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DIGITAL IMAGE PROCESSING

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PIKS Inside

Third Edition

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To my wife, Shelly
whose image needs no enhancement

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PREFACE

In January 1978, I began the preface to the first edition of *Digital Image Processing* with the following statement:

The field of image processing has grown considerably during the past decade with the increased utilization of imagery in myriad applications coupled with improvements in the size, speed, and cost effectiveness of digital computers and related signal processing technologies. Image processing has found a significant role in scientific, industrial, space, and government applications.

In January 1991, in the preface to the second edition, I stated:

Thirteen years later as I write this preface to the second edition, I find the quoted statement still to be valid. The 1980s have been a decade of significant growth and maturity in this field. At the beginning of that decade, many image processing techniques were of academic interest only; their execution was too slow and too costly. Today, thanks to algorithmic and implementation advances, image processing has become a vital cost-effective technology in a host of applications.

Now, in this beginning of the twenty-first century, image processing has become a mature engineering discipline. But advances in the theoretical basis of image processing continue. Some of the reasons for this third edition of the book are to correct defects in the second edition, delete content of marginal interest, and add discussion of new, important topics. Another motivating factor is the inclusion of interactive, computer display imaging examples to illustrate image processing concepts. Finally, this third edition includes computer programming exercises to bolster its theoretical content. These exercises can be implemented using the Programmer's Imaging Kernel System (PIKS) application program interface (API). PIKS is an International

Standards Organization (ISO) standard library of image processing operators and associated utilities. The PIKS Core version is included on a CD affixed to the back cover of this book.

The book is intended to be an "industrial strength" introduction to digital image processing to be used as a text for an electrical engineering or computer science course in the subject. Also, it can be used as a reference manual for scientists who are engaged in image processing research, developers of image processing hardware and software systems, and practicing engineers and scientists who use image processing as a tool in their applications. Mathematical derivations are provided for most algorithms. The reader is assumed to have a basic background in linear system theory, vector space algebra, and random processes. Proficiency in C language programming is necessary for execution of the image processing programming exercises using PIKS.

The book is divided into six parts. The first three parts cover the basic technologies that are needed to support image processing applications. Part 1 contains three chapters concerned with the characterization of continuous images. Topics include the mathematical representation of continuous images, the psychophysical properties of human vision, and photometry and colorimetry. In Part 2, image sampling and quantization techniques are explored along with the mathematical representation of discrete images. Part 3 discusses two-dimensional signal processing techniques, including general linear operators and unitary transforms such as the Fourier, Hadamard, and Karhunen–Loeve transforms. The final chapter in Part 3 analyzes and compares linear processing techniques implemented by direct convolution and Fourier domain filtering.

The next two parts of the book cover the two principal application areas of image processing. Part 4 presents a discussion of image enhancement and restoration techniques, including restoration models, point and spatial restoration, and geometrical image modification. Part 5, entitled "Image Analysis," concentrates on the extraction of information from an image. Specific topics include morphological image processing, edge detection, image feature extraction, image segmentation, object shape analysis, and object detection.

Part 6 discusses the software implementation of image processing applications. This part describes the PIKS API and explains its use as a means of implementing image processing algorithms. Image processing programming exercises are included in Part 6.

This third edition represents a major revision of the second edition. In addition to Part 6, new topics include an expanded description of color spaces, the Hartley and Daubechies transforms, wavelet filtering, watershed and snake image segmentation, and Mellin transform matched filtering. Many of the photographic examples in the book are supplemented by executable programs for which readers can adjust algorithm parameters and even substitute their own source images.

Although readers should find this book reasonably comprehensive, many important topics allied to the field of digital image processing have been omitted to limit the size and cost of the book. Among the most prominent omissions are the topics of pattern recognition, image reconstruction from projections, image understanding,

image coding, scientific visualization, and computer graphics. References to some of these topics are provided in the bibliography.

WILLIAM K. PRATT

Los Altos, California
August 2000

ACKNOWLEDGMENTS

The first edition of this book was written while I was a professor of electrical engineering at the University of Southern California (USC). Image processing research at USC began in 1962 on a very modest scale, but the program increased in size and scope with the attendant international interest in the field. In 1971, Dr. Zohrab Kaprielian, then dean of engineering and vice president of academic research and administration, announced the establishment of the USC Image Processing Institute. This environment contributed significantly to the preparation of the first edition. I am deeply grateful to Professor Kaprielian for his role in providing university support of image processing and for his personal interest in my career.

Also, I wish to thank the following past and present members of the Institute's scientific staff who rendered invaluable assistance in the preparation of the first-edition manuscript: Jean-François Abramatic, Harry C. Andrews, Lee D. Davisson, Olivier Faugeras, Werner Frei, Ali Habibi, Anil K. Jain, Richard P. Kruger, Nasser E. Nahi, Ramakant Nevatia, Keith Price, Guner S. Robinson, Alexander A. Sawchuk, and Lloyd R. Welsh.

In addition, I sincerely acknowledge the technical help of my graduate students at USC during preparation of the first edition: Ikram Abdou, Behnam Ashjari, Wen-Hsiung Chen, Faramarz Davarian, Michael N. Huhns, Kenneth I. Laws, Sang Uk Lee, Clanton Mancill, Nelson Mascarenhas, Clifford Reader, John Roese, and Robert H. Wallis.

The first edition was the outgrowth of notes developed for the USC course "Image Processing." I wish to thank the many students who suffered through the

early versions of the notes for their valuable comments. Also, I appreciate the reviews of the notes provided by Harry C. Andrews, Werner Frei, Ali Habibi, and Ernest L. Hall, who taught the course.

With regard to the first edition, I wish to offer words of appreciation to the Information Processing Techniques Office of the Advanced Research Projects Agency, directed by Larry G. Roberts, which provided partial financial support of my research at USC.

During the academic year 1977–1978, I performed sabbatical research at the Institut de Recherche d'Informatique et Automatique in LeChesney, France and at the Université de Paris. My research was partially supported by these institutions, USC, and a Guggenheim Foundation fellowship. For this support, I am indebted.

I left USC in 1979 with the intention of forming a company that would put some of my research ideas into practice. Toward that end, I joined a startup company, Compression Labs, Inc., of San Jose, California. There I worked on the development of facsimile and video coding products with Dr., Wen-Hsiung Chen and Dr. Robert H. Wallis. Concurrently, I directed a design team that developed a digital image processor called VICOM. The early contributors to its hardware and software design were William Bryant, Howard Halverson, Stephen K. Howell, Jeffrey Shaw, and William Zech. In 1981, I formed Vicom Systems, Inc., of San Jose, California, to manufacture and market the VICOM image processor. Many of the photographic examples in this book were processed on a VICOM.

Work on the second edition began in 1986. In 1988, I joined Sun Microsystems, of Mountain View, California. At Sun, I collaborated with Stephen A. Howell and Ihtisham Kabir on the development of image processing software. During my time at Sun, I participated in the specification of the Programmers Imaging Kernel application program interface which was made an International Standards Organization standard in 1994. Much of the PIKS content is present in this book. Some of the principal contributors to PIKS include Timothy Butler, Adrian Clark, Patrick Krolak, and Gerard A. Paquette.

In 1993, I formed PixelSoft, Inc., of Los Altos, California, to commercialize the PIKS standard. The PIKS Core version of the PixelSoft implementation is affixed to the back cover of this edition. Contributors to its development include Timothy Butler, Larry R. Hubble, and Gerard A. Paquette.

In 1996, I joined Photon Dynamics, Inc., of San Jose, California, a manufacturer of machine vision equipment for the inspection of electronics displays and printed circuit boards. There, I collaborated with Larry R. Hubble, Sunil S. Sawkar, and Gerard A. Paquette on the development of several hardware and software products based on PIKS.

I wish to thank all those previously cited, and many others too numerous to mention, for their assistance in this industrial phase of my career. Having participated in the design of hardware and software products has been an arduous but intellectually rewarding task. This industrial experience, I believe, has significantly enriched this third edition.

I offer my appreciation to Ray Schmidt, who was responsible for many photographic reproductions in the book, and to Kris Pendelton, who created much of the line art. Also, thanks are given to readers of the first two editions who reported errors both typographical and mental.

Most of all, I wish to thank my wife, Shelly, for her support in the writing of the third edition.

W. K. P.