

Digital Signal and Image Processing using MATLAB®

Gerard Blanchet
Maurice Charbit

Contents

Preface	15
Notations and Abbreviations	19
Introduction to MATLAB	23
1 Variables	24
1.1 Vectors and matrices	24
1.2 Arrays	26
1.3 Cells and structures	27
2 Operations and functions	29
2.1 Matrix operations	29
2.2 Pointwise operations	30
2.3 Constants and initialization	31
2.4 Predefined matrices	31
2.5 Mathematical functions	32
2.6 Matrix functions	34
2.7 Other useful functions	34
2.8 Logical operators on boolean variables	35
2.9 Program loops	35
3 Graphically displaying results	36
4 Converting numbers to character strings	39
5 Input/output	39
6 Program writing	40
Part I Deterministic Signals	41
Chapter 1 Signal Fundamentals	43
1.1 The concept of signal	43
1.1.1 A few signals	44
1.1.2 Spectral representation of signals	46
1.2 The Concept of System	48
1.3 Summary	50

8 Digital Signal and Image Processing using MATLAB

Chapter 2 Discrete Time Signals and Sampling	51
2.1 The sampling theorem	52
2.1.1 Perfect reconstruction	52
2.1.2 Digital-to-analog conversion	64
2.2 Plotting a signal as a function of time	65
2.3 Spectral representation'	67
2.3.1 Discrete-time Fourier transform (DTFT)	67
2.3.2 Discrete Fourier transform (DFT)	71
2.4 Fast Fourier transform	77
Chapter 3 Spectral Observation	81
3.1 Spectral accuracy and resolution	81
3.1.1 Observation of a complex exponential,-	81
3.1.2 Plotting accuracy of the DTFT	83
3.1.3 Frequency resolution	84
3.1.4 Effects of windowing on the'resolution	87
3.2 Short term Fourier transform	90
• 3.3 Summing up	94
3.4 Application examples and exercises . . . ;	95
3.4.1 Amplitude modulations	95
3.4.2 Frequency modulation	98
Chapter 4 Linear Filters	101
4.1 Definitions and properties.	101
4.2 The Z-transform	106
4.2.1 Definition and properties.	106
4.2.2 A few examples	107
4.3 Transforms and linear filtering	109
4.4 Difference equations and rational TF,filters	111
4.4.1 Stability considerations	112
"4.4.2 FIR and IIR filters	114
4.4.3 Causal solution and initial conditions	115
4.4.4 Calculating the responses.	117
4.4.5 Stability and the Jury test	118
4.5 Connection between gain and poles/zeros.	119
• 4.6 Minimum phase filters	129
4.7 Filter design methods.	133
4.7.1 Going from the continuous-time filter to the discrete-time filter	133
4.7.2 FIR filter design using the window method	137
4.7.3 IIR filter design	147
• 4.8 Oversampling and undersampling	150
4.8.1 Oversampling	151

4.8.2 Undersampling	155
Chapter 5 Filter Implementation	159
5.1 Filter implementation	159
5.1.1 Examples pf.filter structures	159
5.1.2 Distributing the calculation ,load in an FIR filter . . .	164
5.1.3 FIR block filtering	165
5.1.4 FFT filtering	167
5.2 Filter banks	173
5.2.1 Decimation and expansion	174
5.2.2 Filter banks	177
Chapter 6 An Introduction to Image Processing , ; ,	187
6.1 Introduction	187
6.1.1 Image display, color palette	187
6.1.2 Importing images	191
6.1.3 Arithmetical and logical operations	193
6.2 Geometric transformations of.an image	196
6.2.1 The typical transformations	196
6.2.2 Aligning images	199
6.3 Frequential content of an image	203
6.4 Linear filtering	207
6.5 Other operations on images	217
6.5.1 Undersampling	217
6.5.2 Oversampling	217
6.5.3 Contour detection	220
6.5.4 Mediän filtering	226
6.5.5 Maximum enhancement	227
6.5.6 Image binarization	229
6.5.7 Morphological filtering of binary images	234
6.6 JPEG lossy compression	236
6.6.1 Basic algoritm.	236
6.6.2 Writing the compression function	237
6.6.3 Writing the decompression function	240
8.7 Watermarking	241
6.7.1 Spatial image watermarking	241
6.7.2 Spectral image watermarking	244
Part II Random Signals	245
Chapter 7 Random Variables	247
7.1 Random phenomena in signal processing	247
7.2 Basic conepts of random variables ^7 .	248

10 Digital Signal and Image Processing using MATLAB

7.3	Common probability distributions	256
7.3.1	Uniform probability distribution on (a, b)	256
7.3.2	Real Gaussian random variable	257
7.3.3	Complex Gaussian random variable	258
7.3.4	Generating the common probability distributions	259
7.3.5	/Estimating the probability density.	262
7.3.6	Gaussian random vectors	263
• 7.4	Generating an r.v. with any type of p.d.	265
7.5	Uniform quantization	270
Chapter 8	Random Processes	273
8.1	Introduction	273
8.2	Wide-sense stationary processes	274
8.2.1	Definitions and properties of WSS processes	275
8.2.2	Spectral representation of a WSS process.	278
8.2.3	Sampling a WSS process	285
8.3	Estimating the covariance.	289
8.4	Filtering formulae for WSS random processes	296
8.5	MA, AR and ARMA time series.	302
8.5.1	<i>Q</i> order MA (<i>Moving Average</i>) process.	302
8.5.2	<i>P</i> order AR (<i>Autoregressive</i>) Process	305
8.5.3	The Levinson algorithm	312
8.5.4	ARMA (<i>P,Q</i>) process	315
Chapter 9	Continuous Spectra Estimation	317
9.1	Non-parametric estimation of the PSD.	317
9.1.1	Estimation from the autocovariance function.	317
9.1.2	Estimation based on the periodogram	320
9.2	Parametric estimation.	329
9.2.1	AR estimation	329
9.2.2	Estimating the spectrum of an AR process	337
9.2.3	The Durbin method of MA estimation	338
Chapter 10	Discrete Spectra Estimation	341
10.1	Estimating the amplitudes and the frequencies	341
10.1.1	The case of a single complex exponential	341
10.1.2	Real harmonic mixtures	343
10.1.3	Complex harmonic mixtures	345
10.2	Periodograms and the resolution limit	347
10.3	High resolution methods.	358
10.3.1	Periodic signals and recursive equations	358
10.3.2	The Prony method . /	363
10.3.3	The MUSIC algorithm	366
10.3.4	Introduction to array processing	379

Chapter 11 . The Least Squares Method	; ..	: 389
11.1 The projection theorem	•	389
11.2 The least Squares method	•	393
11.2.1 Formulating the problem'	'	393
11.2.2 The linear model	•	394
11.2.3 The least Squares estimator	'	395
11.2.4 The'RLS algorithm (recursive least Squares)	!	402
11.2.5 Identifying the impulse response of a Channel	!	405
11.3 Linear predictions of the WSS processes	•	407
11.3.1 Yule-Walker equations	•	407
11.3.2 Predicting a WSS harmonic process	•	408
11.3.3 Predicting a causal AR-P process	•	411
11.3.4 Reflection coefficients and lattice filters	•	412
11.4 Wiener filtering	; ..	417
11.4.1 Finite impulse response solution . . . . .	.. . . . .	419
11.4.2 Gradient algorithm	!	420
11.4.3 Wiener, equalization	!	427
11.5 The LMS (least mean Square) algorithm	;"	430
11.5.1 The constant step algorithm . . . . .	.. . . . .	430
11.5.2 The normalized LMS algorithm	"	439
11.5.3 Echo canceling	!	442
11.6 Application: the Kaiman algorithm . . . . .	.. . . . .	446
11.6.1 The Kaiman filter . . . . .	.. . . . .	446
11.6.2 The vector case'	\	449
Chapter 12 Selected Topics	. . . . .	451
12.1 Simulation of continuous-time Systems	451	
12.1.1 Simulation by approximation	451	
12.1.2 Exact model Simulation V	452	
12.2 Dual Tone Multi-Frequency (DTMF)	455	
12.3 Speech processing	461	
12.3.1 A speech signal model	!	461
12.3.2 Compressing a speech signal	!	468
12.4 DTW	471	
12.5 Modifying the duration of an audio signal	474	
12.5.1 PSOLA	475	
12.5.2 Phase Vocoder	477	
12.6 Quantization noise shaping	478	
12.7 Elimination of the background noise in audio	482	
12.8 Eliminating the impulse noise	484	
12.8.1 The signal model	!	484
12.8.2 Click detection	•	485
12.8.3 Restoration	•	

12 Digital Signal and Image Processing using MATLAB

12.9	Tracking the cardiac rhythm of the fetus	490
12.9.1	Objectives	490
12.9.2	Separating the EKG signals	491
12.9.3	Estimating cardiac rhythms	494
12.10	Extracting the contour of a coin	501
12.11	Principal component analysis (PCA)	503
12.11.1	Determining the principal components	503
12.11.2	2-Dimension PCA	507
12.11.3	Linear discriminant analysis (LDA)'	509
12.12	Separating an instantaneous mixture	514
12.13	Matched filters in radar telemetry	516
12.14	Kaiman filtering	518
12.15	Compression	524
12.15.1	Scalar quantization	524
12.15.2	Vector quantization	526
12.16	Digital Communications	538
12.16.1	Introduction	538
12.16.2	8-phase shift keying (PSK)	541
12.16.3	PAM modulation	543
12.16.4	Spectrum of a digital signal	545
12.16.5	The Nyquist criterion in digital Communications	549
12.16.6	The eye pattern	555
12.16.7	PAM modulation on the Nyquist Channel	556
12.17	Linear equalization and the Viterbi algorithm	562
12.17.1	Linear equalization	564
12.17.2	The Viterbi algorithm	566

Part III	Hints and Solutions	571
Chapter 13	Hints and Solutions	573
H1	Signal fundamentals	573
H2	Discrete time signals ,and, sampling	573
H3	Spectral observation	579
H4	Linear filters	590
H5	Filter implementation	610
H6	An Introduction to image processing	614
H7	Random variables	641
H8	Random processes	646
H9	Continuous spectra estimation-	656
H10	Discrete spectra estimation	661
H11	The least Squares method	668
H12	Selected topics	676

Chapter 14 Appendix	727
A1 Fourier transform	727
A2 Discrete time Fourier transform	728
A3 Discrete Fourier transform	729
A4 z-Transform	730
A5 Jury criterion	732
A6 FFT filtering algorithms revisited	734
Bibliography	739
Index	747