

Contents

1	Introduction	1
1.1	A Brief Historical Overview	2
1.2	Image Resolution and Contrast	3
1.3	Systems and Signals: A Short Introduction	6
1.4	The Fourier Transform	9
2	X-Ray Projection Imaging	13
2.1	X-Ray Generation	13
2.1.1	The X-Ray Tube	15
2.1.2	A Focus on Geometry	19
2.2	X-Ray Attenuation	20
2.2.1	Photon-Matter Interaction	20
2.2.2	Macroscopic Attenuation and Lambert-Beer's Law	22
2.2.3	Lambert-Beer's Law in Inhomogeneous Materials	25
2.2.4	Dual-Energy X-Ray Absorptiometry	26
2.3	X-Ray Detectors	28
2.3.1	Film-Based Imaging	28
2.3.2	Fluoroscopes	30
2.3.3	Semiconductor Detectors	32
2.3.4	Photomultiplier Tubes	33
2.4	Factors that Determine X-Ray Image Quality	34
3	Computed Tomography	37
3.1	CT Image Formation Principles	37
3.1.1	The Radon Transform and the Fourier Slice Theorem	39
3.1.2	Practical Image Reconstruction	42
3.2	Engineering Aspects of CT Scanners	49
3.3	Quantitative CT	51
3.4	Image Quality and Artifacts	52
4	Nuclear Imaging	55
4.1	Radiopharmaceuticals	55
4.2	Production of Short-Lived Radioactive Tracers	56

4.3	Detector Systems and the Anger Camera	57
4.4	Single Photon Emission Computed Tomography	59
4.5	Positron Emission Tomography	64
4.6	Multi-Modality Imaging	66
5	Magnetic Resonance Imaging	67
5.1	Proton Spins in an External Magnetic Field	67
5.2	The Spin-Echo Experiment	70
5.3	The Spin-Echo Pulse Sequence	76
5.3.1	Measurement of T_2	77
5.3.2	Measurement of T_1 Through Incomplete Recovery	77
5.3.3	Measurement of Proton Density	78
5.3.4	The Significance of T_E and T_R	78
5.4	From NMR to MRI: The Gradient Fields	79
5.4.1	The Slice Encode Gradient	81
5.4.2	Fourier-Encoding with the Gradient	84
5.4.3	The Frequency Encode Gradient	85
5.4.4	The Phase Encode Gradient	86
5.5	Putting Everything Together: Spatially-Resolved Spin-Echo Acquisition	87
5.6	Other Imaging Sequences	88
5.6.1	Gradient-Recalled Echo Sequences	89
5.6.2	Inversion Recovery Sequence	90
5.6.3	Echo Planar Imaging	92
5.7	Technical Realization	93
5.7.1	B_0 Magnet	93
5.7.2	Gradient Subsystem	94
5.7.3	RF Subsystem	95
6	Ultrasound Imaging	97
6.1	Sound Propagation in Biological Tissue	97
6.2	Ultrasound Image Formation	101
6.2.1	Ultrasound Generation and Echo Detection	101
6.2.2	A-Mode Scans	103
6.2.3	B-Mode Scans	105
6.2.4	M-Mode Scans	107
6.2.5	Volumetric Scans and 3D Ultrasound	108
6.3	Doppler Ultrasound	108
7	Trends in Medical Imaging Technology	111
7.1	Progress in Established Imaging Modalities	112
7.1.1	X-ray and CT	112
7.1.2	Magnetic Resonance Imaging	113
7.1.3	Ultrasound Imaging	114

Contents	ix
7.1.4 PET and Multi-Modality Imaging	114
7.1.5 Molecular Imaging	115
7.2 Optical Tomography	115
7.3 Advanced Image Processing	118
References	121
Index	127