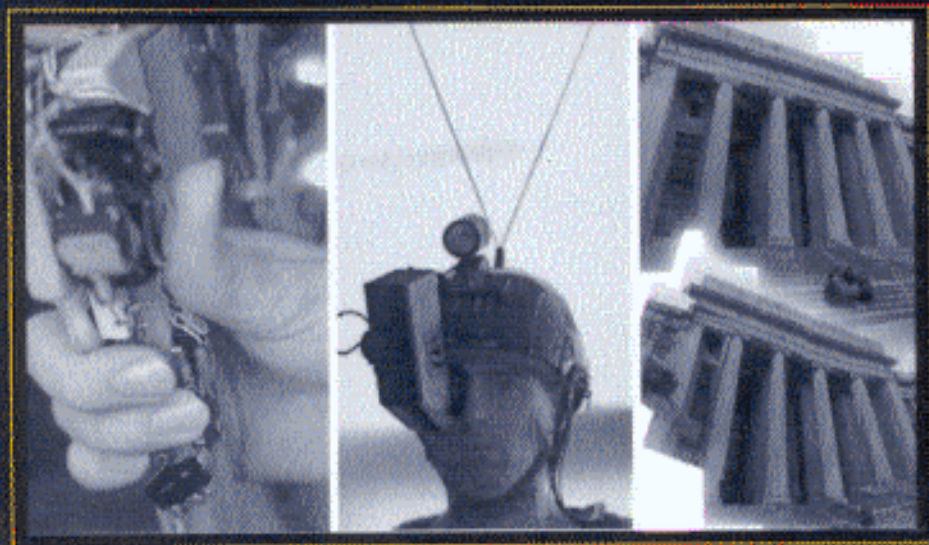


THE ELECTRICAL ENGINEERING AND SIGNAL PROCESSING SERIES

# THE TRANSFORM AND DATA COMPRESSION HANDBOOK



Edited by

**K.R. RAO**

AND

**P.C. YIP**

# Contents

<b>1</b>	<b>Karhunen-Loève Transform</b>	<b>1</b>
1.1	Introduction	1
1.2	Data Decorrelation	2
1.2.1	Calculation of the KLT	9
1.3	Performance of Transforms	11
1.3.1	Information Theory	11
1.3.2	Quantization	13
1.3.3	Truncation Error	13
1.3.4	Block Size	15
1.4	Examples	17
1.4.1	Calculation of KLT	17
1.4.2	Quantization and Encoding	18
1.4.3	Generalization	22
1.4.4	Markov-1 Solution	24
1.4.5	Medical Imaging	25
1.4.6	Color Images	28
1.5	Summary	30
	References	34
<b>2</b>	<b>The Discrete Fourier Transform</b>	<b>37</b>
2.1	Introduction	37
2.2	The DFT Matrix	39
2.3	An Example	40
2.4	DFT Frequency Analysis	41
2.5	Selected Properties of the DFT	45
2.5.1	Symmetry Properties	47
2.6	Real-Valued DFT-Based Transforms	49
2.7	The Fast Fourier Transform	55
2.8	The DFT in Coding Applications	58
2.9	The DFT and Filter Banks	60
2.9.1	Cosine-Modulated Filter Banks	63
2.9.2	Complex DFT-Based Filter Banks	66

2.10	Conclusion	68
2.11	FFT Web sites	72
	References	74
<b>3</b>	<b>Comparametric Transforms for Transmitting Eye Tap Video with Picture Transfer Protocol (PTP)</b>	<b>79</b>
3.1	Introduction: Wearable Cybernetics	79
3.1.1	Historical Overview of WearComp	80
3.1.2	Eye Tap Video	80
3.2	The Edgertonian Image Sequence	81
3.2.1	Edgertonian versus Nyquist Thinking	81
3.2.2	Frames versus Rows, Columns, and Pixels	82
3.3	Picture Transfer Protocol (PTP)	83
3.4	Best Case Imaging and Fear of Functionality	84
3.5	Comparametric Image Sequence Analysis	88
3.5.1	Camera, Eye, or Head Motion: Common Assumptions and Terminology	91
3.5.2	VideoOrbits	92
3.6	Framework: Comparameter Estimation and Optical Flow	94
3.6.1	Feature-Based Methods	94
3.6.2	Featureless Methods Based on Generalized Cross-Correlation	95
3.6.3	Featureless Methods Based on Spatio-Temporal Derivatives	96
3.7	Multiscale Projective Flow Comparameter Estimation	99
3.7.1	Four Point Method for Relating Approximate Model to Exact Model	101
3.7.2	Overview of the New Projective Flow Algorithm	102
3.7.3	Multiscale Repetitive Implementation	103
3.7.4	Exploiting Commutativity for Parameter Estimation	104
3.8	Performance/Applications	106
3.8.1	A Paradigm Reversal in Resolution Enhancement	106
3.8.2	Increasing Resolution in the "Pixel Sense"	107
3.9	Summary	109
3.10	Acknowledgements	111
	References	112
<b>4</b>	<b>Discrete Cosine and Sine Transforms</b>	<b>117</b>
4.1	Introduction	117
4.2	The Family of DCTs and DSTs	118
4.2.1	Definitions of DCTs and DSTs	118
4.2.2	Mathematical Properties	119
4.2.3	Relations to the KLT	121
4.3	A Unified Fast Computation of DCTs and DSTs	122
4.3.1	Definitions of Even-Odd Matrices	123
4.3.2	DCT-II/DST-II and DCT-III/DST-III Computation	124
4.3.3	DCT-I and DST-I Computation	129

4.3.4	DCT-IV/DST-IV Computation . . . . .	131
4.3.5	Implementation of the Unified Fast Computation of DCTs and DSTs . . . . .	134
4.4	The 2-D DCT/DST Universal Computational Structure . . . . .	146
4.4.1	The Fast Direct 2-D DCT/DST Computation . . . . .	146
4.4.2	Implementation of the Direct 2-D DCT/DST Computation . . . . .	152
4.5	DCT and Data Compression . . . . .	161
4.5.1	DCT-Based Image Compression/Decompression . . . . .	162
4.5.2	Data Structures for Compression/Decompression . . . . .	166
4.5.3	Setting the Quantization Table . . . . .	168
4.5.4	Standard Huffman Coding/Decoding Tables . . . . .	170
4.5.5	Compression of One Sub-Image Block . . . . .	172
4.5.6	Decompression of One Sub-Image Block . . . . .	179
4.5.7	Image Compression/Decompression . . . . .	184
4.5.8	Compression of Color Images . . . . .	186
4.5.9	Results of Image Compression . . . . .	188
4.6	Summary . . . . .	191
	References . . . . .	192
<b>5</b>	<b>Lapped Transforms for Image Compression</b> . . . . .	<b>197</b>
5.1	Introduction . . . . .	197
5.1.1	Notation . . . . .	198
5.1.2	Brief History . . . . .	198
5.1.3	Block Transforms . . . . .	199
5.1.4	Factorization of Discrete Transforms . . . . .	200
5.1.5	Discrete MIMO Linear Systems . . . . .	201
5.1.6	Block Transform as a MIMO System . . . . .	203
5.2	Lapped Transforms . . . . .	204
5.2.1	Orthogonal Lapped Transforms . . . . .	204
5.2.2	Nonorthogonal Lapped Transforms . . . . .	210
5.3	LTs as MIMO Systems . . . . .	210
5.4	Factorization of Lapped Transforms . . . . .	213
5.5	Hierarchical Connection of LTs: An Introduction . . . . .	215
5.5.1	Time-Frequency Diagram . . . . .	215
5.5.2	Tree-Structured Hierarchical Lapped Transforms . . . . .	217
5.5.3	Variable-Length LTs . . . . .	219
5.6	Practical Symmetric LTs . . . . .	222
5.6.1	The Lapped Orthogonal Transform: LOT . . . . .	222
5.6.2	The Lapped Bi-Orthogonal Transform: LBT . . . . .	223
5.6.3	The Generalized LOT: GenLOT . . . . .	226
5.6.4	The General Factorization: GLBT . . . . .	230
5.7	The Fast Lapped Transform: FLT . . . . .	233
5.8	Modulated LTs . . . . .	236
5.9	Finite-Length Signals . . . . .	240
5.9.1	Overall Transform . . . . .	241

5.9.2	Recovering Distorted Samples	243
5.9.3	Symmetric Extensions	244
5.10	Design Issues for Compression	246
5.11	Transform-Based Image Compression Systems	248
5.11.1	JPEG	249
5.11.2	Embedded Zerotree Coding	250
5.11.3	Other Coders	252
5.12	Performance Analysis	253
5.12.1	JPEG	253
5.12.2	Embedded Zerotree Coding	255
5.13	Conclusions	258
	References	260
<b>6</b>	<b>Wavelet-Based Image Compression</b>	<b>267</b>
6.1	Introduction	267
6.2	Dyadic Wavelet Transform	268
6.2.1	Two-Channel Perfect-Reconstruction Filter Bank	270
6.2.2	Dyadic Wavelet Transform, Multiresolution Representation	272
6.2.3	Wavelet Smoothness	273
6.3	Wavelet-Based Image Compression	274
6.3.1	Lossy Compression	274
6.3.2	EZW Algorithm	278
6.3.3	SPIHT Algorithm	285
6.3.4	WDR Algorithm	294
6.3.5	ASWDR Algorithm	299
6.3.6	Lossless Compression	305
6.3.7	Color Images	305
6.3.8	Other Compression Algorithms	306
6.3.9	Ringing Artifacts and Postprocessing Algorithms	306
	References	306
<b>7</b>	<b>Fractal-Based Image and Video Compression</b>	<b>313</b>
7.1	Introduction	313
7.2	Basic Properties of Fractals and Image Compression	314
7.3	Contractive Affine Transforms, Iterated Function Systems, and Image Generation	316
7.4	Image Compression Directly Based on the IFS Theory	318
7.5	Image Compression Based on IFS Library	321
7.6	Image Compression Based on Partitioned IFS	322
7.6.1	Image Partitions	323
7.6.2	Distortion Measure	323
7.6.3	A Class of Discrete Image Transformations	324
7.6.4	Encoding and Decoding Procedures	325
7.6.5	Experimental Results	326
7.7	Image Coding Using Quadtree Partitioned IFS (QPIFS)	326

7.7.1	RMS Tolerance Selection . . . . .	328
7.7.2	A Compact Storage Scheme . . . . .	329
7.7.3	Experimental Results . . . . .	331
7.8	Image Coding by Exploiting Scalability of Fractals . . . . .	333
7.8.1	Image Spatial Sub-Sampling . . . . .	334
7.8.2	Decoding to a Larger Image . . . . .	334
7.8.3	Experimental Results . . . . .	334
7.9	Video Sequence Compression using Quadtree PIFS . . . . .	336
7.9.1	Definitions of Types of Range Blocks . . . . .	336
7.9.2	Encoding and Decoding Processes . . . . .	338
7.9.3	Storage Requirements . . . . .	340
7.9.4	Experimental Results . . . . .	340
7.9.5	Discussion . . . . .	341
7.10	Other Fractal-Based Image Compression Techniques . . . . .	341
7.10.1	Segmentation-Based Coding Using Fractal Dimension . . . . .	341
7.10.2	Yardstick Coding . . . . .	342
7.11	Conclusions . . . . .	343
	References . . . . .	343
<b>8</b>	<b>Compression of Wavelet Transform Coefficients</b> . . . . .	<b>347</b>
8.1	Introduction . . . . .	347
8.2	Embedded Coefficient Coding . . . . .	353
8.3	Statistical Context Modeling of Embedded Bit Stream . . . . .	357
8.4	Context Dilution Problem . . . . .	359
8.5	Context Formation . . . . .	360
8.6	Context Quantization . . . . .	362
8.7	Optimization of Context Quantization . . . . .	365
8.8	Dynamic Programming for Minimum Conditional Entropy . . . . .	367
8.9	Fast Algorithms for High-Order Context Modeling . . . . .	369
8.9.1	Context Formation via Convolution . . . . .	370
8.9.2	Shared Modeling Context for Signs and Textures . . . . .	371
8.10	Experimental Results . . . . .	373
8.10.1	Lossy Case . . . . .	373
8.10.2	Lossless Case . . . . .	374
8.11	Summary . . . . .	374
	References . . . . .	375