# Table of Contents

List of Figures ........................................... v  
List of Tables ............................................. vii  

1 Introduction ............................................. 1  
1.1 Preamble .............................................. 1  
1.2 Face Recognition ...................................... 2  
1.2.1 What is Face Recognition? ......................... 2  
1.2.2 Face as a Biometric Trait ......................... 5  
1.2.3 Applications ..................................... 6  
1.2.4 Challenges .................................... 8  
1.3 Literature Survey ..................................... 10  
1.3.1 Model-Based Schemes ............................. 10  
1.3.2 Appearance-Based Schemes ....................... 11  
1.4 Motivation .......................................... 15  
1.5 Highlights of This Thesis ............................ 16  
1.6 Organization of This Thesis ......................... 17  

2 Tools and Techniques ................................. 19  
2.1 Notations and Abbreviations ......................... 19  
2.2 Subspace Methods ................................... 21  
2.2.1 What is a Subspace? ............................. 21  
2.2.2 Principal Component Analysis (PCA) .......... 22  
2.2.3 Linear Discriminant Analysis (LDA) .......... 22  
2.2.4 The Locality Preserving Projections (LPP) ..... 23  
2.3 Transform Domains .................................. 24  
2.3.1 Frequency Domain ............................... 24  
2.3.2 Combined Time-Frequency Domain ............ 26  
2.4 Orthogonalization Techniques ..................... 27  
2.4.1 Gram-Schmidt Decomposition ................. 29  
2.4.2 Singular Value Decomposition (SVD) ........ 29  
2.4.3 QR Factorization ................................ 30  
2.5 Summary ............................................. 30  

3 Spatial Domain Methods and Analysis .......... 31  
3.1 Overview .......................................... 31  
3.2 Methods Based on FLD Analysis .................... 32  
3.2.1 Divide-and-Conquer Strategy Based FLD Algorithm: dcFLD 32  
3.2.2 Reformulated, Alternative and Generalized Versions of 2DLDA 38  
3.2.3 $2D^2LDA$: A Generalized 2DLDA Algorithm .......... 40  
3.2.4 The Diagonal FLD Method: DiaFLD ............. 43  
3.2.5 A Combined Method: DiaFLD+2DFLD ............ 46  
3.3 Orthogonalized Versions of FLD Algorithms .... 48
3.3.1 Foley-Sammon Discriminant Transform .......................... 48
3.3.2 Orthogonalized Fisher Discriminant Vectors ................. 49

3.4 Methods Based on Gaussian Mixture Models ....................... 51
3.4.1 PCA Mixture Model ........................................ 51
3.4.2 LPP Mixture Model ....................................... 53

3.5 Experimental Results and Comparative Study ....................... 54
3.5.1 Experiment-1: Variation in Pose Angle and Training Samples 55
3.5.2 Experiment-2: Variation in Facial Expression and Lighting Configuration ........................................ 57
3.5.3 Experiment-3: Variation With Respect To Time .............. 58
3.5.4 Experiment-4: Effect of Occlusion .......................... 59
3.5.5 Experiment-5: Performance Under Noise Conditions ......... 61
3.5.6 Experiment-6: Effect of Orthogonalization ................. 62
3.5.7 Experiment-7: Different Approaches to Orthogonalization 64

3.6 Summary ..................................................... 65

4 Frequency Domain Methods and Analysis .......................... 67
4.1 Overview ..................................................... 67
4.2 Background Work ............................................. 68
4.3 Proposed Methods ............................................ 69
4.3.1 PCA Mixture Model using DCT Coefficients: DCT+GMM+PCA ........................................ 69
4.3.2 LPP Mixture Model using DCT Coefficients: DCT+GMM+LPP ........................................ 71
4.3.3 The Classification Scheme ................................ 73

4.4 Experimental Results and Comparative Study ....................... 74
4.4.1 Experiment-1: Variation in Pose Angle and Training Samples ........................................ 75
4.4.2 Experiment-2: Variation in Facial Expression and Lighting Configuration ........................................ 77
4.4.3 Experiment-3: Single Sample Per Person Test Condition 78
4.4.4 Experiment-4: Performance Under Noise Conditions ......... 79

4.5 Summary ..................................................... 80

5 Combined Time-Frequency Domain Methods and Analysis .......... 84
5.1 Overview ..................................................... 84
5.2 Subjective Nature of Wavelet Basis ................................ 85
5.3 Proposed Methods ............................................ 86
5.3.1 PCA Mixture Models with Wavelet Coefficients: Wavelet+GMM+PCA ........................................ 87
5.3.2 LPP Mixture Models with Wavelet Coefficients: Wavelet+GMM+LPP ........................................ 89

5.4 Experimental Results and Comparative Study ....................... 91
5.4.1 Experiment-1: Variation in Pose Angle and Training Samples 91