10/20 electrode system, 37, 186	muscle, 74
12-lead vectorcardiogram, 426	asphyxia, 125
	atrioventricular node, 414
50/60 Hz powerline interference, 76, 190,	atrium, 413
202, 441, 473–483	auditory EP, 185, 234, 252
	autocorrelation/covariance methods, 106
abbreviations, 658	automaticity, 414
abrupt changes, 62	autoregressive modeling, 648
action potential, 7, 28	autocorrelation method, 106
activity (Hjorth descriptor), 100	Burg's method, 112
adaptive filter (LMS), 83, 91, 279, 482	covariance method, 106
adaptive signal whitening, 355	impulse input, 67
afferent, 27	model order, 118
Akaike information criterion (AIC), 118	modified covariance method, 110
all-or-nothing principle, 7	multivariate, 67
all-pole modeling, see autoregressive	sampling rate, 119
$\operatorname{modeling}$	segmentation, 131
alpha rhythm, 34, 78	spectral parameters, 119–125
alternate ensemble average, 244	stability, 116
ambiguity function, 142–147	time-invariant, 65, 104
ambulatory monitoring	time-variant, 66
ECG, 439, 441, 444	autoregressive moving average modeling, 64,
EEG, 43	122,647
analysis filter bank, 300	average beat subtraction, 534
analytic signal, 145	average firing rate, 342, 373
angina pectoris, 438	average rectified value, 355
arrhythmia, 430	averaging, see ensemble averaging
atrial, 434	axon, 28, 338
bigeminy, 434	a posteriori filter, 241, 249
bradycardia, 431	
paroxysmal, 431	baroreceptor reflex, 615
persistent/permanent, 431	Bartlett window, 94
respiratory sinus, 432	baseline wander, 441, 457–473
tachycardia, 431	basis functions, 260, 500
trigeminy, 434	cal, 263
ventricular, 436	Karhunen–Loève, 264
artifact cancellation, 78–91	sal , 263
artifacts in EEG, 73–91	sine, cosine, 260, 481
cardiac, 75, 83	Walsh, 263
electrode, 76	beta rhythm, 34, 75, 78
equipment, 76	bias, 645
eye movement, 73	bigeminy, 434

bioelectricity, 6	AZTEC, 520
bispectrum, 63	compression ratio, 541
blinks, 73, 78, 82	direct methods, 519–526
block LMS algorithm, 279	fan method, 525
bradyarrhythmia, 431	long-term predictor, 536
bradycardia, 431	lossless, 514, 517–518
brain-computer interface (BCI), 47	lossy, 514
brainstem auditory EP, 185, 214	PRD, 541
Burg's method, 112	quantization and coding, 540
	rate distortion curve, 542
cascade algorithm, 308	RMS, 542
central sulcus, 30	SAPA, 522
cerebral cortex, 30	transform-based methods, 526–533
characteristic function, 225, 380	wavelet packets, 531
Choi-Williams distribution, 154	wavelets, 531
circadian rhythm disorders, 45	WDD, 543
circulant matrix, 482	databases, 17
clustering, 387	AHA, 18
MUAPs, 387	European ST-T, 18
QRS morphologies, 456	IMPROVE, 18
cognitive EP, 189	LTST, 18
Cohen's class, 153–158	MIMIC, 18
coherence function, 616	MIT-BIH arrhythmia, 18, 542
Coiflet wavelets, 310	Daubechies wavelets, 310
comb filter, 464	decimation (sampling rate), 465
compensatory pause, 433	decomposition (EMG), 383
complexity (Hjorth descriptor), 101	deconvolution, 229
compressed spectral array, 139	delta rhythm, 34, 73
compression ratio, 541	dendrites, 28, 70
conduction blocks, 438	denoising, 312–318
conduction velocity estimation, 365–371	hard thresholding, 313
multichannel, 369	soft thresholding, 313
two-channel, 367	depolarization, 7, 414-419
consistency, 645	direct decomposition, 257
continuous wavelet transform (CWT), 289	direct sum, 257
correlation	discrete wavelet transform (DWT), 291
ergodicity, 645	dyadic sampling, 290
estimator, 93	
function, 643	ECG, see electrocardiogram
$matrix,\ 59,\ 643$	ectopic beat correction, 605–614
cortex, 30, 68, 185, 187	correlation-based, 608
covariance matrix, 59, 643	heart timing, 611
cross Wigner-Ville distribution, 150	interpolation-based, 609
cross-correlation coefficient, 200, 603	EEG, see electroencephalogram
cross-correlation matrix, 643	efferent, 27
cross-power spectrum, 615	eigenvalue, 638
cubic spline baseline estimation, 470	eigenvector, 638
11	electrocardiogram (ECG), 11, 411
damped sinusoids, 272	ambulatory monitoring, 444
data acquisition, 14	beat morphology, 438
data compression, 3	filtering, 454
data compression (ECG), 456, 514–544	

generation, 415–419	ensemble averaging, 83, 181, 192
high-resolution, 447	alternate, 244
intensive care monitoring, 444	as a linear filter, 200–202
late potentials, 447	exponential, 202–205
noise and artifacts, 440–443	homogeneous, 193–200
recording techniques, 419–426	inhomogeneous, 207–218
resting, 443	latency correction, 230
rhythms, 430	robust, 219
stress test, 445	SNR, 200
waves and time intervals, 426–430	weighted, 207–218
electrocorticogram (ECoG), 11	ensemble correlation, 236–241
electrode motion artifacts, 344, 441	ensemble median, 221
electrodes, 9	ensemble variance, 198
ECG, 419	envelope, 501
EEG, 37	EOG, see electrooculogram
EMG, 343	EP, see evoked potentials
electroencephalogram (EEG), 11, 25	epilepsy, 40, 68, 75, 76, 141
10/20 electrode system, 37, 186	partial seizures, 41
alpha rhythm, 34	primary generalized seizures, 41
amplitude, 32	ergodicity, 645
artifacts, 73–91	estimation-subtraction filter, 479
beta rhythm, 34	Euclidean norm, 637
delta rhythm, 34	event series, 373, 576, 582–585
frequency, 32	evoked potentials (EPs), 11, 181
gamma rhythm, 34	auditory, 185, 234, 252
ictal, 35	brainstem auditory, 185, 214
mental tasks, 47	cognitive, 189
mu rhythm, 49	latency, 181
recording techniques, 37	noise and artifacts, 190
sampling rate, 39	somatosensory, 187, 214, 252
sleep rhythms, 35	visual, 188, 197, 214, 223, 234, 252
spikes and sharp waves, 34, 62	wave definitions, 182
theta rhythm, 34	excess mean-square error, 87
video recording, 42	exogenous response, 189
electrogastrogram, 14	exponential averaging, 202-205, 224, 254,
electrogram (EG), 11, 412	285
electromyogram (EMG), 12, 75, 77, 337	eye movement, 73, 78–91, 191
amplitude estimation, 347–360	eye-closing period, 505
diagnostic, 345	
ergonomics, 345	feature extraction, 2, 48, 386, 387, 456
kinesiology, 345	fiducial point, 568
prosthesis control, 346	filter
recording techniques, 343	a posteriori, 241, 249
spectral analysis, 361–364	comb, 464
electromyographic noise, 441, 484	FIR, 88, 105, 110, 250, 460
electroneurogram (ENG), 12	forward-backward IIR, 462
electrooculogram, 73	IIR, 245
electrooculogram (EOG), 14	inverse, 229
electroretinogram (ERG), 13	lattice, 108
EMG, see electromyogram	least mean-square, 83, 91, 279
endogenous response, 189	lowpass differentiator, 498
• /	

noncausal, 245	heart timing 585-580-611
nonlinear, 476	heart timing, 585–589, 611 hemispheres, 30
notch, 473	Hessian matrix, 396
prediction error, 105	higher-order moments, 62, 363
time-varying, 252, 467, 484	Hilbert transform, 502
time-varying Gaussian, 484	Hjorth descriptors, 100–102
filtered-impulse signal model, 374	hypersomnia, 44
firing pattern, 342	hypersonnia, 44 hyperventilation, 42
firing rate, 29, 70	hypoxia, 125
forward-backward IIR, 462	nypoxia, 125
Fourier series, 261	indexing function, 577
Fourier transform	influence function, 223
	inner product, 255, 636
continuous-time, 227	insomnia, 44
discrete-time, 60, 92	instantaneous LMS algorithm, 278
fast (FFT), 92	
short-time, 61	integral pulse frequency modulation model,
Frank lead system, 424	574–578
French-Holden algorithm, 585	interfiring intervals, 342
Frobenius norm, 281, 637	interpolation (sampling rate), 465
garama phathas 24	interval function, 579
gamma rhythm, 34 Gaussian PDF	interval tachogram, 578
	inverse z-transform, 123
definition, 59	inverse filtering, 229
EEG analysis, 57, 197	inverse interval function, 579
EMG analysis, 349	inverse interval tachogram, 578
generalized eigenvalue problem, 209	isoelectric line, 417
generalized Gaussian PDF, 219	isometric force, 343
gradient adaptive lattice algorithm, 160	isopotential map, 183
Haar wavelet, 290, 297	Karhunen-Loève expansion, 264
heart rate variability (HRV), 431, 567	Karhunen-Loève transform (KLT), 528
ectopic beats, 605–614	knee-jerk reflex, 30
generalized IPFM model, 577, 587, 611	kurtosis, 62
heart rhythm representations, 573	K complexes, 35, 67
IPFM model, 574–578	Tr complexes, 60, 61
pNN50, 570	Lagrange multipliers, 107, 209, 266, 640
rMSSD, 570	Laplacian PDF, 219, 353
SDANN, 570	late potentials, 476
SDNN, 570	latency
spectral analysis, 589–603	definition, 181
time domain measures, 570–573	estimation, 229
TINN, 572	shifts, 225
triangular index, 572	lattice filter, 108, 160
heart rhythm representation, 578–589	lead
event series, 582–585	augmented unipolar limb, 420
heart timing, 585–589	bipolar, 419
interval function, 579	bipolar limb, 420
interval tachogram, 578	unipolar, 419
inverse interval function, 579	
inverse interval tachogram, 578	lead system
	ECG, 419
lowpass filtered event series, 583 heart surgery, 140	bipolar, 420 orthogonal, 423
near ourgery, 140	orthogonar, 425

precordial, 420	ensemble correlation, 239
standard, 419	latency, 230
synthesized, 425	occurrence time, 490
Frank, 424	occurrence time and amplitude, 491
lead vector, 416	occurrence time, amplitude and
leader–follower clustering, 387	duration, 494
leakage, 94	signal waveform, 216, 220
least mean-square (LMS), 83	time delay, 367
algorithm, 85, 159, 279, 482	mean frequency (MNF), 361
block, 279	mean instantaneous frequency, 152
block algorithm, 285	mean-square error (MSE), 79, 256, 264, 279
convergence, 85	with constraint, 91
excess mean-square error, 87	median, 221
instantaneous, 278	median frequency (MDF), 361
least-squares error, 106	method of steepest descent, 84
least-squares error, 100 least-squares solution, 392, 641	Mexican hat wavelet, 290
	minimum description length, 118
Levinson–Durbin recursion, 108, 113	mobility (Hjorth descriptor), 101
likelihood function, 217	model order, 118
	Akaike information criterion, 118
hard, 224	minimum description length, 118
sign, 224	modified covariance method, 110
linear equations, 641	
linear models, 63	mother wavelet, 288
list of symbols, 649	motor imagery, 48
lobe	motor nerves, 27
frontal, 30	motor unit, 338–343
occipital, 30	motor unit action potential (MUAP), 338
parietal, 30	motor unit recruitment, 339
temporal, 30	moving average modeling, 648
locked-in syndrome, 47	mu rhythm, 49
Lomb's periodogram, 597–603	MUAP resolution, 391
look-back detection mode, 507	MUAP train, 342, 372
lossless compression (ECG), 514, 517–518	amplitude, 377
lossy compression (ECG), 514	model, 372
lowpass differentiator, 498	power spectrum, 378
lowpass modeling, 261	multiresolution signal analysis, 292–300, 513
lumped-parameter model, 70	myocardial infarction, 439
	myocardial ischemia, 438
magnetoencephalogram, 26	myocardium, 413
magnitude squared coherence, 616	myopathy, 340
Mahalanobi distance, 388	and FMC 242
marginal condition	needle EMG, 343 negative predictive value, 17
frequency, 149	9 -
time, 149	nervous system, 27
matched filter, 232, 490	autonomic, 27
matrix definitions, 633–639	central, 27
matrix inversion lemma, 389, 637	parasympathetic, 27, 414, 430, 431, 570,
matrix optimization, 640	590
maximal voluntary contraction, 342	peripheral, 27
maximum likelihood estimation	somatic, 27
amplitude, 347	sympathetic, 27, 414, 430, 431, 570,
	590

neuromuscular junction, 338, 342	postsynaptic potential
neuron	excitatory, 29, 31, 69
inter-, 28, 68	inhibitory, 29, 69
motor, 28	power spectrum, 60, 92, 646
postsynaptic, 28	powerline interference, 76, 190, 202, 344,
	441, 473–483
sensory, 28	
neuropathy, 340	PQ interval, 429
Newton's method, 395	PQRST delineation, 510–513
noise reduction	prediction error filter, 105
ensemble averaging, 192	premature beat, 433
linear filtering, $241-253$	supraventricular, 433
nonlinear transformation, 68, 486, 492, 500	ventricular, 433
nonparametric spectral analysis, 91–97	probability density function (PDF)
nonstationarity, 61	Gaussian, 59
norm	generalized Gaussian, 219
Euclidean, 637	Laplacian, 219, 353
Frobenius, 637	uniform, 219, 227
	Prony's method
normal equations, 108	
addhall tagle 100	least-squares, 277
oddball task, 190	original, 274
ordinary eigenvalue problem, 266	pseudo Wigner-Ville distribution, 151
orthogonal expansions, 254–272	Purkinje fibers, 414
Karhunen–Loève, 264	
sine, cosine, 260	Q wave, 428
SNR, 258	QRS complex, 428
truncation, 257	QRS detection, 455, 485–509
Walsh, 263	decision rule, 486, 504–507
orthogonal lead system, 423	nonlinear transformation, 486, 500
orthogonal matrix, 635	performance evaluation, 507
outer product, 636	preprocessing, 497
	signal and noise problems, 487
P wave, 427	signal modeling, 488
pacemaker, 412	threshold, 504
parasomnia, 45	QT interval, 429
Parseval's theorem, 130	3 ,
partial fraction expansion, 121	R wave, 428
pattern reversal, 188	rank of a matrix, 634
peak-and-valley picking strategy, 497	rapid eye movement (REM), 35, 58, 74
performance evaluation, 16, 507	rate distortion curve, 542
periodogram	receiver operating characteristic (ROC), 509
definition, 93	recording techniques
Lomb's, 597–603	auditory EP, 185
	ECG, 419
mean, 93	•
variance, 95	EEG, 37
photic stimulation, 42, 139	EMG, 343
Physionet, 19	somatosensory EP, 187
polynomial fitting, 470–473	visual EP, 188
polyphasic MUAPs, 341	recruitment, 339
polysomnography, 46	reentry, 430
positive definite, 636	refinement equation, 294
positive predictive value, 17	reflection coefficients, 113
positive semidefinite, 636	refractory period, 8, 30, 415, 490, 505

	. 1
repolarization, 7, 414–419	spectral parameters
respiratory sinus arrhythmia, 432	AR-based, 119–125
rhythms	Hjorth descriptors, 100
brain, 31	peak frequency, 99
heart, $430, 457$	power in bands, 98
RR interval, 429	spectral purity index, 102
running average, 102	spectral slope, 99
	spectral purity index, 102
S wave, 428	spectrogram, 138
sampling jitter, 227	spectrum of counts, 592–596
sampling rate alteration, 464	spike and sharp waves, 34, 62
scaling function, 292	spike-wave complexes, 35
scalogram, 291	split trial assessment, 198
segmentation, 62, 125–135	ST segment, 429
dissimilarity measure, 127	standard 12-lead ECG, 419
periodogram-based, 128–131	stationarity, 60
reference window, 127	steepest descent, 84
test window, 127	stochastic process, 642
whitening approach, 131–134	subaveraging, 197
seizure, 34, 68, 141, 162	surface EMG, 343
sensitivity, 17	synapse, 28
sensory nerves, 27, 183, 187	synthesis filter bank, 303
septum, 413	synthesized leads, 425
short-time Fourier transform (STFT), 137-	by nonestact reads, 120
142	T wave, 429
sigmoid function, 70	T wave alternans, 439
signal acquisition, 14	tachyarrhythmia, 431
signal decomposition (EMG), 383	tachycardia, 431
similarity measure, 388, 603	theta rhythm, 34, 73
simulation, 21	time delay estimation
single-trial analysis, 182, 197, 253–278	multichannel, 369
singular value decomposition, 639	two-channel, 367
sinoatrial node, 414	time-frequency analysis, 135–162
sinus rhythm, 431	ambiguity function, 142–147
skewness, 62	Choi–Williams distribution, 154
sleep rhythms, 35, 67	Cohen's class, 153–158
sleep spindles, 35	cross Wigner-Ville distribution, 150
sliding window, 352	GAL algorithm, 160
smearing, 94	LMS algorithm, 159
	mean instantaneous frequency, 152
soma, 28 somatosensory EP, 187, 214, 252	pseudo Wigner-Ville distribution, 151
· · · · · · · · · · · · · · · · · · ·	•
spatial correlation, 80, 356	short-time Fourier transform, 137–142
specificity, 17	Wigner-Ville distribution, 147–152
spectral analysis	Toeplitz matrix, 60, 81, 108, 110, 350, 635
EMG, 361	trace of a matrix, 636
model-based, 103–119	triangular window, 94
moments, 100	trigeminy, 434
nonparametric, 91–97	trimmed means, 222
segmentation, 128	
spectral averaging, 95	uncertainty principle, 139
spectral compression, 361	uniform PDF, 219, 227

```
vagus nerve stimulator, 44
vectorcardiogram (VCG), 419
ventricle, 413
vertex waves, 35
visual EP, 188, 197, 214, 223, 234
visualEP, 252
volume conductor, 9
Walsh functions, 263
wave delineation, 455, 510-513
waveform resolution (MUAPs), 391
wavelet data compression, 531
wavelet denoising, 312-318
wavelet equation, 296
wavelet function, 295
wavelet packets, 531
wavelet series expansion, 296
wavelet transform, 288-292, 513
wavelets, 286-318
    Coiflet, 310
    Daubechies, 310
    dyadic sampling, 290
    Haar, 290, 297
    Mexican hat, 290
    sinc, 306
weighted averaging
    Gaussian noise, 216
    MSE, 208
    signal-to-noise ratio, 209
    varying noise variance, 210
    varying signal amplitude, 214
Welch's method, 97
white noise, 63, 230, 488, 646
wide-sense stationary, see stationary, 644
Wiener filtering, 90, 246
Wiener-Hopf equations, 246, 251
Wigner-Ville distribution, 147-152
window
    Bartlett, 94
    Hamming, 143, 461
    rectangular, 460
    triangular, 94
windowing, 95
Woody's method, 229-236
z-transform, 245, 646
```