

# Contents

<b>1 Non-Biological Signals</b> . . . . .	1
1.1 Notation . . . . .	2
1.2 Discrete- and Continuous-Time Determinist Signals . . . . .	2
1.2.1 Sampling Theorem . . . . .	4
1.2.2 Upsampling . . . . .	9
1.2.3 Downsampling and Decimation . . . . .	12
1.2.4 Anti-Aliasing Filter (AAF). . . . .	12
1.2.5 Quantization . . . . .	14
1.2.6 Delta Modulation (DM). . . . .	17
1.2.7 Sigma-Delta ( $\Sigma - \Delta$ ) Modulation. . . . .	20
1.3 Discrete- and Continuous-Time Random Signals . . . . .	23
1.3.1 Stationarity . . . . .	28
1.3.2 Monte Carlo Simulation . . . . .	34
1.3.3 Energy and Power . . . . .	46
1.3.4 Ergodicity . . . . .	49
1.3.5 Power Spectrum Density (PSD) . . . . .	57
1.3.6 Signal Space Representation . . . . .	69
1.3.7 Mean-Square Sense Sampling Theorem. . . . .	82
<b>2 Linear and Nonlinear Systems</b> . . . . .	87
2.1 Linear Systems Theory . . . . .	87
2.1.1 System Function. . . . .	89
2.1.2 Response of Linear Systems to Random Signals. . . . .	91
2.2 Response of Nonlinear Systems to Random Signals . . . . .	104
2.2.1 Nonlinear Processing of Gaussian Signals . . . . .	105
2.2.2 Nonlinear Processing of WSS Gaussian Processes . . . . .	113
2.2.3 Output PSD of DM Devices with WSS Gaussian Input . . . . .	117
2.3 Systems with Signal + Noise . . . . .	120
2.3.1 Signal-to-Noise Ratio (SNR) . . . . .	124
2.3.2 Matched and Optimum Filtering. . . . .	126

<b>3</b>	<b>Biological Signals</b> . . . . .	137
3.1	Electrocardiogram (ECG). . . . .	138
3.1.1	QRS Complex . . . . .	139
3.1.2	The P Wave . . . . .	141
3.1.3	The PR Segment . . . . .	141
3.1.4	The QRS Wave . . . . .	141
3.1.5	The ST Segment . . . . .	142
3.1.6	The T Wave . . . . .	142
3.2	Electroencephalogram (EEG) . . . . .	144
3.2.1	$\delta$ Band . . . . .	169
3.2.2	$\theta$ Band . . . . .	170
3.2.3	$\alpha$ Band . . . . .	170
3.2.4	$\beta$ Band . . . . .	170
3.2.5	$\gamma$ Band . . . . .	170
3.2.6	EEG Signals . . . . .	171
3.3	Electromyogram (EMG) . . . . .	171
<b>4</b>	<b>Signal Processing Methods for Biological Signals</b> . . . . .	175
4.1	Independence . . . . .	176
4.1.1	Uncorrelated . . . . .	176
4.1.2	Orthogonal . . . . .	178
4.2	Is It Gaussian? . . . . .	179
4.2.1	Kurtosis . . . . .	179
4.2.2	Entropy and Negentropy . . . . .	180
4.2.3	Mutual Information. . . . .	183
4.3	“Distance” Between Two PDFs . . . . .	186
4.3.1	Kolmogorov-Smirnov (KS) Distance. . . . .	187
4.3.2	Hellinger Distance (HD) . . . . .	187
4.3.3	Kullback-Leibler (KL) Divergence . . . . .	188
4.4	Detection and Estimation Methods . . . . .	200
4.4.1	Signal Detection Using Hypothesis Testing (HT) . . . . .	200
4.4.2	Specificity and Sensitivity . . . . .	208
4.4.3	Parameter Estimation . . . . .	238
4.4.4	Whittle Likelihood Test (WLT) . . . . .	252
4.4.5	Frequency Estimation . . . . .	258
<b>5</b>	<b>Signal Decomposition Methods</b> . . . . .	277
5.1	Principle Component Analysis . . . . .	277
5.2	Independent Component Analysis. . . . .	288
5.2.1	Infomax . . . . .	291
5.3	Wavelet Decomposition (WD) . . . . .	301
5.3.1	Short Term Fourier Transform (STFT) . . . . .	302
5.3.2	Continuous WT (CWT). . . . .	314
5.3.3	Father Wavelet. . . . .	326

5.3.4	Orthogonal Wavelet . . . . .	326
5.3.5	Wavelet Series Expansion (WSE). . . . .	330
5.3.6	Discrete Wavelet Transform (DWT) . . . . .	334
5.3.7	Efficient Realization of DWT. . . . .	341
5.3.8	Signal Synthesis Using DWT. . . . .	348
<b>6</b>	<b>References and Concluding Remarks. . . . .</b>	<b>377</b>
6.1	Signals, Systems (Linear), Digital Signal Processing . . . . .	377
6.2	Random Signals, System Response to Random Signals, and Detection/Estimation Theory . . . . .	378
6.3	Biological Signals. . . . .	379
6.4	Principle and Independent Component Analysis . . . . .	379
6.5	Wavelet Transform . . . . .	379
	References . . . . .	380