

Contents

Part 1 Fundamentals

1	Physiology of vision	19
1.1	General considerations regarding sensory physiology	19
1.2	The eye	21
1.2.1	Adequate stimulus	21
1.2.2	Anatomy	22
1.3	Functioning of the eye	23
1.3.1	The imaging mechanism	23
1.3.2	Aberrations in image production	23
1.3.3	Eye defects	25
1.3.4	The accommodation process	25
1.3.5	Eye movements	25
1.3.6	Depth of field	27
1.4	Conversion of light into neural impulses	27
1.4.1	Anatomy of the retina	27
1.4.2	Spatial resolution	28
	Visual acuity · Vernier acuity	
1.4.3	Contrast resolution	30
	Differential sensitivity · Glare · Simultaneous contrast · Successive contrast · Contrast gradient (definition)	
1.4.4	Adaptation	32
1.4.5	Sensitivity to color	36
1.4.6	Temporal resolution	38
	Absence of flicker (fusion frequency) · Integration time (response time)	
	Movement threshold	
1.5	Neural processing	40
1.5.1	Anatomy of the visual pathway	40
1.5.2	Three-dimensional vision	40
1.5.3	Depth perception	42
1.5.4	Optical illusions	42
1.5.5	Visual memory	43
	Afterimages · Short-term memory · Recognition	
2	Quantitative assessment of image quality	44
2.1	Description of image quality in the borderline case of negligible image noise	45
	Linearity condition · Spatial invariance condition (displacement invariance)	

2.2	Mathematical introduction of the MTF	46
2.3	The MTF as a criterion for the quality of an imaging system	50
2.4	Practical aspects of MTF measurements	51
2.5	Determination of image disturbances due to noise	53
2.6	Image quality assessment taking into account all influencing variables at the same time ROC curves · Contrast detail diagrams	55
2.7	Final remarks	58
2.8	Relationship between the MTF and the Fourier transformation	58
3	X-ray and gamma radiation	61
3.1	Generation of x-ray and gamma radiation	61
3.1.1	Characteristic radiation	63
3.1.2	X-ray bremsstrahlung	63
3.1.3	Tungsten as a target material	65
3.1.4	Intensity (energy flux density) of x-radiation	68
3.1.5	Efficiency of bremsstrahlung generation	69
3.2	Interaction of x-rays and gamma rays with matter	70
3.2.1	Effects occurring when x-rays and gamma rays penetrate matter The photoelectric effect · Scattering · Pair production	71
3.2.2	Phenomenological description of the effects Attenuation coefficients · Cross sections	72
3.2.3	The photoelectric effect, quantitative approach Ionization, x-ray-induced fluorescence, Auger electrons · Dependence of the absorption on energy and atomic number · Angular distribution of the photoelectrons · Energy transfer to the photoelectrons	76
3.2.4	Scattering processes Classical scattering at free electrons · Compton effect · Incoherent scattering off free electrons · Scattering at bound electrons	80
3.2.5	Interactions with real objects Scattering and energy absorption · X-ray detectors	86
4	X-ray computed tomography	89
4.1	Principles of computed tomography	89
4.1.1	Introduction	89
4.1.2	Basic principle	91
4.1.3	Attenuation scale	94
4.1.4	Image generation	95
4.1.5	Types and properties of equipment	97
4.1.6	Beam quality and measurement value corrections	103
4.2	CT image reconstruction	107

4.2.1	Principles of image reconstruction	109
	Algebraic reconstruction methods · Integral transformation methods (convolution methods) · Critique of the various reconstruction principles · Remarks on image reconstruction algorithms for the fan-beam principle	
4.2.2	Image quality	118
	The different reaction of different scanner types to measured value disturbances · Typical CT image disturbances · Systematic measurement errors · Statistical fluctuation phenomena · Basic remarks on the perceptibility of artifacts · Matching of the system parameters · Discussion of a few frequently observed CT artifacts	
4.2.3	Mathematical appendix: description of the convolution method	131
	Filter equation · One-dimensional form of the filter equation · Discretization of the filter equation	
5	Magnetic resonance imaging	138
5.1	Basic principles	138
5.1.1	Macroscopic magnetization	138
5.1.2	The Bloch equations	141
5.1.3	Relaxation	143
5.1.4	The magnetic resonance experiment	146
5.1.5	Pulse method for determining T_2	149
5.1.6	Pulse method for determining T_1	152
5.1.7	Magnetic resonance spectroscopy	154
5.1.8	Signal-to-noise ratio	156
5.2	Methods of spatial resolution	159
5.2.1	Classification of imaging procedures	159
5.2.2	Selective excitation	161
5.2.3	Imaging procedures	164
5.2.4	Pulse sequences and contrast	166
5.2.5	Flow in the magnetic resonance image	171
5.2.6	Spatially resolved spectroscopy	175
6	Ultrasonic techniques	183
6.1	Basic physical principles	183
6.1.1	Ultrasonic field parameters and derived concepts	183
6.1.2	Wave equations and the plane wave	189
6.1.3	Physical effects	192
	Reflection · Refraction · Diffraction · Scattering · Absorption	
6.1.4	Acoustic beam and transducer	200
6.2	Technical procedures	204
6.2.1	The Doppler methods	205
6.2.2	Other methods	206
6.3	Limitations of the methods (image quality criteria)	207

6.3.1	Penetration depth, signal dynamics	207
6.3.2	Spatial resolution	208
6.3.3	Amplitude resolution	212
6.3.4	Tissue inhomogeneity	213
6.3.5	Line density	215
6.3.6	Image frequency	215
6.3.7	Geometrical display accuracy	216
6.4	Safety considerations	216

Part 2 Technical solutions

7	X-ray diagnostics	221
7.1	Image generation	222
7.1.1	The x-ray tube Cathode assembly · Anode assembly · Vacuum envelope · X-ray tube assembly · Load capacity of x-ray tubes	222
7.1.2	Scattered radiation and its reduction	246
7.1.2.1	Effect of scattered radiation on the x-ray image	246
7.1.2.2	Dependence of the percentage of scattered radiation on the beam parameters	249
7.1.2.3	Reduction of scattered radiation by means of compression and collimation	250
7.1.2.5	Reduction of scattered radiation by grids Geometrical grid characteristics · Physical characteristics · Application · Other types of grid	251
7.1.2.6	Reduction of scattered radiation by filters and slot dia- phragms Filters · Moving slot	261
7.1.3	Intensifying screens, films, storage phosphor screens	262
7.1.3.1	Intensifying screens Screen composition · Luminescent materials · Physical properties of intensifying screens · Siemens intensifying screens	263
7.1.3.2	Films Composition of the film · Optical density (blackening) of the film and gradation	277
7.1.3.3	Storage phosphor screens	281
7.1.4	X-ray generators and control circuits	284
7.1.4.1	Power circuits Conventional generators from single-pulse to 12 pulse · Direct current generator · High frequency generator (multipulse generator) · Types of design	287

7.1.4.2	Filament circuit	294
7.1.4.3	High speed starter	298
7.1.4.4	Timer circuits and exposure circuits	299
	Timing devices · "mAs switching" · Automatic exposure control system · Time-controlled exposures	
7.1.4.5	Automatic control systems and operation	307
	Fluoroscopy · Indirect exposure techniques · Direct exposure techniques · Tube load indicator · Control circuits and safety circuits	
7.1.4.6	Documentation	317
7.1.5	X-ray image intensifiers	318
7.1.5.1	Principles of operation of the x-ray image intensifier	319
7.1.5.2	X-ray fluorescent screens (input screens)	322
7.1.5.3	Photocathode	324
7.1.5.4	Electron-optical imaging	324
7.1.5.5	Output screens	327
7.1.5.6	Total gain factor, conversion factor	327
7.1.5.7	Resolving power, modulation transfer function (MTF)	328
7.1.5.8	Further processing of the x-ray image intensifier output image	328
7.1.5.9	Panel-type image intensifiers	330
7.1.6	X-ray television	331
7.1.6.1	Television camera tubes (pick-up tube)	331
7.1.6.2	Video amplifiers	335
	Electric noise · Methods of measurement for obtaining the signal-to-noise ratio (S/N) · Video signal control · Brightness and gain control · Dominant	
7.1.6.3	Monitors	340
	Operating principle · Color tone · Contrast and brightness adjustment, picture tube characteristic · DC restoration · Measures for enhancing the contrast	
7.1.6.4	Spatial modulation transfer function (MTF)	345
7.1.6.5	Temporal modulation transfer function (MTF)	347
7.1.6.6	Quantum noise, amplifier noise	348
7.1.6.7	Scanning systems	349
	Interlaced scanning · Progressive scanning · Slow progressive scanning	
7.2	Digital image storage and image processing	352
7.2.1	Single image storage	352
7.2.1.1	Principles and technology	352
	Analog-to-digital conversion · Solid state memories · Digital-to-analog conversion	
7.2.1.2	Medical application	355
7.2.2	Multiple image storage	356
	Digital solid state memory · Digital disk storage (Winchester) · Digital magnetic tape · Floppy disks · Digital optical disks · Comparison of the various types of storage · Data compression	
7.2.3	Digital image processing	361
	Methods of single image processing · Multiple image processing	

7.2.4	Digital subtraction angiography (DSA)	369
	Basic principle · Technical realization · Postprocessing · Conversion to the logarithm · Road-mapping	
7.2.5	Dual energy imaging and hybrid subtraction	375
	Theoretical basis · Application in DSA: hybrid subtraction	
7.2.6	Digital multilayer tomography	380
7.2.7	Functional images	383
7.2.8	Image analysis	385
	Geometrical analysis · Densitometric analysis	
7.2.9	Multiformat cameras	388
7.2.9.1	Cameras with a cathode ray tube	389
	Documentation monitor · Exposure regulation · Film characteristic, resulting gradation · Contrast and resolution	
7.2.9.2	Film processors for magazine cameras	393
7.2.9.3	Attachment of 35 mm and cine cameras	394
7.2.9.4	Multiformat cameras with laser	395
	Types of laser · Deflection and modulation · Camera interfaces	
7.3	X-ray systems for angiography and lithotripsy	399
7.3.1	Universal angiographic systems	401
	Area of application · Requirements · Example of a system · Image results	
7.3.2	Systems for cardiac angiography	408
	Area of application · Requirements · Example of a system · Image results	
7.3.3	Systems for digital subtraction angiography (DSA)	415
	Area of application · Requirements · Example of a system · Image results	
7.3.4	System for lithotripsy	424
	Area of application · Requirements · Example of a system	
8	X-ray computed tomography	430
8.1	Equipment design	430
8.1.1	The CT system and its components	430
8.1.2	Scanning unit	431
8.1.2.1	Gantry	432
8.1.2.2	Patient positioning and slice positioning	433
8.1.3	Scanning system	436
8.1.3.1	High-voltage generation and x-ray tube	436
8.1.3.2	Measurement system	437
8.1.3.3	Beam path	440
8.1.3.4	Dose distribution	440
8.1.4	Computer system	442
8.1.5	Operating concept	444
8.2	Image display, documentation and evaluation	445
8.2.1	Image display	445

8.2.2	Image documentation and archiving	446
8.2.2.1	Photography	447
8.2.2.2	Digital image storage	447
8.2.3	Image evaluation	448
8.2.3.1	Subjective image evaluation procedures	449
8.2.3.2	Objective image evaluation procedures	451
8.2.4	Applications	452
	Evaluation of dynamic image series after contrast medium injection ·	
	Evaluation of dynamic image series after xenon inhalation · Evaluation	
	of ECG-triggered cardiac images · CT image for biopsy and	
	stereotaxy · Generation of images from the dual energy method ·	
	Determination of the mineral calcium content in the vertebrae ·	
	The CT image in radiation therapy planning	
9	Nuclear medical diagnostics	458
9.1	Measurement technology	459
9.1.1	Structure and function of a radiation measurement channel	459
9.1.2	Effect of information density on the measured results	461
9.2	The scanner, the first imaging unit in nuclear medicine	462
9.3	Gamma cameras	463
9.3.1	Design and operation of the Anger gamma camera	464
	Collimator · Detector system	
9.4	Scintigraphic data processing	475
9.5	Emission computed tomography (ECT)	475
9.5.1	SPECT	476
9.5.2	PET	
10	Magnetic resonance imaging	479
10.1	System overview	479
10.2	System components	481
10.2.1	Magnet	481
	Criteria for the selection of field strength · Types of magnets · Super-	
	conducting magnets · Fringe field shielding · Shimming ·	
10.2.2	Gradient system	500
	Criteria for required gradient field strength · Gradient coil · Pulsed	
	gradient power supply · Eddy current effects	
10.2.3	RF system	511
	Transmit and receive system · Coils and resonators · RF-shielded	
	room	
10.2.4	System control	528
	Processor systems for examination sequence, monitoring and image	
	reconstruction · Operating program	
10.3	Imaging techniques	535
10.3.1	Subject-dependent system calibrations	535

10.3.2	Spin-echo pulse sequences	537
10.3.3	Fast MR imaging methods	544
10.3.4	MR angiography	550
	Clinical studies	
11	Sonography	557
11.1	Scanning methods	557
11.1.1	Echo pulse technique	557
11.1.2	Ultrasound field, axial and lateral resolution	559
11.1.3	Imaging methods	563
11.1.4	Doppler methods	564
11.2	Scanner designs	566
11.2.1	Mechanical sector scanners	571
	Scanning principles · Design of the transducer · Annular array	
11.2.2	Electronic scanners	579
	Electronic focussing · Linear and curved arrays · Phased arrays	
11.2.3	Duplex scanners	590
12	Biomagnetic diagnostics	592
12.1	Biomagnetic fields	592
12.2	Measurement of biomagnetic fields	593
12.3	Technical realization	595
12.4	Source localization	599
12.5	Application	600
	References	602
	Formula symbols	622
	Index	625