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A Novel Approach to Fourier Spectral Enhancement of Laser-Luminescent Fingerprint Images

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ABSTRACT: The present work reports an efficient adaptive Fourier transform domain filter for enhancement of laser-luminescent fingerprints. The transform domain filter involves selective amplification of the spectral band containing the highest energy, and subsequent use of a band-pass filter. The resulting enhanced image is almost noise-free, and shows prominent features in the fingerprints that cannot be extracted by other conventional enhancement techniques.

KEYWORDS: forensic science, laser-luminescent fingerprint imaging, Fourier spectral enhancement, spectral amplification, image enhancement

Employment of fingerprints as evidence of crime has been one of the most important utilities in forensics since the late 19th century. When there are no witnesses to a certain crime, fingerprints can be very useful in determining the offenders, and later, during the trial, in proving that they were present at the crime scene.

The pores on the skin constantly release perspiration which is made of water, salt, oils, and other substances produced by the body. When the skin comes in contact with a surface, these substances are transferred to the surface touched. The impressions left on the surface are called latent fingerprints, and are caused by the ridges on the skin. In most cases, they are incomplete and degraded as shown in Fig. 1. There are three classes of latent fingerprints: visible prints, caused by skin covered by substances such as blood or ink; invisible prints, made by contact of the clean skin with a smooth surface; plastic prints that are left on soft substances such as wax or grease [*1*].

All fingerprints are unique. The differences between fingerprints are due to the type and position of the ridge characteristics. The individual features that uniquely identify a fingerprint are called minutiae, which can be described as various ridge-pattern deviations as shown in Fig. 2. On the other hand, fingerprints can be classified according to their patterns. Some general fingerprint patterns are given in Fig. 3. Thus, the basic ridge patterns together with the minutiae and their locations on the fingerprint pattern, uniquely characterize a fingerprint [*2*].

Enhancement of fingerprints pose a difficult problem in image analysis applications. Laser-luminescent image acquisition offers a novel technique for recovery of latent fingerprints [*3*]. However, an attempt to electronically amplify the intensity of such faint

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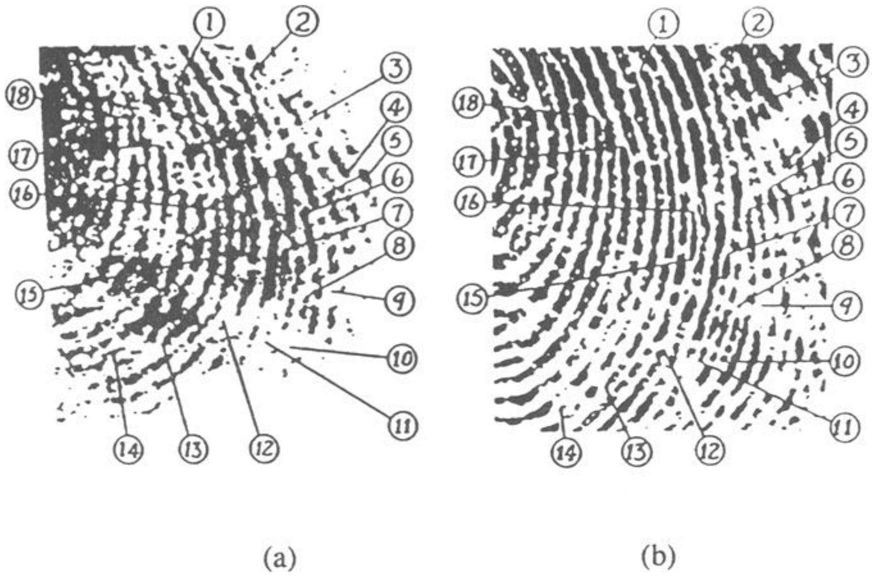

FIG. 1—*Comparison between: (a) lifted fingerprint (b) inked fingerprint. Source: (Moenssens/1971)* [2].

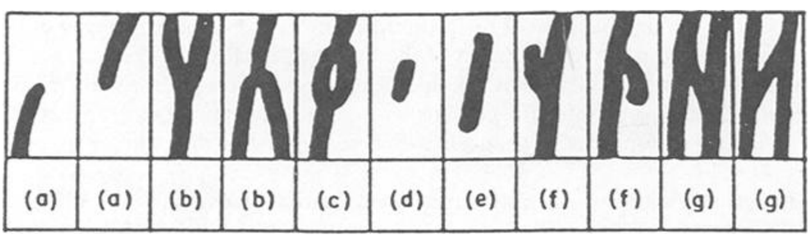

FIG. 2—*Seven basic types of minutiae. (a) ridge termination, (b) fork or bifurcation, (c) enclosure or lake, (d) island, (e) short independent ridge, (f) spur or hook, and (g) crossover* [2].

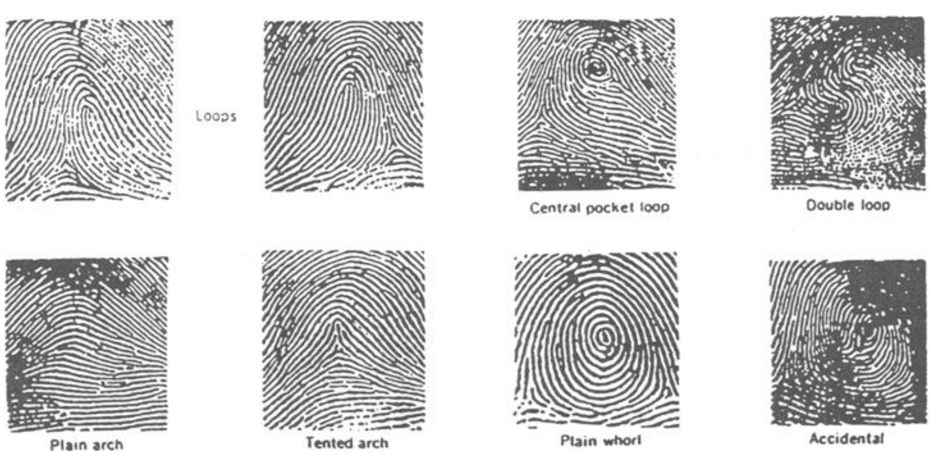

FIG. 3—*General fingerprint patterns. Source: (FBI/1963)* [2].

laser-luminescent images result in extremely noisy images with nonuniform intensity levels and poor contrast. Therefore, in most cases the acquired fingerprint has to be enhanced first. By doing so, the degradation and noise are suppressed, and the contrast is improved. Simple enhancement techniques such as adaptive binarization yield poor results [2,4]. Regionwise wedge filtering yields significant loss of information [5].

The present work involves an adaptive Fourier transform domain filter for enhancement. This adaptive transform domain filter employs selective amplification of the Fourier spectral band containing the highest energy and subsequent use of a band-pass filter. The resulting image is almost noise-free and shows prominent features in fingerprints that cannot be extracted by other conventional enhancement techniques.

The paper is arranged into three subsequent sections. The first discusses the image acquisition system and the adaptive Fourier spectral enhancement method.

In the second, results obtained by applying the technique given in the first are presented.

The third contains comments on the results obtained and the efficiency of the technique applied.

Fourier Spectral Enhancement

The principal objective of enhancement techniques is to process a given image so that the result is more suitable than the original image for a specific application. The enhancement process does not increase the inherent information content in the data. However, it does increase the dynamic range of the chosen features so that they can be detected easily. Digital enhancement methods can be divided into two broad categories: spatial domain methods and frequency domain methods. The spatial domain techniques are based on direct manipulation of the pixels in an image, whereas the frequency domain methods are based on the modification of the Fourier transform of the image.

Computers play a very important role in enhancement of fingerprints. By making use of computers, enhancement of fingerprints with both linear and nonlinear methods can be achieved. Law enforcement agencies are increasingly utilizing computerized search systems [4].

The fingerprint images used in this study are acquired by a system that involves time-resolved luminescence imaging, using a gateable digital camera, under chopped laser excitation to permit fingerprint detection on strongly fluorescent surfaces [3]. The image is then digitized and stored in an 80386 based computer for subsequent application of digital enhancement and matching algorithms. The image acquisition and analysis system is shown in Fig. 4. The images are of the size 512 × 512 and contain 256 gray levels.

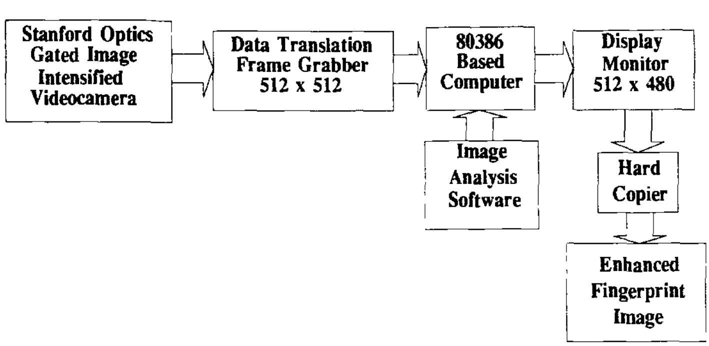

FIG. 4—*The image acquisition and analysis system.*

Transform theory has played a key role in image processing in many years. Because of its wide range of applications, the Fourier Transform is one of the most important transforms.

A continuous function $f(x,y)$ may be discretized by taking $N \times N$ samples Δx and Δy units apart to obtain a sequence $\{f(x_0 + k\Delta x, y_0 + l\Delta y)\} = \{f(k, l)\}$ where k and l assume the integer values $0, 1, \ldots, N-1$. The discrete Fourier transform (DFT) pair applicable to such sampled continuous function is given by

$$F(u, v) = \frac{1}{N^2} \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} f(k, l) \exp[-j2\pi(uk + vl)/N] \tag{1}$$

for $u, v = 0, 1, \ldots, N-1$, and

$$f(k, l) = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} F(u, v) \exp[j2\pi(uk + vl)/N] \tag{2}$$

for $k, l = 0, 1, \ldots, N-1$.

Enhancement of an image can be achieved in the frequency domain by removing a particular frequency band which corresponds to the degrading function, and transforming the modified spectrum back to the spatial domain [6,7]. However, a better enhancement can be achieved by amplifying the spectral components containing the most information in the image prior to applying the required filter [8,9].

The fingerprint patterns consist of ridges of specific spatial frequencies. Hence, the corresponding frequency bands contain more energy than other regions in the Fourier spectrum. This is verified by (i) blocking the band with highest energy, and (ii) passing only that particular band demonstrating no information content or the pattern, respectively. As seen in Fig. 5, the fingerprint pattern vanishes when the band with the highest energy is blocked, and the pattern is preserved when only that band is passed. Since almost all the information of the fingerprint pattern is contained in those particular bands, the fingerprint can be enhanced by amplifying those bands while attenuating the others or keeping them as they are.

As seen from the flowchart in Fig. 6, in this spectral enhancement technique, the fingerprint image is divided into subimages with 50% or 75% overlap to ensure the linearity of the fingerprint pattern in the window. The subimages are processed individually. The processed subimage is multiplied by a Hanning or Hamming window to achieve smoothness toward the edges, and is copied to its corresponding location in the output file. In this study, Hamming window is employed since it yielded a slightly better result for this particular application. The procedure is applied to the next subimage until all subimages are processed. The computation time depends on the amount of overlap as well as the size of the subimages.

As seen in Fig. 7, the technique yields prominent features in the fingerprint. When band-pass filtering is utilized following the amplification of the spectral band containing the highest energy, the noise is suppressed and the performance is further improved.

Results

Conventional spatial domain enhancement techniques such as adaptive binarization, histogram equalization, contrast stretching and median filtering and Fourier domain filtering techniques such as low-pass, high-pass and band-pass filtering, as well as the spectral enhancement technique given in section II were applied to fingerprints for enhancement and their performances were compared. In all cases, the spectral enhancement

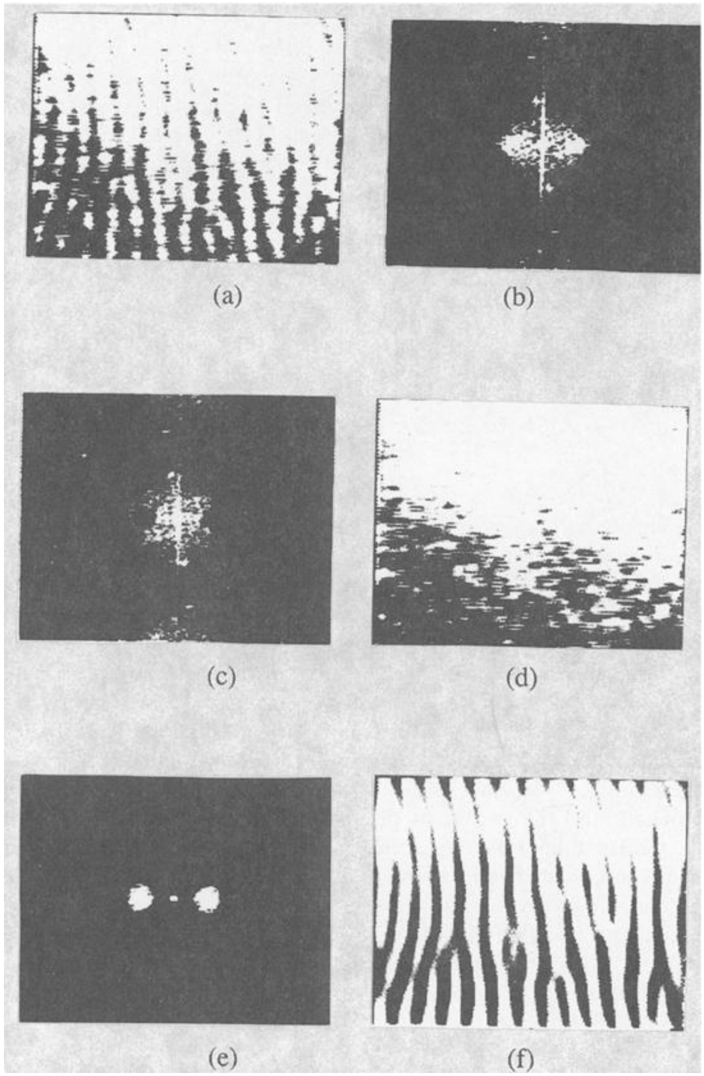

FIG. 5—*Spectral bands containing the fingerprint information. (a) A typical fingerprint subimage acquired by the system described, (b) Fourier transform of (a), (c) Fourier spectrum of (a) when the band with highest energy is blocked, (d) Inverse FFT of (c), (e) Fourier spectrum of (a) when only the band with highest energy is passed, (f) Inverse FFT of (e).*

method yielded the best results in terms of both suppression of noise and extraction of prominent features.

The spatial domain methods enhanced the contrast, but did not suppress the noise. On the other hand, low-pass and median filtering suppressed the noise while blurring the images. High-pass filtering and adaptive binarization amplified the noise. Band-pass filtering suppressed the noise, but did not extract the prominent features.

In Fig. 8, a fingerprint image acquired by the system described in section II, and the enhanced images obtained by utilizing the techniques given are shown.

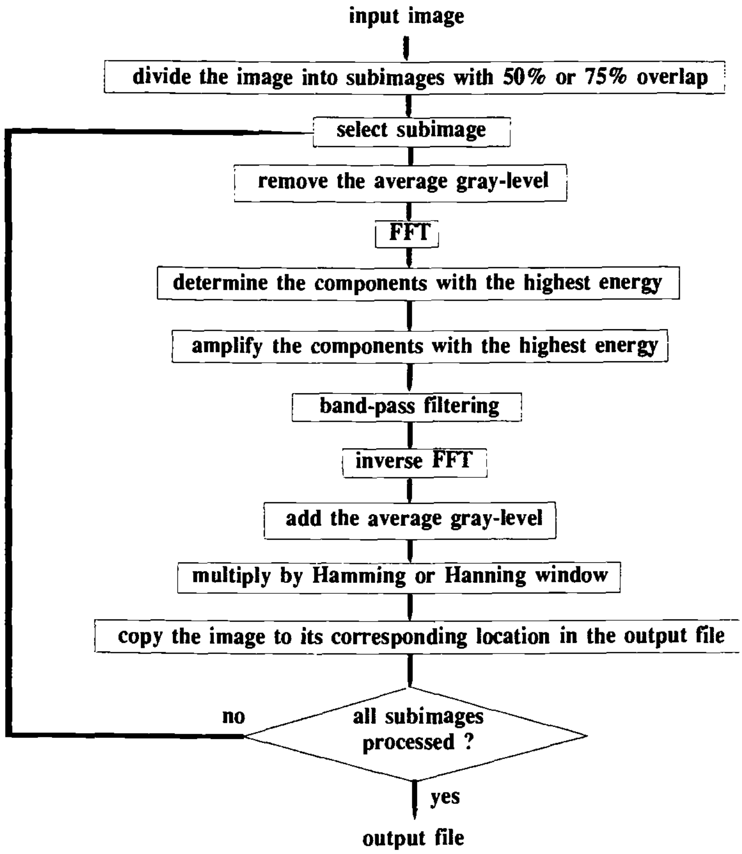

FIG. 6—*Flowchart of the spectral enhancement technique.*

Conclusions

In this study, enhancement techniques were applied to noisy fingerprints with non-uniform contrast. The degraded images were very noisy due to the acquisition system. For enhancement, spatial domain as well as frequency domain techniques were utilized.

Results obtained by applying conventional enhancement techniques were not satisfactory. Adaptive binarization and high-pass filtering produced noisy images, while low-pass and median filtering blurred the images. Contrast enhancement techniques and band-pass filtering yielded relatively better results. However, the results obtained by contrast enhancement techniques contained noise, and the results obtained by band-pass filtering did not show prominent features even though the noise was suppressed.

The adaptive Fourier spectral enhancement technique introduced in this study yielded prominent features in fingerprints. Subsequent employment of a band-pass filter suppressed the noise. The results obtained by utilizing this technique were superior to those obtained by applying other conventional enhancement techniques.

Additionally, the noise-free fingerprint images obtained by adaptive Fourier spectral enhancement are quite easy to match by conventional statistical matching techniques such as k-nearest neighbor [*10*] when clearly distinctive features exist among the fingerprints to be matched [*11,12*]. Even in the presence of overlapping features among certain classes of fingerprints, an adaptive fuzzy leader clustering algorithm can be used for

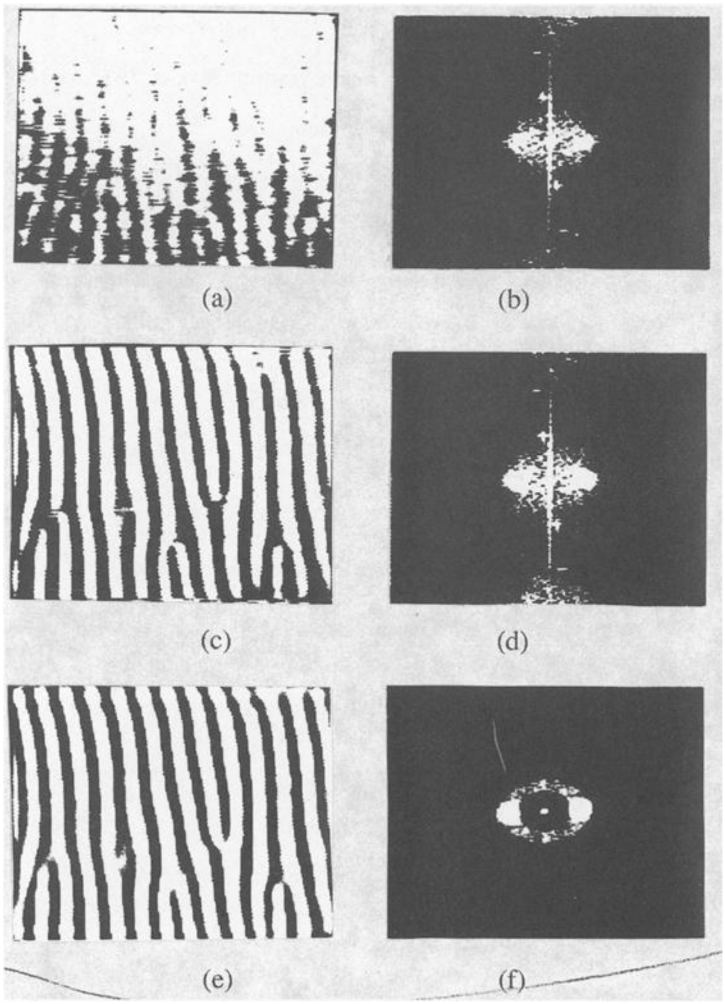

FIG. 7—*Spectral enhancement technique. (a) The original subimage, (b) Fourier spectrum of (a), (c) the enhanced image by spectral amplification, (d) Fourier spectrum of (c), (e) the enhanced image by spectral amplification along with band-pass filtering, (f) Fourier spectrum of (e).*

efficient matching [*13*]. The enhancement as well as the matching algorithms mentioned can be implemented in any desktop computer, although the present system uses an 80386 based IBM compatible computer.

This paper clearly establishes the use of a more cost-efficient and compact system for fingerprint analysis and enhancement than the rather expensive systems currently in use. Since the proposed methodology is capable of enhancing and matching even noisy latent fingerprints, this technique can be used for either latent (laser-luminescent) or inked fingerprints.

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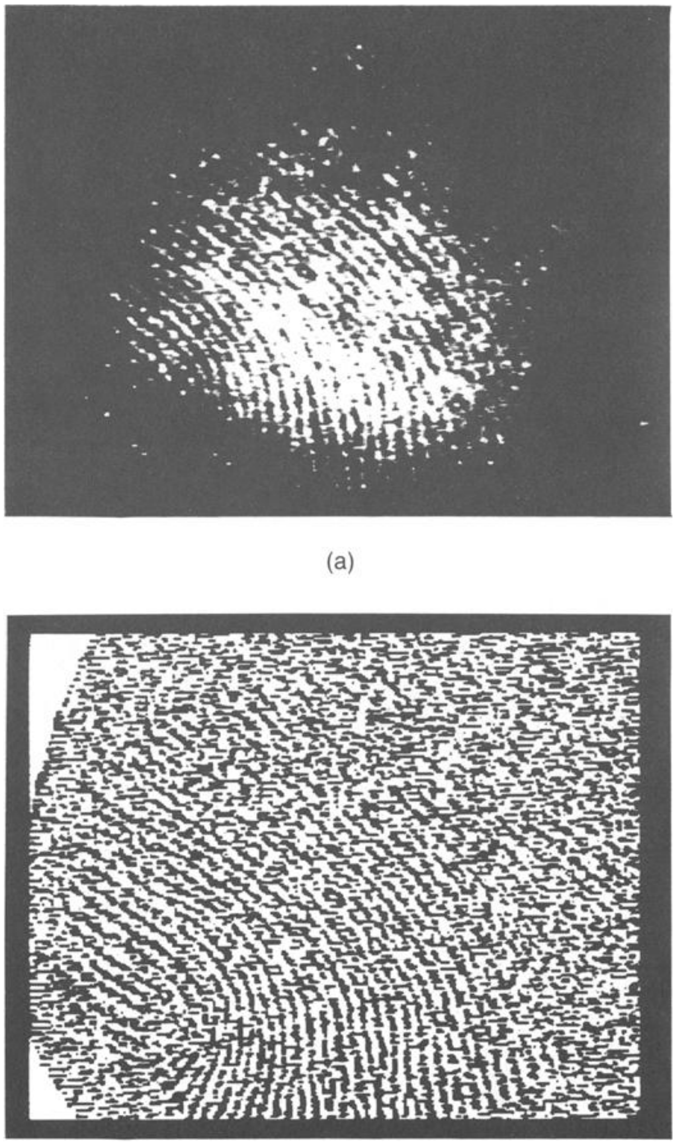
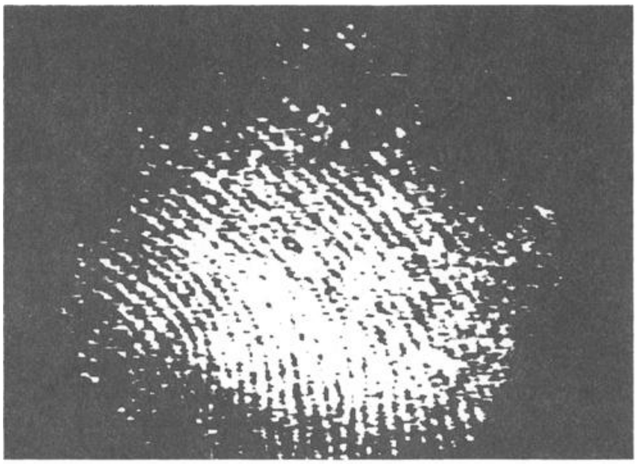


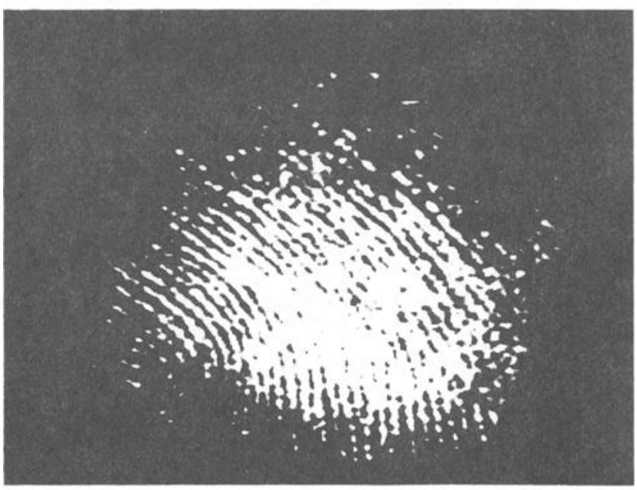
(a)

(b)

FIG. 8—*Results obtained by applying the enhancement techniques.* (a) *The original image.* (b) *enhancement of* (a) *by adaptive binarization.*

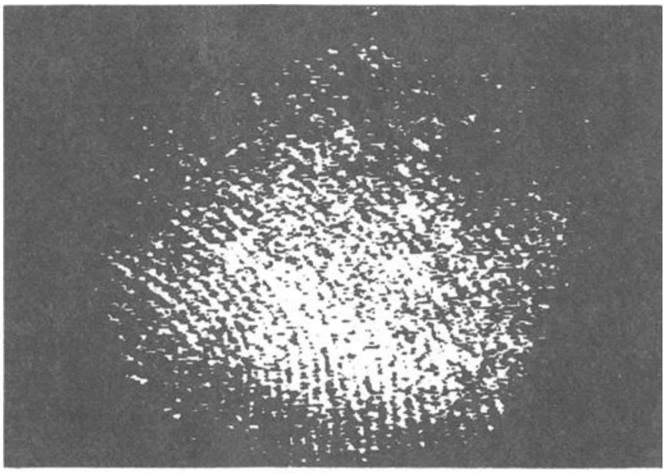


(c)

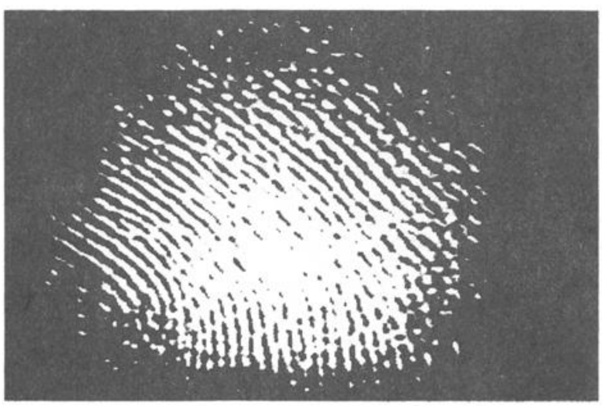


(d)

FIG. 8—*Continued.* (c) *enhancement of* (a) *by histogram equalization,* (d) *enhancement of* (a) *by low-pass filtering.*

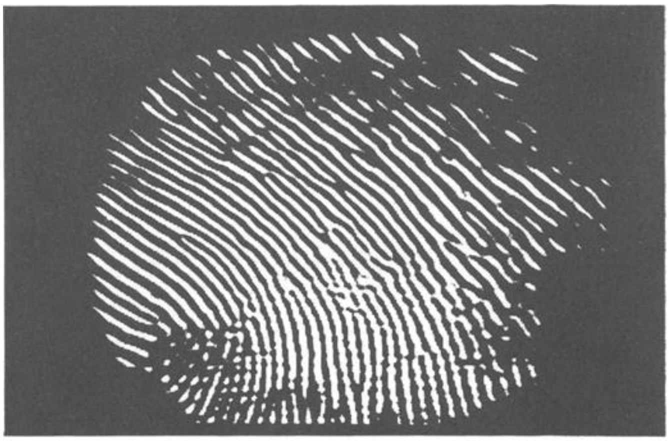


(e)



(f)

FIG. 8—*Continued.* (e) *enhancement of* (a) *by high-pass filtering,* (f) *enhancement of* (a) *by band-pass filtering.*



(g)

FIG. 8—*Continued.* (g) *enhancement of* (a) *by spectral enhancement and band-pass filtering.*

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