

# Contents

<b>Preface</b>	<b>xi</b>
<b>Nomenclature and Abbreviations</b>	<b>xiii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Conventional X-ray Tomography	2
1.2 History of Computed Tomography	7
1.3 Different Generations of CT Scanners	14
1.4 Problems	19
References	19
<b>2 Preliminaries</b>	<b>23</b>
2.1 Mathematics Fundamentals	23
2.1.1 Fourier transform and convolution	23
2.1.2 Random variables	27
2.1.3 Linear algebra	30
2.2 Fundamentals of X-ray Physics	33
2.2.1 Production of x rays	33
2.2.2 Interaction of x rays with matter	36
2.3 Measurement of Line Integrals and Data Conditioning	42
2.4 Sampling Geometry and Sinogram	46
2.5 Problems	48
References	52
<b>3 Image Reconstruction</b>	<b>55</b>
3.1 Introduction	55
3.2 Several Approaches to Image Reconstruction	57
3.3 The Fourier Slice Theorem	61
3.4 The Filtered Backprojection Algorithm	65
3.4.1 Derivation of the filtered back-projection formula	68
3.4.2 Computer implementation	71
3.4.3 Targeted reconstruction	85
3.5 Fan-Beam Reconstruction	88
3.5.1 Reconstruction formula for equiangular sampling	89

3.5.2	Reconstruction formula for equal-spaced sampling	95
3.5.3	Fan-beam to parallel-beam rebinning	97
3.6	Iterative Reconstruction	101
3.6.1	Mathematics verses reality	102
3.6.2	The general approach to iterative reconstruction	103
3.6.3	Modeling of the scanner's optics and physics	105
3.6.4	Updating strategy	109
3.7	Problems	112
	References	114
<b>4</b>	<b>Image Presentation</b>	<b>119</b>
4.1	CT Image Display	119
4.2	Volume Visualization	123
4.2.1	Multiplanar reformation	123
4.2.2	MIP, minMIP, and volume rendering	128
4.2.3	Surface rendering	136
4.3	Impact of Visualization Tools	137
4.4	Problems	140
	References	142
<b>5</b>	<b>Key Performance Parameters of the CT Scanner</b>	<b>143</b>
5.1	High-Contrast Spatial Resolution	143
5.1.1	In-plane resolution	144
5.1.2	Slice sensitivity profile	150
5.2	Low-Contrast Resolution	154
5.3	Temporal Resolution	160
5.4	CT Number Accuracy and Noise	167
5.5	Performance of the Scanogram	172
5.6	Problems	174
	References	176
<b>6</b>	<b>Major Components of the CT Scanner</b>	<b>179</b>
6.1	System Overview	179
6.2	The X-ray Tube and High-Voltage Generator	180
6.3	The X-ray Detector and Data-Acquisition Electronics	190
6.4	The Gantry and Slip Ring	197
6.5	Collimation and Filtration	199
6.6	The Reconstruction Engine	202
6.7	Problems	203
	References	205

<b>7</b>	<b>Image Artifacts: Appearances, Causes, and Corrections</b>	<b>207</b>
7.1	What Is an Image Artifact?	207
7.2	Different Appearances of Image Artifacts	209
7.3	Artifacts Related to System Design	214
7.3.1	Aliasing	214
7.3.2	Partial volume	226
7.3.3	Scatter	231
7.3.4	Noise-induced streaks	235
7.4	Artifacts Related to X-ray Tubes	239
7.4.1	Off-focal radiation	239
7.4.2	Tube arcing	242
7.4.3	Tube rotor wobble	244
7.5	Detector-induced Artifacts	244
7.5.1	Offset, gain, nonlinearity, and radiation damage	244
7.5.2	Primary speed and afterglow	248
7.5.3	Detector response uniformity	253
7.6	Patient-induced Artifacts	258
7.6.1	Patient motion	258
7.6.2	Beam hardening	270
7.6.3	Metal artifacts	280
7.6.4	Incomplete projections	283
7.7	Operator-induced Artifacts	288
7.8	Problems	291
	References	295
<b>8</b>	<b>Computer Simulation and Analysis</b>	<b>301</b>
8.1	What Is Computer Simulation?	301
8.2	Simulation Overview	303
8.3	Simulation of Optics	305
8.4	Computer Simulation of Physics-related Performance	316
8.5	Problems	323
	References	324
<b>9</b>	<b>Helical or Spiral CT</b>	<b>327</b>
9.1	Introduction	327
9.1.1	Clinical needs	327
9.1.2	Enabling technology	331
9.2	Terminology and Reconstruction	332
9.2.1	Helical pitch	332
9.2.2	Basic reconstruction approaches	333
9.2.3	Selection of the interpolation algorithm and reconstruction plane	339
9.2.4	Helical fan-to-parallel rebinning	343
9.3	Slice Sensitivity Profile and Noise	348

9.4	Helically Related Image Artifacts	355
9.4.1	High-pitch helical artifacts	355
9.4.2	Noise-induced artifacts	360
9.4.3	System-misalignment-induced artifacts	364
9.4.4	Helical artifacts caused by object slope	368
9.5	Problems	371
	References	372
<b>10</b>	<b>Multislice CT</b>	<b>375</b>
10.1	The Need for Multislice CT	375
10.2	Detector Configurations of Multislice CT	378
10.3	Nonhelical Mode of Reconstruction	385
10.4	Multislice Helical Reconstruction	396
10.4.1	Selection of interpolation samples	398
10.4.2	Selection of region of reconstruction	402
10.4.3	Reconstruction algorithms with 3D backprojection	405
10.5	Multislice Artifacts	410
10.5.1	General description	410
10.5.2	Multislice CT cone-beam effects	411
10.5.3	Interpolation-related image artifacts	413
10.5.4	Noise-induced multislice artifacts	416
10.5.5	Tilt artifacts in multislice helical CT	416
10.5.6	Distortion in step-and-shoot mode SSP	419
10.5.7	Artifacts due to geometric alignment	420
10.5.8	Comparison of multislice and single-slice helical CT	422
10.6	Problems	422
	References	425
<b>11</b>	<b>X-ray Radiation and Dose-Reduction Techniques</b>	<b>433</b>
11.1	Biological Effects of X-ray Radiation	434
11.2	Measurement of X-ray dose	436
11.2.1	Terminology and the measurement standard	436
11.2.2	Other measurement units and methods	442
11.2.3	Issues with the current CTDI	443
11.3	Methodologies for Dose Reduction	445
11.3.1	Tube-current modulation	446
11.3.2	Umbra-penumbra and overbeam issues	448
11.3.3	Physiological gating	451
11.3.4	Organ-specific dose reduction	454
11.3.5	Protocol optimization and impact of the operator	456
11.3.6	Postprocessing techniques	461

---

11.3.7 Advanced reconstruction	462
11.4 Problems	463
References	465
<b>12 Advanced CT Applications</b>	<b>469</b>
12.1 Introduction	469
12.2 Cardiac Imaging	471
12.2.1 Coronary artery calcification (CAC)	472
12.2.2 Coronary artery imaging (CAI)	476
12.2.2.1 Data acquisition and reconstruction	478
12.2.2.2 Temporal resolution improvement	485
12.2.2.3 Spatial resolution improvement	492
12.2.2.4 Dose and coverage	493
12.3 CT Fluoroscopy	497
12.4 CT Perfusion	503
12.5 Screening and Quantitative CT	512
12.5.1 Lung cancer screening	512
12.5.2 Quantitative CT	516
12.5.3 CT colonography	519
12.6 Dual-Energy CT	522
12.7 Problems	532
References	534
<b>Glossary</b>	<b>545</b>
<b>Index</b>	<b>551</b>