

DESIGN OF A BIOMETRIC AUTHENTICATION METHODOLOGY USING PALMPRI

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INFORMATION TECHNOLOGY
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DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations, summaries and references, which have been duly acknowledged.

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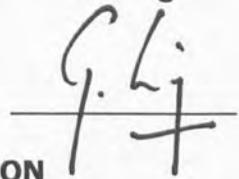
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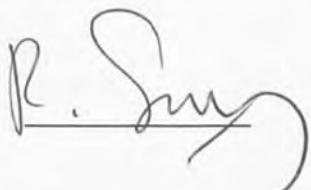
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ABSTRACT

DESIGN OF A BIOMETRIC AUTHENTICATION METHODOLOGY USING PALMPRINT

Biometric is the science of measuring human characteristics for the purpose of authentication or identification. Palmprint, one of the human physiological characteristics, is gaining attention among researchers as the mean of security. This is because palmprint is rich in unique features. The objectives of this thesis are to design an image processing methodology for palmprint image extraction, to design an efficient feature extraction method and an efficient classification method for palmprint biometric. The hand image is acquired using a digital camera. From the acquired hand image, the hand region are segmented from the background. The gaps between the fingers are located and marked as key points. Using the key points, the palmprint image rotational angle and the palmprint area are estimated. The palmprint image is rotated and extracted from the hand image. The palmprint image is enhanced using image adjustment and histogram equalization. The enhanced palmprint image is resized to a predefined size. Five types of palmprint features, namely, Geometric Line features, Discrete Cosine Energy features, Wavelet Energy features, Sequential Haar Energy features and SobelCode features, are extracted from the palmprint image. The palmprint features are represented using different feature representation method to form feature vectors. The feature vector is compared with the palmprint database using Hamming Distance similarity measurement, Euclidean Distance similarity measurement and Scaled Conjugated Gradient (SCG) based feedforward backpropagation neural network. Different types of feature extraction methods and classification methods have been tested to find the best discriminating palmprint feature. For comparison using distance similarity, the SobelCode features can achieve up to 97.44% accuracy, followed by the Discrete Cosine Energy features with 94.58%. The Sequential Haar Energy feature and Wavelet Energy feature can achieve 93.99% and 92.95% accuracy respectively. Using SCG-based feedforward backpropagation neural network, the accuracy of the Wavelet Energy Feature and Discrete Cosine Energy Feature can be slightly increased to 99%. Geometric Line Feature can achieve 89.41% accuracy.



ABSTRAK

Biometrik adalah bidang sains yang mengukur sifat-sifat manusia untuk tujuan pengesahan atau pengenalan. Cap tapak tangan merupakan salah satu daripada sifat-sifat fisiologi manusia yang mendapat tumpuan para penyelidik bagi tujuan keselamatan. Ini kerana cap tapak tangan mempunyai pelbagai ciri yang unik. Objektif-objektif tesis ini adalah untuk mereka cipta metodologi pemprosesan imej bagi tujuan pengekstraktan imej cap tapak tangan, mereka cipta kaedah pengekstrakan ciri-ciri dan kaedah perbandingan ciri-ciri cap tapak tangan yang efektif untuk biometrik cap tapak tangan. Pada mulanya, imej tangan akan diperolehi dari sebuah kamera digital. Kawasan tangan di dalam imej tangan ini akan diasinkan daripada latar belakang imej. Setelah itu, celah-celah jari akan dikenalpasti dan ditandakan sebagai titik-titik utama. Dengan menggunakan titik-titik utama tersebut, sudut putaran untuk imej tapak tangan dan kawasan tapak tangan akan dianggarkan. Imej cap tapak tangan diputarkan dan dikeluarkan daripada imej tangan. Selepas itu, imej cap tapak tangan akan diperbaiki dengan menggunakan kaedah pelarasian imej dan kaaedah penyamaan histogram. Kemudian, saiz imej tapak tangan akan diubah kepada saiz yang dikehendaki. Lima ciri-ciri cap tapak tangan, iaitu, ciri-ciri geometri garis, ciri-ciri tenaga kosine diskrit, ciri-ciri tenaga Wavelet, ciri-ciri tenaga Haar berurutan dan ciri-ciri SobelCode, akan diekstrak daripada imej cap tapak tangan. Ciri-ciri cap tapak tangan ini akan diwakili dengan pelbagai kaedah perwakilan ciri-ciri untuk membentuk vektor-vektor ciri. Vektor-vektor ciri ini kemudiannya dibandingkan dengan pangkalan data cap tapak tangan dengan menggunakan kaedah-kaedah pengukuran persamaan Hamming Distance, pengukuran persamaan Euclidean Distance dan feedforward backpropagation neural network berdasarkan Scaled Conjugated Gradient (SCG). Pelbagai jenis kaedah perwakilan ciri-ciri dan kaedah perbandingan telah dikaji untuk mengenal pasti kaedah membezakan perwakilan ciri-ciri yang terbaik. Dalam perbandingan menggunakan kaedah pengukuran persamaan, peratusan ketepatan ciri-ciri SobelCode adalah 97.44 peratus, diikuti dengan ciri-ciri tenaga kosine diskrit sebanyak 94.58 peratus. Ciri-ciri tenaga Haar berurutan dan ciri-ciri tenaga Wavelet masing-masing mencapai 93.99 peratus dan 92.95 peratus ketepatan. Dengan menggunakan feedforward backpropagation neural network berdasarkan SCG, peratusan ketepatan ciri-ciri tenaga Wavelet dan ciri-ciri tenaga kosine diskrit dapat dipertingkatkan kepada 99 peratus. Ciri-ciri geometri garis cuma mencapai 89.41 peratus ketepatan.

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LIST OF ABBREVIATIONS

1-2DPCA	One dimensional PCA applied on two dimensional PCA
1D	One dimensional
2D	Two Dimensional
CCD	Charge Coupled Device
Coif1	Coiflets Order 1 Wavelet
Coif2	Coiflets Order 2 Wavelet
Db2	Daubechies Order 2 Wavelet
Db3	Daubechies Order 3 Wavelet
Db4	Daubechies Order 4Wavelet
Db5	Daubechies Order 5 Wavelet
Db6	Daubechies Order 6 Wavelet
DCE	Discrete Cosine Energy
DCT	Discrete Cosine Transform
Dpi	Dot per inch
EER	Equal Error Rate
FAR	False Acceptance Rate
FRR	False Rejection Rate
GL	Geometric Line
GWN	Gabor Wavelet Network
GWPNN	Gabor Wavelet Probabilistic Neural Networks
Ha	Haar Wavelet
ICA	Independent Component Analysis
LDA	Linear Discriminant Analysis
Logsig	Logarithmic sigmoid activation function



MTER	Minimum Total Error Rate
NN	Neural network
PCA	Principal Component Analysis
PNN	Probabilistic Neural Network
Purelin	Pure linear activation function
RGB	Red-Green-Blue color space
ROI	Region of Interest
SCG	Scaled Conjugate Gradient algorithm
SHE	Sequential Haar Energy
Sym3	Symlets Order 3 Wavelet
Sym4	Symlets Order 4 Wavelet
Sym5	Symlets Order 5 Wavelet
Sym6	Symlets Order 6 Wavelet
Tansig	Tangent sigmoid activation function
TAR	True Acceptance Rate
TRR	True Rejection Rate
WE	Wavelet Energy
WT	Wavelet Transform
XOR	Operation exclusive OR

LIST OF SYMBOLS

&	Operator AND
\oplus	Operation exclusive OP
α_{1D}	1D-DCT Normalization factor
A_B	AND-ed binary hand image border array
ag_2	Adjusted pg
A_i	Orientation between R_G and palmprint principal line
A_R	White pixels in A_B
B	Binary hand image
bg_2	Thresholded ag_2
C_{1D}	1D-DCT coefficients
$cD_{(i,j,k)}$	Wavelet decomposition details coefficients in direction i, j level decomposition and sub block k
C_{HD}	Head line centroid
C_{HQ}	Interception of the line connecting H_{Q1} and H_{Q2}
C_{HT}	Heart line centroid
CI_{dx}	First non-zero pixel of the diagonal pixels array
C_L	Life line centroid
CWE	Concatenated Wavelet Energy
d_{CHD}	Distance measures from C_{HD} to heart line and life line.
d_{CHT}	Distance measures from C_{HT} to head line and life line.
d_{CL}	Distance measures from C_L to heart line and head line.
D_{KP}	Distance between $P1$ and $P2$
d_{P1}	Distance measures from P1 to palm lines.
d_{P2}	Distance measures from P2 to palm lines.

$D_{PB,PW}$	Distance between P_B and P_W
ED	Euclidean Distance
FV_{DE1}	(16 x 16) pixels DCT blocks DCE features
FV_{DE2}	(16 x 16) pixels DCT blocks with (2 x 2) sub blocks DCE Features
FV_{DE3}	(8 x 8) pixels DCT blocks DCE Features
FV_{GL}	Geometric Line features
FV_{GR}	Geometric and relative distance measures
FV_{H1}	NHE ₁
FV_{H10}	Combination of NHE ₁ , NHE ₂ , NHE ₃ , NHE ₄ and NHE ₅ .
FV_{H11}	Combination of NHE ₁ , NHE ₂ , NHE ₃ , NHE ₄ , NHE ₅ and NHE ₆ .
FV_{H12}	Weighted combination of NHE ₁ and NHE ₂ .
FV_{H13}	Weighted combination of NHE ₁ , NHE ₂ and NHE ₃ .
FV_{H14}	Weighted combination of NHE ₁ , NHE ₂ , NHE ₃ and NHE ₄ .
FV_{H15}	Weight combination of NHE ₁ , NHE ₂ , NHE ₃ , NHE ₄ and NHE ₅ .
FV_{H16}	Weight combination of NHE ₁ , NHE ₂ , NHE ₃ , NHE ₄ , NHE ₅ and NHE ₆ .
FV_{H2}	NHE ₂
FV_{H3}	NHE ₃
FV_{H4}	NHE ₄
FV_{H5}	NHE ₅
FV_{H6}	NHE ₆
FV_{H7}	Combination of NHE ₁ and NHE ₂ .
FV_{H8}	Combination of NHE ₁ , NHE ₂ and NHE ₃ .
FV_{H9}	Combination of NHE ₁ , NHE ₂ , NHE ₃ and NHE ₄ .
FV_S	SobelCode Feature Vector
FV_{S1}	TSC ₀

FV_{S10}	$HSC_0 + HSC_{45} + HSC_{90} + HSC_{135}$
FV_{S11}	$w_1 HSC_0 + w_2 HSC_{90}$
FV_{S12}	$w_1 HSC_{45} + w_2 HSC_{135}$
FV_{S13}	$w_1 HSC_0 + w_2 HSC_{45} + w_3 HSC_{90} + w_4 HSC_{135}$
FV_{S14}	$w_1 (HSC_0 \& HSC_{90}) + w_2 (HSC_{45} \& HSC_{135})$
FV_{S15}	$w_1 (HSC_0 + HSC_{90}) + w_2 (HSC_{45} + HSC_{135})$
FV_{S16}	$w_1 (FV_{S11}) + w_2 (FV_{S12})$
FV_{S2}	TSC ₄₅
FV_{S3}	TSC ₉₀
FV_{S4}	TSC ₁₃₅
FV_{S5}	$HSC_0 \& HSC_{90}$
FV_{S6}	$HSC_{45} \& HSC_{135}$
FV_{S7}	$HSC_0 \& HSC_{45} \& HSC_{90} \& HSC_{135}$
FV_{S8}	$HSC_0 + HSC_{90}$
FV_{S9}	$HSC_{45} + HSC_{135}$
FV_{WE1}	WE features vector for decomposition level normalization
FV_{WE2}	WE features vector for feature vector level normalization
g_n	N th order Gaussian derivative
HD	Hamming Distance
H_{P1}	Point 1 in Hough Lines
H_{P2}	Point 2 in Hough Line
H_{Q1}	Coordinates for the point with H_{P1_MaxY}
H_{Q2}	Coordinates for the intersection between line H_{P2_MinY} and H_{P2_MaxX}
HSC_x	Hamming distance results for TSC_x
I_{AG}	Adjusted grayscale format palmprint image

I_{AR}	Adjusted RGB format palmprint image
I_{GS}	Grayscale format palmprint image
I_{HG}	Histogram equalized grayscale format palmprint image
I_{HR}	Histogram equalized adjusted RGB format palmprint image
I_W	Index for middle pixels of wrist
L_{HD}	Head line
L_{HT}	Heart line
L_L	Life line
$M1$	First local minimum in the distance graph
$M3$	Third local minimum in the distance graph
m_{HQ}	Gradient of the line connecting H_{Q1} and H_{Q2}
NHE_i	Normalized i decomposition level SHE features
NWE_i	Normalized WE for i decomposition level
O	Orientation
$P1$	Key point 1 – Gap between the little finger and ring finger
$P2$	Key point 2 – Gap between the middle finger and index finger
P_{Ai}	Palmprint line point with A_i
P_B	Boundary pixels
P_D	Diagonal pixels of the rotated hand image
pg	Positive values range of second order Gaussian derivative coefficients
P_W	Middle pixels of the wrist
r	Red component of the hand image
RA	Total rotational angle
R_G	Global Geometric Line features

REFERENCES

- Ajay K., Wong D. C. M., Shen H. C. and Anil K. J. 2003. Personal Verification Using Palmprint and Hand Geometry Biometric. *Proceeding of 4th International Conference on Audio- and Video-Based Biometric Person Authentication (AVBPA)*. Guildford, UK. 668–678.
- Chen J., Zhang C. S. and Rong G. 2001. Palmprint recognition using crease. *Proceedings of International Conference on Image Processing 2001*. Thessaloniki, Greece. **3**: 234-237.
- Chen W. S., Chiang Y. S. and Chiu Y. H. 2007. Biometric Verification by Fusing Hand Geometry and Palmprint. *Third International Conference on Intelligent Information Hiding and Multimedia Signal Processing, 2007. IIHMSP 2007*, Kaohsiung, Taiwan. **2**: 403-406.
- Daugman, J. 2004. How Iris Recognition Works. *IEEE Transactions on Circuits and Systems for Video Technology*. **14**(1):21-30.
- Doi, J. and Yamanaka, M. 2003. Personal authentication using feature points on finger and palmar creases. *Proceedings of 32nd Applied Imagery Pattern Recognition Workshop 2003*. Washington, DC, United States of America. 282-287.
- Duta N., Anil K. J. and Kanti V. M. 2002. Matching of palmprints. *Pattern Recognition Letters*. **23**(4):477-485.
- EVIDENT Crime Scene Products. 2008 Fingerprinting Supplies, <http://www.evidentcrimescene.com/cata/print/print.html>. Retrieved 25 June 2008.
- Goh, M. K. O., Connie, T., Teoh, A. B. J. and Ngo, D. C. L. 2006. A Fast Palm Print Verification System. *International Conference on Computer Graphics, Imaging and Visualisation 2006*. Sydney, Australia. 168–172.
- Gonzalez R. C. and Woods R. E. 2002, Digital Image Processing (2nd Edition). Boston: Addison-Wesley Longman Publishing Co.
- Gonzalez R. C., Woods R. E. and Eddins S. L. 2004. Digital Image Processing Using Matlab. Upper Saddle River: Prentice-Hall Inc.
- Han C. C., Cheng H. L., Lin C. L. and Fan K. C. 2003. Personal authentication using palm-print features. *Pattern Recognition*. **36**(2): 371-381.
- Heijmans and Goutsias. 2000. Nonlinear Multiresolution Signal Decomposition Scheme – Part II: Morphological Wavelets. *IEEE Transactions on Image Processing*. **9**(11).

- Jain, A., Bolle, R. and Pankanti S. 2006. BIOMETRICS: Personal Identification in Networked Society. United States of America: Springer Science+Business Media, Inc.
- Jing X. Y. and Zhang D. 2004. A face and palmprint recognition approach based on discriminant DCT feature extraction. *IEEE Transactions on Systems, Man and Cybernetics Part B*. **34**(6): 2405-2415.
- Kent J. 2005. Malaysia car thieves steal finger. *BBC News, Kuala Lumpur*, <http://news.bbc.co.uk/go/pr/fr/-/2/asia-pacific/4396831.stm>. Retrieved on 22nd January 2009.
- Khayam, S. A. 2003. The Discrete Cosine Transform (DCT): Theory and Application 1. *ECE 802-602: Information Theory and Coding*. Michigan State University. 10th March 2003.
- Kong W. K. and Zhang D. 2002. Palmprint texture analysis based on low-resolution images for personal authentication. *Proceedings of 16th International Conference on Pattern Recognition 2002*. Quebec city, QC, Canada. **3**:807-810.
- Kong A. W. K., Zhang D. and Lu G. 2006. A study of identical twins' palmprints for personal verification. *Pattern Recognition*. **39**(11): 2149-2156.
- Kumar, A. and Shen, H.C. 2004. Palmprint identification using palmcodes. *Proceedings of Third International Conference on Image and Graphics 2004*. Hong Kong, China. 258-261.
- Li F. and Leung M. K. H. 2006. Hierarchical Identification of Palmprint using Line-based Hough Transform. *18th International Conference on Pattern Recognition, ICPR 2006*. Hong Kong. **4**: 149-152.
- Li F., Leung M. K. H., Shikhare, T., Chan V. and Choon K. F. 2006. Palmprint Classification. *IEEE International Conference on Systems, Man and Cybernetics 2006, SMC '06*. Taipei, Taiwan. **4**: 2965-2969.
- Li W. X., Zhang D. and Xu Z. Q. 2003. Image alignment based on invariant features for palmprint identification. *Signal Processing: Image Communication*. **18**(5): 373-379.
- Li W., Zhang D., and Xu Z. 2002. Palmprint Identification by Fourier Transform. *International Journal of Pattern Recognition and Artificial Intelligence*, **16**(4): 417-432.
- Lu G. M., Wang K. Q. and Zhang, D. 2004. Wavelet based independent component analysis for palmprint identification. *Proceedings of 2004 International Conference on Machine Learning and Cybernetics 2004*. Shanghai, China. **6**: 3547-3550.

- Mathworks. 2008. Matlab: Neural Network Toolbox User's Guide, http://www.mathworks.com/access/helpdesk/help/pdf_doc/nnet/nnet.pdf. Retrieved on 1 November 2008.
- Mathworks. 2009. Matlab: Image Processing Toolbox 6 User's Guide, http://www.mathworks.com/access/helpdesk/help/pdf_doc/images/images_tb.pdf. Retrieved on 1 April 2009.
- Michael Negnevitsky. 2002. Artificial Intelligence: A Guide to Intelligent Systems. Great Britain: Pearson Education Limited.
- Moller M.F. 1993. A Scaled Conjugate Gradient Algorithm for Fast Supervised Learning. Preprint for *Neural Networks*. **6**: 525-533.
- Mythbusters. 2007. Hacking Fingerprint, http://gagspace.com/video/how_to_hack_a_fingerprint_scanner. Retrieved on 7 March 2009.
- Noh J. S. and Rhee K. H. 2005. Palmprint identification algorithm using Hu invariant moments and Otsu binarization. *Fourth Annual ACIS International Conference on Computer and Information Science*. Jeju Island, South Korea. 94-99.
- Otsu, N. 1959. A Threshold Selection Method from Gray-Level Histograms. *IEEE Transactions on Systems, Man and Cybernetics*. **9**(1): 62-66.
- PolyU Palmprint Database. 2005. The Hong Kong Polytechnic University (PolyU) Palmprint Database, <http://www.comp.polyu.edu.hk/~biometrics/>. Retrieved on 9th November 2005.
- Rafael D. M., Travieso, C. M., Alonso, J. B. and Ferrer, M. A. 2004. Biometric system based in the feature of hand palm. *38th Annual 2004 International Carnahan Conference on Security Technology 2004*. Albuquerque, New Mexico, United States of America. 136-139.
- Sonka M., Hlavac V. and Boyle R. 2008. Image Processing, Analysis and Machine Vision. Third Edision. Toronto : Thompson Learning.
- Sun D. M., Qiu Z. D. and Li Q. 2006. Palmprint Identification using Gabor Wavelet Probabilistic Neural Networks. *The 8th International Conference on Signal Processing 2006*. Honolulu, Hawaii, United States of America. **4**.
- Tantachun, S., Pintavirooj, C., Lertprasart P. and Bunluechokchai S. 2006. Biometrics with Eigen-Hand. *1st IEEE Conference on Industrial Electronics and Applications 2006*. Singapore. 1-4.
- Tao J. W., Jiang W., Gao Z., Chen S. and Wang C. 2006. Palmprint Recognition Based on 2-Dimension PCA. *First International Conference on Innovative Computing, Information and Control 2006, ICICIC '06*. Beijing, China. **1**: 326-330.

- Tee C., Teoh A. B. J., Goh M. K. O. and Ngo D. C. L. 2005. An automated palmprint recognition system. *Image and Vision Computing*. **23**(5): 501-515.
- Wang M. and Ruan Q. Q. 2006. Palmprint Recognition Based on Two-Dimensional Methods. *The 8th International Conference on Signal Processing*. Guilin, China. **4**: 16-20.
- Wei X. Y., Xu D. and Ngo C. W. 2005. Multibiometrics based on palmprint and handgeometry. *Proceeding of the Fourth Annual ACIS International Conference on Computer and Information Science*. Jeju Island, South Korea. 495-500.
- Wikipedia. 2008. Otsu's Method, <http://en.wikipedia.org/wiki/Otsu's%20method>. Retrieved on 20 November 2008.
- Wong, M., Zhang, D., Kong, W. K. and Lu, G. 2005. Real-time palmprint acquisition system design. *IEE Proceedings - Vision, Image and Signal Processing*. **152**(5): 527-534.
- Woodward, Jr. J. D., Orlans N. M. and Higgins P. T. 2003. Biometrics: Identity Assurance in the Information Age. New York: The McGraw-Hil/ Osborne.
- Wu X. Q., Wang K. Q. and Zhang D. 2002. Wavelet based palm print recognition. *Proceedings of International Conference on Machine Learning and Cybernetics 2002*. Beijing, China. **3**:1253-1257.
- Wu X. Q., Wang K. Q. and Zhang D. 2005. Wavelet Energy Feature Extraction and Matching for Palmprint Recognition. *Journal of Computer Science and Technology*. **20**(3): 411-418.
- Wu X. Q., Zhang D., Wang K. Q. and Huang B. 2004. Palmprint Classification Using Principal Line. *Pattern Recognition*. **37**(10): 1987-1998.
- Zhang, D. 2004. Palmprint Authentication. Boston: Kluwer Academic Publishers.
- Zhang, D., Kong, W. K., You, J. and Wong, M. 2003. Online palmprint identification. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. **25**(9): 1041-1050.