国外电子与通信教材系列

英文版

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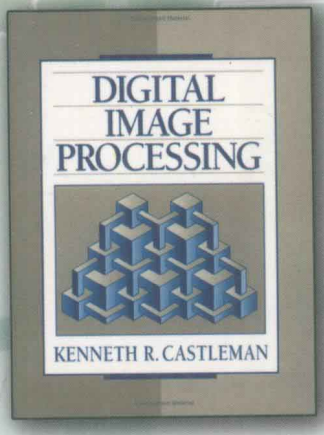
数字图像处理



Digital Image Processing

[美] Kenneth R. Castleman 著

電子工業出版社
PUBLISHING HOUSE OF ELECTRONICS INDUSTRY
http://www.phei.com.cn

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［美］ Kenneth R. Castleman 著

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北京 · BEIJING

内容简介

本书是数字图像处理理论与实践相结合的成功之作，强调如何应用理论知识解决工业和科学研究中常见的实际问题。本书着重阐述了数字图像处理的基本概念和实用技术，使读者能够使用这些技术解决数字图像处理过程中所遇到的各种问题。全书共22章，第1章至第5章讲述数字化图像及其显示，图像处理软件；第6章至第8章讲授点、代数和几何运算；第9章至第15章讲授线性系统理论、傅里叶变换、离散图像变换和小波变换；第16章至第20章讲授图像复原、图像压缩及模式识别；第21章至第22章讲授彩色、多光谱图像处理及三维图像处理。

本书可供大学本科生和研究生作为教材或参考书，也可作为从事数字图像处理研究和开发的技术人员的参考书。

版权贸易合同登记号　图字：01-2008-1831

图书在版编目（CIP）数据

数字图像处理 = Digital Image Processing: 英文 /（美）卡斯尔曼（Castleman K. R.）著.
北京：电子工业出版社，2008.5
（国外电子与通信教材系列）
ISBN 978-7-121-06364-0

Ⅰ.数… Ⅱ.卡… Ⅲ.数字图像处理－教材－英文 Ⅳ.TN911.73

中国版本图书馆CIP数据核字（2008）第048649号

责任编辑：冯小贝
印　　刷：北京市天竺颖华印刷厂
装　　订：三河市金马印装有限公司
出版发行：电子工业出版社
　　北京市海淀区万寿路173信箱　邮编：100036
开　　本：787 × 980　1/16　　印张：43　　字数：963千字
印　　次：2008年5月第1次印刷
定　　价：69.00元

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序

2001年7月间，电子工业出版社的领导同志邀请各高校十几位通信领域方面的老师，商量引进国外教材问题。与会同志对出版社提出的计划十分赞同，大家认为，这对我国通信事业、特别是对高等院校通信学科的教学工作会很有好处。

教材建设是高校教学建设的主要内容之一。编写、出版一本好的教材，意味着开设了一门好的课程，甚至可能预示着一个崭新学科的诞生。20世纪40年代MIT林肯实验室出版的一套28本雷达丛书，对近代电子学科、特别是对雷达技术的推动作用，就是一个很好的例子。

我国领导部门对教材建设一直非常重视。20世纪80年代，在原教委教材编审委员会的领导下，汇集了高等院校几百位富有教学经验的专家，编写、出版了一大批教材；很多院校还根据学校的特点和需要，陆续编写了大量的讲义和参考书。这些教材对高校的教学工作发挥了极好的作用。近年来，随着教学改革不断深入和科学技术的飞速进步，有的教材内容已比较陈旧、落后，难以适应教学的要求，特别是在电子学和通信技术发展神速、可以讲是日新月异的今天，如何适应这种情况，更是一个必须认真考虑的问题。解决这个问题，除了依靠高校的老师和专家撰写新的符合要求的教科书外，引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，是会有好处的。

一年多来，电子工业出版社为此做了很多工作。他们成立了一个“国外电子与通信教材系列”项目组，选派了富有经验的业务骨干负责有关工作，收集了230余种通信教材和参考书的详细资料，调来了100余种原版教材样书，依靠由20余位专家组成的出版委员会，从中精选了40多种，内容丰富，覆盖了电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等方面，既可作为通信专业本科生和研究生的教学用书，也可作为有关专业人员的参考材料。此外，这批教材，有的翻译为中文，还有部分教材直接影印出版，以供教师用英语直接授课。希望这些教材的引进和出版对高校通信教学和教材改革能起一定作用。

在这里，我还要感谢参加工作的各位教授、专家、老师与参加翻译、编辑和出版的同志们。各位专家认真负责、严谨细致、不辞辛劳、不怕琐碎和精益求精的态度，充分体现了中国教育工作者和出版工作者的良好美德。

随着我国经济建设的发展和科学技术的不断进步，对高校教学工作会不断提出新的要求和希望。我想，无论如何，要做好引进国外教材的工作，一定要联系我国的实际。教材和学术专著不同，既要注意科学性、学术性，也要重视可读性，要深入浅出，便于读者自学；引进的教材要适应高校教学改革的需要，针对目前一些教材内容较为陈旧的问题，有目的地引进一些先进的和正在发展中的交叉学科的参考书；要与国内出版的教材相配套，安排好出版英文原版教材和翻译教材的比例。我们努力使这套教材能尽量满足上述要求，希望它们能放在学生们的课桌上，发挥一定的作用。

最后，预祝“国外电子与通信教材系列”项目取得成功，为我国电子与通信教学和通信产业的发展培土施肥。也恳切希望读者能对这些书籍的不足之处、特别是翻译中存在的问题，提出意见和建议，以便再版时更正。

吴佑寿

中国工程院院士、清华大学教授

“国外电子与通信教材系列”出版委员会主任

出 版 说 明

进入21世纪以来，我国信息产业在生产和科研方面都大大加快了发展速度，并已成为国民经济发展的支柱产业之一。但是，与世界上其他信息产业发达的国家相比，我国在技术开发、教育培训等方面都还存在着较大的差距。特别是在加入WTO后的今天，我国信息产业面临着国外竞争对手的严峻挑战。

作为我国信息产业的专业科技出版社，我们始终关注着全球电子信息技术的发展方向，始终把引进国外优秀电子与通信信息技术教材和专业书籍放在我们工作的重要位置上。在2000年至2001年间，我社先后从世界著名出版公司引进出版了40余种教材，形成了一套“国外计算机科学教材系列”，在全国高校以及科研部门中受到了欢迎和好评，得到了计算机领域的广大教师与科研工作者的充分肯定。

引进和出版一些国外优秀电子与通信教材，尤其是有选择地引进一批英文原版教材，将有助于我国信息产业培养具有国际竞争能力的技术人才，也将有助于我国国内在电子与通信教学工作中掌握和跟踪国际发展水平。根据国内信息产业的现状、教育部《关于“十五”期间普通高等教育教材建设与改革的意见》的指示精神以及高等院校老师们反映的各种意见，我们决定引进“国外电子与通信教材系列”，并随后开展了大量准备工作。此次引进的国外电子与通信教材均来自国际著名出版商，其中影印教材约占一半。教材内容涉及的学科方向包括电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等，其中既有本科专业课程教材，也有研究生课程教材，以适应不同院系、不同专业、不同层次的师生对教材的需求，广大师生可自由选择和自由组合使用。我们还将与国外出版商一起，陆续推出一些教材的教学支持资料，为授课教师提供帮助。

此外，“国外电子与通信教材系列”的引进和出版工作得到了教育部高等教育司的大力支持和帮助，其中的部分引进教材已通过“教育部高等学校电子信息科学与工程类专业教学指导委员会”的审核，并得到教育部高等教育司的批准，纳入了“教育部高等教育司推荐——国外优秀信息科学与技术系列教学用书”。

为做好该系列教材的翻译工作，我们聘请了清华大学、北京大学、北京邮电大学、南京邮电大学、东南大学、西安交通大学、天津大学、西安电子科技大学、电子科技大学、中山大学、哈尔滨工业大学、西南交通大学等著名高校的教授和骨干教师参与教材的翻译和审校工作。许多教授在国内电子与通信专业领域享有较高的声望，具有丰富的教学经验，他们的渊博学识从根本上保证了教材的翻译质量和专业学术方面的严格与准确。我们在此对他们的辛勤工作与贡献表示衷心的感谢。此外，对于编辑的选择，我们达到了专业对口；对于从英文原书中发现的错误，我们通过与作者联络、从网上下载勘误表等方式，逐一进行了修订；同时，我们对审校、排版、印制质量进行了严格把关。

今后，我们将进一步加强同各高校教师的密切关系，努力引进更多的国外优秀教材和教学参考书，为我国电子与通信教材达到世界先进水平而努力。由于我们对国内外电子与通信教育的发展仍存在一些认识上的不足，在选题、翻译、出版等方面的工作中还有许多需要改进的地方，恳请广大师生和读者提出批评及建议。

电子工业出版社

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Preface

In the 16 years since the publication of my first book on this topic, there has been a major expansion in the utilization of digital image processing. Algorithms that could run only on mainframe computers in the 1960s and minicomputers in the 1970s migrated to the desktop in the 1980s. Personal computers transformed from something a few dedicated hobbyists built in the mid-1970s into a common home office component. The jargon of personal computers became a universal language that bridged the oceans between the United States, Europe, and Asia.

Public awareness of digital image processing has been greatly increased by video games, digital video special effects used in the entertainment industry, and articles in the popular press. Present trends indicate a continuation of the explosive growth of digital image-processing applications well into the next century.

Perhaps the most significant impact of digital image processing in the 1990s will be in the area of applications to real-world problems. This book is aimed at the reader who intends to use the technology for research or commercial purposes. It also provides a foundation for those who seek to advance the state of the art.

While the scope and scale of digital image-processing applications have changed dramatically, other aspects of the field have not. For example, many of the basic techniques that perform reliably in practice today are those that were first applied in the early days of digital imaging. While several exciting new theoretical areas have opened up, generally they build upon, rather than replace, what has served well in the past.

With the recent advances in computer technology, some of the issues treated in the earlier work are no longer of major concern. These are deemphasized in this book, while several

relevant new topics have been included. New examples serve to illustrate further how the theory can be applied to the type of problems that commonly occur in industry and research.

Perhaps most significantly, a set of exercises and suggestions for projects completes each chapter. These have been selected to build the insight and understanding that are most useful to one endeavoring to apply the technology to problems of the real world. The majority of the exercises and projects emulate actual situations a professional faces working in the field of digital image processing. They are intended to give the reader a head start in gaining the insight that supplements a theoretical knowledge and can come only from the experience of solving real problems. In my own estimation, one who not only knows how to solve the problems and carry out the projects, but has actually done most of them, will be ready to take his or her place on the most productive image-processing applications team.

For about 25 years, I have had the opportunity to observe the efforts of many individuals applying digital image-processing techniques to problems offered by the real world. A few of these individuals have established an enduring track record of solid success on almost every attempt. They have consistently contributed innovative and effective solutions that creatively employ the tools of the discipline.

These highly productive individuals demonstrably hold several characteristics in common. One can venture to assume that these characteristics constitute a formula for success, to *whatever extent such a thing can exist in this field.*

Uniformly, these successful persons have (1) a genuine interest in—even a fascination with—the technology involved, (2) a thorough understanding of the fundamentals of this highly multidisciplinary technology, (3) a conceptual type of understanding (as opposed to rote memorization of totally abstract theory), and (4) a knack for seeing problems visually, graphically, and from more than one viewpoint. In line with this last point, they often find themselves hard pressed to explain their ideas without the aid of a graph or drawing.

This book is designed to help the reader develop the last three of these traits and perhaps enhance the first as well. The selection of materials for inclusion (and, equally important, for omission), the examples used, the references cited, and the exercises and suggestions for projects are all directed toward this goal.

In the field of digital image processing, mathematical analysis forms the stable basis upon which one can make definite predictions regarding the performance of a digital imaging system. In this treatment, however, mathematics is employed more as a faithful servant than as a ruthless master. The emphasis is on developing a conceptual understanding, and the analysis is used to support this goal.

The organization of this book generally follows that of the earlier text, simply because that particular flow of development proved to serve its purpose well. The level of mathematical complexity increases gradually through the first two parts of the book. While many readers have the background in mathematics required to begin the discussion with sampling theory and the Fourier transform, others do not.

More importantly, though, many of the most important concepts can be presented without the aid of advanced mathmatics. Thus, we are able to avoid an additional element of complexity in the interest of making the learning process less burdensome and more appealing to all readers. As a general rule, topics receive attention in relation to their importance, rather than their complexity.

The field of digital image processing has now become so rich with technology that it is impossible to cover all aspects of it in a single volume of reasonable size. Hence, we concentrate upon those techniques that prove most useful in practice and leave most of the mathematical proofs to the references. Constraints of paper and ink further make it impossible to include nearly as many examples of images as would be desirable. (See [1] for an excellent source of these.)

Part 1 presents several important concepts that do not require detailed mathematical analysis for a basic understanding of them. Part 2 addresses techniques that rely more heavily upon their mathematical underpinning and elaborates analytically upon certain concepts introduced in Part 1. Part 3 addresses applications more specifically than they are addressed in earlier chapters.

A Note to Instructors. The development of this text has been accompanied by an accumulation of example digital images and problem solutions worked out in MathCAD™ [2] and WiT™ [3]. These are available from the World Wide Web site that supports this book (http://www.phoenix.net/~castlman/). The author can be reached via the publisher, through Compuserve (70214,1275), on the Internet (castleman@persci.com or castlman@phoenix.net) or Usenet (sci.image.processing).

A Note to Students. Digital imaging is a merger of several disciplines, and its nomenclature comes from many diverse fields. Often ordinary words are pressed into special new usage without warning. This can be quite confusing when it catches the reader unaware. Many of these specialized words are defined in Appendix 1. If the concept presented in a paragraph is not clear, check for a word that doesn't seem to fit. If there is one, look in the glossary or a dictionary for clarification. Frequent reference to the glossary and a dictionary is good insurance against difficulties in understanding the subject.

Image processing is best learned by a combination of study and application. One develops considerable insight by *using* the theory, working with actual imaging problems and image processing equipment. A balance between theory and practice keeps the subject interesting. Problems and projects are included at the end of each chapter for this purpose.

REFERENCES

1. G. A. Baxes, *Digital Image Processing: Principles and Applications*, Wiley, New York, 1994.
2. MathSoft, Inc., 201 Broadway, Cambridge, MA 02139.
3. Logical Vision, Ltd., 4299 Canada Way, Ste. 265, Bunaby, B.C., Canada V5G 1H3.

Acknowledgments

The author wishes to thank the following people who have contributed significantly to the publication of this book: Dr. Henry Fuchs, Dr. Michael Shantz and Dr. Meir Weinstein collaborated in the work on three-dimensional reconstruction from optical sections in Chapter 22. Terry Riopka of Perceptive Scientific Instruments. Inc. (PSII) contributed to the discussion of neural networks in Chapter 20. Robert Selzer and Nancy Cornelius of the Jet Propulsion Laboratory (NASA/JPL) contributed to the discussion of curve and surface fitting in Chapter 19. Dr. Qiang Wu (PSII) contributed to the chapter on wavelet transforms.

Figures were generously supplied by Prof I. T. Young of the Delft Institute of Technology, The Netherlands; Henry Hui Li of HNC Software, Inc., in San Diego; Dr. Jian Lu of the University of California, Davis; Mr. Shishir Shah and Dr. J. K. Aggarwal of The University of Texas at Austin; Marcus Gross and Lars Lippert of the Swiss Federal Institute of Technology, Zurich; Dr. James Blinn of NASA/JPL; Luc Nocente of Noesis Vision; Dr. Bruce Cameron and Dr. Qiang Wu of PSII; and NASA/JPL.

Several reviewers made valuable comments and suggestions that improved the presentation considerably. These include Dr. Stuart Taylor (Mayo Foundation) and Dr. David Shotton (Oxford University). Also among them are Dr. Bruce F. Cameron, Steve Clarner, Chuck Johnson, Robert McGill, Robert S. Rosser, and Dr. Qiang Wu, all of PSII. Special thanks go to the four publishers' reviewers whose thoughtful comments on an early manuscript resulted in considerable improvement thereto, and to Mr. Brian Baker, publisher's copy editor, whose thoughtful comments significantly improved the clarity of the text.

Preparation of the manuscript and figures was transformed from a burdensome task to an enjoyable journey by the competent and tireless assistance of Deborah K. Cate, Sheri D.

Breaux, and Donna Call of PSII. I would also like to thank Mr. Robin Downes, Director of University Libraries, the University of Houston, and his staff at the M. D. Anderson Library for making available their excellent research facilities.

Luc Nocente of Noesis Vision made available Visilog 4.3, which was used in the preparation of several of the figures. The manuscript was prepared in Word 6.0 (Microsoft). The numerical examples were computed in MathCAD+ 5.0 (MathSoft, Inc.), and many of the drawings were done in Visio 3.0 (Shapeware Corporation).

The author has benefited significantly over the years from discussions with gifted colleagues. These include Dr. Robert Nathan, Dr. Ray Wall, and Robert Selzer (all of NASA/JPL), Dr. Benjamin S. White (Exxon Research Laboratory), Dr. Kenneth Price (Stephen F. Austin State University), and Donald Winkler (PSII), as well as many of the authors whose work is cited herein. Also of note in this regard are Prof. I. T. Young (Delft Institute of Technology), Dr. M. Don Graham (Coulter Corp.), Dr. David Zahniser (Cytyc Corp.), Dr. Jeff Brenner (Tufts New England Medical Center), Dr. James Baccus (Cell Analysis Systems) Dr. Mortimer Mendelsohn (Lawrence Livermore Laboratory) and Dr. Brian Mayall (University of California, San Francisco).

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