

Figure 1. Examples of minutiae (ridge ending and bifurcation) in a fingerprint image

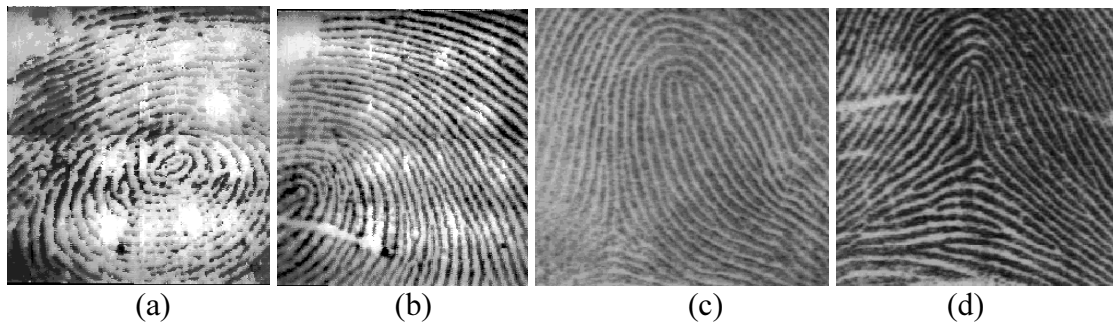


Figure 2. Examples of poor quality fingerprint images due to: noisy acquisition device (a), (b) and variation in impression conditions (c), (d), results in corrupted ridgelines

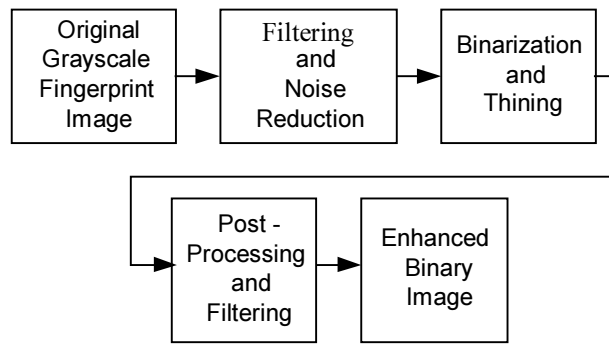


Figure 3. Filtering and binarization-based enhancement process

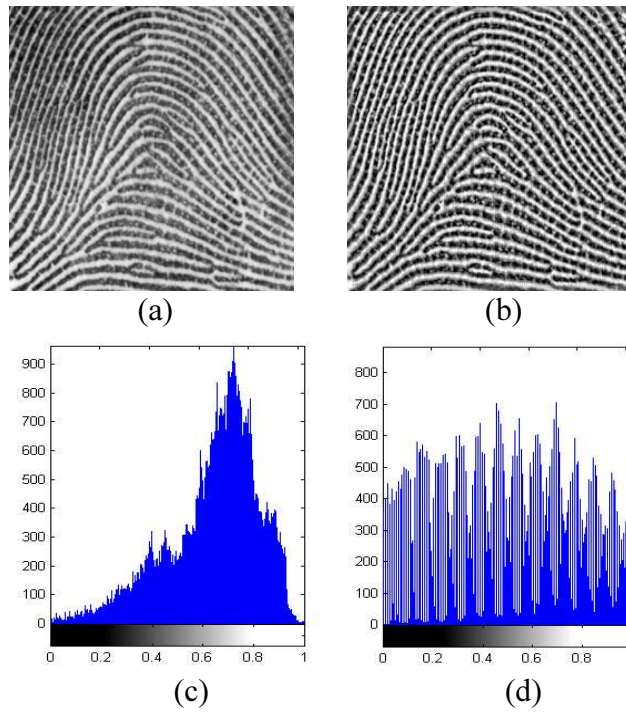
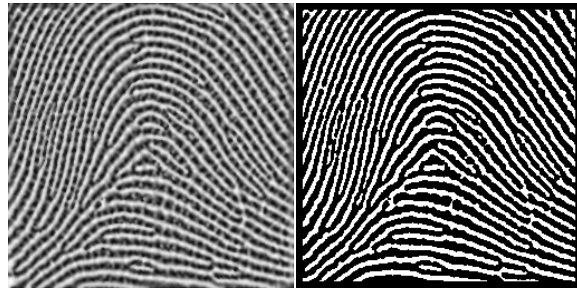


Figure 4. Histogram equalization: original image (a) and its histogram (c), and after equalization (b)(d) respectively



(a)

(b)

Figure 5. (a) Wiener filtering result using local neighborhood of 3x3 pixels and (b) Binary image

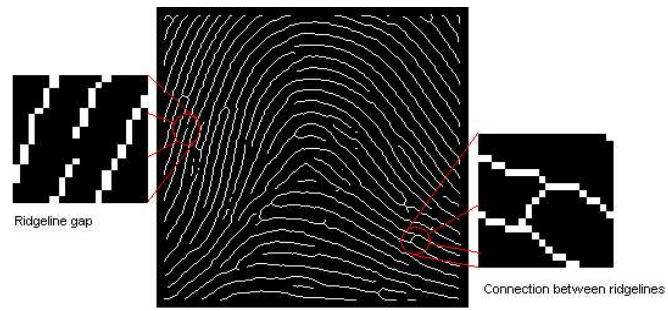


Figure 6. Typical noise in the thinned binary image: False connections between ridgelines (right), and ridgeline gaps (left).

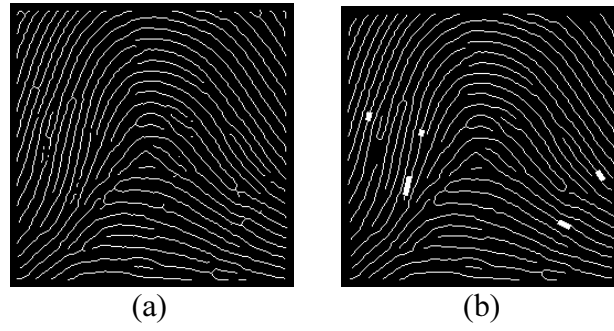


Figure 7. Post processing: Thinned binary image (a) and removing false ridges and filling gaps (b)

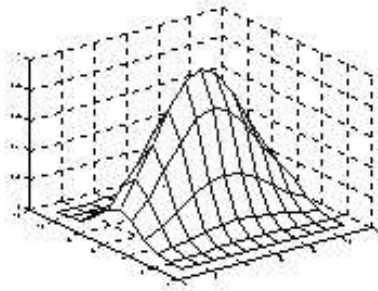


Figure 8a

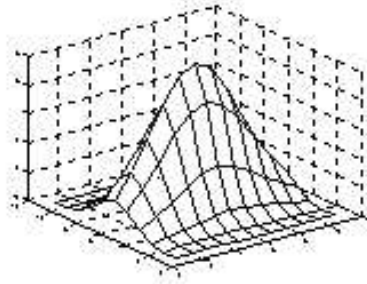


Figure 8b

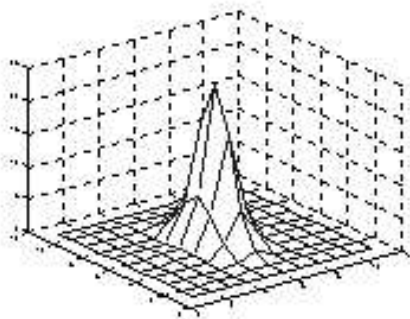


Figure 8c

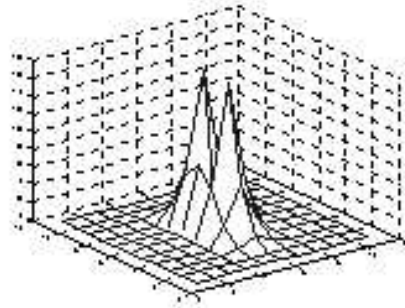


Figure 8d

Figure 8: Comparison of impulse and frequency response between the original (a) and the modified (b) anisotropic filters ($V = -2, S = 10$). Both filters have an 11×11 pixels kernel size. Both filters have a directional Gaussian-like shaped kernel in a space domain (a)(b). However they are different in the frequency domain: (c) the original anisotropic filter shows lowpass (one peak in the center) filter characteristics, while (d) the modified anisotropic filter represents bandpass filter characteristics (two peaks).

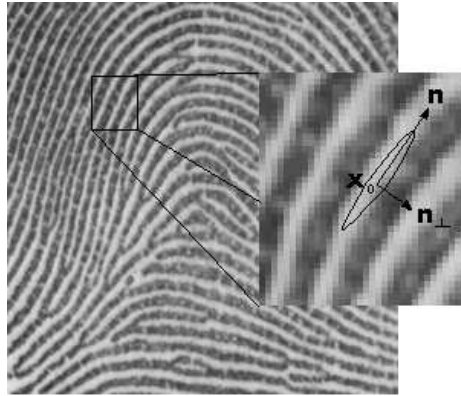


Figure 9. Controlling the shape of an anisotropic filter kernel

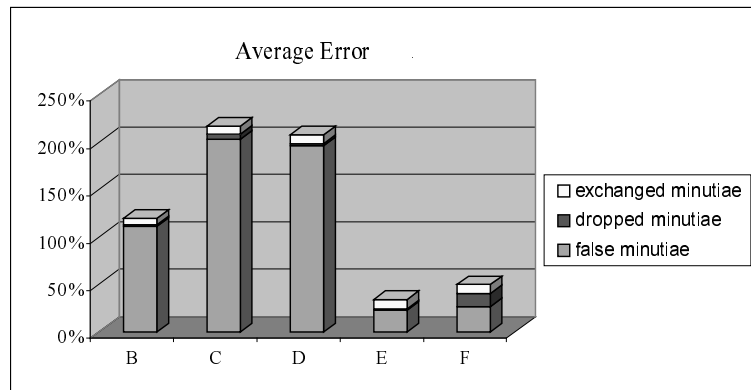


Figure 10. Comparison of 5 binarization-based schemes: B,C,D,E are based on binarization and thinning (taken from [1] Fig.20), F is based on our binarization scheme

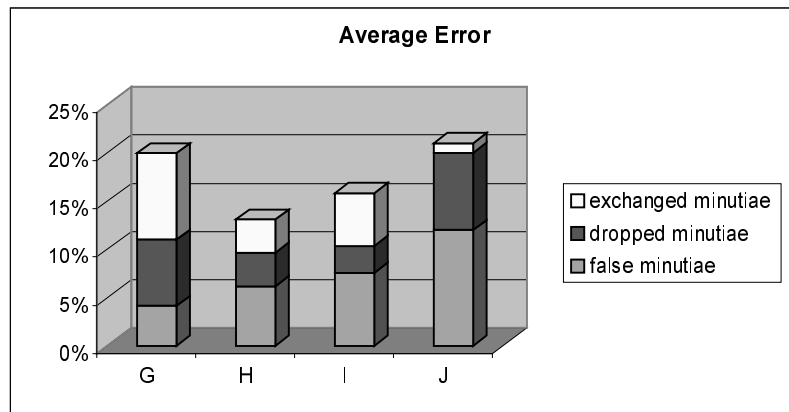


Figure 11: Performance comparison of the gray-scale approaches: G-Gabor filter, H-modified Gabor filter, I- modified anisotropic filter and J- the original anisotropic filter

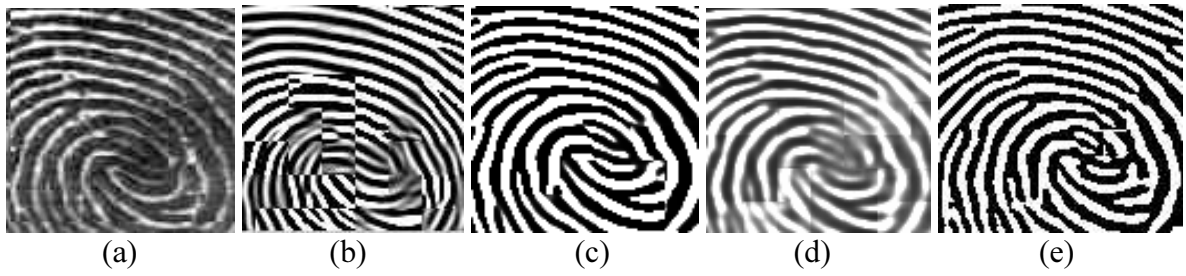


Figure 12: Enhancement results for poor fingerprint images: Original image (a); Enhanced image using Gabor filter (b), modified Gabor filter (c), original anisotropic filter (d) and the modified anisotropic filter (e).

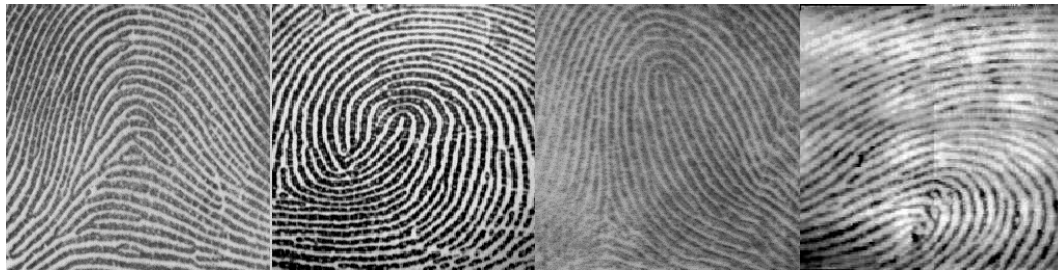


Figure 13a

Figure 13b

Figure 13c

Figure 13d



Figure 13e

Figure 13f

Figure 13g

Figure 13h



Figure 13i

Figure 13j

Figure 13k

Figure 13l

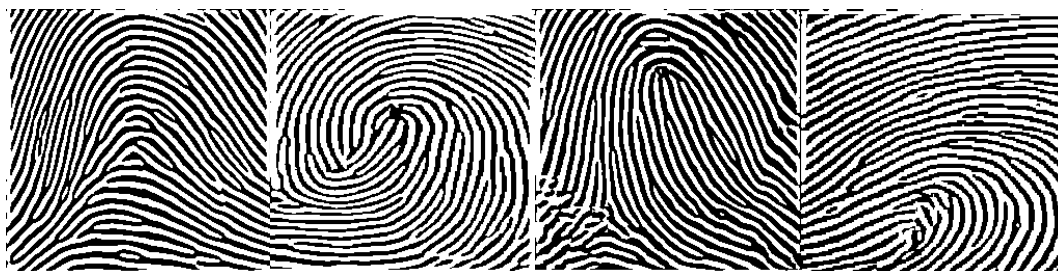


Figure 13m

Figure 13n

Figure 13o

Figure 13p

Figure 13: Enhancement results of applying different filters to fingerprint images: (a)-(d) original fingerprint images and after enhancement by using (e)-(h) original anisotropic filter, (i)-(l) the modified anisotropic filter and (m)-(p) the improved Gabor filter.

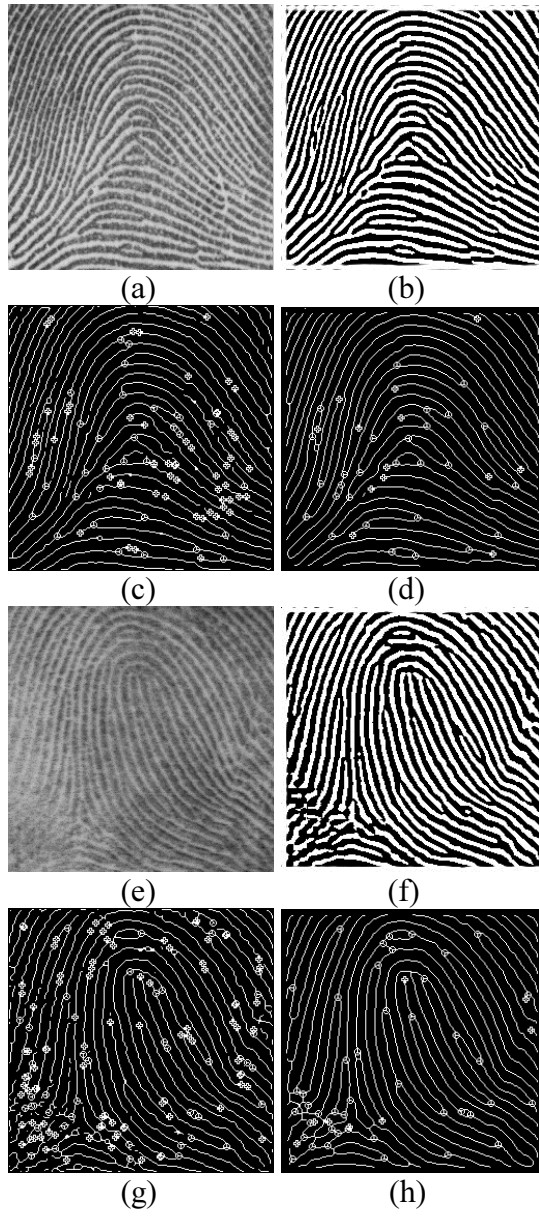


Figure 14: Minutiae extracted from some input images and from the corresponding filtered images. Input images (a)(e), their filtered images (b)(f) and images with extracted minutiae (c)(d)(g)(h), correspondingly.

Normalization (seconds)	Orientation (seconds)	Frequency (seconds)	Region Mask (seconds)	Filtering (seconds)	Total (seconds)
0.11	0.14	0.09	0.07	2.08	2.49

Table 1: The wall time of the Gabor-based enhancement algorithm on a Pentium 200MHZ PC (taken from [2], Table 2)