

Syllabus of the course “Methods for Image Processing” a.y. 2014/15

January 12, 2015

This document reports a description of the topics covered in the course *Methods for Image processing* for the academic year 2014/15, in relation to those covered in the textbook:

R.C. Gonzalez and R.E. Woods, *Digital Image Processing*, (3 ed.), Prentice Hall, 2008. ISBN 9780131687288.

The topics have been organized in the following categories:

- Topics that cannot be ignored: the topics belonging to this category are considered fundamental and belong to the cultural background of image processing experts; these topics should not be considered as a subject of choice, if during the oral exam the student is asked to pick a subject.
- Topics to be studied well: the topics belonging to this category are those that have been studied during the course and will be considered for the exams.
- Topics that it would not hurt to know: topics not covered during the course for lack of time, but that can inspire a project (to be agreed with the teacher).

NOTE The syllabus here described refers mainly to the 6 cfu course, but it should be reduced for the 5 cfu course. In the following a possible reduction has been considered, but any other suitable downsizing of the syllabus can be agreed with the teacher.

Topics that cannot be ignored

These topics are given for granted and are marked in **cyan** in the Table of contents reported at the end of the present document. They are:

- Chapter 1 - Introduction
- Section 2.4 - Image Sampling and Quantization (excluding 2.4.4, not covered during the lessons)
- Section 2.6 - An Introduction to the Mathematical Tools Used in Digital Image Processing
- Sections 4.1 e 4.2 - Background e Preliminary concepts in Filtering in the Frequency Domain

Topics to be studied well

The topics covered during the lessons are marked in **red** in the Table of contents reported at the end of the present document. They are:

- Chapter 2 - Digital Image Fundamentals (excluding 2.4.4)

- Chapter 3 - Intensity Transformations and Spatial Filtering
- Chapter 4 - Filtering in the Frequency Domain (excluding 4.10 and 4.11)
- Chapter 6 - Color Image Processing (excluding 6.8 and 6.9)
- Chapter 8 - Image Compression (excluding 8.2.6, 8.2.7, 8.2.9, 8.2.10, and 8.3)
- Chapter 9 - Morphological Image Processing
- Chapter 10 - Image Segmentation (excluding 10.3.6, 10.3.8, and 10.6)

Syllabus reduction (5 CFU)

Students that have in learning agreement the 5 cfu course can consider the reduced syllabus. Some topics **required** for the 6 cfu course can be considered **optional** for the 5 cfu course (and they are marked in **orange**). In detail:

- Section 6.7 - Image Segmentation Based on Color
- Section 8.2.2 - Golomb Coding
- Section 9.6 - Gray-Scale Morphology
- Section 10.3.7 - Variable Thresholding
- Section 10.5 - Segmentation Using Morphological Watersheds

Topics that it would not hurt to know

Topics not covered during the lessons, but that worth at least a reading, are marked in **yellow** in the Table of contents reported at the end of the present document. They are:

- Section 2.4.4 - Image Interpolation
- Section 4.10 - Selective Filtering
- Section 4.11 - Implementation (of FFT)
- Chapter 5 - Image Restoration and Reconstruction
- Section 6.8 - Noise in Color Images
- Section 6.9 - Color Image Compression
- Chapter 7 - Wavelets and Multiresolution Processing
- Section 8.2.6 - Symbol-Based Coding
- Section 8.2.7 - Bit-Plane Coding
- Section 8.2.9 - Predictive Coding
- Section 8.2.10 - Wavelet Coding
- Section 8.3 - Digital Image Watermarking
- Section 10.3.6 - Multiple Thresholds (in Image Segmentation)
- Section 10.3.8 - Multivariable Thresholding (in Image Segmentation)
- Section 10.6 - The Use of Motion in Segmentation

Table of contents of the textbook

In the following, the Table of contents of the textbook (R.C. Gonzalez and R.E. Woods, Digital Image Processing, 3 ed., Prentice Hall, 2008. ISBN 9780131687288) is reported with the Chapters and Sections marked using different colors for the categories the topics belong to:

- cyan : topics that cannot be ignored;
- red : topics to be studied well;
- yellow : topics that it would not hurt to know.

For any clarification please contact the teacher.



Digital Image Processing

Third Edition

Rafael C. Gonzalez
University of Tennessee

Richard E. Woods
MedData Interactive



Upper Saddle River, NJ 07458

Vice President and Editorial Director, ECS: *Marcia J. Horton*
Executive Editor: *Michael McDonald*
Associate Editor: *Alice Dworkin*
Editorial Assistant: *William Opaluch*
Managing Editor: *Scott Dismanno*
Production Editor: *Rose Kernan*
Director of Creative Services: *Paul Beljanti*
Creative Director: *Juan Lopez*
Art Director: *Heather Scott*
Art Editors: *Gregory Dulles and Thomas Benfatti*
Manufacturing Manager: *Alexis Heydt-Long*
Manufacturing Buyer: *Lisa McDowell*
Senior Marketing Manager: *Tim Galligan*

© 2008 by Pearson Education, Inc.
Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, New Jersey 07458

All rights reserved. No part of this book may be reproduced, in any form, or by any means, without permission in writing from the publisher.

Pearson Prentice Hall® is a trademark of Pearson Education, Inc.

The authors and publisher of this book have used their best efforts in preparing this book. These efforts include the development, research, and testing of the theories and programs to determine their effectiveness. The authors and publisher make no warranty of any kind, expressed or implied, with regard to these programs or the documentation contained in this book. The authors and publisher shall not be liable in any event for incidental or consequential damages with, or arising out of, the furnishing, performance, or use of these programs.

Printed in the United States of America.
10 9 8 7 6 5 4 3 2 1

ISBN 0-13-168728-x
978-0-13-168728-8

Pearson Education Ltd., *London*
Pearson Education Australia Pty. Ltd., *Sydney*
Pearson Education Singapore, Pte., Ltd.
Pearson Education North Asia Ltd., *Hong Kong*
Pearson Education Canada, Inc., *Toronto*
Pearson Educación de México, S.A. de C.V.
Pearson Education—Japan, *Tokyo*
Pearson Education Malaysia, Pte. Ltd.
Pearson Education, Inc., *Upper Saddle River, New Jersey*

Contents

<i>Preface</i>	<i>xv</i>
<i>Acknowledgments</i>	<i>xix</i>
<i>The Book Web Site</i>	<i>xx</i>
<i>About the Authors</i>	<i>xxi</i>

1 Introduction 1

1.1	What Is Digital Image Processing?	1
1.2	The Origins of Digital Image Processing	3
1.3	Examples of Fields that Use Digital Image Processing	7
1.3.1	Gamma-Ray Imaging	8
1.3.2	X-Ray Imaging	9
1.3.3	Imaging in the Ultraviolet Band	11
1.3.4	Imaging in the Visible and Infrared Bands	12
1.3.5	Imaging in the Microwave Band	18
1.3.6	Imaging in the Radio Band	20
1.3.7	Examples in which Other Imaging Modalities Are Used	20
1.4	Fundamental Steps in Digital Image Processing	25
1.5	Components of an Image Processing System	28
	Summary	31
	References and Further Reading	31

2 Digital Image Fundamentals 35

2.1	Elements of Visual Perception	36
2.1.1	Structure of the Human Eye	36
2.1.2	Image Formation in the Eye	38
2.1.3	Brightness Adaptation and Discrimination	39
2.2	Light and the Electromagnetic Spectrum	43
2.3	Image Sensing and Acquisition	46
2.3.1	Image Acquisition Using a Single Sensor	48
2.3.2	Image Acquisition Using Sensor Strips	48
2.3.3	Image Acquisition Using Sensor Arrays	50
2.3.4	A Simple Image Formation Model	50
2.4	Image Sampling and Quantization	52
2.4.1	Basic Concepts in Sampling and Quantization	52
2.4.2	Representing Digital Images	55
2.4.3	Spatial and Intensity Resolution	59
2.4.4	Image Interpolation	65

2.5	Some Basic Relationships between Pixels	68
2.5.1	Neighbors of a Pixel	68
2.5.2	Adjacency, Connectivity, Regions, and Boundaries	68
2.5.3	Distance Measures	71

2.6 An Introduction to the Mathematical Tools Used in Digital Image Processing 72

2.6.1	Array versus Matrix Operations	72
2.6.2	Linear versus Nonlinear Operations	73
2.6.3	Arithmetic Operations	74
2.6.4	Set and Logical Operations	80
2.6.5	Spatial Operations	85
2.6.6	Vector and Matrix Operations	92
2.6.7	Image Transforms	93
2.6.8	Probabilistic Methods	96
	Summary	98
	References and Further Reading	98
	Problems	99

3 Intensity Transformations and Spatial Filtering 104

3.1	Background	105
3.1.1	The Basics of Intensity Transformations and Spatial Filtering	105
3.1.2	About the Examples in This Chapter	107
3.2	Some Basic Intensity Transformation Functions	107
3.2.1	Image Negatives	108
3.2.2	Log Transformations	109
3.2.3	Power-Law (Gamma) Transformations	110
3.2.4	Piecewise-Linear Transformation Functions	115
3.3	Histogram Processing	120
3.3.1	Histogram Equalization	122
3.3.2	Histogram Matching (Specification)	128
3.3.3	Local Histogram Processing	139
3.3.4	Using Histogram Statistics for Image Enhancement	139
3.4	Fundamentals of Spatial Filtering	144
3.4.1	The Mechanics of Spatial Filtering	145
3.4.2	Spatial Correlation and Convolution	146
3.4.3	Vector Representation of Linear Filtering	150
3.4.4	Generating Spatial Filter Masks	151
3.5	Smoothing Spatial Filters	152
3.5.1	Smoothing Linear Filters	152
3.5.2	Order-Statistic (Nonlinear) Filters	156
3.6	Sharpening Spatial Filters	157
3.6.1	Foundation	158
3.6.2	Using the Second Derivative for Image Sharpening—The Laplacian	160

- 3.6.3 Unsharp Masking and Highboost Filtering 162
- 3.6.4 Using First-Order Derivatives for (Nonlinear) Image Sharpening—The Gradient 165
- 3.7 Combining Spatial Enhancement Methods 169**
- 3.8 Using Fuzzy Techniques for Intensity Transformations and Spatial Filtering 173**
 - 3.8.1 Introduction 173
 - 3.8.2 Principles of Fuzzy Set Theory 174
 - 3.8.3 Using Fuzzy Sets 178
 - 3.8.4 Using Fuzzy Sets for Intensity Transformations 186
 - 3.8.5 Using Fuzzy Sets for Spatial Filtering 189
- Summary 192**
- References and Further Reading 192**
- Problems 193**

4 Filtering in the Frequency Domain 199

- 4.1 Background 200**
 - 4.1.1 A Brief History of the Fourier Series and Transform 200
 - 4.1.2 About the Examples in this Chapter 201
- 4.2 Preliminary Concepts 202**
 - 4.2.1 Complex Numbers 202**
 - 4.2.2 Fourier Series 203**
 - 4.2.3 Impulses and Their Sifting Property 203
 - 4.2.4 The Fourier Transform of Functions of One Continuous Variable 205
 - 4.2.5 Convolution 209
- 4.3 Sampling and the Fourier Transform of Sampled Functions 211**
 - 4.3.1 Sampling 211
 - 4.3.2 The Fourier Transform of Sampled Functions 212
 - 4.3.3 The Sampling Theorem 213
 - 4.3.4 Aliasing 217
 - 4.3.5 Function Reconstruction (Recovery) from Sampled Data 219
- 4.4 The Discrete Fourier Transform (DFT) of One Variable 220**
 - 4.4.1 Obtaining the DFT from the Continuous Transform of a Sampled Function 221
 - 4.4.2 Relationship Between the Sampling and Frequency Intervals 223
- 4.5 Extension to Functions of Two Variables 225**
 - 4.5.1 The 2-D Impulse and Its Sifting Property 225
 - 4.5.2 The 2-D Continuous Fourier Transform Pair 226
 - 4.5.3 Two-Dimensional Sampling and the 2-D Sampling Theorem 227
 - 4.5.4 Aliasing in Images 228
 - 4.5.5 The 2-D Discrete Fourier Transform and Its Inverse 235

- 4.6 Some Properties of the 2-D Discrete Fourier Transform 236**
 - 4.6.1 Relationships Between Spatial and Frequency Intervals 236
 - 4.6.2 Translation and Rotation 236
 - 4.6.3 Periodicity 237
 - 4.6.4 Symmetry Properties 239
 - 4.6.5 Fourier Spectrum and Phase Angle 245
 - 4.6.6 The 2-D Convolution Theorem 249
 - 4.6.7 Summary of 2-D Discrete Fourier Transform Properties 253
- 4.7 The Basics of Filtering in the Frequency Domain 255**
 - 4.7.1 Additional Characteristics of the Frequency Domain 255
 - 4.7.2 Frequency Domain Filtering Fundamentals 257
 - 4.7.3 Summary of Steps for Filtering in the Frequency Domain 263
 - 4.7.4 Correspondence Between Filtering in the Spatial and Frequency Domains 263
- 4.8 Image Smoothing Using Frequency Domain Filters 269**
 - 4.8.1 Ideal Lowpass Filters 269
 - 4.8.2 Butterworth Lowpass Filters 273
 - 4.8.3 Gaussian Lowpass Filters 276
 - 4.8.4 Additional Examples of Lowpass Filtering 277
- 4.9 Image Sharpening Using Frequency Domain Filters 280**
 - 4.9.1 Ideal Highpass Filters 281
 - 4.9.2 Butterworth Highpass Filters 284
 - 4.9.3 Gaussian Highpass Filters 285
 - 4.9.4 The Laplacian in the Frequency Domain 286
 - 4.9.5 Unsharp Masking, Highboost Filtering, and High-Frequency-Emphasis Filtering 288
 - 4.9.6 Homomorphic Filtering 289
- 4.10 Selective Filtering 294**
 - 4.10.1 Bandreject and Bandpass Filters 294
 - 4.10.2 Notch Filters 294
- 4.11 Implementation 298**
 - 4.11.1 Separability of the 2-D DFT 298
 - 4.11.2 Computing the IDFT Using a DFT Algorithm 299
 - 4.11.3 The Fast Fourier Transform (FFT) 299
 - 4.11.4 Some Comments on Filter Design 303
- Summary 303**
- References and Further Reading 304**
- Problems 304**

5 Image Restoration and Reconstruction 311

- 5.1 A Model of the Image Degradation/Restoration Process 312**
 - 5.1.1 Noise Models 313
 - 5.2.1 Spatial and Frequency Properties of Noise 313
 - 5.2.2 Some Important Noise Probability Density Functions 314

- 5.2.3 Periodic Noise 318
- 5.2.4 Estimation of Noise Parameters 319
- 5.3 Restoration in the Presence of Noise Only—Spatial Filtering 322**
 - 5.3.1 Mean Filters 322
 - 5.3.2 Order-Statistic Filters 325
 - 5.3.3 Adaptive Filters 330
- 5.4 Periodic Noise Reduction by Frequency Domain Filtering 335**
 - 5.4.1 Bandreject Filters 335
 - 5.4.2 Bandpass Filters 336
 - 5.4.3 Notch Filters 337
 - 5.4.4 Optimum Notch Filtering 338
- 5.5 Linear, Position-Invariant Degradations 343**
- 5.6 Estimating the Degradation Function 346**
 - 5.6.1 Estimation by Image Observation 346
 - 5.6.2 Estimation by Experimentation 347
 - 5.6.3 Estimation by Modeling 347
- 5.7 Inverse Filtering 351**
- 5.8 Minimum Mean Square Error (Wiener) Filtering 352**
- 5.9 Constrained Least Squares Filtering 357**
- 5.10 Geometric Mean Filter 361**
- 5.11 Image Reconstruction from Projections 362**
 - 5.11.1 Introduction 362
 - 5.11.2 Principles of Computed Tomography (CT) 365
 - 5.11.3 Projections and the Radon Transform 368
 - 5.11.4 The Fourier-Slice Theorem 374
 - 5.11.5 Reconstruction Using Parallel-Beam Filtered Backprojections 375
 - 5.11.6 Reconstruction Using Fan-Beam Filtered Backprojections 381
- Summary 387**
- References and Further Reading 388**
- Problems 389**

6 Color Image Processing 394

- 6.1 Color Fundamentals 395**
- 6.2 Color Models 401**
 - 6.2.1 The RGB Color Model 402
 - 6.2.2 The CMY and CMYK Color Models 406
 - 6.2.3 The HSI Color Model 407
- 6.3 Pseudocolor Image Processing 414**
 - 6.3.1 Intensity Slicing 415
 - 6.3.2 Intensity to Color Transformations 418
- 6.4 Basics of Full-Color Image Processing 424**
- 6.5 Color Transformations 426**
 - 6.5.1 Formulation 426
 - 6.5.2 Color Complements 430

- 6.5.3 Color Slicing 431
- 6.5.4 Tone and Color Corrections 433
- 6.5.5 Histogram Processing 438
- 6.6 Smoothing and Sharpening 439**
 - 6.6.1 Color Image Smoothing 439
 - 6.6.2 Color Image Sharpening 442
- 6.7 Image Segmentation Based on Color 443**
 - 6.7.1 Segmentation in HSI Color Space 443
 - 6.7.2 Segmentation in RGB Vector Space 445
 - 6.7.3 Color Edge Detection 447
- 6.8 Noise in Color Images 451**
- 6.9 Color Image Compression 454**
- Summary 455**
- References and Further Reading 456**
- Problems 456**

7 Wavelets and Multiresolution Processing 461

- 7.1 Background 462**
 - 7.1.1 Image Pyramids 463
 - 7.1.2 Subband Coding 466
 - 7.1.3 The Haar Transform 474
- 7.2 Multiresolution Expansions 477**
 - 7.2.1 Series Expansions 477
 - 7.2.2 Scaling Functions 479
 - 7.2.3 Wavelet Functions 483
- 7.3 Wavelet Transforms in One Dimension 486**
 - 7.3.1 The Wavelet Series Expansions 486
 - 7.3.2 The Discrete Wavelet Transform 488
 - 7.3.3 The Continuous Wavelet Transform 491
- 7.4 The Fast Wavelet Transform 493**
- 7.5 Wavelet Transforms in Two Dimensions 501**
- 7.6 Wavelet Packets 510**
- Summary 520**
- References and Further Reading 520**
- Problems 521**

8 Image Compression 525

- 8.1 Fundamentals 526**
 - 8.1.1 Coding Redundancy 528
 - 8.1.2 Spatial and Temporal Redundancy 529
 - 8.1.3 Irrelevant Information 530
- 8.1.4 Measuring Image Information 531**
- 8.1.5 Fidelity Criteria 534

- 8.1.6 Image Compression Models 536
- 8.1.7 Image Formats, Containers, and Compression Standards 538
- 8.2 Some Basic Compression Methods 542**
 - 8.2.1 Huffman Coding 542
 - 8.2.2 Golomb Coding 544
 - 8.2.3 Arithmetic Coding 548
 - 8.2.4 LZW Coding 551
 - 8.2.5 Run-Length Coding 553
 - 8.2.6 Symbol-Based Coding 559**
 - 8.2.7 Bit-Plane Coding 562**
 - 8.2.8 Block Transform Coding 566
 - 8.2.9 Predictive Coding 584**
 - 8.2.10 Wavelet Coding 604**
- 8.3 Digital Image Watermarking 614**
 - Summary 621
- References and Further Reading 622
- Problems 623

9 Morphological Image Processing 627

- 9.1 Preliminaries 628**
- 9.2 Erosion and Dilation 630**
 - 9.2.1 Erosion 631
 - 9.2.2 Dilation 633
 - 9.2.3 Duality 635
- 9.3 Opening and Closing 635**
- 9.4 The Hit-or-Miss Transformation 640**
- 9.5 Some Basic Morphological Algorithms 642**
 - 9.5.1 Boundary Extraction 642
 - 9.5.2 Hole Filling 643
 - 9.5.3 Extraction of Connected Components 645
 - 9.5.4 Convex Hull 647
 - 9.5.5 Thinning 649
 - 9.5.6 Thickening 650
 - 9.5.7 Skeletons 651
 - 9.5.8 Pruning 654
 - 9.5.9 Morphological Reconstruction 656
 - 9.5.10 Summary of Morphological Operations on Binary Images 664
- 9.6 Gray-Scale Morphology 665**
 - 9.6.1 Erosion and Dilation 666
 - 9.6.2 Opening and Closing 668
 - 9.6.3 Some Basic Gray-Scale Morphological Algorithms 670
 - 9.6.4 Gray-Scale Morphological Reconstruction 676
- Summary 679
- References and Further Reading 679
- Problems 680

10 Image Segmentation 689

- 10.1 Fundamentals 690**
- 10.2 Point Line, and Edge Detection 692**
 - 10.2.1 Background 692
 - 10.2.2 Detection of Isolated Points 696
 - 10.2.3 Line Detection 697
 - 10.2.4 Edge Models 700
 - 10.2.5 Basic Edge Detection 706
 - 10.2.6 More Advanced Techniques for Edge Detection 714
 - 10.2.7 Edge Linking and Boundary Detection 725
- 10.3 Thresholding 738**
 - 10.3.1 Foundation 738
 - 10.3.2 Basic Global Thresholding 741
 - 10.3.3 Optimum Global Thresholding Using Otsu's Method 742
 - 10.3.4 Using Image Smoothing to Improve Global Thresholding 747
 - 10.3.5 Using Edges to Improve Global Thresholding 749
 - 10.3.6 Multiple Thresholds 752**
 - 10.3.7 Variable Thresholding 756
 - 10.3.8 Multivariable Thresholding 761**
- 10.4 Region-Based Segmentation 763**
 - 10.4.1 Region Growing 763
 - 10.4.2 Region Splitting and Merging 766
- 10.5 Segmentation Using Morphological Watersheds 769**
 - 10.5.1 Background 769
 - 10.5.2 Dam Construction 772
 - 10.5.3 Watershed Segmentation Algorithm 774
 - 10.5.4 The Use of Markers 776
- 10.6 The Use of Motion in Segmentation 778**
 - 10.6.1 Spatial Techniques 778
 - 10.6.2 Frequency Domain Techniques 782
- Summary 785
- References and Further Reading 785
- Problems 787

11 Representation and Description 795

- 11.1 Representation 796**
 - 11.1.1 Boundary (Border) Following 796
 - 11.1.2 Chain Codes 798
 - 11.1.3 Polygonal Approximations Using Minimum-Perimeter Polygons 801
 - 11.1.4 Other Polygonal Approximation Approaches 807
 - 11.1.5 Signatures 808

11.1.6	Boundary Segments	810
11.1.7	Skeletons	812
11.2	Boundary Descriptors	815
11.2.1	Some Simple Descriptors	815
11.2.2	Shape Numbers	816
11.2.3	Fourier Descriptors	818
11.2.4	Statistical Moments	821
11.3	Regional Descriptors	822
11.3.1	Some Simple Descriptors	822
11.3.2	Topological Descriptors	823
11.3.3	Texture	827
11.3.4	Moment Invariants	839
11.4	Use of Principal Components for Description	842
11.5	Relational Descriptors	852
	Summary	856
	References and Further Reading	856
	Problems	857
12	Object Recognition	861
12.1	Patterns and Pattern Classes	861
12.2	Recognition Based on Decision-Theoretic Methods	866
12.2.1	Matching	866
12.2.2	Optimum Statistical Classifiers	872
12.2.3	Neural Networks	882
12.3	Structural Methods	903
12.3.1	Matching Shape Numbers	903
12.3.2	String Matching	904
	Summary	906
	References and Further Reading	906
	Problems	907
	<i>Appendix A</i>	910
	<i>Bibliography</i>	915
	<i>Index</i>	943