

Fundamentals of Medical Imaging



PAUL SUETENS



Contents

<i>Preface</i>	<i>page xi</i>
<i>Acknowledgments</i>	xiii
PART ONE. INTRODUCTION TO DIGITAL IMAGE PROCESSING	
1 Definitions	3
1.1 Digital Images	3
1.2 Image Quality	5
2 Linear System Theory	8
2.1 Introduction	8
2.2 Signals	8
2.2.1 Definitions and Examples	8
2.2.2 The Dirac Impulse	11
2.3 Systems	12
2.3.1 Definitions and Examples	12
2.3.2 Convolution	14
2.3.3 Response of an LSI System	15
2.4 The Fourier Transform	16
2.4.1 Definitions	16
2.4.2 Examples	17
2.4.3 Properties	20
2.4.4 Polar Form of the Fourier Transform	22
2.5 Sampling	22
3 Image Operations	27
3.1 Introduction	27
3.2 Gray Level Transformations	27
3.3 Multi-Image Operations	29
3.4 Geometric Operations	31
3.5 Filters	32
3.5.1 Linear Filters	32
3.5.2 Nonlinear Filters	37
3.6 Multiscale Image Enhancement	38
3.6.1 Multiscale Image Representation	40
3.6.2 Image Enhancement by Nonlinear Mapping	42

PART TWO. MEDICAL IMAGING MODALITIES

4 Radiography	47
4.1 Introduction	47
4.2 X rays	47
4.3 Interaction with Matter	49
4.3.1 Interaction of Photons with Matter	49
4.3.2 Interaction of an X-ray Beam with Tissue	49
4.4 X-ray Detectors	51
4.4.1 Screen-Film Detector	51
4.4.2 Image Intensifier	53
4.4.3 Detectors for Computed Radiography	54
4.5 Image Quality	56
4.5.1 Resolution	56
4.5.2 Noise	57
4.5.3 Contrast	57
4.5.4 Artifacts	57
4.6 Equipment	57
4.7 Clinical Use	58
4.8 Biologic Effects and Safety	62
4.9 Future Expectations	64
5 X-ray Computed Tomography	66
5.1 Introduction	66
5.2 X-ray Detectors in CT	68
5.2.1 Scintillation Crystal with Photomultiplier Tube	68
5.2.2 Gas Ionization Chambers	69
5.2.3 Scintillation Crystals with Photodiode	69
5.3 Imaging	69
5.3.1 Data Acquisition	69
5.3.2 Image Reconstruction	74
5.3.3 Imaging in Three Dimensions	81
5.4 Image Quality	83
5.4.1 Resolution	83
5.4.2 Noise	84
5.4.3 Contrast	85
5.4.4 Image Artifacts	85
5.5 Equipment	87
5.5.1 Scanner Generations	88
5.5.2 Internal Geometry	89
5.5.3 Multislice CT	90
5.5.4 Dynamic Spatial Reconstructor	92
5.5.5 Electron Beam Tomography	93
5.6 Clinical Use	95
5.7 Biologic Effects and Safety	96
5.8 Future Expectations	97
6 Magnetic Resonance Imaging	99
6.1 Introduction	99
6.2 Physics of the Transmitted Signal	99

6.2.1	Angular Momenta and Magnetic Moments	99
6.2.2	Dynamic Equilibrium: The Net Magnetization Vector of Matter	104
6.3	Interaction with Tissue	105
6.3.1	Disturbing the Dynamic Equilibrium: The RF Field	105
6.3.2	Return to Dynamic Equilibrium: Relaxation	106
6.4	Signal Detection and Detector	108
6.5	Imaging	109
6.5.1	Introduction	109
6.5.2	Slice or Volume Selection	110
6.5.3	Position Encoding: The \vec{k} -Theorem	111
6.5.4	Dephasing Phenomena	113
6.5.5	Basic Pulse Sequences	115
6.5.6	Three-Dimensional Imaging	118
6.5.7	Acquisition and Reconstruction Time	119
6.5.8	Very Fast Imaging Sequences	120
6.5.9	Imaging of Moving Spins	122
6.5.10	Functional Imaging	129
6.6	Image Quality	130
6.6.1	Contrast	130
6.6.2	Resolution	131
6.6.3	Noise	133
6.6.4	Artifacts	134
6.7	Equipment	135
6.8	Clinical Use	138
6.9	Biologic Effects and Safety	141
6.9.1	Biologic Effects	141
6.9.2	Safety	141
6.10	Future Expectations	143
7	Ultrasonic Imaging	145
7.1	Introduction	145
7.2	Physics of Acoustic Waves	146
7.2.1	What Are Ultrasonic Waves?	146
7.2.2	Generation of Ultrasonic Waves	147
7.2.3	Wave Propagation in Homogeneous Media	147
7.2.4	Wave Propagation in Inhomogeneous Media	153
7.2.5	Wave Propagation and Motion: Doppler	156
7.3	Generation and Detection of Ultrasound	158
7.4	Gray Scale Imaging	159
7.4.1	Data Acquisition	159
7.4.2	Image Reconstruction	161
7.4.3	Acquisition and Reconstruction Time	163
7.5	Doppler Imaging	164
7.5.1	Data Acquisition	164
7.5.2	Reconstruction	164
7.5.3	Acquisition and Reconstruction Time	168
7.6	Image Quality	168

7.6.1	Spatial Resolution	168
7.6.2	Noise	170
7.6.3	Image Contrast	171
7.6.4	Gray Scale Image Artifacts	171
7.6.5	Doppler Image Artifacts	172
7.7	Equipment	172
7.7.1	One-Dimensional Array Transducers	172
7.7.2	Transducers for 3D Imaging	174
7.7.3	Special-Purpose Transducers	175
7.8	Clinical Use	175
7.8.1	Gray Scale Imaging	176
7.8.2	Doppler Imaging	181
7.8.3	Contrast Echography	181
7.9	Biologic Effects and Safety	182
7.10	Future Expectations	182
8	Nuclear Medicine Imaging	184
8.1	Introduction	184
8.2	Radionuclides	185
8.2.1	Radioactive Decay Modes	185
8.2.2	Statistics	187
8.3	Interaction of Photons with Matter	187
8.4	Data Acquisition	188
8.4.1	The Detector	188
8.4.2	Detected Number of Photons	191
8.4.3	Energy Resolution	191
8.4.4	Count Rate	191
8.5	Imaging	192
8.5.1	Planar Imaging	192
8.5.2	2D Fourier Reconstruction and Filtered Backprojection	192
8.5.3	2D Iterative Reconstruction	193
8.5.4	3D Reconstruction	197
8.6	Image Quality	199
8.6.1	Contrast	199
8.6.2	Spatial Resolution	199
8.6.3	Noise	200
8.6.4	Artifacts	200
8.7	Equipment	201
8.7.1	Gamma Camera and SPECT Scanner	201
8.7.2	PET Scanner	202
8.8	Clinical Use	204
8.9	Biologic Effects and Safety	207
8.10	Future Expectations	209

**PART THREE. IMAGE ANALYSIS AND VISUALIZATION FOR DIAGNOSIS,
THERAPY, AND SURGERY**

9	Medical Image Analysis	213
9.1	Introduction	213
9.2	Manual Analysis	214

9.3	Automated Analysis	216
9.4	Computational Strategies for Automated Medical Image Analysis	220
9.4.1	Pixel Classification	223
9.4.2	Fitting Rigid Models to Photometry	228
9.4.3	Fitting Flexible Models to Photometry	231
9.5	Validation	239
9.6	Future Expectations	241
10	Image-Guided Interventions	243
10.1	Introduction	243
10.2	Stereotactic Neurosurgery, the Pioneer of Image-Guided Interventions	244
10.3	Stereotactic Neurosurgery Based on Digital Image Volumes	247
10.3.1	Image Acquisition	247
10.3.2	Planning	249
10.3.3	Transfer	250
10.4	Evolutions in Stereotactic Neurosurgery	251
10.4.1	Image Acquisition	252
10.4.2	Planning	254
10.4.3	Transfer	256
10.5	Image Guidance for Rigid Structures	259
10.5.1	Complex Trajectories	260
10.5.2	Templates	260
10.5.3	Tracking Moving Anatomical Structures	263
10.6	Intraoperative Imaging	263
10.6.1	Intraoperative Diagnostic Imaging	263
10.6.2	Transfer by Matching Preoperative with Intraoperative Images	263
10.6.3	Augmented Reality (AR)	264
10.7	Future Expectations	266
<i>References</i>		269
<i>Bibliography</i>		271
<i>Index</i>		273
<i>Color plates follow p. 281</i>		