

Jack Xin · Yingyong Qi

# **Mathematical Modeling and Signal Processing in Speech and Hearing Sciences**

 Springer

# Contents

<b>1</b>	<b>Background Signal Processing, Statistical and Optimization Methods</b>	<b>1</b>
1.1	Introduction	1
1.2	Fourier and z-Transforms	1
1.2.1	Continuous Time Signals	1
1.2.2	Fourier Transform and Basic Properties	3
1.2.3	Discrete Time Signals and Systems	5
1.2.4	Sampling and Shannon Theory	6
1.2.5	Discrete Fourier Transform	9
1.2.6	Discrete Time and Windowed Fourier Transforms	11
1.2.7	Short Time Fourier Transform, Synthesis and Spectrogram	14
1.2.8	z-Transform	16
1.3	Filtering and Convolution	17
1.3.1	Circular Convolution	19
1.3.2	Linear Convolution and z-Transform	22
1.3.3	Circular Convolution and z-Transform	23
1.3.4	Rational Filters, Impulse and Frequency Responses	24
1.3.5	Group and Phase Delays	28
1.3.6	Minimum Phase and All Pass Filters	29
1.4	Random Variables, Correlation and Independence	30
1.4.1	Basic Notion and Examples	30
1.4.2	Joint Distribution and Independent Components	32
1.4.3	Random Number Generation	33
1.4.4	Stochastic Processes	34
1.4.5	Random Walk and Brownian Motion	35
1.5	Data Clustering and K-Means Method	35
1.6	Maximum Likelihood Method	37
1.7	Least Squares and Sparse Optimization Methods	38
1.8	Exercises	41

<b>2</b>	<b>Speech Modeling</b> .....	45
2.1	Introduction .....	45
2.2	Two Mass Vocal Fold Model .....	46
2.3	Matlab Program and Animation of Two Mass Model .....	49
2.4	Hydrodynamic Semi-Continuum Vocal Fold Model .....	53
2.5	Source-Filter Model of Speech Production .....	58
2.5.1	Uniform Lossless Tube Model and Transfer Function .....	58
2.5.2	Concatenated Lossless Tube Model: Traveling Waves and Transfer Function .....	59
2.5.3	Radiation and the Complete Model .....	62
2.5.4	Matlab Programs for Vowel and Consonant Synthesis .....	63
2.6	Exercises .....	66
<b>3</b>	<b>Auditory Modeling</b> .....	67
3.1	Introduction .....	67
3.2	Macromechanics and Passive Models .....	69
3.3	Micromechanics and Two Level Nonlocal Active Models .....	71
3.4	Dispersion and Decay Properties of Plane Waves .....	73
3.5	Time Harmonic Solutions .....	75
3.6	Asymptotic and Transform Techniques .....	78
3.7	Logarithmic Scales and Critical Bands .....	81
3.8	Time Domain Method and Dispersive Instability .....	82
3.9	Boundary Integral Method and Suppression of Instability .....	86
3.10	Computational Methods of Nonlocal Active Models .....	89
3.11	Nonlinear Phenomena and Sound Masking .....	90
3.12	Invertible Auditory Transforms .....	91
3.13	Orthogonal Auditory Transforms .....	93
3.14	Modeling Masking Thresholds .....	98
3.15	Modeling Hearing Loss and Hearing Aids .....	103
3.16	Matlab Programs .....	109
3.17	Exercises .....	113
<b>4</b>	<b>Speech Recognition</b> .....	115
4.1	Introduction .....	115
4.2	Hidden Markov Model (HMM) for Speech Processing .....	115
4.2.1	Speech Spectral Analysis .....	117
4.2.2	Vector Quantization .....	118
4.3	HMM for Isolated Word Recognition .....	119
4.3.1	Forward and Backward Probabilities .....	122
4.3.2	Baum-Welch Re-Estimation .....	123
4.3.3	Viterbi Decoding .....	125
4.4	Summary of Matlab Programs .....	126
4.5	Chapter Summary .....	127
4.6	Matlab Programs .....	128
4.7	Exercises .....	139

<b>5</b>	<b>Blind Source Separation and Speech Enhancement</b>	141
5.1	Introduction	141
5.2	Instantaneous Mixture and Decorrelation Methods	141
5.2.1	Decorrelation with Second Order Statistics	142
5.2.2	Demixing with Joint Second and Third Order Statistics	143
5.3	Instantaneous Mixture and Cumulant Method	145
5.3.1	Moments and Cumulants	145
5.3.2	Source Recovery and Whitening Process	148
5.3.3	Unitary Factor as Joint Diagonalizer of Cumulant Matrices	149
5.3.4	Joint Diagonalization of Eigenmatrices	149
5.3.5	Jacobi Method and Joint Diagonalizer Formula	150
5.4	Instantaneous Mixture and Infomax Methods	153
5.4.1	Statistical Equations for Source Separation	153
5.4.2	Iterative Methods	155
5.4.3	Uniform Bounds	156
5.4.4	Convergence and Source Separation	158
5.4.5	Numerical Example	160
5.5	Convolutional Mixture and Decorrelation Method	160
5.5.1	Decorrelation Equations	162
5.5.2	Constrained and Penalized Optimization	163
5.5.3	Numerical Example	164
5.6	Convolutional Mixture and Infomax Methods	164
5.6.1	Extensions and Analysis of Algorithms	165
5.6.2	Numerical Example	168
5.7	Relative Sparsity and Time-Frequency Domain Methods	169
5.8	Convex Speech Enhancement Model	172
5.8.1	Convex Model and $l_1$ Regularization	172
5.8.2	Minimization by Bregman Method	175
5.9	Summary and Other Methods for Further Reading	178
5.10	Matlab Programs	178
5.11	Exercises	187
	<b>References</b>	189
	<b>Index</b>	199