



Performing Enhancement and Providing Minutiae Matching Score in LQFI

M.Jayalakshmi¹, P. Robert²

PG Student, Veltech Multitech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai¹

Asst. Professor, Veltech Multitech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai²

ABSTRACT: The recital of the fingerprint recognition techniques trusts comprehensively on the eminence of the input fingerprint images. Fingerprint images are frequently of low quality because of the perspectives of the image acquisition procedure. The imperfection of crumple structures from each separable are not archetypally well defined and it is very hard to enhance the contexts of these images. In proposed scheme, enhancement is conceded out two junctures. Algorithm first improves the images in the spatial domain with a spatial crumple compensation filter and then enhances the images in the frequency domain. The limits are crumple direction and frequency of the frequency band pass filters are predictable from the original image and the first-stage enhanced image. The output of the second stage fingerprint images are matches with templates in the public databases and produce the minutiae matching scores.

KEYWORDS: Fingerprint enhancement, learning, fingerprint recognition system, image normalization, two-stage filtering.

I. INTRODUCTION

Biometrics designated as the knowledge of identifying a distinct based on his or her physical or negotiating behaviors is beginning to gain acceptance as a legitimate method for the fortitude of an individual's identity [1]. Biometric systems [46] have now been positioned in various saleable noncombatant and uncontrolled requests as a means of establishing identity in the human machine systems, cybernetics, and [3] computational acumen. In [2] the authors designated an innovative multimodal biometric identification system that is based on fingerprints and iris in a reliable and dependable way, according to a specific target application for security applications. In [3], the authors providing a synopsis of biometrics and deliberated some of the prominent research issues that need to be addressed for making biometric technology an operative tool. Among everything the biometric pointers fingerprints is one of the premier levels of dependability and have been extensively used by forensic experts in criminal inquiries [4]. Fingerprint gratitude has emerged as one of the most reliable means of biometric authentication because of its universality, uniqueness, Perpetuity and precision. But the recital of fingerprint recognition techniques trusts heavily on the quality of the input fingerprint images. Fingerprint images are frequently of low quality, because of the contexts of the image-acquisition process. In general noise from input devices can be easily eliminated using simple filters though the inadequacy of crumple structures from each individual are not typically well defined, and it is very hard to enhance the contexts of these images. The distinction of a fingerprint image may be poor or significantly different because of various factors, such as wetness and dryness, pressure strength, smears, and so on, which lead to different types of degradation in fingerprint images. For example, certain crumples are not connected even if they should be and some parallel crumples are not well separated. Thus finger print enhancement methodologies are needed to deal with all of these influences. Normally speaking, fingerprint gratitude algorithms are unevenly [4] categorized into two classes: minutiae-based and image-based [7] methods [8]–[10], which primarily use minutiae [5] info or a orientation point along with a number of crumple attributes for appreciation The wrong elevation operational information can be fatal to both classes of recognition algorithms since it can change the information of the minutiae points and reference points,



International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol.2, Special Issue 1, March 2014

Proceedings of International Conference On Global Innovations In Computing Technology (ICGICT'14)

Organized by

Department of CSE, JayShriram Group of Institutions, Tirupur, Tamilnadu, India on 6th & 7th March 2014

and it may also cause some errors in feature extraction. To reduce the possibility of [12] recognition error, a robust enhancement algorithm is required, especially for low-quality fingerprint images. Because of the no stationary nature of the fingerprint image, the complex ridge structures are not easily distinguished. A mainstream of the current enhancement techniques [11] [31] are proposed in recent years, [19] and some are based on the use of spatial-domain methods, such as contextual filters [11] or Gabor filters [14], anisotropic filters [15], compensation filters [16], image scale based filters [18] directional filters and enduring alignment modeling. The spatial domain methods take in spatial difficulty of the image with filter masks which is simple [17] for operation. [20] [21] Other enhancement methods are based on using frequency domain method such as Log Gabor filters [23], directional Fourier filters [24], wavelets [25], discrete cosine transform [26], fast Fourier transform (FFT) [27], short-time Fourier transform (STFT) [31], and so on. Filters in the frequency domain can be used to calculate convolutions effectively from the entire image rather than from a small area of the filtered point in the spatial domain; therefore, this leads to more effective noise reduction in the filtered image. However, these research studies are focused on the design of appropriate filters trendy 1 stage any of the spatial or the frequency domain to contest the right local [30] orientation or frequency of the crumples and use the information to improve the ridge structure in fingerprint images. Crumple structures that are affected by unusual input contexts can be very complicated, and any improvement should be attempted with a very delicate approach. Besides, using only one-stage processing any in the spatial domain or the frequency domain for fairly low-quality fingerprint image enhancement is not enough to meet the contexts of a high recital verification system. Moreover, enhancement needs to be conducted in order to enhance the fingerprint image completely. In order to overcome the shortcomings of the existing algorithms on the fairly poor fingerprint images with cracks and scars, dry skin, or poor ridges and valley contrast ridges. Two step preparation to enhance the low-quality fingerprint image in both the spatial domain and the frequency domain based on the learning from the images. Spatial domain uses ridge compensation filter and frequency domain uses band pass filter as a radial filter and apply angular filter in the coherence image. Minutiae extraction done by the block filter and minutiae matching score will be obtained based on the minutiae matching technique. The advantages of proposed method are as follows: 1. Reduce the computational complexity. 2. Minutiae matching score comparatively studied with cancelable biometrics. The features of this proposed method are as follows.

- 1) Using a two-stage scheme to improve the low eminence fingerprint image in together spatial domain and the frequency domain based on the learning from the images.
- 2) The first stage improvement scheme enhances the contrast of ridges and valleys and repairs the ridge structures very well in the low-quality images, and the second-stage filter will obtain the filters' parameters from both the original image and the first-stage enhanced image instead of acquiring from the original image solely, thus helping in the next stage of enhancement.
- 3) In the first-phase local normalization is used to reduce the variations in gray level values along ridges and furrows instead of using traditional global normalization.
- 4) Using a local compensation filter to enhance the fingerprint image with a mask enhances the ridges' pixels' gray level values along the local ridge orientation, while reducing the gray-level values of nonridges' pixels.
- 5) In the second stage dispensation polar coordinates (ρ , ϕ) are used to express the filters as a separable function; the filters used remain distinguishable in the radial and angular domains individually.
- 6) Using an exponential band pass filter as the radial filter, it has a desired steep attenuation in the bandwidth.
- 7) Using local orientation and local frequency as the parameters' estimation based on the learning from the images for fingerprint filter design.
- 8) With this two stage augmentation algorithm, it will enhance fairly low-quality fingerprint image completely, thus help to deal with the various input contexts.

II. ALLIED WORKS

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol.2, Special Issue 1, March 2014

Proceedings of International Conference On Global Innovations In Computing Technology (ICGICT'14)

Organized by

Department of CSE, JayShriram Group of Institutions, Tirupur, Tamilnadu, India on 6th & 7th March 2014

Mortal experts consistently expenditure the background information of fingerprint images, such as crumple endurance and monotony to help in finding. These revenues the essential morphogenetic practice that created the ridges sees not to allow for irregular breaks in the ridges except at ridge endings. The efficiency of a programmed enhancement algorithm hangs on the scope to which they use the background information. Some filters for these enhancement tasks are classified either in the spatial domain or in the frequency domain. Conferring to the sorting of the filter the existing enhancement processing is unevenly classified into either spatial domain filtering.

A. Spatial-Domain Filtering

The spatial domain techniques consist of spatial convolution of the image with filter masks which is simple for operation. For computational reasons, such masks must be small in the spatial extent. In the authors first [11] proposed the use of contextual filters for fingerprint image enhancement. They used an anisotropic smooth out kernel whose major axis was oriented parallel to the ridges. For effectiveness the filter was precomputed in sixteen ways. The filter increased the ridge contrast in a direction perpendicular to the ridges, while it performed smoothing in the direction of the ridges. In the writer's upcoming the use [15] of an isotropic filter based on structure adaptive filtering. The planned filter has band pass filter characteristics and is effective in removing noise while preserving the local ridge frequency of the fingerprint image.

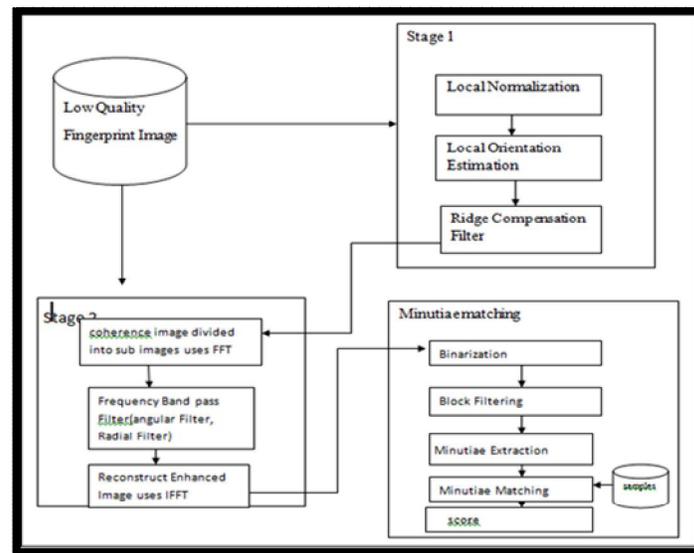


Fig.1 Proposed architecture

The most popular approach to fingerprint enhancement, which was proposed in [12], is based on a directional Gabor filtering kernel. The algorithm uses a properly oriented Gabor kernel, which has frequency discriminating and orientation selective properties, to perform the enhancement. These properties allow the filter to be tuned to give maximal response to ridges at a specific orientation and frequency in the fingerprint image. However, unlike Fourier bases or discrete cosine bases, using Gabor elementary functions has the following problems: Gabor elementary functions do not form a tight frame; they are bi-orthogonal beginnings and there is no rigorously justifiable reason for choosing the Gabor kernel over other directionally selective filters, such as directional derivatives of Gaussians or steerable wedge filters [32]. More recent works that are based on reaction diffusion techniques can be found in [33] and [34].



III. PROPOSED SYSTEM

Affording to the exploration of the outdated prior works the current augmentation algorithms are not always satisfactory in enhancing low-quality fingerprint images. To overcome the demerits of these methods we propose a new and effective scheme in this paper for the enhancement of the images using two consecutive stages as exposed in Fig. 1. The algorithm first enhances the images in the spatial domain with a spatial ridge compensation filter and then enhances the images in the frequency domain. The parameters ridge direction and frequency for the frequency band pass filters are estimated from the original image and the first-stage enhanced image. The details are introduced as trails.

A. Main Phase Improvement: Spatial Crumple Compensation Filter

The first stage performs ridge compensation along the ridges in the spatial field. This step enhances the fingerprint's local ridges using the neighbor pixels in a small window with weighted mask along the orientation of the local bridges each pixel in the fingerprint is swapped with its weighted neighbor sampling pixels in a small window and with the controlled contrast parameters along the orientation of the local crumples. In the meantime the filter improves the gray level standards of crumples pixels along local crumple positioning while reducing the non-crumple pixels gray level values thus, it is able to connect the broken bars and remove the smears in the fingerprint image. Unlike the smoothing operation the compensation filter uses weighted constant values to control the contrast parameters. Although not completely enhancing the fingerprint, the processing enhances the ridge contrast and preserves the ridge structures.

B. Subsequent Phase Improvement: Frequency Band pass Filter

Although the result of the first spatial filter surges the crumple difference in the vertical direction to the crumples this dispensation may haze the image as fine. Therefore a subsequent phase augmentation with a tuned band pass filter is proposed to enhance the fingerprint image serially. The frequency band pass filters used are separable in the radial and angular domains, respectively. The processing is able to enhance the fingerprint. Image both in the radial and the angular domains and enhance the ridges completely. As per a vital feature the parameters of the band pass filter are learnt from both the original image and the enhanced image. The enhancement of fingerprint images with band pass filters may take advantage of the regularity of the spatial structure by filtering the image with a position dependent band pass frequency filter whose pass band is matched everywhere with the local ridge orientation and local ridge frequency. Instead of using the entire image we apply the frequency filters to the blocks to utilize all of the local frequency and local orientation information. Previous research studies [27] must [28] [31] plunge sale band pass frequency filters for fingerprint image augmentation and they have been proven to be effective for enhancement. Yet these methods do have demerits, such as difficult parameters selection and non-effective filtering. To overcome these deficiencies we propose an improved scheme with an exponential band pass filter By polar coordinates (ρ, ϕ) to precise the filters as a separable function, the frequency band pass filters $H(\rho, \phi)$ used are separable in the radial and the angular domains singly and are given as follows:

$$H(\rho, \phi) = H_{\rho}(\rho)H_{\phi}(\phi) \quad (10)$$

$$H_{\rho}(\rho) = \frac{1}{\sqrt{2\pi\rho_{BW}}} \exp\left(-\frac{(\rho - \rho_c)^2}{2\rho_{BW}}\right) \quad (11)$$

$$H_{\phi}(\phi) = \begin{cases} \cos^2 \frac{\pi}{2} \frac{(\phi - \phi_c)}{\phi_{BW}}, & \text{if } |\phi| < \phi_{BW}, \\ 0, & \text{otherwise.} \end{cases} \quad (12)$$

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol.2, Special Issue 1, March 2014

Proceedings of International Conference On Global Innovations In Computing Technology (ICGICT'14)

Organized by

Department of CSE, JayShriram Group of Institutions, Tirupur, Tamilnadu, India on 6th & 7th March 2014

After the execution of a classy minutiae based method, the whole system will have better performance compared with the method that does not use the enhancement.

IV. EXPERIMENTAL RESULTS

We reconnoiter the experimental results in the first stage enhancement of the scheme in the fig.2 to get normalized images. This step takes input as a low quality fingerprint image and used to reduce the local variations and standardize the intensity distributions in order to consistently estimate the local orientation. The pixel wise process does not change the clarity of the ridge and furrow structures but reduces the variations in gray-level values along ridges and furrows, which facilitates the subsequent processing steps. $img(i, j)$ is the gray-level value of the fingerprint image in pixel (i, j) , $nor\ img(i, j)$ is the normalizing value in pixel (i, j) , and $coeff$ is the amplificatory multiple of the normalized image. M is the mean of the sub image, and V is the variance of the sub image. $M0$ and $V0$ are the desired mean and variance values, respectively. In the experiments, we used $M0 = 128$ and $V0 = 128 \times 128$.

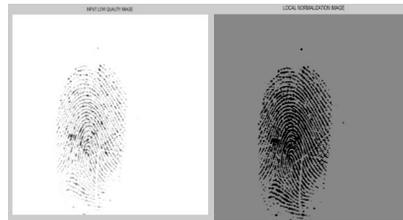


Fig.2 Normalized Images

A fingerprint verification method that uses tessellated invariant moment features [10] is verified mutual with the proposed method and some well-known enhanced algorithms. All of the experiments are based on the tessellation of region of interest with 16 tessellated cells, and each cell has 16×16 pixels the similarity measurement is the eigenvalue-weighted cosine distance. A good fingerprint enhancement is very important mainly for image based fingerprint [43] matchers, since the image based matcher depends on the accuracy of the reference point detection. We define a reference point as the point of the maximum curvature on the convex ridge [10] which is either a core singular point or a point with the maximum [44] curvature on the convex ridge if an image does not have a core point. If core points exist in a fingerprint, the core point on the convex ridge becomes a reference point. In case a fingerprint has two core points, one can automatically be selected as a reference point if it has a larger curvature than the other. For an arch type fingerprint with no core point, the point with the maximum curvature on the convex ridge becomes the reference point. It has been proven that it is more accurate for the detection of the reference point in the enhanced image than in the original image [16]. In order to show that the different enhancement methods benefit the reference point detection in the image-based method, we did the experiments on the FVC2004 four sub databases DB1_a- DB4_a, respectively. To evaluate the performance of the verification system, the false reject rate (FRR) and the false acceptance rate (FAR) are Calculated:

$$FRR = \frac{\text{Number of rejected genuine claims}}{\text{Total number of genuine accesses}} \times 100\% \quad (16)$$

$$FAR = \frac{\text{Number of accepted imposter claims}}{\text{Total number of imposter accesses}} \times 100\% \quad (17)$$

The equal error rate (EER) is used as a recital indicator. The EER indicates the point where the FRR and FAR are equal:

$$EER = \frac{(FAR + FRR)}{2}, \quad \text{if } FAR = FRR. \quad (18)$$

Specifically, if the database has relative higher quality images, we may choose some traditional enhancement



International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol.2, Special Issue 1, March 2014

Proceedings of International Conference On Global Innovations In Computing Technology (ICGICT'14)

Organized by

Department of CSE, JayShriram Group of Institutions, Tirupur, Tamilnadu, India on 6th & 7th March 2014

Algorithms to save the time otherwise we may choose the proposed augmentation algorithm to guarantee the higher gratitude accuracy.

V. CONCLUSION AND FURTHER WORK

In this paper in order to overcome the deficiencies of the existing algorithms on the fairly poor fingerprint images with cracks and scars, dry skin, or poor crumples and valley contrast crumples an effective two-stage enhancement scheme in both the spatial domain and the frequency domain for low quality fingerprint images by learning from the images has been proposed in the theoretical way. Highlighting the augmentation of the low quality images, the main phase augmentation scheme has been designed to use the context information of the local ridges to connect or separate the ridges. In the subsequent phase processing, the filter is separable in the radial and angular domains, respectively. Its parameters have adequately been determined by the information of both the original image and the enhanced images of the first stage instead of acquiring from the original image solely. Thus, the proposed two phase system improves the fingerprint images significantly. As a future works the experimental results, the proposed scheme is able to handle various input contexts and achieves the best performance in combination with two designated corroboration algorithms. It is illustrious that the process has been done using MATLAB platform in our simulation. It can run fast by optimizing the code or run in C code.

REFERENCES

- [1] M. D. Marsico, M. Nappi, and G. Tortora, "NABS: Novel approaches for biometric systems," *IEEE Trans. Syst., Man, Cybern. , Appl. Rev.*, vol. 41, no. 4, pp. 481–493, Jul. 2011.
- [2] V. Conti, C. Militello, F. Sorbello, and S. Vitabile, "A frequency-based approach for features fusion in fingerprint and iris multimodal biometric identification systems," *IEEE Trans. Syst., Man, Cybern. C, Appl. Rev.*, vol. 40, no. 4, pp. 384–395, Jul. 2010.
- [3] A. K. Jain, A. Ross, and S. Pankanti, "Biometrics: A tool for information security," *IEEE Trans. Inf. Forensics Security*, vol. 1, no. 2, pp. 125–143, Jun. 2006.
- [4] D. Maltoni, D. Maio, A. K. Jain, and S. Prabhakar, *Handbook of Fingerprint Recognition*. Berlin, Germany: Springer-Verlag, 2003.
- [5] X. He, J. Tian, L. Li, Y. He, and X. Yang, "Modeling and analysis of local comprehensive minutia relation for fingerprint matching," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 37, no. 5, pp. 1204–1211, Oct. 2007.
- [6] C. Lee, J. Y. Choi, K. A. Toh, S. Lee, and J. Kim, "Alignment-free cancelable fingerprint templates based on local minutiae information," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 37, no. 4, pp. 980–992, Aug. 2007.
- [7] X. J. Tan, B. Bhanu, and Y. Q. A. Lin, "Fingerprint classification based on learned features," *IEEE Trans. Syst., Man, Cybern. C, Appl. Rev.*, vol. 35, no. 3, pp. 287–300, Aug. 2005.
- [8] A. K. Jain, S. Prabhakar, L. Hong, and S. Pankanti, "Filterbank-based fingerprint matching," *IEEE Trans. Image Process.*, vol. 9, no. 5, pp. 846–859, May 2000.
- [9] M. Tico, P. Kuosmanen, and J. Saarinen, "Wavelet domain features for fingerprint recognition," *Electron. Lett.*, vol. 37, no. 1, pp. 21–22, 2001.
- [10] J. C. Yang and D. S. Park, "A fingerprint verification algorithm using tessellated invariant moment features," *Neurocomputing*, vol. 71, no. 10–12, pp. 1939–1946, 2008.
- [11] L. O'Gorman and J. V. Nickerson, "An approach to fingerprint filter design," *Pattern Recog.*, vol. 22, no. 1, pp. 29–38, 1989.
- [12] L. Hong, Y. Wang, and A. K. Jain, "Fingerprint image enhancement: Algorithm and performance evaluation," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 21, no. 4, pp. 777–789, Aug. 1998.
- [13] J. Yang, L. Liu, T. Jiang, and Y. Fan, "A modified Gabor filter design method for fingerprint image enhancement," *Pattern Recog. Lett.*, vol. 24, pp. 1805–1817, 2003.
- [14] X. Jiang, "A study of fingerprint image filtering," in *Proc. Int. Conf. Image Process.*, Thessaloniki, Greece, 2001, pp. 238–241.
- [15] S. Greenberg, M. Aladjem, and D. Kogan, "Fingerprint image enhancement using filtering techniques," *Real-Time Imag.*, vol. 8, no. 3, pp. 227–236, 2002.
- [16] J. C. Yang, D. S. Park, and S. Yoon, "Reference point determination in enhanced fingerprint image," in *Proc. Int. Symp. Comput. Intell. Design*, 2008, pp. 161–164.
- [17] J. C. Yang, D. S. Park, and R. Hitchcock, "Effective enhancement of low-quality fingerprints with local ridge compensation," *IEICE Electron. Exp.*, vol. 5, no. 23, pp. 1002–1009, 2008.
- [18] A. Almansa and T. Lindeberg, "Fingerprint enhancement by shape adaptation of scale-space operators with automatic scale-selection," *IEEE Trans. Image Process.*, vol. 9, no. 12, pp. 2027–2042, Dec. 2000.
- [19] J. Cheng and J. Tian, "Fingerprint enhancement with dyadic scale-space," *Pattern Recog. Lett.*, vol. 25, no. 11, pp. 1273–1284, 2004.



International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol.2, Special Issue 1, March 2014

Proceedings of International Conference On Global Innovations In Computing Technology (ICGICT'14)

Organized by

Department of CSE, JayShriram Group of Institutions, Tirupur, Tamilnadu, India on 6th & 7th March 2014

- [20] H. Fronthaler, K. Kollreider, and J. Bigun, "Local features for enhancement and minutiae extraction in fingerprints," *IEEE Trans. Image Process.*, vol. 17, no. 3, pp. 354–363, Mar. 2008.
- [21] M. Tico, V. Onnia, and P. Kuosmanen, "Fingerprint image enhancement based on second directional derivative of the digital image," *EURASIP J. Appl. Signal Process.*, vol. 2002, no. 10, p. 1135–1144, 2002.
- [22] S. Jirachaweng, Z. Hou, W. Yau, and V. Areekul, "Residual orientation modeling for fingerprint enhancement and singular point detection," *Pattern Recog.*, vol. 44, no. 2, pp. 431–442, 2011.
- [23] W. Wang, J. Li, F. Huang, and H. Feng, "Design and implementation of Log-Gabor filter in fingerprint image enhancement," *Pattern Recog. Lett.*, vol. 29, no. 3, pp. 301–308, 2008.
- [24] B. G. Sherlock, D. M. Monro, and K. Millard, "Fingerprint enhancement by directional Fourier filtering," *IEEE Proc. Visual Imag. Signal Process.*, vol. 141, no. 2, pp. 87–94, Apr. 1994.
- [25] C. T. Hsieh, E. Lai, and Y. C. Wang, "An effective algorithm for fingerprint image enhancement based on wavelet transform," *Pattern Recog.*, vol. 36, no. 2, pp. 303–312, 2003.
- [26] S. Jirachaweng and V. Areekul, "Fingerprint enhancement based on discrete cosine transform," in *International Conference on Advances in Biometrics, ICB 2007 (Lecture Notes in Computer Science Series 4642)*. Berlin, Germany: Springer-Verlag, 2007, pp. 96–105. [27] A. J. Willis and L. Myers, "A cost-effective fingerprint recognition system for use with low-quality prints and damaged fingertips," *Pattern Recog.*, vol. 34, no. 2, pp. 255–270, 2001.
- [28] T. Kamei and M. Mizoguchi, "Image filter design for fingerprint enhancement," in *Proc. Int. Symp. Comput. Vision*, Coral Gables, FL, 1995, pp. 109–114.
- [29] C. I. Watson, G. T. Candela, and P. J. Grother, "Comparison of FFT fingerprint filtering methods for neural network classification," *National Institute of Standards Technology, Gaithersburg, MD, NIST Interagency or Internal Rep. 5493*, Sep. 1994.
- [30] A. M. Tahmasebi and S. Kasaei, "A novel adaptive approach to fingerprint enhancement filter design," *Signal Process., Image Commun.*, vol. 17, no. 10, pp. 849–855, 2002.
- [31] S. Chikkerur, A. N. Cartwright, and V. Govindaraju, "Fingerprint enhancement using STFT analysis," *Pattern Recog.*, vol. 40, no. 1, pp. 198–211, 2007.
- [32] E. P. Simoncelli and H. Farid, "Steerable wedge filters for local orientation analysis," *IEEE Trans. Image Process.*, vol. 5, no. 9, pp. 1377–1382, Sep. 1996.
- [33] A. Sherstinsky and R. W. Picard, "Restoration and enhancement of fingerprint images using m-lattice," in *Proc. Int. Conf. Pattern Recog.*, 1994, pp. 195–200.
- [34] C. Y. Wen and C. C. Yu, "Fingerprint enhancement using AM-FM reaction diffusion systems," *J. Forensic Sci.*, vol. 48, no. 5, pp. 306–310, 2003.
- [35] A. K. Jain, *Fundamentals of Digital Image Processing*. Englewood Cliffs, NJ: Prentice-Hall, 1989.
- [36] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*. Englewood Cliffs, NJ: Prentice-Hall, 2004.
- [37] A. R. Rao, *A Taxonomy for Texture Description and Identification*. New York: Springer-Verlag, 1990.
- [38] (2000 to 2006). [Online]. Available: http://en.wikipedia.org/wiki/Fingerprint_Verification_Competition
- [39] (2004). [Online]. Available: <http://bias.csr.unibo.it/fvc2004/>
- [40] Z. Shi and V. Govindaraju, "A chaincode based scheme for fingerprint feature extraction," *Pattern Recog. Lett.*, vol. 27, no. 5, pp. 462–468, 2006.
- [41] R. Mankiewicz, *The Story of Mathematics*. Princeton, NJ: Princeton Univ. Press, 2004.
- [42] S. L. Chow, *Statistical Significance: Rationale, Validity and Utility*. London, U.K: Sage, 1996.
- [43] L. Nanni and A. Lumini, "Descriptors for image-based fingerprint matchers," *Expert Syst. Appl.*, vol. 39, no. 10, pp. 12414–12422, 2009.
- [44] M. Liu, X. Jiang, and A. C. Kot, "Fingerprint reference-point detection," *EURASIP J. Adv. Signal Process.*, vol. 2005, 2005.
- [45] L. Nanni and A. Lumini, "Local binary patterns for a hybrid fingerprint matcher," *Pattern Recog.*, vol. 41, no. 11, pp. 3461–3466, 2008.
- [46] Two-Stage Enhancement Scheme for Low-Quality Fingerprint Images by Learning From the Images Jucheng Yang, Naixue Xiong, Member, IEEE, and Athanasios V. Vasilakos, Senior Member, *IEEE TRANSACTIONS ON HUMAN-MACHINE SYSTEMS*, VOL. 43, NO. 2, MARCH 2013.