

Contents

Abstract	i
Contents	ix
Preface	xxv
Chapter 1. Introduction to image coding	1
1.1 Data compression for a real world	1
1.2 Digital image coding	2
1.2.1 Image representation and color spaces	3
1.2.2 Lossless and lossy image compression	5
1.3 Background on data compression	6
1.3.1 Entropy coding	6
1.3.2 Definition of entropy	7
1.3.3 Huffman coding	7
1.3.4 Arithmetic coding	8
1.3.5 Adaptive arithmetic coding	9
1.3.6 Models for data compression	10
1.3.7 Differential encoding, run length encoding and other compression techn.	11
1.4 Transform coding	11
1.4.1 DCT-based image compression	13
1.4.2 Wavelet-based image compression	13
1.5 Important factors in the design of an image encoder	14
1.5.1 How to measure the rate/distortion performance	15
1.5.2 How to measure complexity	17
1.5.3 How to measure memory usage	18
1.6 Other features	18
Chapter 2. Wavelet transform computation	21
2.1 Introduction to wavelet transform for image coding	21
2.1.1 Why a new transform?	21
2.1.2 Wavelet transform	24
2.1.3 Multiresolution Analysis	28
2.2 DWT computation using filter banks	29
2.2.1 1D DWT computation	29
2.2.2 Higher order wavelet transform	31
2.2.3 Desired filter and transform properties	32
2.2.4 Popular wavelet transforms for image coding	37
2.3 DWT computation using the lifting scheme	39

CONTENTS

2.3.1	Inverse wavelet transform using the lifting scheme	42
2.3.2	Integer-to-integer transform	43
2.4	Summary	46
Chapter 3.	Efficient memory usage in the 2D DWT	47
3.1	Introduction	47
3.1.1	Previous proposals to reduce memory usage	48
3.1.2	The line-based scheme	49
3.2	A recursive algorithm for buffer synchronization	51
3.2.1	A general algorithm	51
3.2.2	Filter bank implementation	56
3.2.3	Implementation with the lifting scheme	57
3.2.4	Reversible integer-to-integer implementation	62
3.2.5	Some theoretical considerations	63
3.3	Experimental results	64
3.4	Summary	68
Chapter 4.	Coding of wavelet coefficients	71
4.1	Introduction	71
4.2	Tree-based coding	73
4.2.1	Embedded zero-tree wavelet (EZW) coding	73
4.2.2	Set partitioning in hierarchical trees (SPIHT)	77
4.2.3	Non-embedded tree-based coding	78
4.2.3.1	Space-frequency quantization (SFQ)	78
4.2.3.2	Non-embedded SPIHT	79
4.2.3.3	PROGRES (progressive resolution decomposition)	80
4.3	Block-based coding	81
4.3.1	Embedded block coding with optimized truncation (EBCOT)	82
4.3.1.1	Block coding: tier 1 coding	84
4.3.1.2	Bitstream organization: tier 2 coding	87
4.3.1.3	Performance and complexity analysis	88
4.3.2	Set Partitioning Embedded Block (SPECK)	89
4.3.2.1	Subband-Block Hierarchical Partitioning (SBHP)	92
4.3.2.2	Non-embedded SBHP/SPECK	92
4.4	Other wavelet encoders	93
4.4.1	Run-length coding	93
4.4.2	High-order context modeling	94
4.5	Tuning and optimizing the performance of the EZW algorithm	95
4.5.1	Choosing the best filters	96
4.5.2	Coefficient pre-processing	97
4.5.3	Improvements on the main EZW algorithm	99
4.5.4	Improvements on the arithmetic encoder	101
4.6	Summary	102
Chapter 5.	Fast run-length coding of coefficients	103
5.1	Introduction	103
5.2	A simple multiresolution image encoder	105
5.2.1	Quantization method	105
5.2.2	Coding algorithm	106
5.2.3	A simple example	108
5.2.4	Features of the algorithm	109

CONTENTS

5.2.5	Tuning the proposed algorithm	111
5.2.5.1	Tuning the adaptive arithmetic encoder	111
5.2.5.2	Context modeling	112
5.2.6	Discussion	113
5.3	Fast run-length mode	114
5.4	Numerical results	116
5.5	Summary	118
Chapter 6.	Lower tree wavelet image coding	121
6.1	Introduction	121
6.2	Two-pass efficient coding using lower trees	122
6.2.1	Lower tree encoding algorithm	125
6.2.2	Lower tree decoding algorithm	129
6.2.3	A Simple Example	132
6.3	Implementation considerations	134
6.3.1	Analyzing the adaptive arithmetic encoder	134
6.3.2	Analyzing the quantization process	135
6.4	Numerical results	135
6.5	Summary	140
Chapter 7.	Advanced coding: low memory usage and very fast coding	141
7.1	Coding with low memory consumption	141
7.1.1	Run-length coding with low memory usage	142
7.1.1.1	Tradeoff between coding efficiency and, speed and memory req.	143
7.1.2	Fast tree-based coding with efficient use of memory	144
7.1.3	Numerical results	147
7.2	Very fast coding of wavelet lower trees	149
7.2.1	Proposed modifications	150
7.2.2	Efficient Huffman decoding	151
7.2.3	Numerical results	152
7.3	Lossless coding	154
7.4	Summary	155
Chapter 8.	Conclusions and future work	157
8.1	Contributions of this thesis	157
8.2	Conclusions	158
8.3	Future lines of research	159
8.4	Publications resulting from this thesis	163
Appendix A.	Join scalar/bit-plane uniform quantization	179
Appendix B.	Rate control in the proposed algorithms	183
Appendix C.	Implementation of the efficient DWT	187
C.1	Backward Recursion Function	187
C.2	Implementation of the Wavelet Transform	188
C.3	Forward Recursion Function	189
C.4	Implementation of the Inverse Wavelet Transform	190
C.5	Auxiliary Functions and Global Variables	190
C.6	External Headers	193
Appendix D.	Reference images	195
Appendix E.	Post compressed images for subjective comparison	201