FEATURE FUSION USING A MODIFIED GENETIC ALGORITHM FOR FACE AND SIGNATURE RECOGNITION SYSTEM

SURYANTI BINTI AWANG

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JUNE 2015

TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

if-then	-	Rules derived from decision tree
$\{X_1, X_2, X_3,..,X_N\}$	-	Training set
N	-	Number of all samples
N_i	-	Number of samples in each class
n-dimensional	-	Dimensional in image space
m-dimensional	-	Dimensional in feature space
$W_{PCA} \in R^{nxm}$	-	A linear mapping in Eigen space that consist of the highest variance
μ	-	Mean of all samples
μ_i	-	Mean of samples in each class
W_{PCA}	-	Eigen subspace
$W^T S_T W$	-	Scatter matrix of the transformed feature vector
W_{opt}	-	Convex optimization in Linear Discriminant Analysis
S_T	-	The total scatter matrix of samples
$\lfloor w_1 \quad w_2 \quad w_g \rfloor$	-	The set of n-dimensional eigenvectors of S_T corresponding to the g largest eigenvalues
W_{LDA}	-	Mapping direction matrix in Linear Discriminant Analysis
X'	-	Face protocol derived from a mapping direction matrix in Linear Discriminant Analysis
C	-	Number of classes
S_B	-	Scatter matrix between-class

S_W	-	Scatter matrix within-class
Y	-	Samples' label
g	-	The highest eigenvalues
G	-	Pooled within group covariance matrix
x'	-	Normalized value
x	-	Original value
x_{min}	-	Minimum point of original x point
x_{max}	-	Maximum point of original x point
σ	-	Standard deviation of the features
pbest	-	The best position on i^{th} particle in Particle Swarm Optimization
gbest	-	The best position of the particles in swarm in Particle Swarm Optimization
X coordinate	-	X coordinate of signature writing
Y coordinate	-	Y coordinate of signature writing
x_i^o	-	Original x point of signature
y_i^o	-	Original y point of signature
x_i'	-	x point after normalization
y_i'	-	y point after normalization
y_{min}	-	Minimum point of original y point
W	-	Width of normalized signature data
H	-	Height of normalized signature data
Δp	-	A fraction of the total arc length of signature data
L	-	Arc length of signature data
d	-	Distance of point to point in signature data
n	-	The number of points in raw signature data
n_1	-	Fixed number points in signature data
ΔT	-	A fraction of the total time signature
$T(n)$	-	Total time of signature
n_2	-	Determined fixed number of points after re-sampling process
θ	-	Direction of any point in signature

ϕ	-	Curvature of any point in signature
$\sin\theta_X(n)$	-	Direction of x in local time based signature writing
$\sin\theta_Y(n)$	-	Direction of y in local time based signature writing
$\cos\theta(n)$	-	Direction of x in local strokes based signature writing
$\sin\theta(n)$	-	Direction of y in local strokes based signature writing
$\cos\phi(n)$	-	Curvature's angle of the strokes between two elementary segment in signature writing
$\sin\phi(n)$	-	Curvature's angle of the strokes between two elementary segment in signature writing
ρ_c	-	Rate of crossover in GA
ρ_m	-	Rate of mutation in GA
ρ_x	-	Probability of solution in roulette wheel selection in GA
f_x	-	Fitness value for the particular solution in roulette wheel selection in GA
f_{sum}	-	Sum of the fitness for all solutions in roulette wheel selection in GA
function fc	-	Additional function in GA's fitness function to control the balance of selected features
function fx	-	Fitness function which represent the accuracy performance

LIST OF ABBREVIATIONS

GA	-	Genetic Algorithm
LDA	-	Linear Discriminant Analysis
ORL	-	Olivetti Research Laboratory
SUSIG	-	Sabanci University Signature Database
2D	-	Two Dimensional
3D	-	Three Dimensional
PSO	-	Particle Swam Optimization
SVM	-	Support Vector Machine
Min-Max	-	Minimum and Maximum Normalization
Z-score	-	A Statistical Measurement Of A Score's Relationship To The Mean In A Group Of Scores
LR	-	Likelihood Ratio
NN	-	Neural Network
MDR	-	Minimal Distance Rule
FRGC	-	Face Recognition Grand Challenge
MCYT	-	Ministerio de Ciencia y Tecnologıa
LCD	-	Liquid-crystal-display
PCA	-	Principle Component Analysis
GAR	-	Genuine Acceptance Rate
FDA	-	Fisher Discriminant Analysis
EER	-	Equal Error Rate
SIFT	-	Scale Invariant Feature Transform Features
ICA	-	Independent Component Analysis
SFFS	-	Sequential Floating Forward Selection Algorithm

GPR	-	Ground Penetrating Radar
FAR	-	False Acceptance Rate
KDDA	-	Kernel Direct Discriminant Analysis
SFS	-	Sequential Forward Selection (SBS)
SBS	-	Sequential Backward Selection
SBFS	-	Sequential Backward Floating Search
k-NN	-	k-Nearest Neighbour
BIOMET	-	Biometrics Database from TELECOM SudParis
SVC2004	-	Signature Verification Competition 2004
YALE	-	Face Database from Yale University
FERET	-	The Facial Recognition Technology Database
UTSB	-	University of Science and Technology Beijing face database

LIST OF APPENDICES

FEATURE FUSION USING A MODIFIED GENETIC ALGORITHM FOR FACE AND SIGNATURE RECOGNITION SYSTEM

SURYANTI BINTI AWANG

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JUNE 2015

ABSTRACT

Combination of multi biometrics at feature level fusion is able to give more accurate classification result. This thesis focuses on the development of feature level fusion of bimodal biometrics system for face and dynamic signature recognition system. The modalities of biometric are used due to the ability to avoid spoof attack since it is difficult for impostor to imitate two different characteristics (behaviour and physical) at the same time. Most existing systems are dealing with feature fusion of the same domain such as image based of fingerprint and face. Thus, there is no issue of incompatible features to be fused compared to the proposed development. Balance of the combined features has not been assessed whereas it is essential to ensure one of the biometrics does not dominate accuracy performance. To overcome the issue of incompatible features to be combined, Wrapper Genetic Algorithm (GA) was implemented as the feature selection algorithm due to its ability to evaluate the features irrespective of which domain by masking the features with bit number. A modified fitness function in Wrapper GA was introduced by adding a function to maintain the balanced of the selected features. Penalty's value was imposed to the function when there is imbalance occurs in the selected features. Therefore, the accuracy performance of this system based on the fitness function that will rely on the percentage of correctly recognized samples and the balanced of selected features. Several approaches and benchmark data were used to validate the effectiveness of the proposed method compared to the unimodal system and normal feature selection method. Results show that the proposed method yield optimal recognition with the highest accuracy of 97.50%. In addition, the importance of both biometrics remains, while maintaining the balance of the selected features.

ABSTRAK

Penggabungan pelbagai biometrik di peringkat gabungan ciri-ciri mampu memberi hasil pengkelasan yang lebih tepat. Tesis ini memberi tumpuan kepada pembangunan sistem pengecaman muka dan tandatangan di peringkat tersebut. Jenis biometrik tersebut digunakan kerana ia mampu mengatasi isu penyamaran iaitu sukar untuk penyamar meniru dua ciri yang berbeza (tingkah laku dan fizikal) pada masa yang sama. Kebanyakan sistem sedia ada menggabungkan ciri-ciri daripada domain yang sama seperti cap jari dan muka yang berasaskan imej. Oleh itu, tidak ada isu ketidakserasian untuk digabungkan berbanding dengan pembangunan yang dicadangkan. Keseimbangan ciri-ciri yang digabung juga tidak dinilai sedangkan ia penting untuk memastikan salah satu proses pengkelasan tidak dimonopoli oleh hanya satu biometrik. Untuk mengatasi isu ketidakserasian, Algoritma Genetik *Wrapper* (GA) digunakan untuk memilih dan menggabungkan ciri-ciri kerana kemampuannya menilai ciri-ciri tanpa mengambil kira ia dari domain yang mana. Fungsi kecergasan *Wrapper* GA diubah suai dengan menambah satu fungsi yang berperanan untuk mengekalkan keseimbangan dalam ciri-ciri yang dipilih. Nilai penalti dikenakan apabila terdapat ketidakseimbangan dalam ciri-ciri yang dipilih. Oleh itu, prestasi pengkelasan sistem berdasarkan fungsi kecergasan yang bergantung kepada peratusan sampel dikelaskan dengan betul dan keseimbangan ciri-ciri. Beberapa teknik dan data penanda aras digunakan untuk mengesahkan keberkesanan kaedah yang dicadangkan berbanding dengan sistem unimodal dan kaedah pemilihan ciri-ciri yang biasa. Hasil kajian ini telah menunjukkan bahawa prestasi pengkelasan menggunakan kaedah dicadangkan lebih optimum dengan ketepatan tertinggi 97.50%. Di samping itu, kepentingan kedua-dua biometrik sewaktu proses pengkelasan dapat dikekalkan dengan cara mengekalkan keseimbangan ciri-ciri yang dipilih.

REFERENCES

Afsar, F. A., Arif, M., and Farrukh, U. (2005). Wavelet Transform Based Global Features for Online Signature Recognition. *9th International Multitopic Conference, IEEE INMIC.* 24-25 Dec. Karachi, 1-6.

Ahmad, M. I., Woo, W. L., and Dlay, S. S. (2010). Multimodal biometric fusion at feature level: Face and palmprint. *7th International Symposium on Communication Systems Networks and Digital Signal Processing (CSNDSP).* 21-23 July. Newcastle, 801 – 805.

Alsaade, F., Ariyaeeinia, A., Malegaonkar, A., and Pillay, S. (2009). Qualitative fusion of normalised scores in multimodal biometrics. *Pattern Recognition Letters, 30*(5), 564-569.

Altun, A. Alpaslan, Allahverdi, Novruz, and Kocer, H. Erdinc. (2008). Genetic Algorithm Based Feature Selection Level Fusion Using Fingerprint And Iris Biometrics. *International Journal of Pattern Recognition and Artificial Intelligence.* 22(03), 585-600.

Arun, Ross, and Anil, Jain. (2003). Information fusion in biometrics. *Pattern Recognition Letters.* 24(13), 2115-2125.

Bai, Qinghai. (2010). Analysis of Particle Swarm Optimization Algorithm. *Computer and Information Science.* 3(1), 175-179.

Bailly-Bailliére, E., Bengio, S., Bimbot, F., Hamouz, M., Kittler, J., Mariéthoz, J., Thiran, J-P. (2003). The BANCA Database and Evaluation Protocol. In Kittler, J. and Nixon, M. (Eds.), *Audio- and Video-Based Biometric Person Authentication* (Vol. 2688, pp. 625-638). Berlin: Springer Berlin Heidelberg.

Belhumeur, P. N., Hespanha, J. P., and Kriegman, D. J. (1997). Eigenfaces vs. Fisherfaces: recognition using class specific linear projection. *Pattern Analysis and Machine Intelligence, IEEE Transactions on, 19*(7), 711-720.

Ben Khalifa, A., and Ben Amara, N.E. (2009). Bimodal biometric verification with different fusion levels. *6th International Multi-Conference on Systems, Signals and Devices*. 23-26 March. Djerba, 1-6.

Bengherabi, M., Mezai, L., Harizi, F., Guessoum, A., and Cheriet, M. (2009). Robust authentication using Likelihood Ratio and GMM for the fusion of voice and face. *3rd International Conference on Signals, Circuits and Systems*. 1-6.

Besbes, F., Trichili, H., & Solaiman, B. (2008). Multimodal Biometric System Based on Fingerprint Identification and Iris Recognition. *International Conference on Information and Communication Technologies: From Theory to Applications*. 1 -5.

Bouchaffra, D., and Amira, A. (2008). Structural hidden Markov models for biometrics: Fusion of face and fingerprint. *Pattern Recognition*. 41(3), 852-867.

Cadavid, S., Mahoor, M. H., and Abdel-Mottaleb, M. (2009). Multi-modal biometric modeling and recognition of the human face and ear. *IEEE International Workshop on Safety, Security Rescue Robotics*. 3-6 Nov. Denver, 1-6.

Conti, V., Militello, C., Sorbello, F., and Vitabile, S. (2010). A Frequency-based Approach for Features Fusion in Fingerprint and Iris Multimodal Biometric Identification Systems. *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and* Reviews. 40(4), 384 -395.

Cui, J., Li, JP., and Lu, XJ. (2008). Study on Multi-Biometric Feature Fusion and Recognition Model. *International Conference on Apperceiving Computing and Intelligence Analysis*. 13-15 Dec. Chengdu, 66 -69.

Dolfing, J. G. A., Aarts, E. H. L., and Van Oosterhout, J. J. G. M. (1998). On-line signature verification with hidden Markov models. *Proceedings of Fourteenth International Conference on the Pattern Recognition*. 16-20 Aug. Brisbane, 1309-1312.

Dunstone, T., and Neil, Y. (2009). *Biometric System and Data Analysis: Design, Evaluation and Data Mining*. (1st ed). Australia: Springer.

Ekenel, H. K., and Stiefelhagen, R. (2006). Analysis of Local Appearance-Based Face Recognition: Effects of Feature Selection and Feature Normalization. *Conference on the Computer Vision and Pattern Recognition Workshop*. 17-22 June. 34-41.

Fadlil, Abdul. (2006). *Modified approach of online handwriten text recognition and signature verification system.* Doctor Philosophy, Universiti Teknologi Malaysia, Skudai.

Fahmy, M. M. (2010). Online handwritten signature verification system based on DWT features extraction and neural network classification. *Ain Shams Engineering Journal, 1*(1), 59-70.

Faundez-Zanuy, Marcos. (2007). On-line signature recognition based on VQ-DTW. *Pattern Recognition, 40*(3), 981-992.

Feng, G., Dong, K., Hu, D., and Zhang, D. (2004). When Faces Are Combined with Palmprints: A Novel Biometric Fusion Strategy. In Zhang, D. and Jain, A. (Eds.). *Biometric Authentication* (Vol. 3072, pp. 59-68). Berlin: Springer Berlin Heidelberg.

Fierrez-Aguilar, J., Nanni, Loris, Ortega-Garcia, J., Cappelli, Raffaele, and Maltoni, Davide. (2005). Combining Multiple Matchers for Fingerprint Verification: A Case Study in FVC2004. *13th international conference on Image Analysis and Processing*. 6-8 September . Cagliari , 1035-1042.

Fu, Y., Ma, Z., Qi, M., Li, J., Li, Xi., and Lu, Y. (2008). A Novel User-Specific Face and Palmprint Feature Level. *Second International Symposium on Intelligent Information Technology Application.* 20-22 Dec . Shanghai, 296 -300.

Garcia-Salicetti, S., Beumier, C., Chollet, G., Dorizzi, B., Jardins, J., Lunter, J., Ni, Y., and Petrovska-Delacrétaz, D. (2003). BIOMET: A Multimodal Person Authentication Database Including Face, Voice, Fingerprint, Hand and Signature Modalities. In Kittler, J. and Nixon, M. (Eds.), *Audio- and Video-Based Biometric Person Authentication* (Vol. 2688, pp. 845-853). Berlin: Springer Berlin Heidelberg.

Gross, R., Matthews, I., and Baker, S. (2004). Appearance-based face recognition and light-fields. *IEEE Transactions on Pattern Analysis and Machine* Intelligence. 26(4), 449-465.

Hanmandlu, M., Kumar, A., Madasu, V.K., & Yarlagadda, P. (2008). Fusion of Hand Based Biometrics Using Particle Swarm Optimization. *Fifth International Conference on Information Technology: New Generations.* 783 -788.

Hong, L., and Jain, A.. (1998). Integrating faces and fingerprints for personal identification. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 20(12), 1295-1307.

Huilin, Z., Jianbin, W., Yuhao, W., and Mao, T. (2007). Wrapper approach for feature subset selection using GA. *International Symposium on Intelligent Signal Processing and Communication Systems.*

Hussein, F., Kharma, N., and Ward, R. (2001). Genetic algorithms for feature selection and weighting, a review and study. *Sixth International Conference on the Document Analysis and Recognition.* 10-13 Sep. Seattle, 1240-1244.

Jain, A. K., and Ross, A. (2002). Learning user-specific parameters in a multibiometric system. *International Conference on Image Processing.* 22-25 September. Rochester, New York, 57-60.

Jain, A.K., Ross, A., and Prabhakar, S. (2004). An introduction to biometric recognition. *IEEE Transactions on Circuits and Systems for Video Technology,* 14(1), 4 - 20.

Jain, Anil, Nandakumar, Karthik, and Ross, Arun. (2005). Score normalization in multimodal biometric systems. *Pattern Recognition.* 38(12). 2270-2285.

Jain, A. K., Ross, A., and Pankanti, S. (2006). Biometrics: a tool for information security. *IEEE Transactions on Information Forensics and Security.* 1(2), 125-143.

Jiawei, H., and Kamber, M. (2001). Data mining: concepts and techniques. *San Francisco, CA, itd: Morgan Kaufmann, 5.*

Kholmatov, A., and Yanikoglu, B. (2009). SUSIG: an on-line signature database, associated protocols and benchmark results. *Pattern Analysis Applications.* 12(3), 227-236.

Khuwaja, GA. (2013). Features-Level Fusion Of Face And Handwritten Signature In Multimodal Biometric Identification System. *Cybernetics and* Systems. 44(5), 422-443.

Kisku, DR., Gupta, P., and Sing, JK. (2009). Feature Level Fusion of Biometrics Cues: Human Identification with Doddington's Caricature. In Ślęzak, D., Kim, TH., Fang, WC., and Arnett, K. (Eds.) Security Technology. (pp 157-164). Korea: Springer Berlin Heidelberg.

Lee, Y., Lee, K., Jee, H., Gil, Y., Choi, W., Ahn, D., and Pan, S. (2005). Fusion for Multimodal Biometric Identification. In Kanade, T., Jain, A., and Ratha, N. (Eds.), *Audio- and Video-Based Biometric Person Authentication* (pp. 1071-1079) New York: Springer Berlin Heidelberg.

Li, Q., Qiu, Z., and Sun, D. (2005). Feature-Level Fusion of Hand Biometrics for Personal Verification Based on Kernel PCA. *Advances in Biometrics* (Vol. 3832, pp. 744-750): Springer Berlin Heidelberg.

Liau, HF., and Isa, D. (2011). Feature selection for support vector machine-based face-iris multimodal biometric system. *Expert Systems with Applications*. 38(9), 11105-11111.

Lu, C., Wang, J., and Qi, M. (2009). Multimodal Biometric Identification Approach Based on Face and Palmprint. *Second International Symposium on Electronic Commerce and Security*. 22-24 May. Nanchang, 44-47.

Luca, Marcialis Gian, Fabio, Roli, and Luca, Didaci. (2009). Personal identity verification by serial fusion of fingerprint and face matchers. *Pattern Recognition, 42*(11), 2807-2817.

Lumini, A., and Nanni, L. (2008). Over-complete feature generation and feature selection for biometry. *Expert Systems with Applications*. 35(4), 2049-2055.

Marzuki, K.; Rubiyah, Y.; and Hamam,M.;. (2011). Fusion of Multi-Classifiers For online Signature verification using Fuzzy Logic Inference. *International Journal of Innovative Computing, Information and Control (IJICIC),* vol 7.

Meshoul, S., and Batouche, M. (2010). A novel approach for Online signature verification using fisher based probabilistic neural network. *IEEE Symposium on Computers and Communications*. 22-25 June. Riccione, Italy, 314-319.

Monwar, M., and Gavrilova, M. L. (2009). Multimodal Biometric System Using Rank-Level Fusion Approach. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*. 39(4), 867-878.

Muramatsu, D., and Matsumoto, T. (2007). Effectiveness of Pen Pressure, Azimuth, and Altitude Features for Online Signature Verification. In Lee, S.-W. and Li, S. (Eds.), *Advances in Biometrics* (pp. 503-512): Springer Berlin Heidelberg.

Mustaffa, Z., and Yusof, Y. (2010). A Comparison of Normalization Techniques in Predicting Dengue Outbreak. *International Conference on Information and Finance*.

Pan, X., Cao, Y., Xu, X., Lu, Y., and Zhao, Y. (2008). Ear and face based multimodal recognition based on KFDA. *International Conference on Audio, Language and Image Processing*. 7-9 July. Shanghai, 965 -969.

Phillips, P. J., Flynn, P. J., Scruggs, T., Bowyer, K. W., Jin, Chang, Hoffman, K., Marques, J., Jaesik, M., and Worek, W. (2005). Overview of the face recognition grand challenge. *IEEE Computer Society Conference on Computer Vision and Pattern Recognition.* 20-25 June. San Diego, CA, USA, 947 – 954.

Poh, N., Bourlai, T., Kittler, J., Allano, L., Alonso-Fernandez, F., Ambekar, O., Baker, J., Dorizzi, B., Fatukasi, O., Fierrez, J., Ganster, H., Ortega-Garcia, J., Maurer, D., Salah, A.A., Scheidat, T., andVielhauer, C. (2009). Benchmarking Quality-Dependent and Cost-Sensitive Score-Level Multimodal Biometric Fusion Algorithms. *IEEE Transactions on Information Forensics and Security.* 4(4), 849-866.

Priddy, K. L., and Keller, P. E. (2005). *Artificial Neural Networks: An Introduction* (Vol. 1). Washington, USA: SPIE-The International Society for Optical Engineering

Puente, L., Poza, M., Ruiz, B., and García-Crespo, A. (2010). Score Normalization for Multimodal Recognition Systems. *Journal of Information Assurance and Security.* 5, 409-417.

Raghavendra, R., Dorizzi, B., Rao, A., and Hemantha, G. K. (2009). *PSO versus AdaBoost for feature selection in multimodal biometrics.* IEEE 3rd International Conference on Biometrics: Theory, Applications, and Systems. 28-30 Sept. Washington, DC, 1-7.

Raghavendra, R., Dorizzi, B., Rao, A., and Hemantha G. K. (2011). Designing efficient fusion schemes for multimodal biometric systems using face and palmprint. *Pattern Recognition.* 44(5), 1076-1088.

Rattani, A., Kisku, D. R., Bicego, M., and Tistarelli, M. (2006). Robust Feature-Level Multibiometric Classification. Biometrics Symposium: Special Session on Research at the Biometric Consortium Conference. 19 Sept-21 Aug. Baltimore, MD, 1-6.

Rattani, A., Kisku, D.R., Bicego, M., and Tistarelli, M. (2007). Feature Level Fusion of Face and Fingerprint Biometrics. *First IEEE International Conference on Biometrics: Theory, Applications, and Systems.* 27-29 Sept . Crystal City, VA, 1-6.

Rattani, A., and Tistarelli, M. (2009). Robust Multi-modal and Multi-unit Feature Level Fusion of Face and Iris Biometrics. In Tistarelli, M. and Nixon, M.

(Eds.), *Advances in Biometrics* (Vol. 5558, pp. 960-969): Springer Berlin Heidelberg.

Raymer, M. L., Punch, W. F., Goodman, E. D., Kuhn, L. A., and Jain, A. K. (2000). Dimensionality reduction using genetic algorithms. *IEEE Transactions on Evolutionary Computation*. 4(2), 164-171.

Richiardi, J., Hamed, Ketabdar, and Drygajlo, A. (2005). Local and global feature selection for on-line signature verification. *Eighth International Conference on Document Analysis and Recognition*. 29 Aug.-1 Sept. pp. 625 – 629.

Rini, DP., Shamsuddin, Siti Mariyam, and Yuhaniz, Siti Sophiyati. (2011). Particle Swarm Optimization: Technique, System and Challenges. *International Journal of Computer Applications*. 14(1), 19-27.

Ross, A. A., and Govindarajan, R. (2005). Feature level fusion of hand and face biometrics. *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*. pp. 196-204).

Sadeghi, M., Kittler, J., Kostin, A., and Messer, K. (2003). A Comparative Study of Automatic Face Verification Algorithms on the BANCA Database. In J. Kittler and M. Nixon (Eds.), *Audio- and Video-Based Biometric Person Authentication*. (Vol. 2688, pp. 35-43): Springer Berlin Heidelberg.

Samaria, F., and Harter, A. (1994). Parameterisation of a Stochastic Model for Human Face Identification. *Proceedings of 2nd IEEE Workshop on Applications of Computer Vision*.

Schmidt, T., Riffo, V., and Mery, D. (2011). Dynamic Signature Recognition Based on Fisher Discriminant. In San Martin, C., and Kim, S.-W. (Eds.) *Progress in Pattern Recognition, Image Analysis, Computer Vision, and Applications* (Vol. 7042, pp. 433-442): Springer Berlin Heidelberg.

Seungil, H., and Donghun, L.(2010). Linear Discriminant Analysis for Signatures. *IEEE Transactions on Neural Networks*. 21(12), 1990-1996.

Shi-Jinn, H., Yuan-Hsin, C., Run, RS., Rong-Jian, C., Jui-Lin, L., and Sentosal, K. O. (2009). An Improved Score Level Fusion in Multimodal Biometric Systems. *International Conference on Parallel and Distributed Computing, Applications and Technologies*. 8-11 Dec. Higashi Hiroshima, 239-246.

Subbarayudu, V.C., and Prasad, M.V.N.K. (2008). Multimodal Biometric System *First International Conference on Emerging Trends in Engineering and Technology, 2008. ICETET '08.* 635 -640.

Sung, K., and Cho, S. (2005). GA SVM Wrapper Ensemble for Keystroke Dynamics Authentication. In Zhang, D., and Jain, A. (Eds.) *Advances in Biometrics* (Vol. 3832, pp. 654-660): Springer Berlin Heidelberg.

Swiniarski, R.W., and Skowron, A. (2003). Rough set methods in feature selection and recognition. *Pattern Recognition Letters.* 24(6), 833-849.

Teknomo, K. (2006). Discriminant Analysis Tutorial. http://people.revoledu.com/kardi/tutorial/LDA/

Theoharis, T., Passalis, G., Toderici, G., and Kakadiaris, I. A. (2008). Unified 3D face and ear recognition using wavelets on geometry images. *Pattern Recognition.* 41(3), 796 - 804.

Tong, Q., Saddik, A. E., and Adler, A. (2003). Dynamic signature verification system using stroked based features. *The 2nd IEEE Internatioal Workshop on Haptic, Audio and Visual Environments and Their Applications.* 20-21 Sept. pp 83-88.

Turk, M., and Pentland, A. (1991). Eigenfaces for recognition. *J. Cognitive Neuroscience.* 3(1), 71-86.

Varchol, P., Levicky, D., and Juhar, J. (2008). Multimodal biometric authentication using speech and hand geometry fusion. *15th International Conference on Systems, Signals and Image Processing.*25-28 June. Bratislava, 57-60.

Wang, Z. F., Han, Q., Li, Q., Niu, X. M., and Busch, C. (2009). Complex common vector for multimodal biometric recognition. *Electronics Letters.* 45(10), 495-496.

Wang, Z., Han, Q., Niu, X., and Busch, C. (2009). Feature-Level Fusion of Iris and Face for Personal Identification. *6th International Symposium on Neural Networks.* Wuhan, China, 356-364.

Xu, X., and Mu, Z. (2007). Feature Fusion Method Based on KCCA for Ear and Profile Face Based Multimodal Recognition. *IEEE International Conference on Automation and Logistics.* 18-21 Aug. Jinan, 620 -623.

Yan, Y., and Zhang, YJ. (2008). Multimodal biometrics fusion using Correlation Filter Bank. *19th International Conference on Pattern Recognition.* 8-11 Dec. Tampa, FL, 1-4.

Yang, J., Yang, JY, Zhang, D., and Lu, JF. (2003). Feature fusion: parallel strategy vs. serial strategy. *Pattern Recognition.* 36(6), 1369-1381.

Yang, X., Yuan, J., Yuan, J., and Mao, H. (2007). A modified particle swarm optimizer with dynamic adaptation. *Applied Mathematics and Computation.* 189(2), 1205-1213.

Yao, YF., Jing, XY., and Wong, HS. (2007). Face and palmprint feature level fusion for single sample biometrics recognition. *Neurocomputing.* 70(7–9), 1582-1586.

Yeung, DY., Chang, H., Xiong, Y., George, S., Kashi, R., Matsumoto, T., and Gerhard, R. (2004). SVC2004: First International Signature Verification Competition. *Proceedings of the International Conference on Biometric Authentication (ICBA).* 15-17 July. Hong Kong, 16-22.

Yongsheng, G. (2005). Feature-Level Fusion in Personal Identification. *IEEE Computer Society Conference on Computer Vision and Pattern Recognition.* 20-25 June. pp 468-473.

Yu, E., and Cho, S. (2006). Ensemble based on GA wrapper feature selection. *Computers and Industrial Engineering.* 51(1), 111-116.

Zhang, T., Li, X., Tao, D., and Yang, J. (2008). Multimodal biometrics using geometry preserving projections. *Pattern Recognition.* 41(3), 805-813.

Zhao, W., Chellappa, R., Phillips, P. J., and Rosenfeld, A. (2003). Face recognition: A literature survey. *ACM Comput. Surv., 35*(4), 399-458.

Zhou, X., and Bhanu, B. (2008). Feature fusion of side face and gait for video- based human identification. *Pattern Recognition.* 41(3), 778 - 795.

Zhou, H., Wu, J., Wang, Y., Tian, M. (2007). Wrapper approach for feature subset selection using GA. *International Symposium on the Intelligent Signal Processing and Communication Systems.* 28 Nov-1 Dec. Xiamen , 188-191.