

Contents

1	Introduction	1
1.1	Why Write Another Book About Image Processing?	1
1.2	Possibilities and Limitations	3
1.3	Types of Inspection Tasks	5
1.4	Structure of Image Processing Systems	6
1.4.1	Hardware	6
1.4.2	Signal Flow in Process Environment	9
1.4.3	Signal Flow Within the Image Processing System	11
1.5	Process Model	13
1.6	Introductory Example	15
1.6.1	Optical Character Recognition	16
1.6.2	Thread Depth	18
1.6.3	Presence Verification	20
1.7	From Here	21
	References	24
2	Overview: Image Preprocessing	25
2.1	Gray Scale Transformation	26
2.1.1	Look-Up Tables	26
2.1.2	Linear Gray Level Scaling	28
2.1.3	Contrast Enhancement	29
2.1.4	Histogram Equalization	30
2.1.5	Local Contrast Enhancement	31
2.2	Image Arithmetic	33
2.2.1	Image Addition and Averaging	34
2.2.2	Image Subtraction	35
2.2.3	Minimum and Maximum of Two Images	37
2.2.4	Shading Correction	37
2.3	Linear Filters	38
2.3.1	Local Operations and Neighborhoods	39
2.3.2	Principle of Linear Filters	40
2.3.3	Smoothing Filters	43
2.3.4	Edge Filters	48

2.4	Median Filter	52
2.5	Morphological Filters	54
2.6	Other Non-linear Filters	57
2.7	Coordinate Transformations	58
2.8	Integral Transformations	60
2.9	Summary	61
	References	63
3	Positioning	65
3.1	Position of an Individual Object	65
3.1.1	Positioning Using the Entire Object	66
3.1.2	Positioning Using an Edge	68
3.2	Orientation of an Individual Object	70
3.2.1	Orientation Computation Using Principal Axis	71
3.2.2	Distance-Versus-Angle Signature	73
3.3	Robot Positioning	75
3.3.1	Application	76
3.3.2	Image Processing Components	76
3.3.3	Position Determination on One Object	78
3.3.4	Orientation of an Object Group	78
3.3.5	Comments Concerning Position Adjustment	79
3.4	Summary	81
	References	82
4	Overview: Segmentation	83
4.1	Regions of Interest (ROIs)	83
4.2	Binary Segmentation	84
4.2.1	Thresholds	85
4.2.2	Threshold Determination from Histogram Analyses	86
4.2.3	Gray Level Histograms	87
4.2.4	Generalizations of Thresholding	90
4.3	Contour Tracing	92
4.3.1	Connectedness	92
4.3.2	Generating Object Contours	93
4.3.3	Contour Representation	95
4.4	Template Matching	95
4.4.1	Basic Operation	96
4.4.2	Optimizing Template Matching	99
4.4.3	Comments on Template Matching	103
4.4.4	Edge-Based Object Search	104
4.5	Edge Detection	106
4.5.1	Edge Probing in Industrial Image Scenes	106
4.5.2	Edge Search with Subpixel Accuracy	108

4.6	Summary	109
	References	111
5	Mark Identification	113
5.1	Bar Code Identification	113
5.1.1	Principle of Gray-Level-Based Bar Code Identification	114
5.1.2	Types of Bar Codes	115
5.1.3	Examples for Industrial Bar Code Identification	117
5.1.4	Two-Dimensional Codes	119
5.2	Character Recognition	120
5.2.1	Laser-Etched Characters on an IC	121
5.2.2	Basic Configuration of Character Recognition	123
5.2.3	Fundamental Structure of a Classifier Application	126
5.2.4	Position Adjustment on the IC	130
5.2.5	Improving Character Quality	135
5.2.6	Optimization in Operation	137
5.3	Recognition of Pin-Marked Digits on Metal	138
5.3.1	Illumination	138
5.3.2	Preprocessing	139
5.3.3	Segmentation and Classification	140
5.4	Block Codes on Rolls of Film	142
5.5	Print Quality Inspection	144
5.5.1	Methods	145
5.5.2	Print Quality Inspection in Individual Regions	146
5.5.3	Print Quality Inspection with Automatic Subdivision	148
5.6	Summary	149
	References	150
6	Overview: Classification	151
6.1	What is Classification?	151
6.2	Classification as Function Approximation	153
6.2.1	Basic Terms	153
6.2.2	Statistical Foundations	155
6.2.3	Defining Classifiers	156
6.3	Instance-Based Classifiers	158
6.3.1	Nearest Neighbor Classifier	158
6.3.2	RCE Networks	159
6.3.3	Vector Quantization	161
6.3.4	Template Matching	161
6.3.5	Comments on Instance-Based Classifiers	162
6.4	Function-Based Classifiers	162
6.4.1	Polynomial Classifier	163

6.4.2	Multilayer Perceptron-Type Neural Networks.	164
6.5	Comments on the Application of Neural Networks.	167
6.5.1	Composition of the Training Set.	167
6.5.2	Feature Scaling.	167
6.5.3	Rejection.	168
6.5.4	Differentiation from Other Classifiers.	169
6.6	Summary.	170
	References	172
7	Gauging.	173
7.1	Gauging Tasks	174
7.2	Simple Gauging	174
7.2.1	Centroid Distances	175
7.2.2	Contour Distances.	178
7.2.3	Angle Measurements.	182
7.3	Shape Checking on a Punched Part.	183
7.3.1	Inspection Task	183
7.3.2	Modeling Contours by Lines	184
7.3.3	Measuring the Contour Angle	186
7.4	Angle Gauging on Toothed Belt.	186
7.4.1	Illumination Setup	187
7.4.2	Edge Creation	189
7.5	Shape Checking on Injection-Molded Part.	191
7.5.1	Computing Radii	191
7.5.2	Comments on Model Circle Computation	194
7.6	High Accuracy Gauging on Thread Flange	194
7.6.1	Illumination and Image Capture	195
7.6.2	Subpixel-Accurate Gauging of the Thread Depth	196
7.7	Calibration.	196
7.7.1	Calibration Mode	197
7.7.2	Inspection-Related Calibration	199
7.8	Summary.	199
	Reference	201
8	Overview: Image Acquisition and Illumination	203
8.1	Solid-State Sensors	203
8.1.1	Introduction	204
8.1.2	CCD Sensors	206
8.1.3	CMOS Sensors.	208
8.1.4	Special Types.	210
8.1.5	Color Sensors.	211
8.1.6	Properties of Sensors.	213
8.2	Digital Cameras	217
8.2.1	Control of Image Capture	217

8.2.2	Capturing Color Images.	219
8.2.3	Characteristic Values of Digital Cameras.	221
8.2.4	Operating Conditions in Industrial Environments	222
8.3	Image Data Transfer	223
8.3.1	CameraLink®	224
8.3.2	FireWire®	226
8.3.3	USB	228
8.3.4	Gigabit Ethernet	229
8.4	Line-Scan Cameras	231
8.4.1	Types of Line-Scan Camera Applications	232
8.4.2	Spatial Resolution of Line-Scan Cameras	234
8.4.3	Illumination for Line-Scan Cameras	234
8.4.4	Control of Line-Scan Cameras	235
8.5	Optical Foundations	236
8.5.1	f-number	236
8.5.2	Laws of Imaging	238
8.5.3	Depth of Field	242
8.5.4	Typical Capturing Situations	246
8.5.5	Aberrations	248
8.5.6	Lens Determination.	249
8.5.7	Special Lens Types.	251
8.6	Illumination Technology	253
8.6.1	Light Sources.	253
8.6.2	Front Lighting	255
8.6.3	Back Lighting	258
8.7	Summary.	261
	References	264
9	Presence Verification	265
9.1	Presence Verification Using PTZ Cameras	266
9.1.1	Inspection Part Geometry	266
9.1.2	Illumination	267
9.1.3	Positioning.	268
9.1.4	Object Detection.	268
9.1.5	Verification of Results	269
9.2	Simple Gauging for Assembly Verification	270
9.2.1	Illumination	272
9.2.2	Inspection Criteria	273
9.2.3	Object Creation and Measurement Computation.	275
9.2.4	Position Adjustment	276
9.3	Presence Verification Using Classifiers	277
9.3.1	Illumination	279
9.3.2	Check of Crimping	281
9.3.3	Type Verification of the Flange	286

9.4	Contrast-Free Presence Verification	290
9.5	Presence Verification Using Line-Scan Cameras	292
9.5.1	Inspection of Cylindrical Parts with Area-Scan Cameras	292
9.5.2	Inspection of a Valve Body	295
9.5.3	Notes	300
9.6	Summary	301
10	Overview: Object Features	303
10.1	Basic Geometric Features	303
10.1.1	Enclosing Rectangle	303
10.1.2	Area and Perimeter	304
10.1.3	Centroid Coordinates	308
10.1.4	Axes and Radii	309
10.2	Shape Descriptors	310
10.2.1	Contour Curvature	310
10.2.2	Fiber Features	312
10.2.3	Euler Number	313
10.2.4	Moments and Fourier Descriptors	314
10.3	Gray Level Features	315
10.3.1	First-Order Statistics	315
10.3.2	Textural Features	315
10.4	Summary	316
	References	318
11	Color Image Processing	319
11.1	Color Identification	320
11.1.1	Evaluation Strategy	321
11.1.2	Illumination and Image Capture	322
11.1.3	Color Classification	324
11.1.4	Selecting a Camera Image for Character Recognition	327
11.1.5	Recognition of Writing	329
11.2	Color Segmentation	332
11.2.1	Illumination	332
11.2.2	Color Classification	333
11.2.3	Segmentation	336
11.2.4	Presence Verification	336
11.3	Summary	337
	References	338
12	Implementation of Industrial Image Processing Applications	339
12.1	Image Processing Projects	339
12.2	Process Integration	341

12.3 Outlook	344
Reference	345
Appendix A: Mathematical Notes.	347
Appendix B: Software Download	359
Appendix C: Weblinks to Industrial Image Processing	361
Index	363