

# Contents

<b>1</b>	<b>INTRODUCTION</b>	1
1.1	Person Recognition	2
1.2	Biometric Systems	3
1.2.1	Enrollment and recognition phases	4
1.2.2	Sensor module	4
1.2.3	Feature extraction module	6
1.2.4	Database module	9
1.2.5	Matching module	9
1.3	Biometric Functionalities	10
1.3.1	Verification	10
1.3.2	Identification	11
1.4	Biometric System Errors	13
1.4.1	Performance measures	17
1.5	The Design Cycle of Biometric Systems	27
1.5.1	Nature of the application	28
1.5.2	Choice of biometric trait	29
1.5.3	Data collection	36
1.5.4	Choice of features and matching algorithm	36
1.5.5	Evaluation	37
1.6	Applications of Biometric Systems	39
1.7	Security and Privacy Issues	41
1.8	Summary	44
	Bibliographical and Historical Remarks	45
	References	47
<b>2</b>	<b>FINGERPRINT RECOGNITION</b>	51
2.1	Introduction	51
2.2	Friction Ridge Pattern	54
2.2.1	Features	54
2.2.2	Formation	59
2.3	Fingerprint Acquisition	60

2.3.1	Sensing techniques .....	60
2.3.2	Image quality .....	62
2.4	Feature Extraction .....	64
2.4.1	Ridge orientation and frequency estimation .....	64
2.4.2	Singularity extraction .....	67
2.4.3	Ridge extraction .....	70
2.4.4	Minutiae extraction .....	71
2.5	Matching .....	72
2.5.1	Alignment .....	74
2.5.2	Pairing minutiae .....	76
2.5.3	Match score generation .....	77
2.5.4	Latent fingerprint matching .....	78
2.5.5	Fingerprint individuality .....	80
2.5.6	Performance evaluation .....	80
2.6	Fingerprint Indexing .....	81
2.7	Fingerprint Synthesis .....	84
2.7.1	Level 1 feature synthesis .....	84
2.7.2	Level 2 feature synthesis .....	85
2.8	Palmpoint .....	85
2.8.1	Palmpoint features .....	87
2.8.2	Palmpoint recognition in forensics .....	88
2.8.3	Palmpoint recognition for access control .....	90
2.9	Summary .....	91
	Bibliographical and Historical Remarks .....	92
	References .....	94
<b>3</b>	<b>Face Recognition .....</b>	<b>97</b>
3.1	Introduction .....	97
3.1.1	Psychology of face recognition .....	98
3.1.2	Facial features .....	100
3.1.3	Design of a face recognition system .....	103
3.2	Image Acquisition .....	104
3.2.1	2D Sensors .....	105
3.2.2	3D Sensors .....	106
3.2.3	Video sequences .....	107
3.3	Face Detection .....	109
3.3.1	Viola-Jones face detector .....	111
3.4	Feature Extraction and Matching .....	116
3.4.1	Appearance-based face recognition .....	118
3.4.2	Model-based face recognition .....	122
3.4.3	Texture-based face recognition .....	124
3.4.4	Performance evaluation .....	127
3.5	Advanced Topics .....	129
3.5.1	Handling pose, illumination, and expression variations .....	129
3.5.2	Heterogeneous face recognition .....	130

3.5.3	Face modeling . . . . .	132
3.6	Summary . . . . .	137
	Bibliographical and Historical Remarks . . . . .	137
	References . . . . .	138
<b>4</b>	<b>Iris Recognition . . . . .</b>	<b>141</b>
4.1	Introduction . . . . .	141
4.2	Design of an Iris Recognition System . . . . .	144
4.3	Image Acquisition . . . . .	146
4.4	Iris Segmentation . . . . .	151
4.4.1	Segmentation using the integro-differential operator . . . . .	152
4.4.2	Segmentation using Geodesic Active Contours (GAC) . . . . .	153
4.4.3	Generating iris masks . . . . .	159
4.5	Iris Normalization . . . . .	159
4.6	Iris Encoding and Matching . . . . .	161
4.7	Iris Quality . . . . .	164
4.7.1	Quality assessment techniques . . . . .	164
4.8	Performance Evaluation . . . . .	169
4.9	Summary . . . . .	170
	Bibliographical and Historical Remarks . . . . .	171
	References . . . . .	172
<b>5</b>	<b>Additional Biometric Traits . . . . .</b>	<b>175</b>
5.1	Introduction . . . . .	175
5.2	Ear . . . . .	176
5.2.1	Ear detection . . . . .	177
5.2.2	Ear recognition . . . . .	178
5.2.3	Challenges in ear recognition . . . . .	180
5.3	Gait . . . . .	182
5.3.1	Feature extraction and matching . . . . .	183
5.3.2	Challenges in gait recognition . . . . .	185
5.4	Hand Geometry . . . . .	186
5.4.1	Image capture . . . . .	186
5.4.2	Hand segmentation . . . . .	188
5.4.3	Feature Extraction . . . . .	189
5.4.4	Feature matching . . . . .	189
5.4.5	Challenges in hand geometry recognition . . . . .	190
5.5	Soft Biometrics . . . . .	190
5.5.1	Periocular . . . . .	191
5.5.2	Face marks . . . . .	194
5.5.3	Tattoo . . . . .	201
5.6	Summary . . . . .	206
	References . . . . .	207

<b>6 MULTIBIOMETRICS . . . . .</b>	209
6.1 Introduction . . . . .	209
6.2 Sources of Multiple Evidence . . . . .	212
6.2.1 Multi-sensor systems . . . . .	213
6.2.2 Multi-algorithm systems . . . . .	215
6.2.3 Multi-instance systems . . . . .	217
6.2.4 Multi-sample systems . . . . .	218
6.2.5 Multimodal systems . . . . .	219
6.3 Acquisition and Processing Architecture . . . . .	221
6.3.1 Acquisition sequence . . . . .	221
6.3.2 Processing sequence . . . . .	222
6.4 Fusion Levels . . . . .	224
6.4.1 Sensor-level fusion . . . . .	226
6.4.2 Feature-level fusion . . . . .	227
6.4.3 Score-level fusion . . . . .	232
6.4.4 Rank-level fusion . . . . .	246
6.4.5 Decision-level fusion . . . . .	250
6.5 Summary . . . . .	253
Bibliographical and Historical Remarks . . . . .	254
References . . . . .	256
<b>7 SECURITY OF BIOMETRIC SYSTEMS . . . . .</b>	259
7.1 Introduction . . . . .	259
7.2 Adversary Attacks . . . . .	264
7.2.1 Insider attacks . . . . .	264
7.2.2 Infrastructure attacks . . . . .	266
7.3 Attacks at the User Interface . . . . .	268
7.3.1 Impersonation . . . . .	268
7.3.2 Obfuscation . . . . .	269
7.3.3 Spoofing . . . . .	269
7.3.4 Countermeasure: spoof detection . . . . .	272
7.4 Attacks on Biometric Processing . . . . .	278
7.4.1 Attacks on the system modules . . . . .	278
7.4.2 Attacks at the interconnections . . . . .	280
7.5 Attacks on the Template Database . . . . .	283
7.5.1 Countermeasure: biometric template security . . . . .	284
7.6 Summary . . . . .	302
Bibliographical and Historical Remarks . . . . .	302
References . . . . .	304
<b>Index . . . . .</b>	307