MULTI-MODAL ASSOCIATION LEARNING USING SPIKE-TIMING DEPENDENT PLASTICITY (STDP)

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Abstract

We propose an associative learning model that can integrate facial images with speech signals to target a subject in a reinforcement learning (RL) paradigm. Through this approach, the rules of learning will involve associating paired stimuli (stimulus–stimulus, i.e., face–speech), which is also known as *predictor-choice* pairs. Prior to a learning simulation, we extract the features of the biometrics used in the study. For facial features, we experiment by using two approaches: principal component analysis (PCA)-based Eigenfaces and singular value decomposition (SVD). For speech features, we use wavelet packet decomposition (WPD). The experiments show that the PCA-based Eigenfaces feature extraction approach produces better results than SVD. We implement the proposed learning model by using the Spike- Timing-Dependent Plasticity (STDP) algorithm, which depends on the time and rate of pre-post synaptic spikes. The key contribution of our study is the implementation of learning rules via STDP and firing rate in spatiotemporal neural networks based on the Izhikevich spiking model. In our learning, we implement learning for response group association by following the reward-modulated STDP in terms of RL, wherein the firing rate of the response groups determines the reward that will be given. We perform a number of experiments that use existing face samples from the Olivetti Research Laboratory (ORL) dataset, and speech samples from TIDigits. After several experiments and simulations are performed to recognize a subject, the results show that the proposed learning model can associate the predictor (face) with the choice (speech) at optimum performance rates of 77.26% and 82.66% for training and testing, respectively. We also perform learning by using real data, that is, an experiment is conducted on a sample of face–speech data, which have been collected in a manner similar to that of the initial data. The performance results are 79.11% and 77.33% for training and testing, respectively. Based on these results, the proposed learning model can produce high learning performance in terms of combining heterogeneous data (face–speech). This finding opens possibilities to expand RL in the field of biometric authentication.

Keywords: *spiking neural network, feature extraction, spike-timing-dependent plasticity, association learning, reinforcement learning.*

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Table of Contents

Permission to Use i
Abstract ii
Acknowledgement iii
Table of Contents iv
List of Tables vii
List of Figures viii
List of Appendices xi

CHAPTER ONE INTRODUCTION 1
1.1 Introduction 1
1.2 Problem Statement 3
1.3 Research Objectives 5
1.4 Scope of the Study 5
1.5 Significance of the Study 6
1.6 Organization of the Research 7

CHAPTER TWO LITERATURE REVIEW 9
2.1 Introduction 9
2.2 Biometric Technology Overview 9
2.2.1 Face Recognition 11
2.2.2 Speech Recognition 12
2.2.3 Fingerprint Recognition 13
2.2.4 Iris Recognition 13
2.2.5 Hand Geometry Recognition 14
2.2.6 Retina Recognition 14
2.2.7 Signature Recognition 15
2.2.8 Other Biometrics 16
2.3 Biometric Authentication and Classification 19
2.4 Multimodal Biometrics Authentication 23
2.4.1 Multimodal Biometric Systems Based on Fusion Technique 25
2.4.2 Biometric Authentication Based on Neural Networks Approach 29

2.5 Face and Speech Recognition and Features Extraction 31
2.5.1 Face Features Extraction..... 32
2.5.2 Speech Feature Extraction 36
2.5.3 Face and Speech Recognition (Computational Intelligence Approach) ... 39
2.6 Face and Speech Authentication..... 41
2.7 Artificial Neural Networks (ANNs)..... 43
2.8 Spiking Neuron Models..... 47
2.8.1 The Hodgkin-Huxley (HH) Model..... 49
2.8.2 Leaky Integrate-and-Fire (IF) Models..... 49
2.8.3 Izhikevich Spiking Neuron Model (IM)..... 50
2.9 Reinforcement Learning (RL) 52
2.10 Summary..... 58

CHAPTER THREE RESEARCH METHODOLOGY 61

3.1 Research Methodology..... 61
3.2 The Learning and Classification Process 64
3.3 Phase I: Review of the Literatures..... 65
3.4 Phase II: Feature Extraction 65
3.4.1 Face Features Extraction..... 65
3.4.2 Speech Features Extraction..... 78
3.5 Phase III: Spike Encoding 83
3.5.1 The Rules of Synaptic Plasticity 85
3.5.2 Learning Strategy..... 87
3.6 Phase IV: Evaluation..... 89

CHAPTER FOUR IMPLEMENTATION OF STDP AND FINDINGS..... 90

4.1 Introduction 90
4.2 Preliminary Experiment 90
4.2.1 The Simulation Results..... 91
4.2.2 Inter-stimulus Interval 92
4.3 Multimodal Face-Speech Associative Learning..... 94
4.3.1 Feature Extraction 95
4.3.2 Face-Speech Training..... 95

4.3.3 Speech Encoding 97
4.3.4 Implementation of Learning (Face-Speech Features = 100, Number of Response Neurons = 100) 102
4.3.5 The learning Implantation (Number of Response Neurons = 200) 105
4.4 Discussion 109
CHAPTER FIVE LEARNING IN REAL WORLD 111
5.1 Introduction 111
5.2 Data Collection 111
5.3 Face-Speech Feature extraction 112
5.4 Learning Implementation 112
CHAPTER SIX DISCUSSION AND CONCLUSION 116
6.1 Introduction 116
6.2 Conclusion (Objectives Achieved) 116
6.3 Future work 118

List of Tables

Table 2.1: Biometric Comparison 18

Table 2.2: Biometrics Advantages and Disadvantages 18

Table 3.1: TIDigits Speakers' Numbers and Ages 79

Table 3.2: Description of Dialects and Distribution of Speakers 80

Table 4.1: Face-Speech Learning Samples 95

Table 4.2: The Initial Settings of the Association Learning 98

Table 4.3: The Face-Speech Learning Performance 98

Table 4.4: New Settings for the Learning Experiment Parameters 103

Table 4.5: Summary of the Learning Parameters and Performance 109

Table 5.1: Real Dataset for Training and Testing 112

Table 5.2: Simulation Parameters for Real Data Learning 113

List of Figures

Figure 2.1: Types of Biometrics 16

Figure 2.2: Multimodal System Mechanism 24

Figure 2.3: Biometric System Based on Face and Iris 26

Figure 2.4: Score Level Fusion Approach 28

Figure 2.5: Multimodal Biometric System Using ANNs 31

Figure 2.6: Face Recognition Steps 33

Figure 2.7: Speech Recognition System Process 38

Figure 2.8: Face Recognition Based on Three ANN Classifiers 40

Figure 2.9: Thermal Face Recognition 41

Figure 2.10: Buffering Approach Biometric System 42

Figure 2.11: Neurons Network Example 48

Figure 2.12: Izhikevich Spiking Neuron Model 50

Figure 2.13: Associative Learning Experiment 53

Figure 2.14: Markov Decision Processes Representation 54

Figure 2.15: Description of Reinforcement Learning Process 58

Figure 3.1: Design Research Methodology 63

Figure 3.2: Process Flow of the Reinforcement Learning Using STDP for Multimodal Face-Speech Association Learning 64

Figure 3.3: The ORL Face Images Dataset 67

Figure 3.4: Example of Converting 2D Image into 1D Vector. 68

Figure 3.5: Face Image Normalization 69

Figure 3.6: Sample of Eigenfaces for ORL Data Set 72

Figure 3.7: The PCA Features Extraction Steps....73
Figure 3.8: Blocks Generation Process....75
Figure 3.9: SVD Dimensionality Reduction....77
Figure 3.10: Features Extraction Using SVD....77
Figure 3.11: Wavelet Packet Decomposition Tree at Three Levels....78
Figure 3.12: A Part of the Numeric Data for One Speech Sample....82
Figure 3.13: Wavelet Extracted Wave vs. Normal Speech Wave....83
Figure 3.14: Spiking Neural Network (N_E = 80%, N_I= 20%)....84
Figure 3.15: Subpopulations of Neuron Stimulus....85
Figure 3.16: Face-Speech Association Learning Pseudo Code....89
Figure 4.1: : (A) Average Performance when the ISI Is within 10 m to 50 m. (B) The Firing Rate in the Target Response....92
Figure 4.2: The Performance of the Three Recall Correct Rates....94
Figure 4.3: The Learning Performance for the Face-Speech Model....99
Figure 4.4: Spike Raster Plot for the Network Activity after a Number of Trials in One Simulation....101
Figure 4.5: Winner State Details for Four Pairs Based on One Simulation....102
Figure 4.6: Spike Raster Plot for the Learning Simulation with 100 Features and the Number of Response Neurons=100....104
Figure 4.7: Winner State Details Based on the Number of Features= 100, Number of Response Neurons=100....105
Figure 4.8: Spike Raster Plot for the Network Activity with Number of Features=100, Number of Response Neurons=200....106

Figure 4.9: Winner State Sample According to (Number of Features=100, Number of Response Neurons=200). 107
Figure 4.10: Spike Raster Plot for the Network Activity (Number of Response Neurons=250) 108
Figure 4.11: Winner State According for a Simulation with Response Group Neurons = 250 108
Figure 4.12: The Training and Testing Enhancement within Four Experiments 110
Figure 5.1: Spike Raster Plot for the Network Activity during the Simulation of Real Data Experiment. 114
Figure 5.2: Averaged Percentage of Correct Recall with Real Data Experiment 115

List of Appendices

Apendix A: Face and Speech Data File 144

Apendix B: Simulation and Learning 145

CHAPTER ONE

INTRODUCTION

1.1 Introduction

In general, human being depends on five senses to interact with the surrounding environment which are; sight, hearing, touching, smell, and taste. These senses enable the person to capture a huge amount of information to the brain. Then the brain analyzes, classifies, and recognizes this information in a way that is incredibly fast and accurate [1]. It is amazing for the brain to have such great capabilities to comprehend substantial physiological and behavioral biometric traits as well as to process the coming information in terms of human recognition. In computer systems, there are two methods that normally used to perform the authentication which are the traditional systems and the biometric systems.

Traditional person authentication approach can be knowledge-based like the password or PIN code, it also can be token based like an ATM card, credit card, and ID cards. This approach is less reliable and insufficient in terms of security performance [2, 3] because, it is difficult to differentiate between the genuine person and an imposter one. Furthermore, authentication elements like passwords or cards can be borrowed, stolen, and forgotten. That makes this approach suffers from a number of limitations which make it undesirable in terms person authentication [4].

Biometric identification approach is constraining on how to identify the individuals based on their physiological or behavioral characteristics. It based on what the person is, and what the person do. Biometric traits include fingerprint, iris,

The contents of the thesis is for internal user only

References

[1] L. Huang, *Automated Biometrics of Audio-Visual Multiple Modals*: Florida Atlantic University, 2010.

[2] T. B. Long, "Hybrid Multi-Biometric Person Authentication System," in *World Congress on Engineering and Computer Science*, San Francisco, USA, 2012.

[3] S. Sudarvizhi and S. Sumathi, "A Review on Continous Authntication Using Multimodal Biometrics," *International Journal of Emerging Technology and Advanced Engineering*, vol. 3, pp. 192-196, 2013.

[4] D. Bhattacharyya, R. Ranjan, A. Farkhod Alisherov, and M. Choi, "Biometric authentication: A review," *International Journal of u-and e-Service, Science and Technology*, vol. 2, pp. 13-28, 2009.

[5] A. K. Jain and K. Nandakumar, "Biometric Authentication: System Security and User Privacy," *IEEE Computer*, vol. 45, pp. 87-92, 2012.

[6] A. K. Jain and A. Kumar, "Biometrics of next generation: An overview," *Second Generation Biometrics*, 2010.

[7] S. Sahoo and T. Choubisa, "Multimodal Biometric Person Authentication: A Review," *IETE Technical Review*, vol. 29, p. 54, 2012.

[8] J. L. Wayman, "Fundamentals of biometric authentication technologies," *International Journal of Image and Graphics*, vol. 1, pp. 93-113, 2001.

[9] R. N. Rodrigues, L. L. Ling, and V. Govindaraju, "Robustness of multimodal biometric fusion methods against spoof attacks," *Journal of Visual Languages & Computing*, vol. 20, pp. 169-179, 2009.

[10] R. N. Rodrigues, N. Kamat, and V. Govindaraju, "Evaluation of biometric spoofing in a multimodal system," in *Biometrics: Theory Applications and Systems (BTAS), 2010 Fourth IEEE International Conference on*, 2010, pp. 1-5.

[11] Z. Akhtar, G. Fumera, G. L. Marcialis, and F. Roli, "Robustness evaluation of biometric systems under spoof attacks," in *Image Analysis and Processing–ICIAP 2011*, ed: Springer, 2011, pp. 159-168.

[12] Z. Akhtar, S. Kale, and N. Alfarid, "Spoof attacks on multimodal biometric systems," in *Int. Conf. Information and Network Technology*, 2011, pp. 46-51.

[13] R. S. Sutton and A. G. Barto, *Reinforcement learning: An introduction* vol. 1: Cambridge Univ Press, 1998.

[14] R. Bellman, *Adaptive control processes: a guided tour* vol. 4: Princeton university press Princeton, 1961.

[15] P. K. Nayak and D. Narayan, "Multimodal Biometric Face and Fingerprint Recognition Using Neural Network," *International Journal of Engineering*, vol. 1, 2012.

[16] Z. Wang, E. Wang, S. Wang, and Q. Ding, "Multimodal biometric system using face-iris fusion feature," *Journal of Computers*, vol. 6, pp. 931-938, 2011.

[17] H. F. Liau and D. Isa, "Feature selection for support vector machine-based face-iris multimodal biometric system," *Expert Systems with Applications*, vol. 38, pp. 11105-11111, 2011.

[18] Y. G. Kim, K. Y. Shin, E. C. Lee, and K. R. Park, "Multimodal biometric system based on the recognition of face and both irises," *Int J Adv Robotic Sy*, vol. 9, 2012.

[19] A. Darwish, R. A. Elghafar, and A. F. Ali, "Multimodal face and ear images," *Journal of Computer Science*, vol. 5, p. 374, 2009.

[20] Z. Huang, Y. Liu, C. Li, M. Yang, and L. Chen, "A Robust Face and Ear based Multimodal Biometric System using Sparse Representation," *Pattern Recognition*, 2013.

[21] M. Wöllmer, M. Al-Hames, F. Eyben, B. Schuller, and G. Rigoll, "A multidimensional dynamic time warping algorithm for efficient multimodal fusion of asynchronous data streams," *Neurocomputing*, vol. 73, pp. 366-380, 2009.

[22] K. Ahmadian and M. Gavrilova, "Chaotic Neural Network for Biometric Pattern Recognition," *Advances in Artificial Intelligence*, vol. 2012, p. 1, 2012.

[23] R. H. Abiyev and K. Altunkaya, "Neural network based biometric personal identification with fast iris segmentation," *International Journal of Control, Automation and Systems*, vol. 7, pp. 17-23, 2009.

[24] T. Masquelier, R. Guyonneau, and S. J. Thorpe, "Competitive STDP-based spike pattern learning," *Neural computation*, vol. 21, pp. 1259-1276, 2009.

[25] S. G. Wysoski, L. Benuskova, and N. Kasabov, "Evolving spiking neural networks for audiovisual information processing," *Neural Networks*, vol. 23, pp. 819-835, 2010.

[26] P. Gomathi, "A Survey on Biometrics based Key Authentication using Neural Network," *Global Journal of Computer Science and Technology,* vol. 11, 2011.

[27] N. Kasabov, "Evolving spiking neural networks and neurogenetic systems for spatio-and spectro-temporal data modelling and pattern recognition," in *Advances in Computational Intelligence*, ed: Springer, 2012, pp. 234-260.

[28] K. Dhoble, N. Nuntalid, G. Indiveri, and N. Kasabov, "Online spatio-temporal pattern recognition with evolving spiking neural networks utilising address event representation, rank order, and temporal spike learning," in *Neural Networks (IJCNN), The 2012 International Joint Conference on*, 2012, pp. 1-7.

[29] N. Kasabov, K. Dhoble, N. Nuntalid, and G. Indiveri, "Dynamic evolving spiking neural networks for on-line spatio-and spectro-temporal pattern recognition," *Neural Networks*, 2012.

[30] S. Fusi, M. Annunziato, D. Badoni, A. Salamon, and D. J. Amit, "Spike-driven synaptic plasticity: theory, simulation, VLSI implementation," *Neural Computation,* vol. 12, pp. 2227-2258, 2000.

[31] J. M. Brader, W. Senn, and S. Fusi, "Learning real-world stimuli in a neural network with spike-driven synaptic dynamics," *Neural computation,* vol. 19, pp. 2881-2912, 2007.

[32] D. Baras and R. Meir, "Reinforcement learning, spike-time-dependent plasticity, and the BCM rule," *Neural Computation,* vol. 19, pp. 2245-2279, 2007.

[33] B. Glackin, J. A. Wall, T. M. McGinnity, L. P. Maguire, and L. J. McDaid, "A spiking neural network model of the medial superior olive using spike timing dependent plasticity for sound localization," *Frontiers in computational neuroscience*, vol. 4, 2010.

[34] T. Masquelier and S. J. Thorpe, "Learning to recognize objects using waves of spikes and Spike Timing-Dependent Plasticity," in *Neural Networks (IJCNN), The 2010 International Joint Conference on*, 2010, pp. 1-8.

[35] R. G. Leonard and G. R. Doddington. (1984, 21-5-2013). *A Speaker Independant Connected Digit Database*. Available: http://catalog.ldc.upenn.edu/docs/LDC93S10/tidigits.readme.html

[36] R. Newman, *Security and Access Control Using Biometric Technologies*. United States: Course Technology Ptr, 2010.

[37] T. Sabareeswari and S. L. Stuwart, "Identification of a Person Using Multimodal Biometric System," *International Journal of Computer Applications IJCA*, vol. 3, pp. 12-16, 2010.

[38] A. Khairwa, K. Abhishek, S. Prakash, and T. Pratap, "A comprehensive study of various biometric identification techniques," in *Computing Communication & Networking Technologies (ICCCNT), 2012 Third International Conference on*, 2012, pp. 1-6.

[39] I. Marqu´es, "Face Recognition Algorithms," Del Pais Vasco, 2010.

[40] F. Jiao, W. Gao, X. Chen, G. Cui, and S. Shan, "A face recognition method based on local feature analysis," in *Proc. of the 5th Asian Conference on Computer Vision*, 2002, pp. 188-192.

[41] S. Arca, P. Campadelli, and R. Lanzarotti, "A face recognition system based on local feature analysis," in *Audio-and Video-Based Biometric Person Authentication*, 2003, pp. 182-189.

[42] C. Kotropoulos, A. Tefas, and I. Pitas, "Frontal face authentication using morphological elastic graph matching," *Image Processing, IEEE Transactions on*, vol. 9, pp. 555-560, 2000.

[43] M. Agarwal, H. Agrawal, N. Jain, and M. Kumar, "Face recognition using principle component analysis, eigenface and neural network," in *Signal Acquisition and Processing, 2010. ICSAP'10. International Conference on*, 2010, pp. 310-314.

[44] M. Kazi, Y. Rode, S. Dabhade, N. Al-Dawla, A. Mane, R. Manza, *et al.*, "Multimodal Biometric System Using Face and Signature: A Score Level Fusion Approach," *Advances in Computational Research*, vol. 4, 2012.

[45] X. Anguera, "Speaker independent discriminant feature extraction for acoustic pattern-matching," in *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, 2012, pp. 485-488.

[46] R. Terashima, T. Yoshimura, T. Wakita, K. Tokuda, and T. Kitamura, "Prediction method of speech recognition performance based on HMM-based speech synthesis technique," *IEEJ Transactions on Electronics, Information and Systems*, vol. 130, pp. 557-564, 2010.

[47] G. E. Dahl, D. Yu, L. Deng, and A. Acero, "Context-dependent pre-trained deep neural networks for large-vocabulary speech recognition," *Audio,*

Speech, and Language Processing, IEEE Transactions on, vol. 20, pp. 30-42, 2012.

[48] M.-C. Cheung, M.-W. Mak, and S.-Y. Kung, "Intramodal and intermodal fusion for audio-visual biometric authentication," in *Intelligent Multimedia, Video and Speech Processing, 2004. Proceedings of 2004 International Symposium on*, 2004, pp. 25-28.

[49] N. Dahiya and C. Kant, "Biometrics Security Concerns," in *Advanced Computing & Communication Technologies (ACCT), 2012 Second International Conference on*, 2012, pp. 297-302.

[50] S. K. Bandyopadhyay, D. Bhattacharyya, P. Das, D. Ganguly, and S. Mukherjee, "Statistical Approach for Offline Handwritten Signature Verification," *Journal of Computer Science,* vol. 4, pp. 181-185, 2008.

[51] A. Jain, L. Hong, and S. Pankanti, "Biometric identification," *Communications of the ACM*, vol. 43, pp. 90-98, 2000.

[52] J. Adams, D. L. Woodard, G. Dozier, P. Miller, K. Bryant, and G. Glenn, "Genetic-based type II feature extraction for periocular biometric recognition: Less is more," in *Pattern Recognition (ICPR), 2010 20th International Conference on*, 2010, pp. 205-208.

[53] P. Zhang and X. Guo, "A cascade face recognition system using hybrid feature extraction," *Digital Signal Processing,* 2012.

[54] N. Khan, R. Ksantini, I. Ahmad, and B. Boufama, "A novel SVM+ NDA model for classification with an application to face recognition," *Pattern Recognition,* vol. 45, pp. 66-79, 2012.

[55] Y. Wen, L. He, and P. Shi, "Face recognition using difference vector plus KPCA," *Digital Signal Processing,* vol. 22, pp. 140-146, 2012.

[56] W. Gerstner and W. M. Kistler, *Spiking neuron models: Single neurons, populations, plasticity*: Cambridge university press, 2002.

[57] K. Simoens, J. Bringer, H. Chabanne, and S. Seys, "A Framework for Analyzing Template Security and Privacy in Biometric Authentication Systems," *Information Forensics and Security, IEEE Transactions on,* vol. 7, pp. 833-841, 2012.

[58] S. M. S. Ahmad, B. M. Ali, and W. A. W. Adnan, "Technical Issues and Challenges of Biometric Applications as Access Control Tools of Information Ssecurity," *International Journal of Innovative,* vol. 8, pp. 7983-7999, 2012.

[59] B. Chen and V. Chandran, "Biometric template security using higher order spectra," in *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on*, 2010, pp. 1730-1733.

[60] S. Chindaro, F. Deravi, Z. Zhou, M. Ng, M. C. Neves, X. Zhou, *et al.*, "A multibiometric face recognition fusion framework with template protection," in *SPIE Defense, Security, and Sensing*, 2010, pp. 76670U-76670U-6.

[61] Z. Akhtar, "Security of Multimodal Biometric Systems against Spoof Attacks," PhD thesis, University of Cagliari, Italy, 2012.

[62] L. Wang, "Some issues of biometrics: technology intelligence, progress and challenges," *International Journal of Information Technology and Management,* vol. 11, pp. 72-82, 2012.

[63] M. Soltane, N. Doghmane, and N. Guersi, "Face and Speech Based Multi-modal Biometric Authentication," *International Journal of Advanced Science and Technology*, vol. 21, pp. 41-56, 2010.

[64] M. R. Manju, M. A. Rajendrana, and A. S. Nargunab, "Performance Analysis of Multimodal Biometric Based Authentication System," *International Journal of Engineering*, vol. 1, 2012.

[65] R. Raghavendra, B. Dorizzi, A. Rao, and G. Hemantha Kumar, "Designing efficient fusion schemes for multimodal biometric systems using face and palmprint," *Pattern Recognition*, vol. 44, pp. 1076-1088, 2011.

[66] Y. Tong, F. W. Wheeler, and X. Liu, "Improving biometric identification through quality-based face and fingerprint biometric fusion," in *Computer Vision and Pattern Recognition Workshops (CVPRW), 2010 IEEE Computer Society Conference on*, 2010, pp. 53-60.

[67] X. Jing, S. Li, Y. Yao, W. Li, F. Wu, and C. Lan, "Multi-Modal Biometric Feature Extraction and Recognition Based on Subclass Discriminant Analysis (SDA) and Generalized Singular Value Decomposition (GSVD)," in *Hand-Based Biometrics (ICHB), 2011 International Conference on*, 2011, pp. 1-6.

[68] Y. Elmir, S. Al-Maadeed, A. Amira, and A. Hassaïne, "A Multi-modal Face and Signature Biometric Authentication System Using A Max-of-scores Based Fusion," in *Neural Information Processing*, 2012, pp. 576-583.

[69] Z. Akhtar, G. Fumera, G. L. Marcialis, and F. Roli, "Evaluation of Multimodal Biometric Score Fusion Rules Under Spoof Attacks," in

Biometrics (ICB), 2012 5th IAPR International Conference on, 2012, pp. 402-407.

[70] M. Al-Hames and G. Rigoll, "Reduced complexity and scaling for asynchronous HMMs in a bimodal input fusion application," in *Acoustics, Speech and Signal Processing, 2006. ICASSP 2006 Proceedings. 2006 IEEE International Conference on*, 2006, pp. V-V.

[71] H. Ebied, "Feature extraction using PCA and Kernel-PCA for face recognition," in *Informatics and Systems (INFOS), 2012 8th International Conference on*, 2012, pp. MM-72-MM-77.

[72] K. P. Chandar, M. M. Chandra, M. R. Kumar, and B. S. Latha, "Multi scale feature extraction and enhancement using SVD towards secure Face Recognition system," in *Signal Processing, Communication, Computing and Networking Technologies (ICSCCN), 2011 International Conference on*, 2011, pp. 64-69.

[73] B. Gupta, S. Gupta, and A. K. Tiwari, "Face Detection Using Gabor Feature Extraction and Artificial Neural Network," *ABES Engineering College, Ghaziaba*, 2010.

[74] M. A. Hossan, S. Memon, and M. A. Gregory, "A novel approach for MFCC feature extraction," in *Signal Processing and Communication Systems (ICSPCS), 2010 4th International Conference on*, 2010, pp. 1-5.

[75] R. Sarikaya, B. L. Pellom, and J. H. Hansen, "Wavelet packet transform features with application to speaker identification," in *IEEE Nordic Signal Processing Symposium*, 1998, pp. 81-84.

[76] S. Malik and F. A. Afsar, "Wavelet transform based automatic speaker recognition," in *Multitopic Conference, 2009. INMIC 2009. IEEE 13th International*, 2009, pp. 1-4.

[77] P. Wallisch, M. Lusignan, M. Benayoun, T. I. Baker, A. S. Dickey, and N. Hatsopoulos, *MATLAB for Neuroscientists: an Introduction to Scientific Computing in MATLAB*: Elsevier, 2009.

[78] P. Xanthopoulos, P. M. Pardalos, and T. B. Trafalis, "Principal Component Analysis," in *Robust Data Mining*, ed: Springer, 2013, pp. 21-26.

[79] C. Juanjuan, Z. Zheng, S. Han, and Z. Gang, "Facial expression recognition based on PCA reconstruction," in *Computer Science and Education (ICCSE), 2010 5th International Conference on*, 2010, pp. 195-198.

[80] B. Bozorgtabar, F. Noorian, and G. A. R. Rad, "Comparison of different PCA based Face Recognition algorithms using Genetic Programming," in *Telecommunications (IST), 2010 5th International Symposium on*, 2010, pp. 801-805.

[81] Y. Luo, C.-m. Wu, and Y. Zhang, "Facial expression recognition based on fusion feature of PCA and LBP with SVM," *Optik-International Journal for Light and Electron Optics*, 2012.

[82] J. Keche and M. Dhore, "Comparative Study of Feature Extraction Techniques for Face Recognition System," *International Journal*, 2012.

[83] Z. Liang and P. Shi, "Kernel direct discriminant analysis and its theoretical foundation," *Pattern Recognition*, vol. 38, pp. 445-447, 2005.

[84] Y. Wen and P. Shi, "An approach to numeral recognition based on improved LDA and Bhattacharyya distance," in *Communications, Control and Signal Processing, 2008. ISCCSP 2008. 3rd International Symposium on*, 2008, pp. 309-311.

[85] Y. Wen, Y. Lu, J. Yan, Z. Zhou, K. M. von Deneen, and P. Shi, "An algorithm for license plate recognition applied to intelligent transportation system," *Intelligent Transportation Systems, IEEE Transactions on,* vol. 12, pp. 830-845, 2011.

[86] V. Vidya, N. Farheen, K. Manikantan, and S. Ramachandran, "Face Recognition using Threshold Based DWT Feature Extraction and Selective Illumination Enhancement Technique," *Procedia Technology,* vol. 6, pp. 334-343, 2012.

[87] V. Vezhnevets, V. Sazonov, and A. Andreeva, "A survey on pixel-based skin color detection techniques," in *Proc. Graphicon,* 2003, pp. 85-92.

[88] S. K. Singh, D. Chauhan, M. Vatsa, and R. Singh, "A robust skin color based face detection algorithm," *Tamkang Journal of Science and Engineering,* vol. 6, pp. 227-234, 2003.

[89] B. G. Bhatt and Z. H. Shah, "Face feature extraction techniques: a survey," in *National conference on recent trends in engineering & technology*, 2011, pp. 13-14.

[90] Z.-Q. Hong, "Algebraic feature extraction of image for recognition," *Pattern recognition,* vol. 24, pp. 211-219, 1991.

[91] H. Miar-Naimi and P. Davari, "A New Fast and Efficient HMM-Based Face Recognition System Using a 7-State HMM Along With SVD Coefficients," *Iranian Journal of Electrical And Electronic Engineering,* vol. 4, pp. 46-57, 2008.

[92] A. P. Gosavi and S. Khot, "Facial Expression Recognition using Principal Component Analysis with Singular Value Decomposition," *International Journal of Advance Research in Computer Science and Management Studies,* vol. 1, 2013.

[93] R. W. Swiniarski and A. Skowron, "Rough set methods in feature selection and recognition," *Pattern recognition letters,* vol. 24, pp. 833-849, 2003.

[94] H. Demirel, C. Ozcinar, and G. Anbarjafari, "Satellite image contrast enhancement using discrete wavelet transform and singular value decomposition," *Geoscience and Remote Sensing Letters, IEEE,* vol. 7, pp. 333-337, 2010.

[95] H. Demirel, G. Anbarjafari, and M. N. S. Jahromi, "Image equalization based on singular value decomposition," in *Computer and Information Sciences, 2008. ISCIS'08. 23rd International Symposium on*, 2008, pp. 1-5.

[96] J. Baker, L. Deng, J. Glass, S. Khudanpur, C.-H. Lee, N. Morgan, *et al.*, "Developments and directions in speech recognition and understanding," *Signal Processing Magazine, IEEE,* vol. 26, pp. 75-80, 2009.

[97] P. K. Cherupalli and J. S. K. Gari, "A Wavelet based Feature Extraction for Voice-Lock systems," in *TENCON 2005 2005 IEEE Region 10,* 2005, pp. 1-4.

[98] L. Muda, M. Begam, and I. Elamvazuthi, "Voice recognition algorithms using mel frequency cepstral coefficient (mfcc) and dynamic time warping (dtw) techniques," *arXiv preprint arXiv:1003.4083,* 2010.

[99] M. J. Alam, T. Kinnunen, P. Kenny, P. Ouellet, and D. O'Shaughnessy, "Multi-taper MFCC features for speaker verification using I-vectors," in *Automatic Speech Recognition and Understanding (ASRU), 2011 IEEE Workshop on*, 2011, pp. 547-552.

[100] S.-Y. Lung, "Feature extracted from wavelet decomposition using biorthogonal Riesz basis for text-independent speaker recognition," *Pattern Recognition,* vol. 41, pp. 3068-3070, 2008.

[101] T. Kinnunen, "Spectral features for automatic text-independent speaker recognition," *Licentiate's Thesis,* 2003.

[102] Z. Tufekci and J. Gowdy, "Feature extraction using discrete wavelet transform for speech recognition," in *Southeastcon 2000. Proceedings of the IEEE*, 2000, pp. 116-123.

[103] R. N. Khushaba, A. Al-Jumaily, and A. Al-Ani, "Novel feature extraction method based on fuzzy entropy and wavelet packet transform for myoelectric Control," in *Communications and Information Technologies, 2007. ISCIT '07. International Symposium on*, 2007, pp. 352-357.

[104] N. S. Nehe and R. S. Holambe, "New feature extraction methods using DWT and LPC for isolated word recognition," in *TENCON 2008 - 2008 IEEE Region 10 Conference*, 2008, pp. 1-6.

[105] J.-D. Wu and B.-F. Lin, "Speaker identification using discrete wavelet packet transform technique with irregular decomposition," *Expert Systems with Applications,* vol. 36, pp. 3136-3143, 3// 2009.

[106] M. Anusuya and S. Katti, "Comparison of different speech feature extraction techniques with and without wavelet transform to Kannada speech recognition," *International Journal of Computer Applications,* vol. 26, pp. 19-24, 2011.

[107] B. S. Anami, V. B. Pagi, and S. M. Magi, "Wavelet-based acoustic analysis for determining health condition of motorized two-wheelers," *Applied Acoustics,* vol. 72, pp. 464-469, 6// 2011.

[108] R. N. Khushaba, S. Kodagoda, S. Lal, and G. Dissanayake, "Driver Drowsiness Classification Using Fuzzy Wavelet-Packet-Based Feature-Extraction Algorithm," *Biomedical Engineering, IEEE Transactions on,* vol. 58, pp. 121-131, 2011.

[109] A. Seal, S. Gangulyb, D. Bhattacharjee, M. Nasipuri, and D. K. Basu, "Minutiae Based Thermal Human Face Recognition using Label Connected Component Algorithm," *Procedia Technology,* vol. 4, pp. 604-611, 2012.

[110] M. Mansoorizadeh and N. M. Charkari, "Multimodal Information Fusion Application to Human Emotion Recognition From Face and Speech," *Multimedia Tools and Applications,* vol. 49, pp. 277-297, 2010.

[111] S. K. Sahoo and S. M. Prasanna, "Bimodal biometric person authentication using speech and face under degraded condition," in *Communications (NCC), 2011 National Conference on,* 2011, pp. 1-5.

[112] Z. Ciota and M. Gawinowski, "Multilayer neural networks in handwritten recognition," in *Modern Problems of Radio Engineering, Telecommunications and Computer Science, 2004. Proceedings of the International Conference*, 2004, pp. 192-194.

[113] F. Siraj, N. Yusoff, and L. C. Kee, "Emotion classification using neural network," in *Computing & Informatics, 2006. ICOCI'06. International Conference on*, 2006, pp. 1-7.

[114] M. S. B. H. Salam, D. Mohamad, and S. H. S. Salleh, "Malay isolated speech recognition using neural network: a work in finding number of hidden nodes and learning parameters," *Int. Arab J. Inf. Technol.*, vol. 8, pp. 364-371, 2011.

[115] N. Yusoff and A. Grüning, "Learning anticipation through priming in spatio-temporal neural networks," in *Neural Information Processing*, 2012, pp. 168-175.

[116] B. DasGupta and G. Schnitger, "The power of approximating: a comparison of activation functions," *Mathmaticl Research*, vol. 79, pp. 641-641, 1994.

[117] J. Vreeken, "Spiking neural networks, an introduction," *Technical Report UU-CS*, pp. 1-5, 2003.

[118] D. E. Rumelhart, G. E. Hintont, and R. J. Williams, "Learning representations by back-propagating errors," *Nature*, vol. 323, pp. 533-536, 1986.

[119] T. Kohonen, "Self-organized formation of topologically correct feature maps," *Biological cybernetics*, vol. 43, pp. 59-69, 1982.

[120] B. d. B. Pereira, C. R. Rao, R. L. Oliveira, and E. M. do Nascimento, "Combining unsupervised and supervised neural networks in cluster analysis of gamma-ray burst," *Journal of Data Science*, vol. 8, pp. 327-338, 2010.

[121] G. B. Kaplan, N. Şengör, H. Gürvit, and C. Güzeliş, "Modelling the Stroop effect: A connectionist approach," *Neurocomputing*, vol. 70, pp. 1414-1423, 2007.

[122] S. G. Wysoski, L. Benuskova, and N. Kasabov, "Adaptive learning procedure for a network of spiking neurons and visual pattern recognition," in *Advanced Concepts for Intelligent Vision Systems*, 2006, pp. 1133-1142.

[123] N. K. Kasabov and N. Kasabov, *Evolving connectionist systems: the knowledge engineering approach*: Springer, 2007.

[124] N. Kasabov, "To spike or not to spike: A probabilistic spiking neuron model," *Neural Networks*, vol. 23, pp. 16-19, 2010.

[125] S. Schliebs and N. Kasabov, "Evolving spiking neural network—a survey," *Springer-Verlag*, 2013.

[126] E. M. Izhikevich, "Polychronization: computation with spikes," *Neural computation*, vol. 18, pp. 245-282, 2006.

[127] H. Paugam-Moisy, R. Martinez, and S. Bengio, "Delay learning and polychronization for reservoir computing," *Neurocomputing*, vol. 71, pp. 1143-1158, 2008.

[128] T. Grabowski and G. J. Tortora, *Principles of anatomy and physiology*: John Wiley & Sons, 2003.

[129] E. M. Izhikevich and J. Moehlis, "Dynamical Systems in Neuroscience: The geometry of excitability and bursting," *SIAM review*, vol. 50, p. 397, 2008.

[130] E. M. Izhikevich, "Which model to use for cortical spiking neurons?," *Neural Networks, IEEE Transactions on*, vol. 15, pp. 1063-1070, 2004.

[131] E. M. Izhikevich, "Simple model of spiking neurons," *Neural Networks, IEEE Transactions on*, vol. 14, pp. 1569-1572, 2003.

[132] C. A. Erickson and R. Desimone, "Responses of macaque perirhinal neurons during and after visual stimulus association learning," *The Journal of neuroscience*, vol. 19, pp. 10404-10416, 1999.

[133] L. P. Kaelbling, M. L. Littman, and A. W. Moore, "Reinforcement learning: A survey," *arXiv preprint cs/9605103*, 1996.

[134] M. A. Wiering, H. van Hasselt, A. D. Pietersma, and L. Schomaker, "Reinforcement learning algorithms for solving classification problems," in *Adaptive Dynamic Programming And Reinforcement Learning (ADPRL), 2011 IEEE Symposium on*, 2011, pp. 91-96.

[135] L. P. Kaelbling, M. L. Littman, and A. R. Cassandra, "Planning and acting in partially observable stochastic domains," *Artificial intelligence*, vol. 101, pp. 99-134, 1998.

[136] Y. Engel, "Algorithms and representations for reinforcement learning," Citeseer, 2005.

[137] J. Boger, J. Hoey, P. Poupart, C. Boutilier, G. Fernie, and A. Mihailidis, "A planning system based on Markov decision processes to guide people with

dementia through activities of daily living," *Information Technology in Biomedicine, IEEE Transactions on,* vol. 10, pp. 323-333, 2006.

[138] M. G. Lagoudakis and R. Parr, "Reinforcement learning as classification: Leveraging modern classifiers," in *ICML*, 2003, pp. 424-431.

[139] C. J. Watkins and P. Dayan, "Q-learning," *Machine learning,* vol. 8, pp. 279-292, 1992.

[140] S. Singh, T. Jaakkola, M. L. Littman, and C. Szepesvári, "Convergence results for single-step on-policy reinforcement-learning algorithms," *Machine Learning,* vol. 38, pp. 287-308, 2000.

[141] V. R. Konda and V. S. Borkar, "Actor-Critic--Type Learning Algorithms for Markov Decision Processes," *SIAM Journal on control and Optimization,* vol. 38, pp. 94-123, 1999.

[142] M. Pantic, A. Pentland, A. Nijholt, and T. S. Huang, "Human computing and machine understanding of human behavior: A survey," in *Artifical Intelligence for Human Computing*, ed: Springer, 2007, pp. 47-71.

[143] Z. Zeng, Y. Hu, Y. Fu, T. S. Huang, G. I. Roisman, and Z. Wen, "Audio-visual emotion recognition in adult attachment interview," in *Proceedings of the 8th international conference on Multimodal interfaces,* 2006, pp. 139-145.

[144] L. Wang, W. Hu, and T. Tan, "Recent developments in human motion analysis," *Pattern Recognition,* vol. 36, pp. 585-601, 2003.

[145] Q. Yu, Y. Yin, G. Yang, Y. Ning, and Y. Li, "Face and Gait Recognition Based on Semi-supervised Learning," in *Pattern Recognition*, ed: Springer, 2012, pp. 284-291.

[146] F. Roli, L. Didaci, and G. L. Marcialis, "Adaptive biometric systems that can improve with use," in *Advances in Biometrics*, ed: Springer, 2008, pp. 447-471.

[147] C. Shan, "Learning local binary patterns for gender classification on real-world face images," *Pattern Recognition Letters*, vol. 33, pp. 431-437, 2012.

[148] Z. Feng, M. Yang, L. Zhang, Y. Liu, and D. Zhang, "Joint discriminative dimensionality reduction and dictionary learning for face recognition," *Pattern Recognition*, 2013.

[149] N. Caporale and Y. Dan, "Spike timing-dependent plasticity: a Hebbian learning rule," *Annu. Rev. Neurosci.*, vol. 31, pp. 25-46, 2008.

[150] J. Hu and M. P. Wellman, "Multiagent reinforcement learning: theoretical framework and an algorithm," in *ICML*, 1998, pp. 242-250.

[151] P. Dayan, L. F. Abbott, and L. Abbott, "Theoretical neuroscience: Computational and mathematical modeling of neural systems," 2001.

[152] R. V. Florian, "Reinforcement learning through modulation of spike-timing-dependent synaptic plasticity," *Neural Computation*, vol. 19, pp. 1468-1502, 2007.

[153] C. U. C. Laboratory. (2002, 22 June 2013). *The Database of Faces*. Available: http://www.cl.cam.ac.uk/research/dtg/attarchive/

[154] A. Harter, A. Hopper, P. Steggles, A. Ward, and P. Webster, "The anatomy of a context-aware application," *Wireless Networks,* vol. 8, pp. 187-197, 2002.

[155] V. Maheshkar, S. Kamble, and S. Agarwal, "DCT-based unique faces for face recognition using Mahalanobis distance," in *Proceedings of the First International Conference on Intelligent Interactive Technologies and Multimedia*, 2010, pp. 208-212.

[156] E. Gumus, N. Kilic, A. Sertbas, and O. N. Ucan, "Evaluation of face recognition techniques using PCA, wavelets and SVM," *Expert Systems with Applications,* vol. 37, pp. 6404-6408, 2010.

[157] V. Maheshkar, S. Kamble, S. Agarwal, and V. Kumar, "Feature Image Generation Using Low, Mid and High Frequency Regions for Face Recognition," *The International Journal of Multimedia & Its Applications,* vol. 4, 2012.

[158] M. S. El-Bashir, "Face Recognition Using Multi-Classifier," *Applied Mathematical Sciences,* vol. 6, pp. 2235-2244, 2012.

[159] M. R. Faraji and X. Qi, "An effective neutrosophic set-based preprocessing method for face recognition," in *Multimedia and Expo Workshops (ICMEW), 2013 IEEE International Conference on*, 2013, pp. 1-4.

[160] M. Turk and A. Pentland, "Eigenfaces for recognition," *Journal of cognitive neuroscience,* vol. 3, pp. 71-86, 1991.

[161] P. Shemi and M. Ali, "A Principal Component Analysis Method for Recognition of Human Faces: Eigenfaces Approach," *International Journal*

of Electronics Communication and Computer Technology (IJECCT), vol. 2, 2012.

[162] P. N. Belhumeur, J. P. Hespanha, and D. J. Kriegman, "Eigenfaces vs. fisherfaces: Recognition using class specific linear projection," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 19, pp. 711-720, 1997.

[163] D. Pissarenko. (2002, 4 September 2013). *Eigenface-based Facial Recognition*. Available: http://openbio.sourceforge.net/resources/eigenfaces/eigenfaces.pdf

[164] J. Wang, K. N. Plataniotis, and A. N. Venetsanopoulos, "Selecting discriminant eigenfaces for face recognition," *Pattern Recognition Letters*, vol. 26, pp. 1470-1482, 2005.

[165] J. Wang, K. N. Plataniotis, and A. Venetsanopolous, "Selecting kernel eigenfaces for face recognition with one training sample per subject," in *Multimedia and Expo, 2006 IEEE International Conference on*, 2006, pp. 1637-1640.

[166] A. Yu, C. Elder, J. Yeh, and N. Pai. (2009, 17 September 2013). *Facial Recognition Using Eigenfaces: Obtainig Eigenfaces*. Available: http://cnx.org/content/m33173/1.3/

[167] V. Akalin, "Face Recognition Using Eigenfaces and Neural Networks," Master, Electrical and Electronics Engineering, Middle East Tchnical University, 2003.

[168] O. Sakhi. (2012, 13 August). *Face Recognition Guide Using Hidden Markov Models and Singular Value Decomposition (First ed.)*. Available: http://www.facerecognitioncode.com/

[169] J. Yang, K. Yu, Y. Gong, and T. Huang, "Linear spatial pyramid matching using sparse coding for image classification," in *Computer Vision and Pattern Recognition, 2009. CVPR 2009. IEEE Conference on*, 2009, pp. 1794-1801.

[170] Y.-L. Boureau, F. Bach, Y. LeCun, and J. Ponce, "Learning mid-level features for recognition," in *Computer Vision and Pattern Recognition (CVPR), 2010 IEEE Conference on*, 2010, pp. 2559-2566.

[171] A. Coates and A. Ng, "The importance of encoding versus training with sparse coding and vector quantization," in *Proceedings of the 28th International Conference on Machine Learning (ICML-11)*, 2011, pp. 921-928.

[172] A. Jayakumar and P. Babu Anto, "Comparison of wavelet packets and DWT in a gender based multichannel speaker recognition system," in *Information & Communication Technologies (ICT), 2013 IEEE Conference on*, 2013, pp. 847-850.

[173] MathWorks. (2001, 5 October 2013). *Wavelet Packets*. Available: http://www.mathworks.com/help/wavelet/ug/wavelet-packets.html?searchHighlight=Wavelet+Packets

[174] R. Leonard, "A database for speaker-independent digit recognition," in *Acoustics, Speech, and Signal Processing, IEEE International Conference on ICASSP '84.*, 1984, pp. 328-331.

[175] J. Cardenas, E. Castillo, and J. Meng, "Noise-robust speech recognition system based on power spectral subtraction with a geometric approach," *Acoustics 2012 Nantes,* 2012.

[176] H.-G. Hirsch, S. Ganapathy, and H. Hermansky, "Comparison of Different Approaches for Speech Recognition in Hands-free Mode," in *Speech Communication; 10. ITG Symposium; Proceedings of*, 2012, pp. 1-4.

[177] Y. Naya, M. Yoshida, and Y. Miyashita, "Forward processing of long-term associative memory in monkey inferotemporal cortex," *The Journal of neuroscience*, vol. 23, pp. 2861-2871, 2003.

[178] S. Dhawan, "A review of image compression and comparison of its algorithms," *International Journal of electronics & Communication technology,* vol. 2, 2011.

[179] M.-H. Horng, "Vector quantization using the firefly algorithm for image compression," *Expert Systems with Applications,* vol. 39, pp. 1078-1091, 1// 2012.