

# Contents

## Part I – Principles of Image Processing

<b>1 Physiology of vision</b> .....	18
1.1 General considerations regarding sensory physiology .....	18
1.2 The eye .....	19
1.2.1 Adequate stimulus .....	19
1.2.2 Anatomy .....	19
1.3 Functioning of the eye .....	21
1.3.1 The imaging mechanism .....	21
1.3.2 Aberrations in image production .....	21
1.3.3 Eye defects .....	22
1.3.4 The accommodation process .....	23
1.3.5 Eye movements .....	23
1.3.6 Depth of field .....	24
1.4 Conversion of light into neural impulses .....	25
1.4.1 Anatomy of the retina .....	25
1.4.2 Spatial resolution .....	26
1.4.3 Contrast resolution .....	27
1.4.4 Adaptation .....	29
1.4.5 Sensitivity to color .....	33
1.4.6 Temporal resolution .....	34
1.5 Neural processing .....	36
1.5.1 Anatomy of the visual pathway .....	36
1.5.2 Three-dimensional vision .....	36
1.5.3 Depth perception .....	37
1.5.4 Optical illusions .....	38
1.5.5 Visual memory .....	39
1.6 References .....	40
<b>2 Subjective assessment of image quality</b> .....	42
2.1 Introduction .....	42
2.2 ROC Methodology .....	42
2.3 Contrast detail resolution .....	44
2.4 References .....	46
<b>3 Image rendering</b> .....	47
3.1 2D imaging .....	47
3.2 Planar reformation .....	47

3.3 Segmentation .....	48
3.4 Surface rendering .....	49
3.4.1 Extraction of isosurfaces and the marching-cubes algorithm .....	49
3.5 Volume rendering .....	50
3.5.1 Image-order techniques .....	50
3.5.2 Object-order techniques and the shear-warp-factorization .....	52
3.5.3 Compositing .....	53
3.5.4 Conclusion .....	56
3.6 Transfer-functions .....	56
3.7 Local illumination .....	56
3.8 Volume rendering on graphics adapters .....	59
3.9 References .....	60
<b>4 Image fusion .....</b>	<b>62</b>
4.1 Introduction .....	62
4.1.1 Clinical relevance .....	62
4.1.2 Image fusion steps .....	62
4.1.3 General challenges .....	64
4.2 Registration .....	65
4.2.1 Registration by calibration .....	65
4.2.2 Image-based, 3D-3D registration .....	66
4.2.3 Image-based, 2D-3D registration .....	78
4.2.4 Validation of fusion results .....	82
4.3 Visualization .....	83
4.3.1 Visualization of MPR slices .....	83
4.3.2 Fusion result visualization using volume rendering techniques .....	86
4.3.3 Visualization of fused projection images .....	88
4.4 Clinical applications .....	88
4.4.1 Nuclear medicine: fusion of CT/MR and PET/SPECT images .....	88
4.4.2 Surgery .....	89
4.4.3 Treatment planning in radiation oncology .....	91
4.4.4 Interventional radiology .....	92
4.5 References .....	93
<b>5 Navigation .....</b>	<b>96</b>
5.1 Introduction .....	96
5.2 Principles of navigation .....	97
5.3 Localizer technologies .....	99
5.3.1 Principles of optical tracking systems .....	99
5.3.2 Electromagnetic position tracking .....	101
5.3.3 Tool calibration .....	103
5.4 Registration .....	104
5.4.1 Point-pair matching using a 3D localizer .....	105
5.4.2 Surface matching .....	106

5.5 Navigation for image-guided surgery and intervention .....	107
5.5.1 CT/MRI-based navigation .....	107
5.5.2 2D mobile C-arm-based navigation .....	107
5.5.3 3D mobile C-arm-based navigation .....	109
5.6 Navigation accuracy .....	111
5.7 Clinical applications .....	111
5.8 Future prospects .....	113
5.9 References .....	113

## **Part II – Physics of Imaging**

<b>6 X-ray and <math>\gamma</math>-radiation .....</b>	<b>118</b>
6.1 Generation of X-ray and $\gamma$ -radiation .....	118
6.1.1 Properties of X-ray bremsstrahlung .....	119
6.1.2 Characteristic radiation .....	120
6.1.3 Intensity (energy flux density) of X-radiation .....	122
6.1.4 Target material .....	123
6.2 X-ray and $\gamma$ -ray interaction with matter .....	124
6.2.1 Interaction effects and phenomenological description .....	124
6.2.2 The photoelectric effect .....	124
6.2.3 Compton effect .....	127
6.2.4 Coherent scattering .....	130
6.2.5 Interactions with real objects .....	131
6.3 Biological effects of radiation .....	135
6.3.1 Acute or deterministic radiation damage .....	135
6.3.2 Stochastic radiation damage .....	136
6.3.3 Estimate of radiation risk .....	136
6.3.4 Controversy concerning the effects of low radiation doses .....	140
6.4 References .....	141
<b>7 Concepts in magnetic resonance imaging .....</b>	<b>143</b>
7.1 Historical survey .....	143
7.2 The NMR phenomenon .....	144
7.2.1 Magnetization .....	144
7.2.2 Bloch equations .....	146
7.2.3 Relaxation .....	148
7.2.4 Magnetization transfer .....	151
7.2.5 Nuclear induction .....	152
7.2.6 Spin echoes .....	156
7.2.7 Steady-state free precession .....	158
7.2.8 Diffusion .....	161
7.2.9 Spectroscopy .....	165
7.2.10 Signal-to-noise ratio .....	168

7.3 Magnetic resonance imaging .....	170
7.3.1 NMR signal in a magnetic field gradient .....	171
7.3.2 Spatial resolution .....	173
7.3.3 Selective excitation .....	175
7.3.4 Pulse sequence and contrast .....	178
7.4 References .....	181
<b>8 Physical principles of medical ultrasound .....</b>	<b>184</b>
8.1 Introduction .....	184
8.2 Ultrasound field .....	185
8.2.1 Ultrasound field parameters .....	185
8.2.2 Ultrasound propagation .....	187
8.3 Imaging principles .....	197
8.3.1 Echo pulse method .....	197
8.3.2 Ultrasound transducer .....	199
8.3.3 Imaging methods .....	200
8.3.4 Methods of determining flow .....	202
8.4 Safety of diagnostic ultrasound .....	207
8.4.1 Acoustic output regulations .....	207
8.4.2 Bioeffects .....	207
8.4.3 Output display standard using thermal and mechanical indices .....	209
8.4.4 Summary – prudent use of ultrasound .....	210
8.5 References .....	210

## **Part III – Image Reconstruction**

<b>9 System theory .....</b>	<b>214</b>
9.1 Introduction .....	214
9.2 Basic quantities for evaluating image quality .....	214
9.2.1 Contrast .....	214
9.2.2 Spatial resolution .....	216
9.2.3 Noise .....	224
9.3 References .....	228
<b>10 Principles of image reconstruction .....</b>	<b>230</b>
10.1 Introduction .....	230
10.2 Basic principles .....	231
10.3 2D Fourier reconstruction .....	233
10.4 Number of data .....	234
10.5 Filtered backprojection .....	235
10.6 3D projection reconstruction .....	237
10.7 Backprojection applying homogeneous coordinates .....	240
10.8 References .....	241

## **Part IV – Image Instrumentation**

<b>11 Image displays</b> .....	244
11.1 Advantages and challenges of soft-copy reading .....	244
11.2 Impact of the human visual system on display design .....	245
11.2.1 Contrast sensitivity and spatial resolution .....	246
11.2.2 Contrast and dynamic range .....	247
11.2.3 Color vision .....	249
11.3 Medical display technologies .....	249
11.3.1 Cathode ray tube monitors .....	250
11.3.2 Liquid crystal displays .....	252
11.4 Technical display performance values .....	255
11.4.1 Display size .....	255
11.4.2 Spatial resolution .....	255
11.4.3 Luminance, contrast ratio, and veiling glare .....	256
11.4.4 Dynamic range and display curve .....	258
11.4.5 Noise .....	258
11.5 Digital imaging display systems .....	259
11.6 References .....	260
<b>12 X-ray components and systems</b> .....	264
12.1 The X-ray tube .....	264
12.1.1 Emitters .....	265
12.1.2 Specifications for focal spot size and electron beam shape .....	272
12.1.3 The anode assembly .....	280
12.1.4 Anode load capacity .....	289
12.1.5 X-ray tube vacuum envelopes .....	292
12.1.6 Casing design .....	296
12.2 X-ray generators .....	300
12.2.1 General requirements .....	300
12.2.2 Technical aspects .....	303
12.2.3 Control circuits .....	305
12.2.4 Exposure control in direct radiography .....	309
12.2.5 Exposure control in indirect radiography .....	312
12.3 X-ray image detectors .....	315
12.3.1 Static detectors .....	315
12.3.2 X-ray image intensifiers .....	316
12.3.3 Processing the X-ray image intensifier's output image .....	323
12.3.4 Flat detectors .....	333
12.4 X-ray systems .....	349
12.4.1 Classification of X-ray systems .....	350
12.4.2 Intervention – a paradigm for a modern X-ray system .....	357
12.5 Cone-beam CT with C-arm systems .....	378
12.5.1 Introduction .....	378

12.5.2 Acquisition protocols and system properties . . . . .	380
12.5.3 Calibration . . . . .	381
12.5.4 Reconstruction . . . . .	384
12.5.5 Visualization . . . . .	384
12.5.6 Advanced application tools . . . . .	385
12.5.7 Image quality . . . . .	386
12.5.8 Clinical applications and examples . . . . .	389
12.5.9 Outlook . . . . .	393
12.6 Mammography . . . . .	393
12.6.1 System overview . . . . .	394
12.6.2 Digital mammography . . . . .	399
12.6.3 Other and new modalities . . . . .	404
12.7 References . . . . .	404
<b>13 Computed X-ray tomography . . . . .</b>	<b>413</b>
13.1 Principles . . . . .	413
13.1.1 Measurement principle . . . . .	413
13.1.2 Basic image reconstruction . . . . .	415
13.1.3 Single-slice axial CT and spiral CT . . . . .	417
13.1.4 Image quality . . . . .	422
13.2 From single-slice to multi-slice CT . . . . .	434
13.3 Multi-slice CT (MSCT) . . . . .	438
13.3.1 System design . . . . .	439
13.3.2 Detector design for MSCT . . . . .	447
13.3.3 The cone-angle problem . . . . .	451
13.3.4 MSCT spiral scan and reconstruction techniques . . . . .	453
13.3.5 Double z-sampling . . . . .	466
13.3.6 Dose in MDCT . . . . .	468
13.4 Multi-slice cardiac CT . . . . .	470
13.4.1 Introduction . . . . .	470
13.4.2 ECG-triggered MSCT imaging . . . . .	471
13.4.3 ECG-gated MSCT imaging . . . . .	471
13.4.4 Performance evaluation . . . . .	477
13.5 Clinical applications . . . . .	479
13.5.1 Quantification of coronary calcification . . . . .	479
13.5.2 Cardiac and coronary CT angiography . . . . .	482
13.5.3 Evaluation of cardiac function . . . . .	484
13.5.4 Preventive care: CT of the lung and colon . . . . .	486
13.6 The future of CT . . . . .	488
13.6.1 From multi-slice to area-detector CT . . . . .	488
13.6.2 Combined systems . . . . .	490
13.6.3 Alternative system concepts . . . . .	493
13.6.4 Maximum data volumes and theoretical CT limitations . . . . .	494
13.7 References . . . . .	495

<b>14 Nuclear medicine</b>	503
14.1 Introduction	503
14.2 Imaging with single photon emitters – measurement principles and devices	504
14.2.1 The scintillation detector	504
14.2.2 The gamma camera (Anger camera)	506
14.3 SPECT systems	514
14.3.1 General SPECT principle	514
14.3.2 Overview of current systems	516
14.3.3 Clinical applications	521
14.3.4 New detector technologies	523
14.4 PET systems	524
14.4.1 Principles of PET	524
14.4.2 Characterization of PET scanners	530
14.4.3 Clinical applications	532
14.5 References	536
<b>15 Magnetic resonance imaging</b>	540
15.1 MR systems and components	540
15.1.1 System overview	540
15.1.2 The main magnet	542
15.1.3 The gradient system	554
15.1.4 The RF system	563
15.1.5 System control	579
15.1.6 Image quality	579
15.1.7 MR safety	592
15.2 Methods and clinical applications	599
15.2.1 Sequences and contrast	599
15.2.2 Parallel imaging techniques (PAT)	619
15.2.3 Whole-body imaging	628
15.2.4 MRI and macroscopic motion	631
15.2.5 MRI and microscopic motion	669
15.2.6 Clinical examples	686
15.2.7 Clinical MR spectroscopy	698
15.2.8 Hyperpolarization	710
15.3 References	716
<b>16 Ultrasound imaging systems</b>	732
16.1 Introduction	732
16.1.1 Operation	732
16.1.2 Typical modes	733
16.2 System architecture	745
16.2.1 Beamformer	746
16.2.2 Mid-processor	758
16.2.3 Display	765

16.3 Transducer types (from a system perspective) .....	768
16.3.1 Sector and vector transducers .....	768
16.3.2 Linear transducers .....	769
16.3.3 Curved transducers .....	770
16.3.4 Intra-cavity transducers .....	770
16.3.5 Multi-row arrays (1.25 and 1.5 dimensional arrays) .....	770
16.3.6 Hanafy lens approach to control elevation beamwidth .....	771
16.3.7 Summary of different transducer types .....	772
16.4 B-mode imaging .....	773
16.4.1 Harmonics for clutter reduction .....	773
16.4.2 Transmit pulse coding .....	776
16.4.3 Compounding .....	779
16.5 Contrast agent imaging .....	782
16.5.1 Brief discussion of the physics of contrast agents .....	782
16.5.2 Destructive contrast agent detection techniques (disruption) .....	783
16.5.3 Pulse inversion as a nondestructive contrast agent detection technique .....	784
16.5.4 Third order scattering for nondestructive contrast agent detection .....	785
16.6 Quantification .....	786
16.7 3D imaging .....	788
16.7.1 Wobblers .....	788
16.7.2 2D arrays .....	789
16.7.3 3D transesophageal imaging .....	790
16.8 Conclusion .....	791
16.9 Methods and applications in sonography .....	792
16.9.1 2D-imaging .....	792
16.9.2 Doppler imaging .....	794
16.9.3 Harmonic imaging .....	801
16.9.4 Compounding technologies and applications .....	805
16.9.5 Workflow-improvement and standardization technologies .....	814
16.9.6 Special cardiac transducers and evaluations .....	815
16.10 References .....	820
<b>17 Special and hybrid systems .....</b>	<b>821</b>
17.1 Imaging for radiation therapy .....	821
17.1.1 Introduction .....	821
17.1.2 The portal imaging beam .....	823
17.1.3 Portal imaging detectors .....	825
17.1.4 Advanced techniques .....	827
17.1.5 Summary .....	830
17.2 Hybrid systems: PET/CT and SPECT-CT .....	830
17.2.1 Clinical benefits of combined functional and morphological imaging ..	831
17.2.2 Design criteria for PET/CT systems .....	831
17.2.3 PET/CT applications .....	832
17.2.4 SPECT and CT .....	835

17.3 Combining imaging modalities for interventional procedures .....	836
17.3.1 Interventional angiography combined with CT imaging .....	837
17.3.2 Interventional angiography combined with MRI imaging .....	839
17.4 Imaging in the operating room .....	842
17.4.1 Intraoperative imaging .....	842
17.4.2 Integrated surgical workplaces .....	855
17.5 References .....	860
<b>18 Molecular imaging .....</b>	<b>863</b>
18.1 Introduction .....	863
18.2 Imaging probes .....	864
18.3 Signal amplification strategies .....	868
18.4 Imaging modalities .....	868
18.4.1 Nuclear imaging .....	869
18.4.2 Magnetic resonance imaging (MRI) .....	871
18.4.3 Optical imaging .....	873
18.4.4 Computed tomography .....	878
18.4.5 Ultrasound .....	878
18.4.6 Combined systems .....	879
18.5 Outlook .....	879
18.6 References .....	880

## Part V – Information Processing and Distribution

<b>19 Software platform for medical imaging .....</b>	<b>888</b>
19.1 Overview .....	888
19.2 Introduction to medical imaging software domain .....	888
19.2.1 Aspects of a common style guide .....	891
19.2.2 A sample workflow .....	893
19.2.3 Analysis of the problem domain .....	905
19.2.4 From programming to software configuration .....	907
19.3 Software terminology .....	908
19.4 Application architecture .....	910
19.4.1 Three-tiered architecture model .....	912
19.4.2 Application architecture and component-runtime management .....	915
19.4.3 Presentation-logic containerware and componentware .....	918
19.4.4 Business logic containerware and componentware .....	918
19.4.5 Asynchronous communication: decoupling presentation and business logic .....	919
19.5 Business objects for medical imaging .....	920
19.6 Services for medical imaging .....	921
19.6.1 Data management services .....	921
19.6.2 DICOM work list, storage, query and print-management services .....	921

19.6.3 2D/3D/4D image processing services and framework .....	922
19.6.4 Security management services .....	923
19.6.5 Basic services .....	924
19.6.6 Systems management service .....	925
19.7 Tool support for <i>syngo</i> 's product-line architecture .....	926
19.8 Medical enterprise application integration (EAI) .....	928
19.9 References .....	929
<b>20 Computer-aided detection and diagnosis (CAD)</b> .....	931
20.1 Introduction .....	931
20.2 Performance measurement of CAD systems .....	934
20.3 Computer-aided detection dataflow .....	934
20.4 Development and validation of CAD systems – databases, training and testing of classifiers .....	937
20.5 Future directions in CAD .....	939
20.6 References .....	941
<b>21 Hospital information systems</b> .....	943
21.1 Information system basics .....	944
21.2 Introduction to hospital information systems .....	949
21.3 Purpose and classification .....	950
21.4 Hospital workflow and integration .....	953
21.5 HIS architecture .....	954
21.6 Patient administration and revenue management .....	958
21.6.1 Functionality .....	958
21.6.2 Technical realization of reimbursement workflow .....	961
21.7 The electronic medical record (EMR) .....	964
21.7.1 Functionality .....	964
21.7.2 User interface and technical realization .....	965
21.8 Clinical workflow applications .....	967
21.8.1 Functionality .....	967
21.8.2 Technical realization of system intelligence .....	971
21.9 Departmental information system: radiology .....	974
21.9.1 The radiology workflow .....	974
21.9.2 The radiology information system (RIS) .....	975
21.9.3 The picture archiving and communication system (PACS) .....	977
21.10 Integrated workplaces .....	979
21.10.1 Integrated workplaces in radiology .....	979
21.10.2 Integrated workplaces in cardiology .....	981
21.11 The digital hospital and beyond – a vision .....	983
21.12 References .....	988
<b>Index</b> .....	990