprints and the uniqueness of a fingerprint is exclusively determined by the local ridge characteristics and their relationships. Furthermore, the objective of a fingerprint enhancement method is to improve the details of ridges structures in each fingerprint image.

Since 1997 our Laboratory has been helping the EAAF solving this kind of problems [3]. Although various image restoration and enhancement methods have been proposed for removing degradations in digital images, few researchers have reported results in fingerprints restoration.

In this paper a combination of spatial, frequency and morphological fingerprint enhancement techniques is presented using different three methods.

The first method applies a combination of spatial domain filters (High-Pass-Gaussian) including a technique called Differential Hysteresis Processing [4][5].

The second one uses spatial (Gamma-Correction) and frequency filters (Spike-Boost, Spike-Cut) to reduce repetitive patterns and to enhance details [4].

The third method (morphological filters by reconstruction) is employed not only to enhance the information in fingerprint, but also to reduce the noise [6].

A brief summary of the theoretical background of each method is described in the next section.

2. METHODS

2.1- Differential Hysteresis Processing (DHP)

This technique allows extracting and highlighting desired levels of contrast inside a digital image. This feature can be used to improve and emphasize certain aspects of visual information [7].

DHP process is applied to hundreds of radial imaginary lines traced from each pixel of image and is used to amplify or suppress a specific range of contrast information selected. The level of contrast variation that is

desired to remove can be specified by a number, named *contrast window size*. Hysteresis Process is applied to each line of pixels, applying specific rules that can modify each pixel intensity value.

An important aspect of the hysteresis process is that the window size may be any value, depending on the desired effect. A small window size will filter out only small variations in contrast, leaving most of the image unchanged. Conversely, with a large window size, most of the contrast variation in the image will be filtered out, leaving only areas of large contrast change. If the window size spans the range of all contrast intensities in the image, the hysteresis output will simply be flat, producing an image of only one grayscale intensity equal to the midpoint of the window size.

One way to preserve and enhance the small contrast variations in an image is to subtract the output of the hysteresis processing from the original data. Since the hysteresis output removes small variations but preserves large variations, subtracting the hysteresis output from the original image effectively reduces the large variations, leaving the small variations in the image.

The difference between the original image data and the hysteresis data is almost exclusively composed of small variations in contrast from pixel to pixel. Therefore, DHP is the result of performing the hysteresis-then-subtraction process on two copies of the original data.

2.2- Frequency filters

An image can also be represented as a collection of frequencies displayed as an energy spectrum. The mathematical operation used to perform this conversion from spatial to frequency domain in Digital Image Processing is known as Fast Fourier Transform (FFT) [8].

When the FFT is applied to the original image, the energy spectrum is represented as a "cloud of points" displayed symmetrically around the center. The center of the spectrum represents the average intensity across the image, the distance of each point from the center is the frequency and the direction from the center stands the direction of the variations of gray levels [9]. Generally the spectrum is brighter and denser in the center. Repetitive patterns such as parallel lines or dots are manifested as bright spots or lines [10].

It is possible to enhance or suppress frequencies applying a FFT and selective Spike-Boost and Spike-Cut filters [11]. These filters enhance or suppress certain selected frequencies better than the spatial-domain filters do. Furthermore, when working with the spectrum components, the more selective the filter is, the better the results obtained. The orientation of ridge-pattern would be more evident in the resulting image if only those spikes that correspond to the ridge detail are amplified or reduced.

2.3- Morphological Filters

The basic idea of Mathematical Morphology is comparing the objects contained in an image with a known object called structuring element [12][13].

The language of this important theory is set theory. Sets represent the shapes of the objects in an image. Every time the structuring element is superimposed on the image, a set operation is done for each pixel.

A gray - level fingerprint image is a function from Z^2 into $[0, N-1]$, where N is a positive integer (e.g. $[0,255]$). From now on, **f** will be a gray - level fingerprint image.

Basic operators are defined, with respect to the structuring element **b** and due to the linear property of fingerprint, morphological filters with linear structuring elements are used:

Erosion:
$$\varepsilon(f,b)(s,t) = \min\{f(s+x,t+y) - b(x,y)/$$
$$(s+x,t+y) \in D_f;(x,y) \in D_b\} \qquad (1)$$

Dilation:
$$\delta(f,b)(s,t) = \max\{f(s-x,t-y) + b(x,y)/$$
$$(s-x,t-y) \in D_f;(x,y) \in D_b\} \qquad (2)$$

where D_f and D_b are the domains of the functions f and b, respectively.

Opening:
$$\gamma(f,b) = \delta(\varepsilon(f,b),b) \qquad (3)$$

Closing:
$$\phi(f,b) = \varepsilon(\delta(f,b),b) \qquad (4)$$

Top-hat:
$$T(f,b) = f - \gamma(f,b) \qquad (5)$$

Top-hat transform is a well-known and commonly used morphological technique for extracting locally bright (or dark) objects from a grayscale image.

The possibility of combining these operators in order to filter an image presents interesting aspects of this theory.

Reconstruction is a very useful operator provided by Mathematical Morphology [6]. The Reconstruction transformation is relatively well-known in the binary case, where it simply extracts the connected components of an image which are "marked" by another image [14].

Openings and closings by Reconstruction, which are the elementary pieces of the filter by reconstruction class, are defined by:

Openings by Reconstruction:
$$\gamma_{bero,bc}^{rec}(f) = \gamma_g^{rec}(f,bc) \qquad (6)$$

where $g = \varepsilon(f,bero)$

This operator creates a image by an infimum reconstruction of the image **f** from its erosion by the structuring element *bero*, using the connectivity defined by the structuring element *bc*.

Closings by Reconstruction:
$$\phi_{bdil,bc}^{rec}(f) = \phi_g^{rec}(f,bc) \qquad (7)$$

where $g = \delta(f,bdil)$

This operator creates a image by a supremum reconstruction (with the connectivity defined by the structuring element *bc*) of the image **f** from its dilation by the structuring element *bdil*. Linear bright shapes can easily be identified using this operators [15].

The algorithm can be summarized as follows:

Step 1: Recognition of linear parts using linear opening by Reconstruction, with linear structuring element. It generates the image S_{ap}.

Step 2: The image S_{sum} is obtained as follows:

$$S_{sum} = \sum_{i=1}^{12} \left[S_{ap} - \delta(f,L_i) \right] \qquad (8)$$

where each structuring element L_i (every 15°) is k-pixels long (1-pixel wide), $k \in N$.

Step 3: Binarization using by optimal threshold.

3. MATERIALS

The microfilm fingerprint images were digitized with a LEICA DMLB microscope with a LEICA DC100 camera connected to a capture frame board. The images were stored in a Personal Computer by means of a LEICA DC Viewer Software v3.1.0.0.

Software used for processing the images included both commercial *Image Pro Plus v4.1* from *Media Cybernetics* and *DHP algorithm* from *Image Content Technology LLC,* SDC Morphology Toolbox and custom packages (*PDI v2.0* developed in our Laboratory using Delphi). The custom software allows the use of filters that are not commercially available [16][17].

4. RESULTS AND DISCUSSION

At present, 100 fingerprint images have been processed and each one required particular process.

The following resulting images are examples that show prominent features in fingerprints that cannot be extracted by other enhancement techniques.

In order to solve the problem the following methods were used, involving the techniques previously explained and their combinations:

- Method A

High-Pass-Gaussian Convolution filters in combination with Differential Hysteresis Processing (DHP) were applied. The difference between the original image data and the hysteresis data is almost exclusively composed of small variations in contrast from pixel to pixel. Hysteresis processing removes these small variations, therefore subtracting the hysteresis output from the original data retrieves this information. This allows simultaneous suppression of one range of contrast variation while highlighting another range. This provides maximum flexibility in emphasizing the contrast variation of interest.

Figure 1 (a and c) shows two different original fingerprint subimages. The first sample is very inky. The second one shows a fingerprint taken a long time post mortem.

Figure 1 (b and d) shows the fingerprint processed by this method, revealing the main morphology of the fingerprint.

(a)   (b)

(c)   (d)
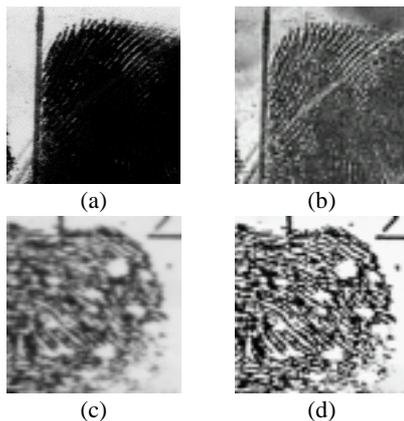
Figure 1: (a) (c) Original subimages; (b) (d) Images Processed by DHP

- Method B

Frequency domain filters (using adaptive FFT) were used. Fingerprint ridges appear on the frequency spectrum as bright spots, although not generally as bright or sharp as the spikes corresponding to uniform repetition. Thus, frequencies filters were not only applied to the entire image, but to small proper areas, in order to enhance the details of interest. Small areas of images were enhanced

applying the FFT and a Spike-Boost filter to a "cloud" of relevant frequency information. The reduction of a group of frequency can be done by Spike-Cut filter anywhere in the transformed image. It is also possible to enclose desirable frequencies within the mask. The choice of these areas cannot be standardised since it depends on the particular image to be processed. After selecting the filter-mask, the Inverse FFT is applied to convert the resulting image back to spatial domain.

Figure 2 (a and c) shows original fingerprint subimages where it is difficult to see the ridges.

In Figure 2 (b and c) Gamma Correction spatial technique, Spike-Boost and Spike-Cut filters were applied. The details appear more clearly.

(a)   (b)

(c)   (d)
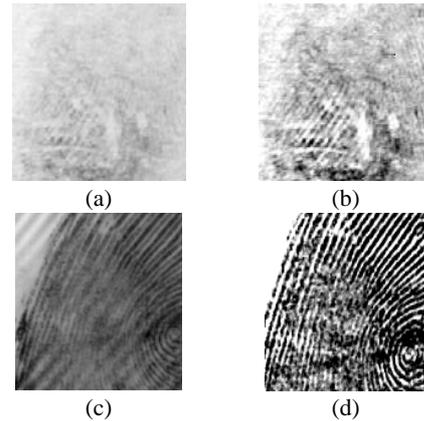
Figure 2: (a) (c) Original subimages; (b) (d) Images processed by frequency filters

- Method C

The algorithm described involving morphological techniques was applied. Lineal and cross structuring elements were used in the different operations, with 30 pixels and 4x4 pixels respectively.

Figure 3 (a, c and d) shows three different original fingerprint subimages. The images processed are shown in Figure 3 (b, d and f) appreciating the enhancement of the details.

(a)   (b)

(c)   (d)

(e)   (f)
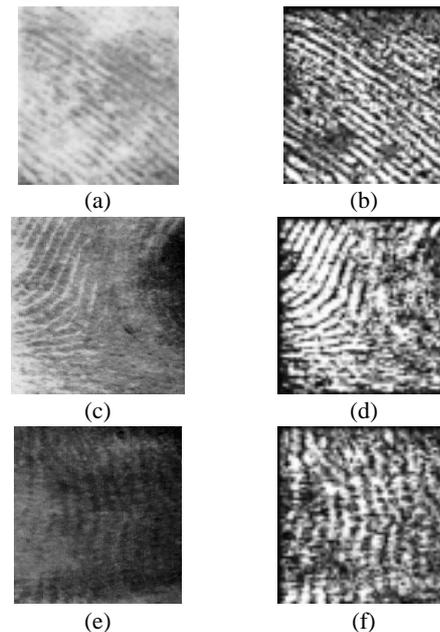
Figure 3: (a) (c) (e) Original Subimages; (b) (d) (f) Images processed by opening by Reconstruction

5. CONCLUSIONS

Computers have a very important role in fingerprint restoration. In this work, spatial, frequency and morphological techniques were applied. Filters had to be combined because the results obtained by applying conventional enhancement techniques were not satisfactory. Experimental results show that the methods are effective in several cases and have potential application in forensic analysis of fingerprints.

The processed fingerprints were sent to the Court of Justice and through these, new fingerprints experts of the Department of Dactiloscopy of the Police were able to find out the identity of two persons who had been unknown during fifteen years.

There are still other sets of fingerprints waiting to be processed with these techniques with which it is expected to obtain the same good results. These techniques can be applied not only to fingerprints but to other questioned documents too.

6. ACKNOWLEDGEMENTS

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