

J. R. Parker

Algorithms for Image Processing and Computer Vision



SECOND EDITION
2

Algorithms for Image Processing and Computer Vision

Second Edition



Algorithms for Image Processing and Computer Vision

Second Edition

J.R. Parker



WILEY

Wiley Publishing, Inc.

Algorithms for Image Processing and Computer Vision, Second Edition

Published by
Wiley Publishing, Inc.
10475 Crosspoint Boulevard
Indianapolis, IN 46256
www.wiley.com

Copyright © 2011 by J.R. Parker

Published by Wiley Publishing, Inc., Indianapolis, Indiana
Published simultaneously in Canada

ISBN: 978-0-470-64385-3
ISBN: 978-1-118-02188-0 (ebk)
ISBN: 978-1-118-02189-7 (ebk)
ISBN: 978-1-118-01962-7 (ebk)

Manufactured in the United States of America

10 9 8 7 6 5 4 3 2 1

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 646-8600. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permissions>.

Limit of Liability/Disclaimer of Warranty: The publisher and the author make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation warranties of fitness for a particular purpose. No warranty may be created or extended by sales or promotional materials. The advice and strategies contained herein may not be suitable for every situation. This work is sold with the understanding that the publisher is not engaged in rendering legal, accounting, or other professional services. If professional assistance is required, the services of a competent professional person should be sought. Neither the publisher nor the author shall be liable for damages arising herefrom. The fact that an organization or Web site is referred to in this work as a citation and/or a potential source of further information does not mean that the author or the publisher endorses the information the organization or website may provide or recommendations it may make. Further, readers should be aware that Internet websites listed in this work may have changed or disappeared between when this work was written and when it is read.

For general information on our other products and services please contact our Customer Care Department within the United States at (877) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Library of Congress Control Number: 2010939957

Trademarks: Wiley and the Wiley logo are trademarks or registered trademarks of John Wiley & Sons, Inc. and/or its affiliates, in the United States and other countries, and may not be used without written permission. All other trademarks are the property of their respective owners. Wiley Publishing, Inc. is not associated with any product or vendor mentioned in this book.

*“Sin lies only in hurting other people unnecessarily.
All other ‘sins’ are invented nonsense.
(Hurting yourself is not a sin – just stupid.)”*

– Robert A. Heinlein

Thanks, Bob.



Credits

Executive Editor

Carol Long

Project Editor

John Sleeva

Technical Editor

Kostas Terzidis

Production Editor

Daniel Scribner

Copy Editor

Christopher Jones

Editorial Director

Robyn B. Siesky

Editorial Manager

Mary Beth Wakefield

**Freelancer Editorial
Manager**

Rosemarie Graham

Marketing Manager

Ashley Zurcher

Production Manager

Tim Tate

**Vice President and Executive
Group Publisher**

Richard Swadley

**Vice President and Executive
Publisher**

Barry Pruett

Associate Publisher

Jim Minatel

Project Coordinator, Cover

Lynsey Stanford

Proofreaders

Nancy Hanger, Paul Sagan

Indexer

Ron Strauss

Cover Image

Ryan Sneed

Cover Designer

© GYRO PHOTOGRAPHY/
amanaimagesRB/Getty Images



About the Author

J.R. Parker is a computer expert and teacher, with special interests in image processing and vision, video game technologies, and computer simulations. With a Ph.D. in Informatics from the State University of Gent, Dr. Parker has taught computer science, art, and drama at the University of Calgary in Canada, where he is a full professor. He has more than 150 technical papers and four books to his credit, as well as video games such as the *Booze Cruise*, a simulation of impaired driving designed to demonstrate its folly, and a number of educational games. Jim lives on a small ranch near Cochrane, Alberta, Canada with family and a host of legged and winged creatures.



About the Technical Editor

Kostas Terzidis is an Associate Professor at the Harvard Graduate School of Design. He holds a Ph.D. in Architecture from the University of Michigan (1994), a Masters of Architecture from Ohio State University (1989), and a Diploma of Engineering from the Aristotle University of Thessaloniki (1986). His most recent work is in the development of theories and techniques for the use of algorithms in architecture. His book *Expressive Form: A Conceptual Approach to Computational Design*, published by London-based Spon Press (2003), offers a unique perspective on the use of computation as it relates to aesthetics, specifically in architecture and design. His book *Algorithmic Architecture* (Architectural Press/Elsevier, 2006) provides an ontological investigation into the terms, concepts, and processes of algorithmic architecture and provides a theoretical framework for design implementations. His latest book, *Algorithms for Visual Design* (Wiley, 2009), provides students, programmers, and researchers the technical, theoretical, and design means to develop computer code that will allow them to experiment with design problems.



Acknowledgments

Thanks this time to Sonny Chan, for the inspiration for the parallel computing chapter, to Jeff Boyd, for introducing me repeatedly to OpenCV, and to Ralph Huntsinger and Ghislain C. Vansteenkiste, for getting me into and successfully out of my Ph.D. program.

Almost all the images used in this book were created by me, using an IBM PC with a frame grabber and a Sony CCD camera, an HP scanner, and a Sony Eyetoy as a webcam. Credits for the few images that were not acquired in this way are as follows:

Corel Corporation made available the color image of the grasshopper on a leaf shown in Figure 3.33, and also was the origin of the example search images in Figure 10.5.

The sample images in Figure 10.1 were a part of the ALOI data set, use of which was allowed by J. M. Geusebroek.

Thanks to Big Hill Veterinary Clinic in Cochrane, Alberta, Canada, for the X-ray image shown in Figure 3.10e.

Finally, thanks to Dr. N. Wardlaw, of the University of Calgary Department of Geology, for the geological micropore image of Figure 3.16.

Most importantly, I need to thank my family: my wife, Katrin, and children, Bailey and Max. They sacrificed time and energy so that this work could be completed. I appreciate it and hope that the effort has been worthwhile.



Contents at a Glance

Preface		xxi
Chapter 1	Practical Aspects of a Vision System – Image Display, Input/Output, and Library Calls	1
Chapter 2	Edge-Detection Techniques	21
Chapter 3	Digital Morphology	85
Chapter 4	Grey-Level Segmentation	137
Chapter 5	Texture and Color	177
Chapter 6	Thinning	209
Chapter 7	Image Restoration	251
Chapter 8	Classification	285
Chapter 9	Symbol Recognition	321
Chapter 10	Content-Based Search – Finding Images by Example	395
Chapter 11	High-Performance Computing for Vision and Image Processing	425
Index		465



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

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
Index	465



Preface

Humans still obtain the vast majority of their sensory input through their visual system, and an enormous effort has been made to artificially enhance this sense. Eyeglasses, binoculars, telescopes, radar, infrared sensors, and photomultipliers all function to improve our view of the world and the universe. We even have telescopes in orbit (eyes outside the atmosphere) and many of those “see” in other spectra: infrared, ultraviolet, X-rays. These give us views that we could not have imagined only a few years ago, and in colors that we’ll never see with the naked eye. The computer has been essential for creating the incredible images we’ve all seen from these devices.

When the first edition of this book was written, the Hubble Space Telescope was in orbit and producing images at a great rate. It and the European Hipparcos telescope were the only optical instruments above the atmosphere. Now there is COROT, Kepler, MOST (Canada’s space telescope), and Swift Gamma Ray Burst Explorer. In addition, there is the Spitzer (infrared), Chandra (X-ray), GALEX (ultraviolet), and a score of others. The first edition was written on a 450-Mhz Pentium III with 256 MB of memory. In 1999, the first major digital SLR camera was placed on the market: the Nikon D1. It had only 2.74 million pixels and cost just under \$6,000. A typical PC disk drive held 100–200 MB. Webcams existed in 1997, but they were expensive and low-resolution. Persons using computer images needed to have a special image acquisition card and a relatively expensive camera to conduct their work, generally amounting to \$1–2,000 worth of equipment. The technology of personal computers and image acquisition has changed a lot since then.

The 1997 first edition was inspired by my numerous scans through the Internet news groups related to image processing and computer vision. I noted that some requests appeared over and over again, sometimes answered and sometimes not, and wondered if it would be possible to answer the more

frequently asked questions in book form, which would allow the development of some of the background necessary for a complete explanation. However, since I had just completed a book (*Practical Computer Vision Using C*), I was in no mood to pursue the issue. I continued to collect information from the Net, hoping to one day collate it into a sensible form. I did that, and the first edition was very well received. (Thanks!)

Fifteen years later, given the changes in technology, I'm surprised at how little has changed in the field of vision and image processing, at least at the accessible level. Yes, the theory has become more sophisticated and three-dimensional vision methods have certainly improved. Some robot vision systems have accomplished rather interesting things, and face recognition has been taken to a new level. However, cheap character recognition is still, well, cheap, and is still not up to a level where it can be used reliably in most cases. Unlike other kinds of software, vision systems are not ubiquitous features of daily life. Why not? Possibly because the vision problem is really a hard one. Perhaps there is room for a revision of the original book?

My goal has changed somewhat. I am now also interested in "democratization" of this technology — that is, in allowing it to be used by anyone, at home, in their business, or at schools. Of course, you need to be able to program a computer, but that skill is more common than it was. All the software needed to build the programs in this edition is freely available on the Internet. I have used a free compiler (Microsoft Visual Studio Express), and OpenCV is also a free download. The only impediment to the development of your own image-analysis systems is your own programming ability.

Some of the original material has not changed very much. Edge detection, thinning, thresholding, and morphology have not been hot areas of research, and the chapters in this edition are quite similar to those in the original. The software has been updated to use Intel's OpenCV system, which makes image IO and display much easier for programmers. It is even a simple matter to capture images from a webcam in real time and use them as input to the programs. Chapter 1 contains a discussion of the basics of OpenCV use, and all software in this book uses OpenCV as a basis.

Much of the mathematics in this book is still necessary for the detailed understanding of the algorithms described. Advanced methods in image processing and vision require the motivation and justification that only mathematics can provide. In some cases, I have only scratched the surface, and have left a more detailed study for those willing to follow the references given at the ends of chapters. I have tried to select references that provide a range of approaches, from detailed and complex mathematical analyses to clear and concise exposition. However, in some cases there are very few clear descriptions in the literature, and none that do not require at least a university-level math course. Here I have attempted to describe the situation in an intuitive manner, sacrificing rigor (which can be found almost anywhere else) for as

- [LabVIEW Graphical Programming Cookbook pdf, azw \(kindle\)](#)
- [click De stripman van Slubice](#)
- [click Hockey Confidential: Inside Stories from People Inside The Game online](#)
- [**read online Data-driven Generation of Policies**](#)

- <http://schroff.de/books/Facebook-Dating--A-Guy-s-Only-Guide-to-the-World-s-Largest-Online-Dating-Site.pdf>
- <http://monkeybubblemedia.com/lib/De-stripman-van-Slubice.pdf>
- <http://www.celebritychat.in/?ebooks/Virus-of-the-Mind.pdf>
- <http://academialanguagebar.com/?ebooks/Gillian-McKeith-s-Food-Bible--How-to-Use-Food-to-Cure-What-Ails-You.pdf>