



Contents

Preface	xxi
Chapter 1 Practical Aspects of a Vision System – Image Display, Input/Output, and Library Calls	1
OpenCV	2
The Basic OpenCV Code	2
The IplImage Data Structure	3
Reading and Writing Images	6
Image Display	7
An Example	7
Image Capture	10
Interfacing with the AIPCV Library	14
Website Files	18
References	18
Chapter 2 Edge-Detection Techniques	21
The Purpose of Edge Detection	21
Traditional Approaches and Theory	23
Models of Edges	24
Noise	26
Derivative Operators	30
Template-Based Edge Detection	36
Edge Models: The Marr-Hildreth Edge Detector	39
The Canny Edge Detector	42
The Shen-Castan (ISEF) Edge Detector	48
A Comparison of Two Optimal Edge Detectors	51

Color Edges	53
Source Code for the Marr-Hildreth Edge Detector	58
Source Code for the Canny Edge Detector	62
Source Code for the Shen-Castan Edge Detector	70
Website Files	80
References	82
Chapter 3 Digital Morphology	85
Morphology Defined	85
Connectedness	86
Elements of Digital Morphology — Binary Operations	87
Binary Dilation	88
Implementing Binary Dilation	92
Binary Erosion	94
Implementation of Binary Erosion	100
Opening and Closing	101
MAX — A High-Level Programming Language for Morphology	107
The “Hit-and-Miss” Transform	113
Identifying Region Boundaries	116
Conditional Dilation	116
Counting Regions	119
Grey-Level Morphology	121
Opening and Closing	123
Smoothing	126
Gradient	128
Segmentation of Textures	129
Size Distribution of Objects	130
Color Morphology	131
Website Files	132
References	135
Chapter 4 Grey-Level Segmentation	137
Basics of Grey-Level Segmentation	137
Using Edge Pixels	139
Iterative Selection	140
The Method of Grey-Level Histograms	141
Using Entropy	142
Fuzzy Sets	146
Minimum Error Thresholding	148
Sample Results From Single Threshold Selection	149

The Use of Regional Thresholds	151
Chow and Kaneko	152
Modeling Illumination Using Edges	156
Implementation and Results	159
Comparisons	160
Relaxation Methods	161
Moving Averages	167
Cluster-Based Thresholds	170
Multiple Thresholds	171
Website Files	172
References	173
Chapter 5 Texture and Color	177
Texture and Segmentation	177
A Simple Analysis of Texture in Grey-Level Images	179
Grey-Level Co-Occurrence	182
Maximum Probability	185
Moments	185
Contrast	185
Homogeneity	185
Entropy	186
Results from the GLCM Descriptors	186
Speeding Up the Texture Operators	186
Edges and Texture	188
Energy and Texture	191
Surfaces and Texture	193
Vector Dispersion	193
Surface Curvature	195
Fractal Dimension	198
Color Segmentation	201
Color Textures	205
Website Files	205
References	206
Chapter 6 Thinning	209
What Is a Skeleton?	209
The Medial Axis Transform	210
Iterative Morphological Methods	212
The Use of Contours	221
Choi/Lam/Siu Algorithm	224
Treating the Object as a Polygon	226
Triangulation Methods	227

Contents

Force-Based Thinning	228
Definitions	229
Use of a Force Field	230
Subpixel Skeletons	234
Source Code for Zhang-Suen/Stentiford/Holt Combined	
Algorithm	235
Website Files	246
References	247
Chapter 7 Image Restoration	251
Image Degradations — The Real World	251
The Frequency Domain	253
The Fourier Transform	254
The Fast Fourier Transform	256
The Inverse Fourier Transform	260
Two-Dimensional Fourier Transforms	260
Fourier Transforms in OpenCV	262
Creating Artificial Blur	264
The Inverse Filter	270
The Wiener Filter	271
Structured Noise	273
Motion Blur — A Special Case	276
The Homomorphic Filter — Illumination	277
Frequency Filters in General	278
Isolating Illumination Effects	280
Website Files	281
References	283
Chapter 8 Classification	285
Objects, Patterns, and Statistics	285
Features and Regions	288
Training and Testing	292
Variation: In-Class and Out-Class	295
Minimum Distance Classifiers	299
Distance Metrics	300
Distances Between Features	302
Cross Validation	304
Support Vector Machines	306
Multiple Classifiers — Ensembles	309
Merging Multiple Methods	309
Merging Type 1 Responses	310
Evaluation	311
Converting Between Response Types	312

Merging Type 2 Responses	313
Merging Type 3 Responses	315
Bagging and Boosting	315
Bagging	315
Boosting	316
Website Files	317
References	318
Chapter 9 Symbol Recognition	321
The Problem	321
OCR on Simple Perfect Images	322
OCR on Scanned Images — Segmentation	326
Noise	327
Isolating Individual Glyphs	329
Matching Templates	333
Statistical Recognition	337
OCR on Fax Images — Printed Characters	339
Orientation — Skew Detection	340
The Use of Edges	345
Handprinted Characters	348
Properties of the Character Outline	349
Convex Deficiencies	353
Vector Templates	357
Neural Nets	363
A Simple Neural Net	364
A Backpropagation Net for Digit Recognition	368
The Use of Multiple Classifiers	372
Merging Multiple Methods	372
Results From the Multiple Classifier	375
Printed Music Recognition — A Study	375
Staff Lines	376
Segmentation	378
Music Symbol Recognition	381
Source Code for Neural Net Recognition System	383
Website Files	390
References	392
Chapter 10 Content-Based Search — Finding Images by Example	395
Searching Images	395
Maintaining Collections of Images	396
Features for Query by Example	399
Color Image Features	399
Mean Color	400
Color Quad Tree	400

Hue and Intensity Histograms	401
Comparing Histograms	402
Requantization	403
Results from Simple Color Features	404
Other Color-Based Methods	407
Grey-Level Image Features	408
Grey Histograms	409
Grey Sigma — Moments	409
Edge Density — Boundaries Between Objects	409
Edge Direction	410
Boolean Edge Density	410
Spatial Considerations	411
Overall Regions	411
Rectangular Regions	412
Angular Regions	412
Circular Regions	414
Hybrid Regions	414
Test of Spatial Sampling	414
Additional Considerations	417
Texture	418
Objects, Contours, Boundaries	418
Data Sets	418
Website Files	419
References	420
Systems	424
Chapter 11 High-Performance Computing for Vision and Image Processing	425
Paradigms for Multiple-Processor Computation	426
Shared Memory	426
Message Passing	427
Execution Timing	427
Using <i>clock()</i>	428
Using <code>QueryPerformanceCounter</code>	430
The Message-Passing Interface System	432
Installing MPI	432
Using MPI	433
Inter-Process Communication	434
Running MPI Programs	436
Real Image Computations	437
Using a Computer Network — Cluster Computing	440

A Shared Memory System — Using the PC Graphics Processor	444
GLSL	444
OpenGL Fundamentals	445
Practical Textures in OpenGL	448
Shader Programming Basics	451
Vertex and Fragment Shaders	452
Required GLSL Initializations	453
Reading and Converting the Image	454
Passing Parameters to Shader Programs	456
Putting It All Together	457
Speedup Using the GPU	459
Developing and Testing Shader Code	459
Finding the Needed Software	460
Website Files	461
References	461