TABLE OF CONTENTS

1. INTRODUCTION.....1

1.1 DIGITAL HOLOGRAPHY AND EVOLUTION OF IMAGING TECHNIQUES..... 1

1.2 CONTENTS OF THIS BOOK 5

REFERENCES 10

2. OPTICAL SIGNALS AND TRANSFORMS.....11

2.1 MATHEMATICAL MODELS OF OPTICAL SIGNALS.....11

2.1.1 Primary definitions and classification..... 11

2.1.2 Signal space..... 13

2.1.3 Linear signal space, basis functions and signal representation as expansion over a set of basis functions..... 17

2.1.4 Integral representation of signals..... 22

2.2 SIGNAL TRANSFORMATIONS 24

2.3 IMAGING SYSTEMS AND INTEGRAL TRANSFORMS.....27

2.3.1 Direct imaging: Convolution integral..... 27

2.3.2 Imaging in Fourier domain: Holography and diffraction integrals..... 30

2.4 FOURIER TRANSFORM AND ITS DERIVATIVES 39

2.4.1 Properties of integral Fourier Transform..... 39

2.4.2 Special cases of the integral Fourier transform: integral Cosine, Hartley, Hankel and Mellin transforms..... 44

2.4.3 Integral Fresnel and related transform..... 49

2.4.4 Hilbert transform..... 53

2.5 IMAGING FROM PROJECTIONS: RADON AND ABEL TRANSFORMS 57

2.6 MULTI RESOLUTION IMAGING: WAVELET TRANSFORMS ...61

2.7 SLIDING WINDOW TRANSFORMS AND "TIME-FREQUENCY" (SPACE-TRANSFORM) SIGNAL REPRESENTATION 63
2.7.1 Transforms in sliding window (windowed transforms) 63
2.7.2 Sliding window Fourier Transform 53
2.7.3 Sliding window and wavelet transforms as signal sub-band decomposition 64

2.8 STOCHASTIC TRANSFORMATIONS AND STATISTICAL MODELS 67
2.8.1 Additive, multiplicative, Poisson noise and impulse noise models 67
2.8.2 Speckle noise model 72

References 77

3. DIGITAL REPRESENTATION OF SIGNALS 79

3.1 PRINCIPLES OF SIGNAL DIGITIZATION 79

3.2 SIGNAL DISCRETIZATION AS EXPANSION OVER A SET OF BASIS FUNCTIONS. TYPICAL BASIS FUNCTIONS AND CLASSIFICATION 80
3.2.1 Shift (convolution) basis functions 81
3.2.2 Scale (multiplicative) basis functions 85
3.2.3 Wavelets 92
3.2.4 Discrete bases 94
3.2.5 Optimality of bases. Karhunen-Loeve, Hotelling and Singular Values Decomposition Transforms 97
3.2.6 Two dimensional and multi dimensional bases 103

3.3 SHIFT (CONVOLUTION) BASES FUNCTIONS AND SAMPLING THEOREM 106
3.3.1 1-D sampling theorem 106
3.3.2 Sampling 2-D and multidimensional signals 113
3.3.3 Sampling artifacts: qualitative analysis 120
3.3.4 Sampling artifacts: quantitative analysis 124

3.4 MULTI-RESOLUTION SAMPLING 129

3.5 UNCONVENTIONAL DIGITAL IMAGING METHODS 131

3.6 PRINCIPLES OF SIGNAL SCALAR QUANTIZATION 133
3.6.1 Optimal homogeneous non-uniform quantization 133

3.6.2 Quantization in digital holography 143

3.7 BASICS OF SIGNAL CODING AND DATA COMPRESSION 147

3.1.1 Signal rate distortion function, entropy and statistical coding..... 147

3.7.2 Image compression methods: a review 152

4. DIGITAL REPRESENTATION OF SIGNAL TRANSFORMATIONS..... 161

4.1 THE PRINCIPLES 161

4.2 DISCRETE REPRESENTATION OF CONVOLUTION INTEGRAL. DIGITAL FILTERS 170

4.3 DISCRETE REPRESENTATION OF FOURIER INTEGRAL TRANSFORM. 170

4.3.1 Discrete Fourier Transforms 170

4.3.2 Properties of Discrete Fourier Transforms 175

4.3.3 Discrete cosine and sine transforms 189

4.3.4 Lapped Transforms 195

4.4 DISCRETE REPRESENTATION OF FRESNEL INTEGRAL TRANSFORM 199

4.4.1 Discrete Fresnel Transform 199

4.4.2 Properties of Discrete Fresnel Transforms 205

References 209

5. METHODS AND ALGORITHMS OF DIGITAL FILTERING.....211

5.1 FILTERING IN SIGNAL DOMAIN 211

5.1.1 Transversal and recursive filtering 211

5.1.2 Separable, cascade, parallel and parallel recursive filtering..... 213

5.1.3 Recursive algorithms of sliding window DFT and DCT/DcST 220

5.1.4 Border processing in digital filtering..... 223

5.2 FILTERING IN TRANSFORM DOMAIN 226

5.2.1 DFT and cyclic convolution. Border processing..... 226

5.2.2 Signal convolution in the DCT domain..... 227

5.3 COMBINED ALGORITHMS FOR COMPUTING DFT AND DCT OF REAL VALUED SIGNALS 231
5.3.1 Combined algorithms for computing DFT of signals with real samples 231
5.3.2 Combined algorithm for computing the DCT via FFT 234

References 237

6. FAST ALGORITHMS 239

6.1 THE PRINCIPLE OF FAST FOURIER TRANSFORMS.....239

6.2 MATRIX TECHNIQUES IN FAST TRANSFORMS.....243

6.3 TRANSFORMS AND THEIR FAST ALGORITHMS IN MATRIX REPRESENTATION 249
6.3.1 Walsh-Hadamard transform 249
6.3.2 Walsh-Paley Transform and Bit Reversal Permutation..... 250
6.3.3 Walsh Transform and Binary-to-Gray Code and Hadamard Permutations 252
6.3.4 Haar Transform 254
6.3.5 Discrete Fourier Transform..... 255
6.3.6 DCT and DcST 260

6.4 PRUNED ALGORITHMS 264

6.5 QUANTIZED DFT 269

REFERENCES 274

7. STATISTICAL METHODS AND ALGORITHMS.....275

7.1 MEASURING SIGNAL STATISTICAL CHARACTERISTICS....275
7.1.1 Measuring probability distribution and its moments and order statistics 275
7.1.2 Measuring signal correlation functions and spectra.....280
7.1.3 Measuring parameters of random interferences in sensor and imaging systems 284

7.2 DIGITAL STATISTICAL MODELS AND MONTE CARLO METHODS 291

7.2.1 Principles of generating pseudo-random numbers. Generating independent uniformly distributed pseudo-random numbers 291
7.2.2 Generating pseudo-random numbers with special statistical properties 292
7.2.3 Generating pseudo-random images 297
7.2.4 Generating correlated phase masks. Kinoform and programmed diffuser holograms 300

7.3 STATISTICAL (MONTE CARLO) SIMULATION. CASE STUDY: SPECKLE NOISE PHENOMENA IN COHERENT IMAGING AND DIGITAL HOLOGRAPHY 305
7.3.1 Computer model 306
7.3.2 Simulation results 307

References 312

8. SENSOR SIGNAL PERFECTING, IMAGE RESTORATION, RECONSTRUCTION AND ENHANCEMENT 313

8.1 MATHEMATICAL MODELS OF IMAGING SYSTEMS 313

8.2 LINEAR FILTERS FOR IMAGE RESTORATION 315
8.2.1 Transform domain MSE optimal scalar Wiener Filters 315
8.2.2 Empirical Wiener filters for image denoising 317
8.2.3 Image deblurring, inverse filters and aperture correction 323

8.3 SLIDING WINDOW TRANSFORM DOMAIN ADAPTIVE SIGNAL RESTORATION 328
8.3.1 Local adaptive filtering 328
8.3.2 Sliding window transform domain DCT filtering 330
8.3.3 Hybrid DCT/wavelet filtering. 334

8.4 MULTI-COMPONENT IMAGE RESTORATION 340

8.5 FILTERING IMPULSE NOISE 343

8.6 METHODS FOR CORRECTING GRAY SCALE NONLINEAR DISTORTIONS 348

8.7 IMAGE RECONSTRUCTION 353

8.8 IMAGE ENHANCEMENT.....361
8.8.1 Image enhancement as an image processing task. Classification of image enhancement methods 361
8.8.2 Gray level histogram modification methods 362
8.8.3 Image spectra modification methods.....367
8.8.4 Using color, stereo and dynamical vision for image enhancement...369
References 371

9. IMAGE RESAMPLING AND GEOMETRICAL TRANSFORMATIONS 373

9.1 PRINCIPLES OF IMAGE RESAMPLING 373

9.2 NEAREST NEIGHBOR, LINEAR AND SPLINE INTERPOLATION METHODS 376

9.3 ALGORITHMS OF DISCRETE SINC-INTERPOLATION 380
9.3.1 Discrete sinc-interpolation by zero padding signal DFT spectrum..380
9.3.2 DFT based discrete sinc-interpolation algorithm for signal arbitrary translation.....382
9.3.3 DCT based discrete sinc-interpolation algorithm for signal arbitrary translation 386
9.3.4 Sliding window adaptive discrete sinc-interpolation algorithms 388

9.4 Application examples.....395
9.4.1 Signal and image resizing and localization with sub-pixel accuracy 395
9.4.2 Fast algorithm for image rotation with discrete-sinc-interpolation..398
9.4.3 Signal differentiating and filtered back projection method for tomographic reconstruction.....400
9.4.4 Signal integrating and reconstructing surfaces from their slope 403
9.4.5 Polar-to-Cartesian coordinate conversion, interpolation of DFT spectra of projections and the direct Fourier method of image reconstruction from projections.....407

References 410

10. SIGNAL PARAMETER ESTIMATION AND MEASUREMENT. OBJECT LOCALIZATION 411

10.1 PROBLEM FORMULATION. OPTIMAL STATISTICAL ESTIMATES 411

10.2 LOCALIZATION OF AN OBJECT IN THE PRESENCE OF ADDITIVE WHITE GAUSSIAN NOISE 414

10.2.1 Optimal localization device. Correlator and matched filter 414

10.2.2 Computer and optical implementations of the matched filter correlator 417

10.2.3 Performance of optimal estimators: normal and anomalous localization errors.....419

10.3 PERFORMANCE OF THE OPTIMAL LOCALIZATION DEVICE 421

10.3.1 Distribution density and variance of normal errors.....421

10.3.2 Illustrative examples 431

10.3.3 Localization accuracy for non-optimal localization devices. 436

10.3.4 Localization reliability. Probability of anomalous localization errors 439

10.4 LOCALIZATION OF AN OBJECT IN THE PRESENCE OF ADDITIVE CORRELATED GAUSSIAN NOISE 443

10.4.1 Localization of a target object in the presence of non-white (correlated) additive Gaussian noise 443

10.4.2 Localization accuracy of the optimal filter.....445

10.5 OPTIMAL LOCALIZATION IN COLOR AND MULTI COMPONENT IMAGES 449

10.5.1 Optimal localization device.....449

10.5.2 Localization accuracy and reliability.....451

10.5.3 Optimal localization in multi component images with correlated noise. 452

10.6 OBJECT LOCALIZATION IN THE PRESENCE OF MULTIPLE NONOVERLAPPNING NON-TARGET OBJECTS 454

References 459

11. TARGET LOCATION IN CLUTTER 461

11.1 PROBLEM FORMULATION 461

11.2 LOCALIZATION OF PRECISELY KNOWN OBJECTS: SPATIALLY HOMOGENEOUS OPTIMALITY CRITERION 465

11.2.1 Optimal adaptive correlator..... 465

11.2.2 Implementation issues, practical recommendations and illustrative examples 469

11.3 LOCALIZATION OF INEXACTLY KNOWN OBJECT: SPATIALLY HOMOGENEOUS CRITERION.....474

11.4 LOCALIZATION METHODS FOR SPATIALLY INHOMOGENEOUS CRITERIA 478

11.5 OBJECT LOCALIZATION AND IMAGE BLUR 483

11.6 OBJECT LOCALIZATION AND EDGE DETECTION. SELECTION OF REFERENCE OBJECTS FOR TARGET TRACKING 485

11.7 OPTIMAL ADAPTIVE CORRELATOR AND OPTICAL CORRELATORS 490

11.7.1 Optical correlators with improved discrimination capability 490

11.7.2 Computer and optical implementations of the optimal adaptive correlator 493

11.8 TARGET LOCATING IN COLOR AND MULTI COMPONENT IMAGES 499

11.8.1 Theoretical framework..... 499

11.8.2 Separable component-wise implementations of the optimal adaptive multi-component correlator..... 501

References 507

12. NONLINEAR FILTERS IN SIGNAL/IMAGE PROCESSING 509

12.1 CLASIFICATION PRINCIPLES 510

12.1.1 Main assumptions and definitions..... 510

12.1.2 Typical signal attributes 511
12.1.3 Estimation operations 512
12.1.4 Neighborhood building operations 515

12.2 FILTER CLASSIFICATION TABLES 519
12.2.1 Transferential filters 519
12.2.2 Iterative filtering 522
12.2.3 Multiple branch parallel, cascade and recursive filters 523
12.2.4 Miscellaneous new filters 524

12.3 PRACTICAL EXAMPLES 527
12.3.1 Image denoising 527
12.3.2 Image enhancement 531
12.3.3 Image segmentation and edge detection 535
12.3.4 Implementation issues 538

References 540

13. COMPUTER GENERATED HOLOGRAMS 541

13.1 MATHEMATICAL MODELS.....541

13.2 METHODS FOR ENCODING AND RECORDING COMPUTER GENERATED HOLOGRAMS.....548

13.3 RECONSTRUCTION OF COMPUTER GENERATED HOLOGRAMS 565

References.....575