



PERGAMON

Pattern Recognition 36 (2003) 2339–2347

**PATTERN
RECOGNITION**

THE JOURNAL OF THE PATTERN RECOGNITION SOCIETY

www.elsevier.com/locate/patcog

Palmprint feature extraction using 2-D Gabor filters

Wai Kin Kong, David Zhang*, Wenxin Li

Department of Computing, Biometrics Research Centre, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Received 15 May 2002; received in revised form 14 January 2003; accepted 14 February 2003

Abstract

Biometric identification is an emerging technology that can solve security problems in our networked society. A few years ago, a new branch of biometric technology, palmprint authentication, was proposed (Pattern Recognition 32(4) (1999) 691) whereby lines and points are extracted from palms for personal identification. In this paper, we consider the palmprint as a piece of texture and apply texture-based feature extraction techniques to palmprint authentication. A 2-D Gabor filter is used to obtain texture information and two palmprint images are compared in terms of their hamming distance. The experimental results illustrate the effectiveness of our method.

© 2003 Pattern Recognition Society. Published by Elsevier Ltd. All rights reserved.

Keywords: Palmprint; Gabor filter; Biometrics; Feature extraction; Texture analysis

1. Introduction

Computer-based personal identification, also known as biometric computing, which attempts to recognize a person by his/her body or behavioral characteristics, has more than 30 years of history. The first commercial system, called *Identimat*, which measured the shape of the hand and the length of fingers, was developed in the 1970s. At the same time, fingerprint-based automatic checking systems were widely used in law enforcement. Because of the rapid development of hardware, including computation speed and capture devices, iris, retina, face, voice, signature and DNA have joined the biometric family [2,3,24].

Fingerprint identification has drawn considerable attention over the last 25 years. However, some people do not have clear fingerprints because of their physical work or problematic skin. Iris and retina recognition provide very high accuracy but suffer from high costs of input devices or intrusion into users. Recently, many researchers have focused on face and voice verification systems; nevertheless,

their performance is still far from satisfactory [20]. The accuracy and uniqueness of 3-D hand geometry are still open questions [2,4,20]. Compared with the other physical characteristics, palmprint authentication has several advantages: (1) low-resolution imaging; (2) low intrusiveness; (3) stable line features and (4) high user acceptance.

Palmprint authentication can be divided into two categories, *on-line* and *off-line*. Fig. 1(a) and (b) show an on-line palmprint image and an off-line palmprint image, respectively. Research on off-line palmprint authentication has been the main focus in the past few years [1,5,22,23], where all palmprint samples are inked on paper, then transmitted into a computer through a digital scanner. Due to the relative high-resolution off-line palmprint images (up to 500 dpi), some techniques applied to fingerprint images could be useful for off-line palmprint authentication, where lines, datum points and singular points can be extracted [1,5]. For on-line palmprint authentication, the samples are directly obtained by a palmprint scanner [25]. Recently, a CCD based palmprint capture device has been developed by us. Fig. 2(a) shows a palmprint image captured by our palmprint scanner and Fig. 2(b) shows the outlook of the device. Note that a low-resolution technique (75 dpi) is adopted to reduce the image size, which is comparable with fingerprint images even though a palm is much larger than a fingerprint. It is evident that on-line identification is more important for

* Corresponding author. Tel.: +852-2766-7271;
fax: +852-2774-0842.

E-mail address: csdzhang@comp.polyu.edu.hk (D. Zhang).

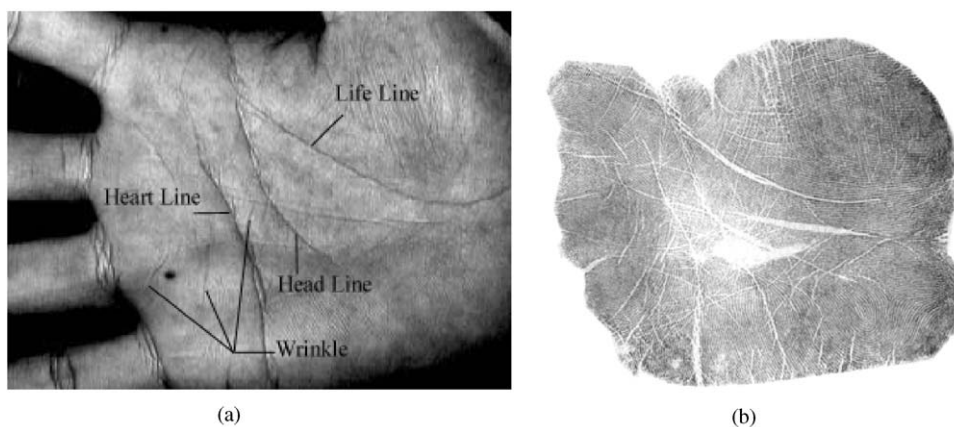


Fig. 1. Examples of (a) on-line, with line definitions and (b) off-line palmprint images.

many real-time applications, so that it draws our attention to investigate.

Our on-line palmprint verification system contains five modules, palmprint acquisition, preprocessing, feature extraction, matching and storage. Fig. 3 gives a block diagram to describe the relationship between the five modules. The five modules are described below:

- (1) *Palmprint Acquisition*: A palmprint image is captured by our palmprint scanner and then the AC signal is converted into a digital signal, which is transmitted to a computer for further processing.
- (2) *Preprocessing*: A coordinate system is set up on basis of the boundaries of fingers so as to extract a central part of a palmprint for feature extraction.
- (3) *Textured Feature Extraction*: We apply a 2-D Gabor filter to extract textural information from the central part.
- (4) *Matching*: A distance measure is used to measure the similarity of two palmprints.
- (5) *Database*: It is used to store the templates obtained from the enrollment phase.

Our palmprint authentication system can operate in two modes, enrollment and verification. In the enrollment mode, a user is to provide several palmprint samples to the system. The samples are captured by our palmprint scanner and passes through preprocessing and feature extraction to produce the templates stored in a given database. In the verification mode, the user is asked to provide his/her user ID and his/her palmprint sample. Then the palmprint sample passes through preprocessing and feature extraction. The extracted features are compared with templates in the database belonging to the same user ID.

In this paper, we attempt to apply a textural extraction method to palmprint images for personal authentication. The remaining sections are organized as follows: preprocessing steps are mentioned in Section 2. Palmprint feature extrac-

tion by texture analysis is explained in Section 3. Experimental results are given in Section 4. Finally, Section 5 summarizes the main results of this paper.

2. Palmprint image preprocessing

Before feature extraction, it is necessary to obtain a sub-image from the captured palmprint image and to eliminate the variations caused by rotation and translation. The five main steps of palmprint image preprocessing are as follows (see Fig. 4):

Step 1: Apply a low-pass filter to the original image. Then use a threshold, T_p , to convert this original image into a binary image as shown in Fig. 4(b). Mathematically, this transformation can be represented as

$$B(x, y) = 1 \quad \text{if } O(x, y) * L(x, y) \geq T_p, \quad (1)$$

$$B(x, y) = 0 \quad \text{if } O(x, y) * L(x, y) < T_p, \quad (2)$$

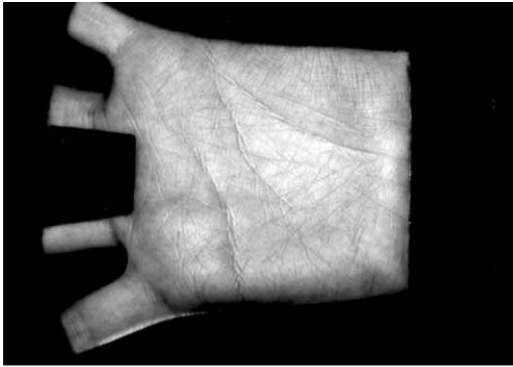
where $B(x, y)$ and $O(x, y)$ are the binary image and the original image, respectively; $L(x, y)$ is a lowpass filter, such as Gaussian, and “*” represents an operator of convolution.

Step 2: Extract the boundaries of the holes, $(F_i x_j, F_i y_j)$ ($i = 1, 2$), between fingers using a boundary-tracking algorithm. The start points, (S_x, S_y) , and end points, (E_x, E_y) of the holes are then marked in the process (see Fig. 4(c)).

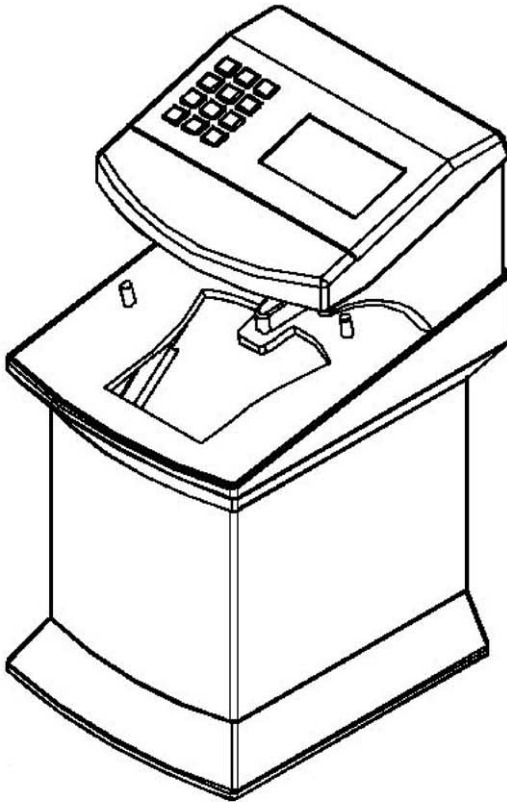
Step 3: Compute the center of gravity, (C_x, C_y) , of each hole with the following equations:

$$C_x = \frac{\sum_{j=1}^{M(i)} F_i x_j}{M(i)}, \quad (3)$$

$$C_y = \frac{\sum_{j=1}^{M(i)} F_i y_j}{M(i)}, \quad (4)$$



(a)



(b)

Fig. 2. Capture device and captured palmprint images. (a) on-line palmprint image obtained by our palmprint scanner and (b) our palmprint capture device.

where $M(i)$ represents the number of boundary points in the hole, i . Then construct a line that passes through (Cx_i, Cy_i) and the midpoint of (Sx_i, Sy_i) and (Ex_i, Ey_i) . The line equation is defined as

$$y = x \frac{(Cy_i - My_i)}{(Cx_i - Mx_i)} + \frac{My_i Cx_i - Mx_i Cy_i}{Cx_i - Mx_i}, \quad (5)$$

where (Mx_i, My_i) is the midpoint of (Sx_i, Sy_i) and (Ex_i, Ey_i) . Based on these lines, two key points, (k_1, k_2) , can easily be detected (see Fig. 4(d)).

Step 4: Line up k_1 and k_2 to get the Y-axis of the palmprint coordinate system and make a line through their mid point which is perpendicular to the Y-axis, to determine the origin of the coordinate system (see Fig. 4(e)). This coordinate system can align different palmprint images.

Step 5: Extract a sub-image with the fixed size on the basis of coordinate system, which is located at the certain part of the palmprint for feature extraction (see Fig. 4(f)).

3. Palmprint feature extraction by texture analysis

This section defines our palmprint feature extraction method, which includes filtering and matching. The motivation for using a Gabor filter in our palmprint research is first discussed.

3.1. Gabor function

Gabor filter, Gabor filter bank, Gabor transform and Gabor wavelet are widely applied to image processing, computer vision and pattern recognition. This function can provide accurate time-frequency location governed by the ‘‘Uncertainty Principle’’ [6,7]. A circular 2-D Gabor filter in the spatial domain has the following general form [8,9],

$$G(x, y, \theta, u, \sigma) = \frac{1}{2\pi\sigma^2} \exp\left\{-\frac{x^2 + y^2}{2\sigma^2}\right\} \times \exp\{2\pi i(ux \cos \theta + uy \sin \theta)\}, \quad (6)$$

where $i = \sqrt{-1}$; u is the frequency of the sinusoidal wave; θ controls the orientation of the function and σ is the standard deviation of the Gaussian envelope. Such Gabor filters have been widely used in various applications [10–19]. In addition to accurate time-frequency location, they also provide robustness against varying brightness and contrast of images. Furthermore, the filters can model the receptive fields of a simple cell in the primary visual cortex. Based on these properties, in this paper, we try to apply a Gabor filter to palmprint authentication.

3.2. Filtering and feature extraction

Generally, principal lines and wrinkles can be observed from our captured palmprint images (see Fig. 1(a)). Some algorithms such as the stack filter [21] can obtain the principal lines. However, these lines do not contribute adequately to high accuracy because of their similarity amongst different palms. Fig. 5 shows six palmprint images with similar principal lines. Thus, wrinkles play an important role in palmprint authentication but accurately extracting them is still a difficult task. This motivates us to apply texture analysis to palmprint authentication.

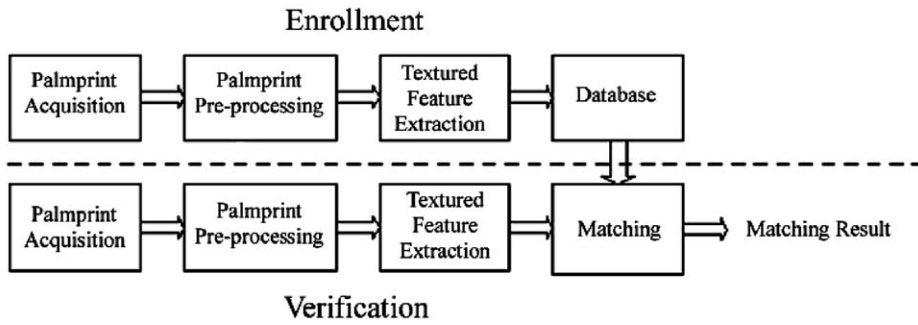


Fig. 3. Block diagram of our palmprint verification system.

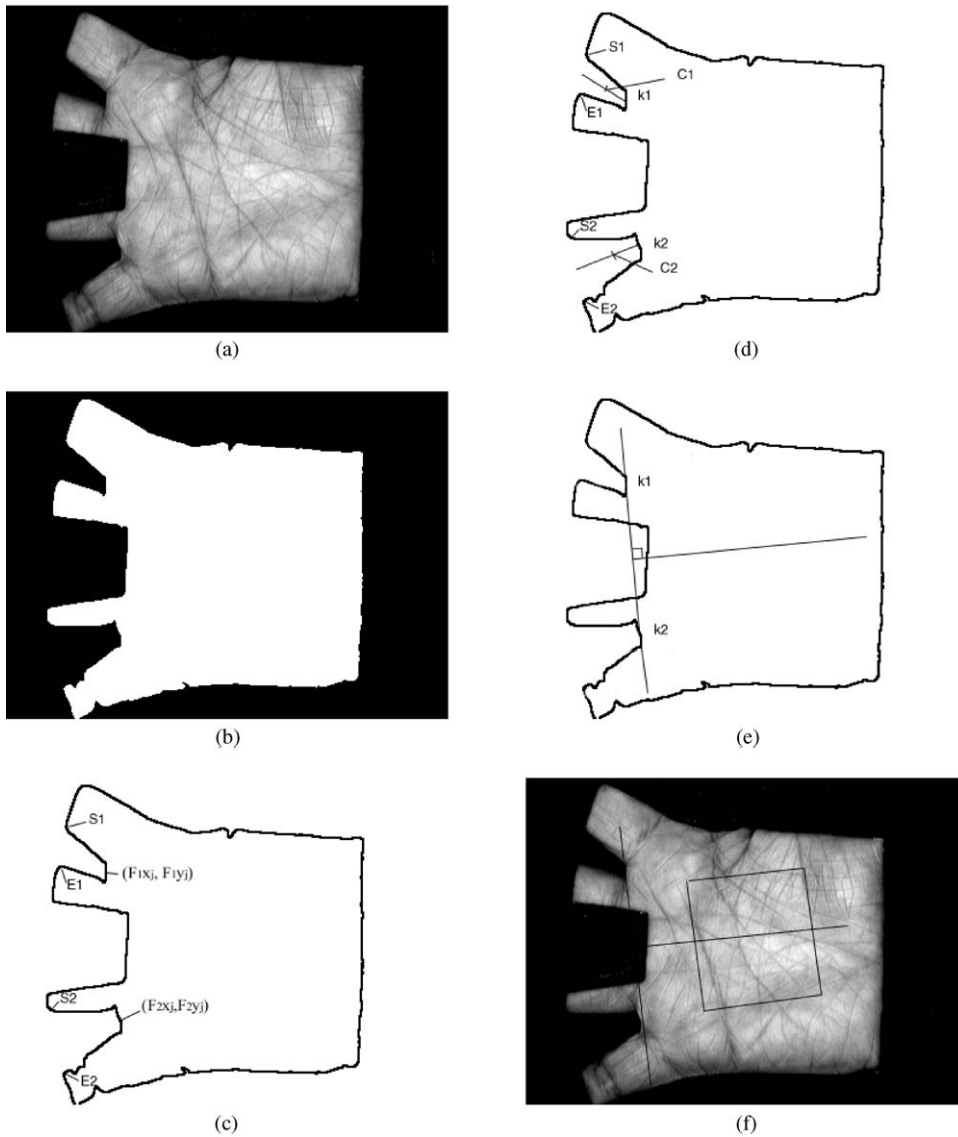


Fig. 4. Main steps of preprocessing: (a) original image, (b) binary image, (c) boundary tracking, (d) key points (k_1 and k_3) detecting, (e) the coordinate system and (f) The central part of a palmprint.

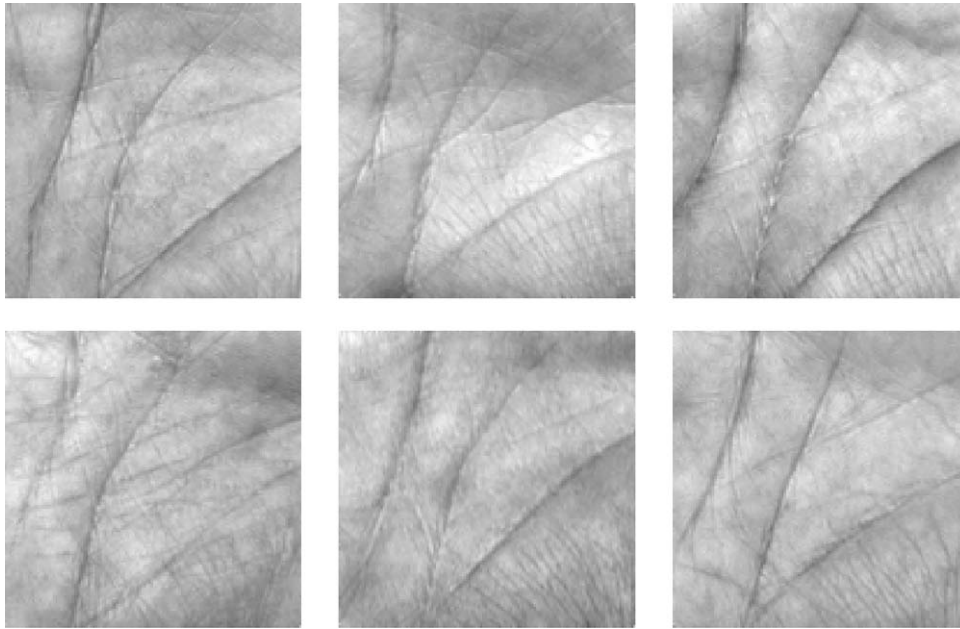


Fig. 5. Three six images with similar principal lines.

Table 1
The parameters of the 12 filters

Levels	No	Sizes	θ	u	σ
1	1	9×9	0	0.3666	1.4045
	2	9×9	45	0.3666	1.4045
	3	9×9	90	0.3666	1.4045
	4	9×9	135	0.3666	1.4045
2	5	17×17	0	0.1833	2.8090
	6	17×17	45	0.1833	2.8090
	7	17×17	90	0.1833	2.8090
	8	17×17	135	0.1833	2.8090
3	9	35×35	0	0.0916	5.6179
	10	35×35	45	0.0916	5.6179
	11	35×35	90	0.0916	5.6179
	12	35×35	135	0.0916	5.6179

In fact, a Gabor function, $G(x, y, \theta, u, \sigma)$ with a special set of parameters (σ, θ, u) , is transformed into a discrete Gabor filter, $G[x, y, \theta, u, \sigma]$. The parameters are chosen from 12 sets of parameters listed in Table 1 based on the experimental results in the next section. In order to provide more robustness to brightness, the Gabor filter is turned to zero DC (direct current) with the application of the following formula:

$$\tilde{G}[x, y, \theta, u, \sigma] = G[x, y, \theta, u, \sigma] - \frac{\sum_{i=-n}^n \sum_{j=-n}^n G[i, j, \theta, u, \sigma]}{(2n + 1)^2}, \quad (7)$$

where $(2n + 1)^2$ is the size of the filter. In fact, the imaginary part of the Gabor filter automatically has zero DC because

of odd symmetry. This adjusted Gabor filter will convolute with a sub-image defined in Section 2. The sample point in the filtered image is coded to two bits, (b_r, b_i) , by the following inequalities,

$$b_r = 1 \quad \text{if } \text{Re}[\tilde{G}[x, y, \theta, u, \sigma]^* I] \geq 0, \quad (8)$$

$$b_r = 0 \quad \text{if } \text{Re}[\tilde{G}[x, y, \theta, u, \sigma]^* I] < 0, \quad (9)$$

$$b_i = 1 \quad \text{if } \text{Im}[\tilde{G}[x, y, \theta, u, \sigma]^* I] \geq 0, \quad (10)$$

$$b_i = 0 \quad \text{if } \text{Im}[\tilde{G}[x, y, \theta, u, \sigma]^* I] < 0, \quad (11)$$

where I is the sub-image of a palmprint. Using this coding method, only the phase information in palmprint images is stored in the feature vector. The size of the feature is 256 bytes. Fig. 6 shows the features generated by the 12 filters listed in Table 1. This texture feature extraction method has been applied to iris recognition [13].

3.3. Palmprint matching

In order to describe clearly the matching process, each feature vector is considered as two 2-D feature matrices, real and imaginary. Palmprint matching is based on a normalized hamming distance. Let P and Q be two palmprint feature matrices. The normalized hamming distance can be defined as

$$D_0 = \frac{\sum_{i=1}^n \sum_{j=1}^n (P_R(i, j) \otimes Q_R(i, j) + P_I(i, j) \otimes Q_I(i, j))}{2N^2}, \quad (12)$$

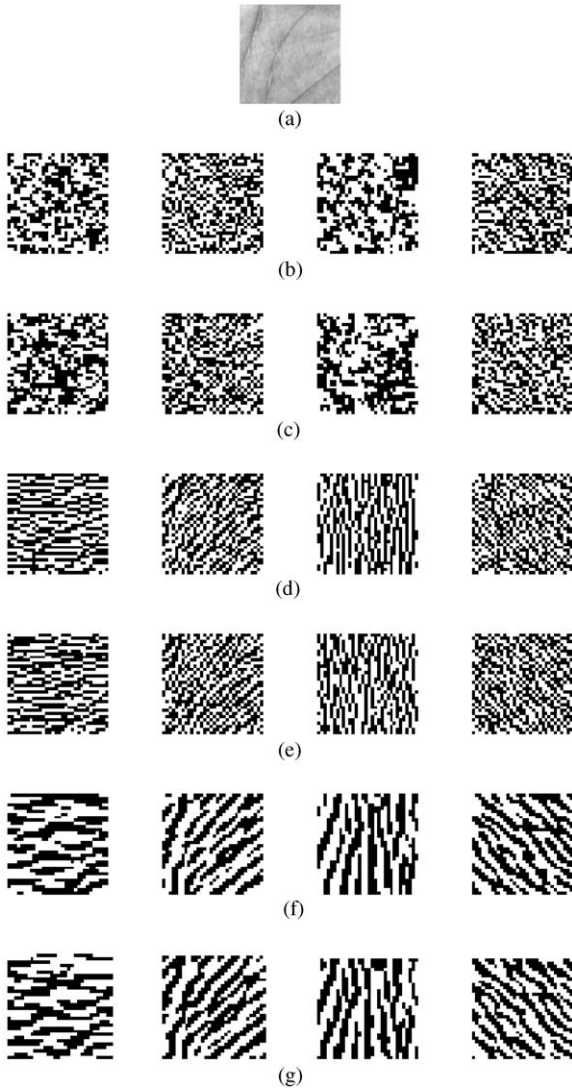


Fig. 6. Original image from DBI and their features generated by 12 filters listed in the Table: (a) original image, (b), (d) and (f) real parts of features from Levels 1–3 filters, respectively, (c), (e) and (g) imaginary parts of from Levels 1–3 filters, respectively.

where $P_R(Q_R)$ and $P_I(Q_I)$ are the real part and the imaginary part of $P(Q)$, respectively; the Boolean operator, “ \otimes ”, is equal to zero if and only if the two bits, $P_{R(I)}(i, j)$ and $Q_{R(I)}(i, j)$ are equal and the size of the feature matrices is $N \times N$. It is noted that D_0 is between 1 and 0. The hamming distance for perfect matching is zero. In order to provide translation invariance matching, Eq. (12) can be improved as

$$D_{\min} = \min_{|s| < S, |t| < T} \frac{\sum_{i=\max(1, 1+s)}^{\min(N, N+s)} \sum_{j=\max(1, 1+t)}^{\min(N, N+t)} (P_R(i+s, j+t) \otimes Q_R(i, j) + P_I(i+s, j+t) \otimes Q_I(i, j))}{2H(s)H(t)}, \quad (13)$$

where $S = 2$ and $T = 2$ control the range of horizontal and vertical translation of a feature in the matching process, respectively and

$$H(s) = \min(N, N + s) - \max(1, 1 + s). \quad (14)$$

The hamming distance, D_{\min} , can support translation matching; nevertheless, because of unstable preprocessing, it is not a rotational invariant matching. Therefore, in enrollment mode, the coordinate system is rotated by a few degrees and then the sub-images are extracted for feature extraction. Finally, combining the effect of preprocessing and rotated features, Eq. (13) can provide both approximately rotational and translation invariance matching.

4. Experimental results

4.1. Palmprint database

In the following experiments, a palmprint database contains 4647 palmprint images collected from 120 individuals by using our palmprint scanner. Forty-three of them are female, 111 of them are less than 30 years old and 2 of them are more than 50 years old. Each of them is asked to provide about 10 images for their left palm and 10 images for their right palm in each of two occasions. In total, each subject provides about 40 images. The average time difference of the first and second occasions is 81 days. The maximum and minimum are 4 and 162 days, respectively. Originally, the collected images have two sizes, 384×284 and 768×568 . The large images are resized to 384×284 ; consequently, the size of all the test images in the following experiments is 384×284 with 75 dpi resolution. The central parts of each image extracted with size 128×128 are named DBI. The preprocessed images in DBI resized to 64×64 are named DBII. The DBII is used to test the possibility of using lower-resolution palmprint images for personal identification. Fig. 7 shows nine typical images from our databases.

4.2. Verification tests

To obtain better parameters for our system, 12 different sets of parameters listed in Table 1 are used to test the method. The first four filters are named as Level 1 filters since they are different in the parameter, θ . Similarly, the other filters are named as Levels 2 and 3. Each of the images in DBI (DBII) is matched with all other palmprint images in the same database. A matching is counted as a correct matching if two palmprint images are collected from the same palm; otherwise it is an incorrect matching. The total number of matchings for one verification test is 10,794,981.

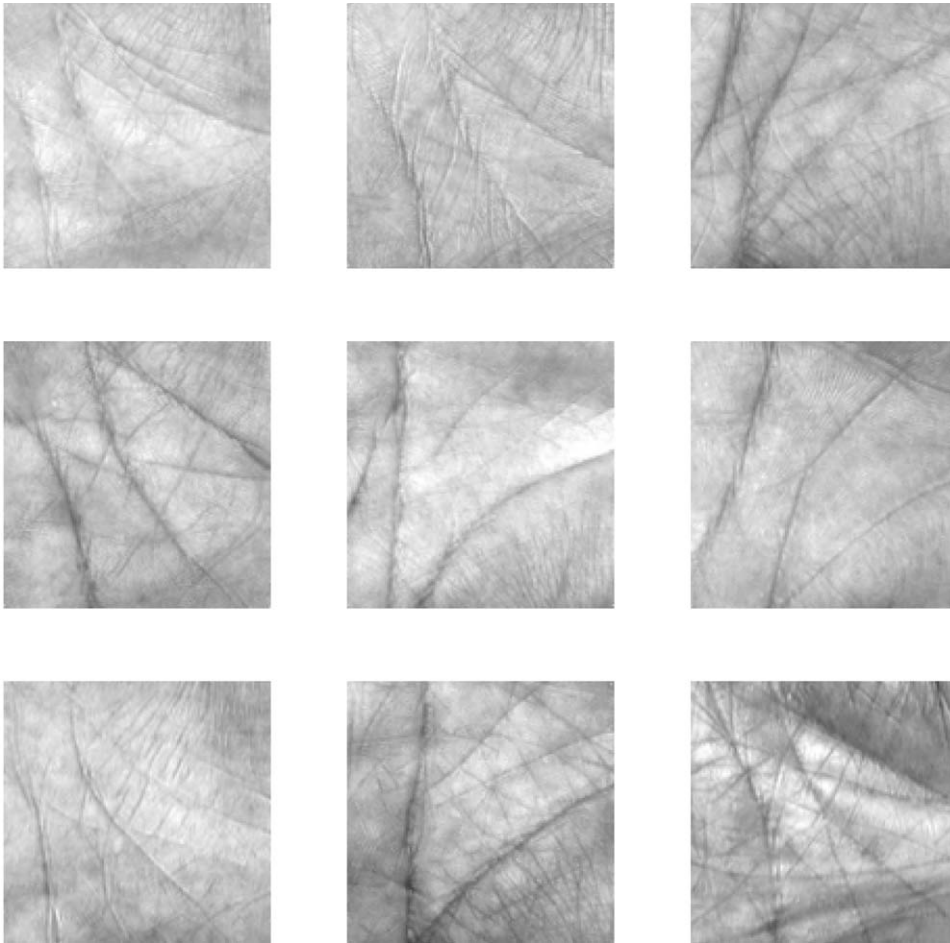


Fig. 7. Nine typical images from DBI.

Forty three thousand six hundred and sixty of them are correct matchings and rest of them are incorrect matchings. In total, 24 verification tests are carried out for testing the 12 sets of parameters on the two databases. The performance of different parameters on the two databases is presented by Receiver Operating Characteristic (ROC) curves, which are a plot of genuine acceptance rate against false acceptance rate for all possible operating points. Figs. 8(a)–(c), (8(d)–(f)) show the ROC curves for DBI (DBII) generated by Levels 1–3 filters, respectively. According to the ROC curves, Level 3 filters are better than Levels 1 and 2 filters for DBI. According to Fig. 8(c), Filters 9–11 provide similar performance when the false acceptance rate is greater than 10^{-2} . For false acceptance rates smaller than 10^{-2} , Filters 9 and 11 are better than Filter 10. For DBII, Level 1 filters are better than Level 2 and 3 filters. In fact, Filter 2 is the best for DBII. Although using very low-resolution images as DBII's images cannot provide very good performance, it still gives us an insight into using very low-resolution palmprint images for personal identification.

5. Conclusions

This paper reports a textured-based feature extraction method using low-resolution palmprint images for personal authentication. A palmprint is considered as a texture image, so an adjusted Gabor filter is employed to capture the texture information on palmprints. Based on our tests, Filter 11 is the best of 12 filters in terms of accuracy. Combined with the effects of preprocessing and rotated preprocessed images, our matching process is translation and rotational invariance. Experimental results illustrate the effectiveness of the method.

Acknowledgements

The work is partially supported by the UGC (CRC) fund from Hong Kong Government and the central fund from The Hong Kong Polytechnic University.

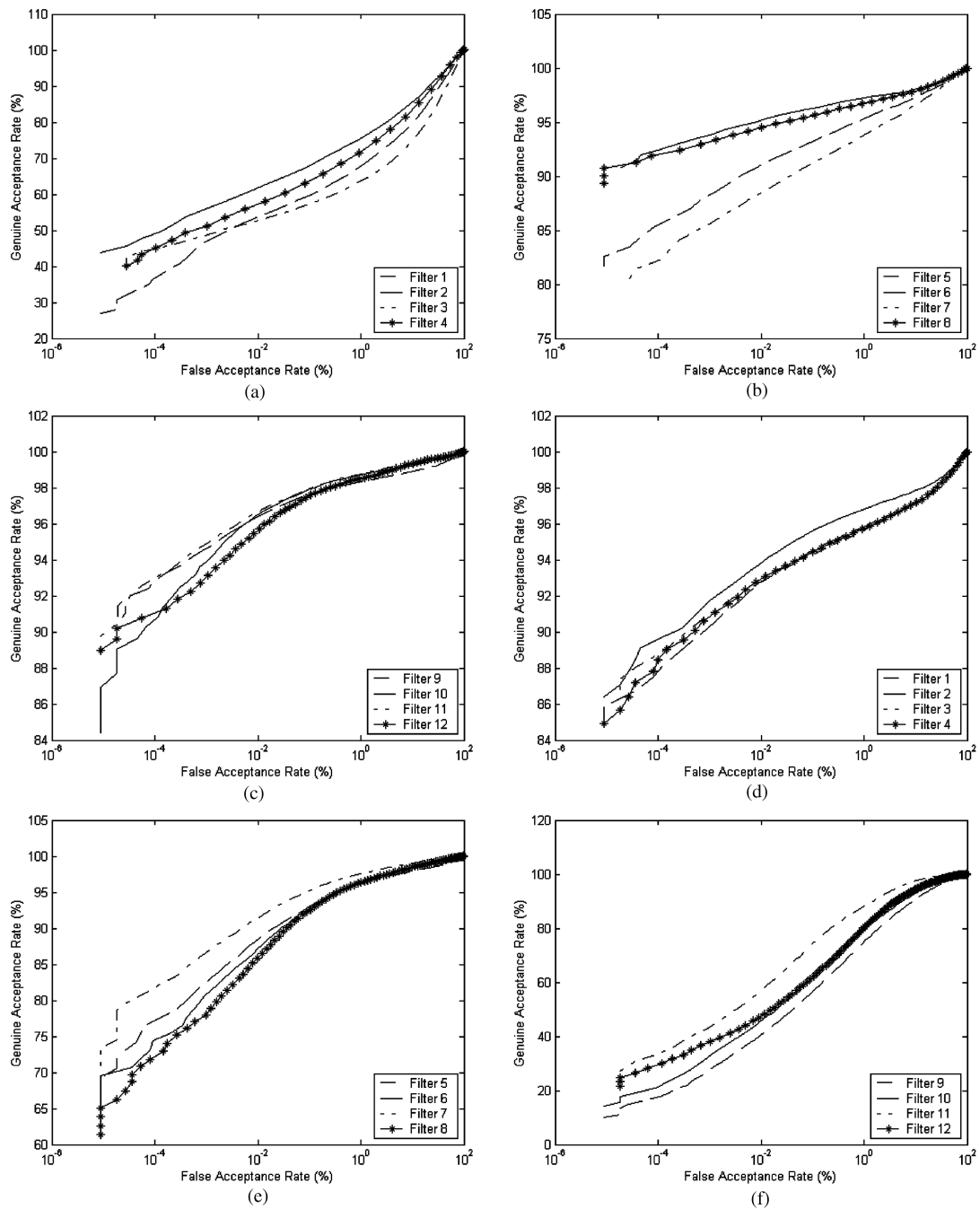


Fig. 8. Verification test results: (a)–(c), ((d)–(f)) the ROC curves of Levels 1–3 filters from DBI (DBII), respectively.

References

- [1] D. Zhang, W. Shu, Two novel characteristics in palmprint verification: datum point invariance and line feature matching, *Pattern Recognition* 32 (4) (1999) 691–702.
- [2] A. Jain, R. Bolle, S. Pankanti (Eds.), *Biometrics: Personal Identification in Networked Society*, Kluwer Academic, Dordrecht, 1999.
- [3] D. Zhang, *Automated Biometrics—Technologies and Systems*, Kluwer Academic, Dordrecht, 2000.

- [4] R. Sanchez, C. Sanchez-Avila, A. Gonzalez-Marcos, Biometric identification through geometry measurements, *IEEE Trans. Pattern Anal. Mach. Intell.* 22 (10) (2000) 1168–1171.
- [5] W. Shu, D. Zhang, Automated personal identification by palmprint, *Opt. Eng.* 37 (8) (1998) 2659–2662.
- [6] D. Gabor, Theory of communications, *J. IEE* 93 (1946) 429–457.
- [7] C.K. Chui, *An Introduction to Wavelets*, Academic Press, Boston, 1992.
- [8] J.G. Daugman, Two-dimensional spectral analysis of cortical receptive field profiles, *Vision Res.* 20 (1980) 847–856.
- [9] J. Daugman, Uncertainty relation for resolution in space, spatial frequency and orientation optimized by two-dimensional visual cortical filters, *J. Opt. Soc. Am. A* 2 (1985) 1160–1169.
- [10] A. Jain, G. Healey, A multiscale representation including opponent color features for texture recognition, *IEEE Trans. Image Process.* 7 (1) (1998) 124–128.
- [11] D. Dunn, W.E. Higgins, Optimal Gabor filters for texture segmentation, *IEEE Trans. Image Process.* 4 (4) (1995) 947–964.
- [12] A.C. Bovik, M. Clark, W.S. Geisler, Multichannel texture analysis using localized spatial filters, *IEEE Trans. Pattern Anal. Mach. Intell.* 12 (1) (1990) 55–73.
- [13] J. Daugman, High confidence visual recognition of persons by a test of statistical independence, *IEEE Trans. Pattern Anal. Mach. Intel.* 15 (11) (1993) 1148–1161.
- [14] A.K. Jain, S. Prabhakar, L. Hong, S. Pankanti, Filterbank-based fingerprint matching, *IEEE Trans. Image Process.* 9 (5) (2000) 846–859.
- [15] L. Hong, Y. Wan, A. Jain, Fingerprint image enhancement algorithm and performance evaluation, *IEEE Trans. Pattern Anal. Mach. Intell.* 20 (8) (1998) 777–789.
- [16] C.J. Lee, S.D. Wang, Fingerprint feature extraction using Gabor filters, *Electron. Lett.* 35 (4) (1999) 288–290.
- [17] M.J. Lyons, J. Budynek, S. Akamatsu, Automatic classification of single facial images, *IEEE Trans. Pattern Anal. Mach. Intell.* 21 (12) (1999) 1357–1362.
- [18] B. Duc, S. Fischer, J. Bigun, Face authentication with Gabor information on deformable graphs, *IEEE Trans. Image Process.* 8 (4) (1999) 504–516.
- [19] Y. Adini, Y. Moses, S. Ullman, Face recognition: the problem of compensation for changes in illumination direction, *IEEE Trans. Pattern Anal. Mach. Intell.* 19 (7) (1997) 721–732.
- [20] S. Pankanti, R.M. Bolle, A. Jain, Biometrics: the future of identification, *IEEE Comput.* 33 (2) (2000) 46–49.
- [21] P.S. Wu, M. Li, Pyramid edge detection based on stack filter, *Pattern Recognition Lett.* 18 (4) (1997) 239–248.
- [22] J. You, W. Li, D. Zhang, Hierarchical palmprint identification via multiple feature extraction, *Pattern Recognition* 35 (4) (2002) 847–859.
- [23] N. Duta, A.K. Jain, K.V. Mardia, Matching of palmprint, *Pattern Recognition Lett.* 23 (4) (2001) 477–485.
- [24] D. Zhang (Ed.), *Biometric Resolutions for Authentication in an e-World*, Kluwer Academic, Dordrecht, 2002.
- [25] C.C. Han, H.L. Cheng, K.C. Fan, C.L. Lin, Personal authentication using palmprint features, *Pattern Recognition (Special issue: Biometrics)* 36 (2) (2003) 371–381.

About the Author—KONG WAI-KIN received his B.Sc degree in mathematical science in 1998 from Hong Kong Baptist University with first class honors and his M.Phil degree from Hong Kong Polytechnic University in 2002. Now, he is working as a Research Associate at Biometrics Research Centre (UGC/CRC), Hong Kong Polytechnic University. His main research interest are biometric computing, pattern recognition and image processing.

About the Author—DAVID ZHANG graduated in computer science from Peking University in 1974 and received his M.Sc. and Ph.D. degrees in computer science and engineering from the Harbin Institute of Technology (HIT) in 1983 and 1985, respectively. From 1986 to 1988, he was a postdoctoral fellow at Tsinghua University and became an associate professor at Academia Sinica, Beijing, China. He received his second Ph.D. in electrical and computer engineering at the University of Waterloo, Ontario, Canada, in 1994. Currently, he is a Professor in the Hong Kong Polytechnic University. He is Founder and Director of both Biometrics Research Centers in PolyU and HIT, supported by UGC/CRC, Hong Kong Government, and National Scientific Foundation (NSFC) of China, respectively. In addition, he is Founder and Editor-in-Chief, *International Journal of Image and Graphics*, and an Associate Editor, *IEEE Trans. on Systems, Man and Cybernetics*, *Pattern Recognition*, *International Journal of Pattern Recognition and Artificial Intelligence*, *Information: International Journal*, *International Journal of Robotics and Automation and Neural, Parallel and Scientific Computations*. So far, he has published over 180 articles including seven books around his research areas.

About the Author—WENXIN LI received her B.S. Degree and M.S. Degree in computer science from Peking University, Beijing, in 1990 and 1993, respectively. She has been a lecturer at the Department of Computer Science and Technology, Peking University from 1993 to 1998. She is currently a Ph.D. student in the Department of Computing at the Hong Kong Polytechnic University. Her research interests include pattern recognition, image analysis and biometrics.