# BOOK REVIEW

Digital Image Processing, Third Edition

Rafael C. Gonzalez and Richard E. Woods, 954 pages +xxii
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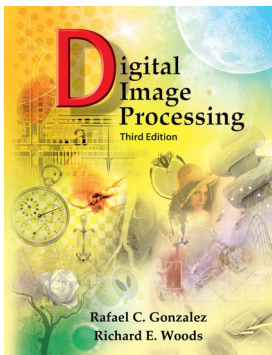
Digital image processing is all about images, definitions, and algorithms. First it is necessary to define two terms: digital images and digital image processing. In this textbook we read that an analog image is a two-dimensional function of spatial (plane) coordinates x and y and an intensity at each point. When the spatial coordinates and the intensity at each point are finite discrete quantities, then the image is defined as a digital image. Digital image processing is the processing of digital images with a digital computer. Each digital image is composed of a finite number of elements, each with a particular location, called pixels.

Digital image processing is an important technique for scientists and engineers who acquire, manipulate, measure, compare, restore, compress, analyze, and data mine images. One interesting feature of a digital image is its scale invariance—an infrared image of a galaxy, a magnetic resonance imaging (MRI) image of the brain, an optical microscope image of cells, an electron microscope image of nuclear pores, and an atomic force microscopy image of gold atoms on a graphite substrate all differ in scale, but they all can be subjected to the techniques of digital image processing. A second feature is the ubiquitous nature of digital image processing. Readers of the *Journal of Biomedical Optics* (JBO) should be familiar with digital images that are acquired with a microscope or an endoscope. In the field of medical imaging, images acquired with MRI, ultrasound, x-ray, and positron emission tomography techniques are subjected to image processing for enhancement, segmentation, measurement, and compression. The key point is that digital image processing can be applied to any digital image. This is a true statement and is not dependent on the scale of the image, nor on the type of instrument that is used to obtain the image. Digital images are acquired, digitally processed, and displayed. The human eye and the visual system enter the domain of digital image processing since visual perception is an important component of the process as well as the subjective assessment of image displays.

The modern investigator has a wide range of free, open-source software packages; for example, *ImageJ* is a public domain Java-based image processing program, complete with tutorials and examples, developed at the National Institutes of Health (http://rsbWeb.nih.gov/ij/docs/index.html). Alternatively, there are many commercial digital imaging processing packages. For example, The Mathworks™ (www.mathworks.com) is the developer of MATLAB® and the Image Processing Toolbox™. To learn the techniques of this toolbox there is a 1256-page *User's Guide to the Image Processing Toolbox™*. In addition, The Mathworks Web site provides many demonstrations of image processing techniques: deblurring, enhancement, image arithmetic, image compression, spatial transforms, image registration, measuring image features, image segmentation, and transforms. Of course, the reader may search the World Wide Web for many other free as well as commercial digital imaging products with varied features, platforms, and prices. Additionally, there are free image processing tutorials available on the World Wide Web. As an example, the Biomedical Imaging Group at the Swiss Federal Institute of Technology Lausanne, Switzerland, provides a free set of image processing tutorials (http://bigwww.epfl.ch/teaching/iplabsite/index.php).

Why then do we need a textbook of digital image processing? Can we not use the free or commercial software packages and learn and teach digital image processing techniques from the World Wide Web? There are several answers to this question. With the plethora of digital image software packages that are available to the researcher, the choice of a software package is best made by one who understands the algorithms used in each digital processing operation. I define the term "understand" to mean that the user has access to the mathematical procedures used as well as the source code used to formulate the software. It also implies a detailed knowledge of the mathematical approximations made in writing the software, the validity of these assumptions, and the limitations of the algorithms.

One approach is to read the original peer-reviewed publications. I strongly recommend the value of studying the original papers in order to understand the thought processes that provide the solutions to research problems. Researchers who are competent in writing code in high-level languages, such as C or C++, can write the necessary software to meet their arbitrary requirements. Experienced researchers will acknowledge that no matter how many functions are available in digital software packages there are always situations that require new code to be written to implement the required algorithms. All of this leads the author to the conclusion and recommendation that a complete understanding of the mathematical basis upon which the techniques of digital image processing are constructed will be beneficial to the end user.

The myriad of books on digital image processing put the researcher and the course instructor in a difficult situation: the

key question is how to select the appropriate textbook. I highly recommend *Digital Image Processing, Third Edition* as an outstanding textbook, and I will provide the reader with the basis of this conclusion. Additionally, there is a companion book, *Digital Image Processing Using MATLAB*, by Gonzalez, Woods, and Eddins that was published in 2004.

In 1977, Gonzalez and Wintz published the first edition of *Digital Image Processing*, and the second edition was published in 1987. Gonzalez and Woods published their editions of *Digital Image Processing* in 1992, 2002, and 2008. While consensus is not the sole factor in selecting a textbook, the fact that *Digital Image Processing* has been adopted in more than 1000 institutions in over 50 countries is very significant. The authors maintain a dialogue with their readers in order to gain suggestions for the required revisions and the addition of new material. For the third edition of their classic textbook they polled faculty, students, and independent reviewers in 134 institutions from 32 countries.

In their third edition, the authors of this classic textbook continue to place their pedagogical emphasis on the fundamentals. Many new features were added: a revision of the material on intensity transformation, spatial correlation, convolution, and their application to spatial filtering; a new discussion of fuzzy sets; a new chapter on the discrete Fourier transform and frequency domain processing; a new section on computerized tomography; a new discussion of wavelets; a new chapter on data compression; a revised discussion of gray-scale morphology and advanced morphological algorithms; a new discussion of the Marr-Hildreth and Canny edge-detection algorithms; and updated references and exercises.

There are several features that increase the readability and utility of this textbook. Each chapter begins with a preview that gives the overview and describes the content of each section. All of the terms are set in italics for emphasis. The figures, many of which are in full color, are well designed and located adjacent to the subject matter that they illustrate. Every equation is given a separate number, and all of the terms are clearly defined. Each mathematical image processing operation is illustrated with real-world examples. At the end of each chapter there is a concise summary, an annotated list of references, and suggestions for further reading. Also, there are exercises that force the reader to apply the previous materials explained in the chapter and also to be creative in their approach to problem solving. The book's Web site contains the solutions to many of the problems. There is an appendix that contains code tables for use in compression, a comprehensive bibliography, and an index.

The publisher maintains a book Web site that is open to everyone (not only purchasers of the book): http://www.prenhall.com/gonzalezwoods. I recommend this Web site, and I have found the numerous tutorials, many of which are related to MATLAB®, to be good learning tools. The projected audience is college seniors and first-year graduate students who are familiar with matrices, vectors, probability, statistics, linear systems, and computer programming. For other readers the tutorial on matrices, vectors, and eigenvalues and the tutorial on probability and random variables are useful preparations for studying the textbook.

Digital Image Processing is an advanced textbook and is most suitable for those with an appropriate mathematical background. The book gives many complete derivations, and that alone separates it from many other books. The derivation of the discrete Fourier transform is one example of the comprehensive nature of the textbook.

Several chapters of the book are devoted to mathematical morphology that is based on the language of set theory. Readers of JBO will find these chapters extremely well written, clear in exposition, replete with examples of real images, and applicable to the extraction of features in the images. The modern techniques of mathematical morphology provide the researcher with powerful tools for image segmentation. The basic techniques of point, line, and edge detection are extended to several of the more advanced techniques, such as the Marr-Hildreth edge detector, the Canny edge detector, the Hough transform for curve detection, and segmentation using morphological watersheds. The final chapter is devoted to the topic of object recognition, something that humans are very good at; we can easily recognize family members, even with different clothing, posture, and viewing orientation. However, it is still difficult to achieve machine vision techniques that can identify nuclei that are associated with cancer cells.

In summary, I found *Digital Image Processing, Third Edition* eminently suitable as a textbook for the senior-level university student or for graduate students. I recommend that students take a course (two semesters) that covers the full content of the textbook, and also that they work out the exercises that are provided at the end of each chapter. These fundamentals of image processing will give them the tools to solve problems as they arise during their research. *Digital Image Processing, Third Edition*, together with the materials on the books Web site, is highly recommended for all researchers and educators concerned with digital images and their manipulation and analysis.

Barry R. Masters is a visiting scientist in the Department of Biological Engineering at the Massachusetts Institute of Technology, and was formerly a professor in anatomy at the Uniformed Services University of the Health Sciences. He is a Fellow of both the Optical Society of America and SPIE. He has published 80 refereed research papers and 110 book chapters. He is the editor or author of *Noninvasive Diagnostic Techniques in Ophthalmology*; *Medical Optical Tomography: Functional Imaging and Monitoring*; *Selected Papers on Confocal Microscopy*; *Selected Papers on Optical Low-Coherence Reflectometry and Tomography*; *Selected Papers on Multiphoton Excitation Microscopy*; and *Confocal Microscopy and Multiphoton Excitation Microscopy: the Genesis of Live Cell Imaging*, and (with Peter So) *Handbook of Biomedical Nonlinear Optical Microscopy*. He is a member of the editorial board of three journals: *Computerized Medical Imaging and Graphics*; *Graefes Archive for Clinical and Experimental Ophthalmology*; and *Ophthalmic Research*. His research interests include the development of *in vivo* microscopy of the human eye and skin and the fractal analysis of branching vascular patterns.