

Contents

Chapter 1 Introduction	1
1.1 Computed Tomography Examinations	1
1.2 Towards Low-Dose CT	2
1.3 Scientific Contributions	4
1.4 Dissertation Outline	6
Chapter 2 Principles of Computed Tomography	9
2.1 Setup of a Computer Tomograph	9
2.2 Lambert–Beer’s Law	10
2.3 Generations of CT Scanners.	12
2.3.1 First Generation CT Scanner	12
2.3.2 Second Generation CT Scanner.	12
2.3.3 Third Generation CT Scanner.	13
2.4 Projection Sampling Geometries	14
2.5 Scan Modes.	15
2.6 X-ray Beam Filtration	16
2.7 Quarter Detector Offset and Flying Focal Spot.	16
2.8 Hounsfield Units.	17
Chapter 3 Mathematical Description of the Data Acquisition Process	19
3.1 Scanner Geometry	19
3.2 Two-Dimensional Radon Transform.	20
3.3 Divergent Beam Transform in 2D	22
3.4 Divergent Beam Transform in 3D	24
Chapter 4 Iterative Reconstruction Techniques	27
4.1 General Approach to Iterative Reconstruction.	27
4.2 Framework of Iterative Reconstruction Methods	29
4.2.1 Non-Constrained Iterative Image Reconstruction	29
4.2.2 Constrained Iterative Image Reconstruction	30
4.3 Iterative Reconstruction Algorithms	32
4.3.1 Landweber Method	32
4.3.2 Iterative Coordinate Descent Method.	34
4.4 Strengths and Weaknesses of Iterative Reconstruction Methods	36
Chapter 5 Image Quality Assessment	37
5.1 Phantom	37
5.2 Quantitative Evaluation: Basic Metrics	38
5.2.1 Spatial Resolution	38

5.2.2 Computational Cost	40
5.2.3 Overshoot Evaluation	41
5.2.4 Reconstruction Error	41
5.2.5 Noise.	42
5.2.5.1 Mean Standard Deviation.	42
5.2.5.2 Mean Correlation Coefficient	43
5.3 Quantitative Evaluation: Task-Based Metrics	44
5.3.1 Observer Performance Measures	44
5.3.1.1 Area Under the Receiver Operating Characteristic Curve	44
5.3.1.2 Signal-to-Noise Ratio.	45
5.3.2 Ideal Observer	46
5.3.3 Channelized Hotelling Observer.	47
5.3.3.1 Theory.	47
5.3.3.2 Channel Selection	48
5.3.3.3 Internal Noise.	49
5.3.4 Human Observer.	50
5.4 Basic Metrics versus Task-based Metrics	51
Chapter 6 Impact of Discrete Image Representation Techniques on Image Quality	53
6.1 Motivation and Limitations	54
6.2 Discrete Image Representation Techniques.	54
6.2.1 Sampling Approach	54
6.2.2 Strip Integral Approach	56
6.2.3 Basis Function Approach	57
6.2.3.1 General Concept	58
6.2.3.2 B-splines	58
6.2.3.3 Blobs.	63
6.2.4 Comparative Discussion	64
6.3 Experimental Setup	65
6.3.1 Reconstruction Method	65
6.3.2 Geometrical Settings	66
6.3.3 Phantom Selection and Data Simulation	68
6.4 Preliminary Study.	69
6.4.1 Study design.	69
6.4.2 Visual Appearance of Some Reconstructions.	69
6.4.3 Quantitative Evaluation: Basic Metrics	71
6.4.4 Summary Discussion	74
6.5 Quantitative Evaluation of Linear Interpolation Models: Basic Metrics.	75
6.5.1 Presentation of the Results.	75
6.5.1.1 Figure-of-Merit	75
6.5.1.2 Display Concept	76
6.5.2 Visual Appearance of Some Reconstructions.	77
6.5.3 Results	77
6.5.4 Summary Discussion	82

6.6 Quantitative Evaluation of Linear Interpolation Models: Task-based Metrics . .	85
6.6.1 Ideal Observer Study	86
6.6.1.1 Task Selection	86
6.6.1.2 Controlling Statistical Variability	88
6.6.1.3 Results	89
6.6.2 Channelized Hotelling Observer Study	91
6.6.2.1 Task Selection	91
6.6.2.2 Controlling Statistical Variability	91
6.6.2.3 Results	91
6.6.3 Human Observer Study	93
6.6.3.1 Task Selection	93
6.6.3.2 Results	94
6.6.4 Summary Discussion	97
6.7 Discussion and Conclusion	97

Chapter 7 Challenges posed by Statistical Weights and Data Redundancies	101
7.1 Motivation and Limitations	102
7.2 Experimental Setup	102
7.2.1 Study Setup	102
7.2.2 Geometrical Settings	103
7.2.3 Phantom Selection and Data Simulation	103
7.2.4 Reconstruction Methods	103
7.2.5 Forward Projection Model	104
7.3 Concept of ICD Parameter Selection	105
7.4 Part I: Reconstruction with Statistical Weights	107
7.4.1 Bowtie Filter Model	107
7.4.2 Experimental Details	107
7.4.2.1 Parameter Selection	107
7.4.2.2 Image Quality Assessment	109
7.4.3 Results	110
7.4.3.1 Influence of Statistical Weights	110
7.4.3.2 Influence of Statistical Weights and Penalty Term	118
7.4.4 Summary Discussion	122
7.5 Part II: Reconstruction with Data Redundancies	124
7.5.1 Data Redundancy Handling	125
7.5.2 Experimental Details	125
7.5.2.1 Parameter Selection	125
7.5.2.2 Image Quality Assessment	126
7.5.3 Results	126
7.5.3.1 Influence of Statistical Weights	126
7.5.3.2 Influence of Statistical Weights and Penalty Term	133
7.5.4 Summary Discussion	137
7.6 Discussion and Conclusion	139

Chapter 8 FINESSE: a Fast Iterative Non-linear Exact Sub-space Search based Algorithm	141
8.1 Motivation and Clinical Application.	141
8.2 Algorithm Design	142
8.2.1 Problem Formulation	142
8.2.2 Description of FISTA	142
8.2.3 Description of FINESSE	144
8.2.3.1 General Concept	144
8.2.3.2 Mathematical Description	145
8.2.3.3 What Sets FINESSE Apart From Other Algorithms	146
8.3 Simulation Study	147
8.3.1 Experimental Setup	147
8.3.1.1 Geometrical Settings	147
8.3.1.2 Phantom Selection and Data Simulation	148
8.3.1.3 FINESSE Settings	148
8.3.1.4 Reconstruction Methods	149
8.3.1.5 Image Quality Assessment	149
8.3.1.6 Computational Cost	150
8.3.2 Results	150
8.3.3 Summary Discussion	155
8.4 Real Data Study.	157
8.4.1 Measurement Setup.	157
8.4.2 Scanner and Phantom Selection	157
8.4.2.1 FINESSE settings	158
8.4.2.2 Reconstruction Methods	159
8.4.3 Results	159
8.4.4 Summary Discussion	159
8.5 Discussion and Conclusion	160
Chapter 9 Summary and Outlook	163
9.1 Summary.	163
9.2 Outlook	165
Chapter A Proofs and Derivations	167
A.1 Proofs for the Landweber algorithm	167
List of Abbreviations and Symbols	169
List of Figures	177
List of Tables	181
List of Algorithms	183
Bibliography	185