CASE REPORT

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Fingerprint Identification Using Image Enhancement Techniques

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ABSTRACT: This report presents an application of image enhancement techniques in fingerprints as a tool for forensic sciences. Digital image processing technology was applied to restore fingerprints with non-uniform contrast. Whenever the results obtained by applying conventional enhancement techniques were not satisfactory, we combined spatial domain as well as frequency domain techniques in order to enhance the features that allowed later identification. The fingerprints correspond to a person who was murdered by military forces in 1976. The processed fingerprints where sent to the Court of Justice where forensic experts could finally find out the identity of a person who had been unknown until that moment.

KEYWORDS: forensic science, digital image processing, fingerprints, identification

From 1976 to 1983 Argentina was under a military dictatorship. During that time, many were murdered or disappeared. Nowadays, victims' identification is still very difficult to complete. The Forensic Anthropology Argentine Team (FAAT) is a group in charge of the identification of missing people and the determination of the cause of death through search and exhumation of remains. Its work consists of submitting evidence for present or future criminal cases. They began their work in 1985, when democracy was restored in Argentina. People began to petition to establish the destiny of their missing relatives, victims of the dictatorship. As an important means for recovering the truth and the history of our recent past, the FAAT has successfully identified several persons; however, most of the victims remain unidentified.

Case History

In November of 1976, a woman was killed by military forces in Buenos Aires. At that time, the woman had a counterfeit document so identification was not possible. Under those circumstances, fingerprints were intentionally taken very deficiently in order to obstruct later corpse identification. When these fingerprints were presented to the Court of Justice as an evidence of the woman's disappearance, they were not accepted due to their lack of intelligibility. Finally, the remains were buried with a false name, and in 1982 they were transferred to an ossuary. A lawyer who knew the case and wanted to find out the identity of the woman contacted the FAAT. In this case, the evidence consisted of ten fingerprints.

Methods

Image Processing Techniques

The fingerprints were digitized and stored in an IBM PC compatible computer for subsequent application of digital image enhancement. The images were digitized with a 400-dpi (dots per inch) scanner with 256 gray levels. The fingerprints were blurred, i.e., their spatial definition was not clear. These peculiarities made their classification and comparison impractical. The differences between fingerprints, which allow identification, are due to the type and position of the ridge characteristics. Therefore, the main objective of our work was to apply enhancement techniques to make these important features unambiguous.

The principal idea behind enhancement techniques is to process an image so that the result is more suitable than the original for a specific application. The enhancement process does not increase inherent information in the data. However, it does increase the dynamic range of the chosen features so that they can be readily detected. Digital enhancement methods can be divided into two broad categories: spatial domain methods and frequency domain methods. Spatial domain techniques refer to the image plane itself and are based on direct manipulation of the pixels in an image. Frequency domain processing techniques are based on modifying the Fourier transform of an image (1).

The simplest spatial domain enhancement techniques are based on point processing, which modify the gray level of a pixel regardless the nature of its neighbors. On the other hand, masks, which are also called windows or filters, are defined as small subimages, and consider the values in a predefined neighborhood of the central pixel to be processed. The frequency domain shows the frequency of brightness variations and the direction of the variation patterns and then it is possible to applied selective filters to the Fourier spectrum obtaining images with prominent features that could not be extracted by the spatial domain techniques. Each domain leads to a different approach in the conception of the filter.

To solve the problem of image enhancement, we found that enhancement techniques based on various combinations of methods from these two categories produce the desired results. While the effect of each technique can be described in general, there is no way to accurately predict the exact result a particular filter will have on a given image. Enhancement of fingerprints poses a difficult problem in image analysis applications (2).

Other than the standard techniques such as contrast enhancement, we used histogram modification and a sharpening filtering.

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To solve the problem, we applied the following techniques and their combinations: (A) Gamma correction. Gamma correction is a point processing technique that enhances the contrast in an image through a non-linear mapping of the gray or color components values; (B) A spatial non-linear filter that uses the mean and the standard deviation of each pixel's neighborhood; (C) A spatial linear filter called High Boost; and (D) Some frequency domain filters using adaptive Fast Fourier Transform (FFT). Other standard techniques by themselves are not good enough to solve this specific question.

Spatial Filters

Single-point operations are among the simplest of all image spatial domain enhancement techniques. By applying these methods it is possible to enhance the images that have poor illumination, low-contrast or suffer from the wrong setting of the lens aperture during the image acquisition stage.

In this category we chose gamma correction. Gamma correction curves are well-defined functions that compensate for differences in responses of input and output devices. By selecting an appropriate gamma correction factor it is possible to change the contrast in the dark areas of the image, as it can be seen in Fig. 1. The greater the gamma value, the more boosted the dark areas (3).

Since it is necessary to enhance details over small areas, an approach to this problem is to devise transformation functions based on the gray-level distribution in the neighborhoods of every pixel in the image. The mean and variance of the intensity are two frequently used properties because of their close relationship to the appearance of the image. It is a way of evaluating the contrast of each pixel related to its surrounding pixels. The non-linear spatial filter based on these ideas maps the intensity of an input image $f(i,j)$ into a new image $g(i,j)$ by performing the following transformation at each pixel in the location (i,j):

$$g(i,j) = A(i,j) \cdot [f(i,j) - m(i,j)] + m(i,j)$$

where

$$A(i,j) = k\frac{M}{\sigma(i,j)},\ 0 < k < 1$$

$m(i,j)$ and $\sigma(i,j)$ are the gray-level mean and the standard deviation computed in a neighborhood centered at the pixel (i,j). M is the global mean of $f(i,j)$ and k is a parameter of the filter. By knowing the local mean and variance together with the global mean the local amplification coefficient k can be calculated. In this way, intensity level variations that would not be evident with a global approach, are enhanced. We determined different values of k for each image in order to obtain the optimum filter. In addition, when this filter is combined with the frequency filters, results are even better.

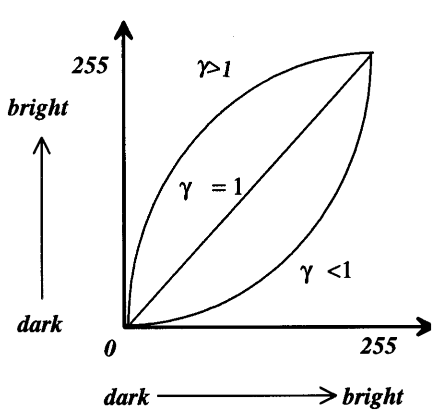

FIG. 1—*Gamma correction curves. More dynamic range in bright areas, less in dark, $\gamma > 1$. More dynamic range in dark areas, less in bright, $\gamma < 1$. No change $\gamma = 1$.*

Besides enhancing details, the overall appearance of the fingerprint must be conserved. We must keep the subjective information brought by the background, the low-frequency components. Therefore, a standard high-pass filter does not help to obtain good results. For this reason a High Boost filter was used.

This filter responds to the following definition:

$$\begin{aligned}\text{High Boost} &= \text{A Original} - \text{Lowpass} \\ &= (\text{A} - 1)\ \text{Original} + \text{Highpass}\end{aligned}$$

When $A > 1$, part of the original image is added back to the highpass result, which partially restores the low-frequency components lost in the highpass filtering operation. The result is that the high boost image looks better than the original image, with relative degree of edge enhancement that depends on the value of A. In this case it is also important to select a suitable value of A. We empirically selected a different value of A for each case. This filter was combined with the frequency filter and it contributed to the improvement of the image intelligibility (4).

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 the spatial to the spatial-frequency domain is known as the Discrete Fourier Transform (DFT). This transformation requires N complex multiplications and $N-1$ additions. Thus, FFT is usually used in Digital Image Processing because it offers considerable computational complexity reduction over direct implementation of the DFT, specially when N is large (5).

When we apply the FFT to the original image, the energy spectrum is represented as a ''cloud of points,'' displayed symmetrically around the origin. The spectral origin represents the average intensity across the image. The distance of each point from the center represents the frequency, and the direction about the center relates to the direction of the variations of gray levels (6). In general, the spectrum is brighter and denser in the center. Repetitive patterns such as parallel lines are manifested as bright spots or lines in the frequency domain (7).

A better enhancement can be achieved by amplifying the spectral components of the low frequencies that contain relevant information in the image (8). It is possible to perform this process by applying a FFT and a narrow-band spike-boost filter. This filter enhances certain selected low frequencies more selectively than the spatial-domain filters do. Furthermore, when working with the spectral components, the more selective the filter, the better the results we obtain. That is to say, if we amplify only those spikes that correspond to the ridge detail, the orientation of the ridge-pattern will be more evident in the resulting image, as shown in Fig. 2.

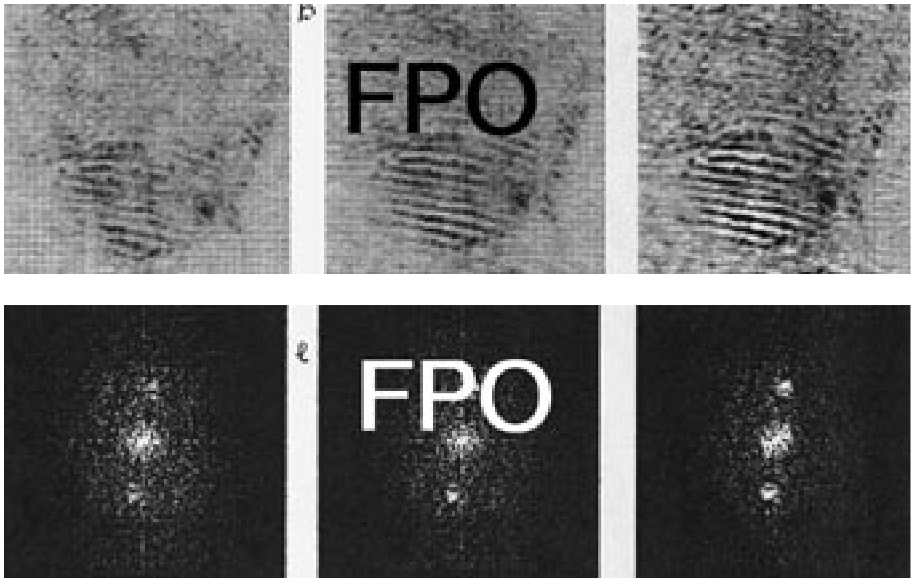

FIG. 2—*Frequency enhancement technique. (a) The original subimage; (d) Fourier spectrum of (a); (e) Fourier spectrum after amplifying selected frequencies; (b) Inverse FFT of (e); (f) Fourier spectrum after amplifying other selected frequencies; (c) Inverse FFT of (f).*

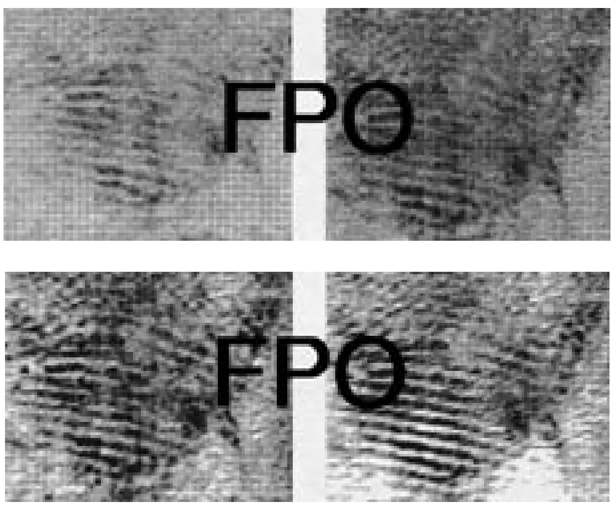

FIG. 3—*Fingerprint subimage of the left ring finger. (a) The original subimage; (b) Gamma correction of (a) with $\gamma = 0.8$; (c) High Boost filtering of (b) with $A = 1.9$; (d) Spike-boost filtering of (c).*

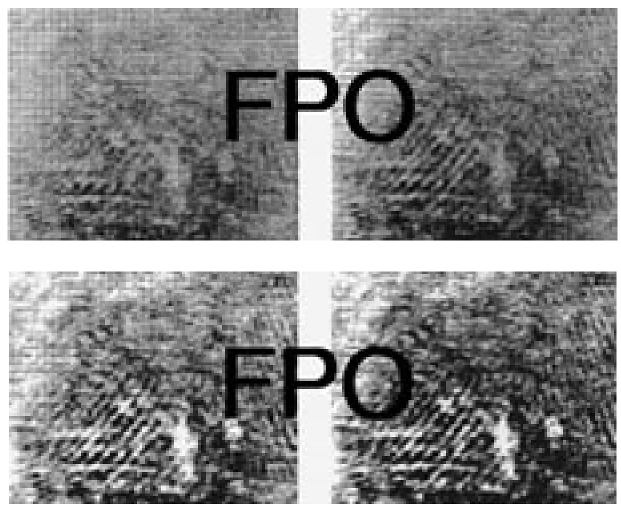

FIG. 4—*Fingerprint subimage of the left thumb. (a) The original subimage; (b) Gamma correction of (a) with $\gamma = 0.87$; (c) Spike-Boost Filtering of (b); (d) Spatial non-linear filtering of (c) using a 3×3 mask and $K = 0.18$.*

Results and Discussion

Several Digital Image Processing techniques were applied to fingerprints in order to enhance the ridge patterns. Fingerprint ridges appear on the frequency spectrum as bright spots, although not as bright or sharp as the spikes corresponding to uniform repetition. Thus, frequency filters were applied not only to the entire image, but also to small suitable areas, in order to enhance the details of our interest. As it is seen in Fig. 1, a small area of an image was enhanced by applying the FFT and a spike-boost filter to a ''cloud'' of relevant frequency information. A spike-boost filter allows one to enhance groups of frequencies anywhere in the transformed image. It is possible to precisely enclose desirable frequencies within the mask and amplify them. Still, the choice of these areas cannot be standardized since it depends on the particular image that is to be processed. The ability and experience in visualizing the frequency domain data and applying a suitable filter have a direct effect on the resulting image, allowing one to satisfactorily solve the problem of feature enhancement. After selecting the filter-mask, we applied the Inverse FFT to convert the resulting image back to the spatial domain.

Figure 3 shows an original fingerprint subimage of the left ring finger and three enhancement techniques. In the original, the details are difficult to see. The gamma correction technique was applied to the original image and the result is shown in Fig. 3*b*. The results are better than applying standard bright and contrast enhancement techniques. In Fig. 3*c* it can be seen that the details appear even more clearly when combining this technique with a High-Boostfilter. The best image is finally obtained after applying the spike-boost filter to the former image as in Fig. 3*d*.

Figure 4 shows another original fingerprint, the left forefinger, and three processed images. In this case we used similar enhancement techniques but the best results were obtained by applying a spatial non-linear filter after spike-boost filtering. Spatial non-linear filters use the mean and the standard deviation of each pixel's neighborhood allowing a local enhancement. In this case we used a 3×3 neighborhood to calculate the statistics and a constant K equal to 0.18, as shown in Fig. 4*c*.

For this work we used a standard Digital Image Processing package (Image Pro Plus) and we also developed custom software in C language. In this way, we were able to make a great number of empirical tests with the existing Digital Image Processing software in order to select those techniques that best approximate the solution of the problem. Development of custom software allowed us to modify, expand, and make these techniques more flexible. In addition, there are particular characteristics of the problem that required algorithms not included in the package (as High-Boost and local enhancement).

Conclusions

Computers play a very important role in fingerprint enhancement techniques. After applying standard pre-processing algorithms, we applied both spatial-domain and frequency-domain techniques. Filters had to be combined because the results obtained by applying conventional enhancement techniques were not entirely satisfactory. The resulting images show prominent features in fingerprints that cannot be adequately extracted by other enhancement techniques.

The processed fingerprints were sent to the Court of Justice and through this evidence, fingerprint experts of the Department of dactiloscopy of the Police were able to find out the identity of a person who had been unknown for fifteen years.

There are still other nine sets of fingerprints, waiting to be processed with these techniques with which we expect to obtain the same favorable results. These techniques can be applied not only to fingerprints but also to other questioned documents too (9–11) bringing Digital Image Processing technology up to a prominent role supporting the forensic sciences.

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