

Digital Image Compression Techniques

BOOKS IN THE SPIE TUTORIAL TEXTS SERIES

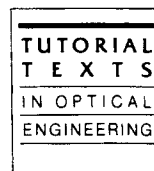
- *Basic Electro-Optics for Electrical Engineers*, Glenn D. Boreman, Vol. TT31
- *Optical Engineering Fundamentals*, Bruce H. Walker, Vol. TT30
- *Introduction to Radiometry*, William L. Wolfe, Vol. TT29
- *An Introduction to Interpretation of Graphic Images*, Sergey Ablameyko, Vol. TT27
- *Thermal Infrared Characterization of Ground Targets and Backgrounds*, Pieter A. Jacobs, Vol. TT26
- *Introduction to Imaging Spectrometers*, William L. Wolfe, Vol. TT25
- *Introduction to Infrared System Design*, William L. Wolfe, Vol. TT24
- *Introduction to Computer-based Imaging Systems*, Divyendu Sinha, Edward R. Dougherty, Vol. TT23
- *Optical Communication Receiver Design*, Stephen B. Alexander, Vol. TT22
- *Mounting Lenses in Optical Instruments*, Paul R. Yoder, Jr., Vol. TT21
- *Optical Design Fundamentals for Infrared Systems*, Max J. Riedl, Vol. TT20
- *An Introduction to Real-Time Imaging*, Edward R. Dougherty, Phillip A. Laplante, Vol. TT19
- *Introduction to Wavefront Sensors*, Joseph M. Geary, Vol. TT18
- *Integration of Lasers and Fiber Optics into Robotic Systems*, Janusz A. Marszalec, Elzbieta A. Marszalec, Vol. TT17
- *An Introduction to Nonlinear Image Processing*, Edward R. Dougherty, Jaakko Astola, Vol. TT16
- *Introduction to Optical Testing*, Joseph M. Geary, Vol. TT15
- *Sensor and Data Fusion Concepts and Applications*, Lawrence A. Klein, Vol. TT14
- *Practical Applications of Infrared Thermal Sensing and Imaging Equipment*, Herbert Kaplan, Vol. TT13
- *Image Formation in Low-Voltage Scanning Electron Microscopy*, L. Reimer, Vol. TT12
- *Diazonaphthoquinone-based Resists*, Ralph Dammel, Vol. TT11
- *Infrared Window and Dome Materials*, Daniel C. Harris, Vol. TT10
- *An Introduction to Morphological Image Processing*, Edward R. Dougherty, Vol. TT9
- *An Introduction to Optics in Computers*, Henri H. Arsenault, Yunlong Sheng, Vol. TT8
- *Digital Image Compression Techniques*, Majid Rabbani, Paul W. Jones, Vol. TT7
- *Aberration Theory Made Simple*, Virendra N. Mahajan, Vol. TT6
- *Single-Frequency Semiconductor Lasers*, Jens Buus, Vol. TT5
- *An Introduction to Biological and Artificial Neural Networks for Pattern Recognition*, Steven K. Rogers, Matthew Kabrisky, Vol. TT4
- *Laser Beam Propagation in the Atmosphere*, Hugo Weichel, Vol. TT3
- *Infrared Fiber Optics*, Paul Klocek, George H. Sigel, Jr., Vol. TT2
- *Spectrally Selective Surfaces for Heating and Cooling Applications*, C. G. Granqvist, Vol. TT1

Digital Image Compression Techniques

Majid Rabbani
Paul W. Jones

Eastman Kodak Company

Donald C. O'Shea, Series Editor
Georgia Institute of Technology



Volume TT 7



S P I E O P T I C A L E N G I N E E R I N G P R E S S

A Publication of SPIE—The International Society for Optical Engineering
Bellingham, Washington USA

Library of Congress Cataloging-in-Publication Data

Rabbani, Majid, 1955-

Digital image compression techniques / Majid Rabbani and Paul W. Jones.

p. cm. — (Tutorial texts in optical engineering : v. TT 7)

Includes bibliographical references.

ISBN 0-8194-0648-1

1. Image processing—Digital techniques. 2. Coding theory.

I. Jones, Paul W., 1958- . II. Title. III. Series.

TA1632.R23 1991

621.367—dc20

91-7509

CIP

Published by

SPIE—The International Society for Optical Engineering

P.O. Box 10

Bellingham, Washington 98227-0010

Copyright © 1991 The Society of Photo-Optical Instrumentation Engineers

All rights reserved. No part of this publication may be reproduced or distributed in any form or by any means without written permission of the publisher.

Printed in the United States of America

Seventh Printing

Introduction to the Series

These Tutorial Texts provide an introduction to specific optical technologies for both professionals and students. Based on selected SPIE short courses, they are intended to be accessible to readers with a basic physics or engineering background. Each text presents the fundamental theory to build a basic understanding as well as the information necessary to give the reader practical working knowledge. The included references form an essential part of each text for the reader requiring a more in-depth study.

Many of the books in the series will be aimed to readers looking for a concise tutorial introduction to new technical fields, such as CCDs, fiber optic amplifiers, sensor fusion, computer vision, or neural networks, where there may be only limited introductory material. Still others will present topics in classical optics tailored to the interests of a specific audience such as mechanical or electrical engineers. In this respect the Tutorial Text serves the function of a textbook. With its focus on a specialized or advanced topic, the Tutorial Text may also serve as a monograph, although with a marked emphasis on fundamentals.

As the series develops, a broad spectrum of technical fields will be represented. One advantage of this series and a major factor in the planning of future titles is our ability to cover new fields as they are developing, giving people the basic knowledge necessary to understand and apply new technologies.

Donald C. O'Shea
Georgia Institute of Technology

January 1991

To our precious wives, Mojgan and Teresa.

Contents

Preface	xiii
Acknowledgments	xv
I Background	1
1 Digital Images and Image Compression	3
1.1 Digital Image Formation	4
1.2 The Need for Image Compression	5
1.3 Classification of Compression Techniques	6
1.4 Effect of Digitization Parameters on Compression	7
1.5 Image Compression Standardization Activities	8
References	11
II Information Theory Concepts	13
2 Source Models and Entropy	15
2.1 Discrete Memoryless Sources	15
2.2 Extensions of a Discrete Memoryless Source	16
2.3 Markov Sources	17
2.3.1 Example	18
2.4 Extensions of a Markov Source and Adjoint Sources	19
2.4.1 Example	20
2.5 The Noiseless Source Coding Theorem	21
3 Variable-Length Codes	22
3.1 Code Efficiency and Source Extensions	23
3.2 Huffman Codes	24
3.3 Modified Huffman Codes	25
3.4 Limitations of Huffman Coding	27

3.5	Arithmetic Coding	28
3.5.1	The IBM Q-coder	31
4	Entropy Estimation and Lossless Compression	33
4.1	Structure and Entropy of the English Language	34
4.2	Predictability and Entropy of the English Language	36
4.3	Predictability and Entropy of Natural Images	37
5	Rate-Distortion Theory and Lossy Compression	39
	References	42
III	Lossless Compression Techniques	45
	Introduction	47
6	Bit Plane Encoding	49
6.1	Gray Code	49
6.2	Runlength Encoding of Bit Planes	51
6.3	Arithmetic Encoding of Bit Planes	54
7	Lossless Predictive Coding	58
7.1	DPCM Predictor	59
7.2	Huffman Encoding of Differential Images	60
7.3	Arithmetic Encoding of Differential Images	65
8	Lossy Plus Lossless Residual Encoding	68
	References	70
IV	Lossy Compression Techniques	73
	Introduction	75
9	Lossy Predictive Coding	79
9.1	Differential Pulse Code Modulation (DPCM)	79
9.1.1	Predictor optimization	81
9.1.2	Quantizer optimization	83
9.2	Adaptive DPCM	87
9.2.1	Adaptive prediction	88
9.2.2	Adaptive quantization	88
9.3	DPCM Results	92
9.4	Implementation Issues/Complexity of ADPCM	92

10	Transform Coding	102
10.1	Transforms as Coordinate Axes Rotations	103
10.2	Transforms as Basis Function Decompositions	105
10.3	Image Transforms	106
10.3.1	Karhunen-Loève transform (KLT)	107
10.3.2	Discrete Fourier transform (DFT)	107
10.3.3	Discrete cosine transform (DCT)	108
10.3.4	Walsh-Hadamard transform (WHT)	111
10.4	Transform Coding Strategies	111
10.4.1	Zonal sample selection	111
10.4.2	Threshold sample selection	113
10.5	JPEG DCT Algorithm	113
10.5.1	JPEG baseline system	114
10.5.2	JPEG DCT example	116
10.6	JPEG DCT Results	121
10.7	Implementation Issues/Complexity of JPEG DCT	121
11	Block Truncation Coding	129
11.1	Quantizer Design	131
11.1.1	Moment-preserving quantizers	131
11.1.2	Error-minimizing quantizers	133
11.2	Source Coding of Bit Map and Reconstruction Levels	134
11.2.1	Reduced bit representation/joint quantization	135
11.2.2	Vector quantization encoding of reconstruction levels	136
11.2.3	Bit map omission	136
11.2.4	Independent/dependent bits	136
11.2.5	VQ encoding of bit map	137
11.3	Adaptive Block Size BTC	137
11.4	BTC Results	138
11.5	Implementation Issues/Complexity of Adaptive AMBTC	139
12	Vector Quantization	144
12.1	Codebook Generation	146
12.1.1	Linde-Buzo-Gray (LBG) algorithm	146
12.1.2	Codebook initialization	148
12.2	Codebook Design: Tree-Structured Codebooks	150
12.3	Codebook Design: Product Codes	151
12.4	Mean/Residual VQ (M/RVQ)	152
12.5	Interpolative/Residual VQ (I/RVQ)	153
12.6	Gain/Shape VQ (G/SVQ)	154
12.7	Classified VQ (CVQ)	154
12.8	Finite-State VQ (FSVQ)	156
12.9	VQ Results	157

12.10	Implementation/Complexity of M/RTVQ and I/RTVQ . . .	159
13	Subband Coding	170
13.1	Analysis/Synthesis Filtering for 1-D Signals	171
13.2	Extension to 2-D Signals	174
13.3	Subband Coding Techniques	180
13.3.1	DPCM encoding	180
13.3.2	DPCM/PCM encoding	180
13.3.3	VQ encoding	180
13.4	Relationship Between Subband and Transform Coding . . .	181
13.5	SBC Results	182
13.6	Implementation Issues/Complexity of SBC/VQ	183
14	Hierarchical Coding	190
14.1	Progressive Transmission	190
14.2	Multiuse Environments	191
14.3	Image Hierarchies	192
14.4	Fixed-Resolution Hierarchies	194
14.4.1	Bit planes	194
14.4.2	Tree-structured VQ	194
14.4.3	Transform-based hierarchical coding	194
14.5	Variable-Resolution Hierarchies	195
14.5.1	Subsampling pyramid	195
14.5.2	Mean pyramids	196
14.5.3	Knowlton's technique	198
14.5.4	Prediction/residual pyramid	199
14.5.5	Hierarchical interpolation	202
14.5.6	Subband pyramid	202
15	Choosing a Lossy Compression Technique	203
15.1	Bit Rate/Quality Performance Summary	207
	References	210
A	Compression of Color Images	217
A.1	Statistical Spectral Compression	218
A.2	HVS Color Encoding	218
	References	221

Preface

Information, in its many forms, is a valuable commodity in today's society, and the amount of information is increasing at a phenomenal rate. As a result, the ability to store, access, and transmit information in an efficient manner has become crucial. This is particularly true in the case of digital images. A large number of bits is typically required to represent even a single digital image, and with the rapid advances in sensor technology and digital electronics, this number grows larger with each new generation of products. Furthermore, the number of digital images created each day increases as more applications are found.

In order to utilize digital images effectively, specific techniques are needed to reduce the number of bits required for their representation. The branch of digital image processing that deals with this problem is called image compression (also picture coding). A wide range of techniques has been developed over the years, and novel approaches continue to emerge. The goal of this book is to lay the groundwork for understanding image compression techniques and to present a number of specific schemes that have proven to be useful. The algorithms discussed in this book are mainly concerned with the compression of continuous-tone, still-frame, monochrome and color images. A consistent image set has been used to illustrate the effect of each compression technique on typical images, thus allowing for a direct comparison of bit rates and reconstructed image quality. However, an important point to consider when viewing these images is that due to limitations of the printing reproduction process, the resolution of these printed images may not be adequate to reveal subtle differences between the various techniques.

This book is divided into four parts. Part I is an introduction to the process of digital image formation and outlines the need for image compression as well as related worldwide standardization activities. Part II presents an overview of information theory concepts commonly used in image compression. The approach in this part is to give the reader a feel for the utility of information theory, and no attempt is made to be mathematically rigorous. The concepts are of general utility in the compression of both bilevel and continuous-tone images. Part III describes techniques for the lossless compression of images, that is, techniques that allow the original image to be reconstructed exactly after compression. Part IV covers the field of lossy image compression as applied to still, continuous-tone images, where much lower bit rates are achieved as compared to lossless techniques, at the expense of errors in the reconstructed image. This part also includes a chapter on hierarchical coding techniques (which may be lossless or lossy). Finally, an appendix on the compression of color images is included.

Acknowledgments

The authors would like to acknowledge our colleagues, Paul Melnychuck and Scott Daly of the Image Coding and Restoration Group at Eastman Kodak Company, who provided valuable insights and information during the writing of this book. We also thank the management of Eastman Kodak Company, and in particular Terry Lund, for providing the necessary resources and support. The comments provided by our reviewers and editors are also gratefully acknowledged.

Digital Image Compression Techniques

