INDEX

chemicals, 91, 118 A Chinese, ancient, 17 Cholesky decomposition, 160, 180, 473 α filter, 203 Cholesky triangle, 160 α - β filter, 199, 491 choose function, 50 α - β - γ filter, 202, 491 communication system, 480 acronyms, xv condensation algorithm, see particle filter active set method, 216, 340, 384 consider state, 311 aircraft, 181, 184, 397, 423, 457, 494, 499 constrained filter, 212, 223, 381 applications of state estimation, xxii H_{∞} , 381 astrophysics, 100 model reduction, 212 auxiliary particle filter, 470 pdf truncation, 212, 218 В perfect measurements, 212-213 projection approach, 212, 214 Babylonians, 17, 490 banana, 494 general, 216 bandwidth, 496 least squares, 215 batch filter, 178 maximum probability, 214 battery, 102-103 constrained optimization, 337 Bayes' rule, 52 control vector, 19 Bayesian estimator, 462, 465 controllability grammian, 38-39 biomedical engineering, 227 controllability matrix, 38-39 black hole, 470 convolution, 94 bootstrap filter, see particle filter correction term, 84 cost function, 80 \mathbf{C} augmented, 338 calculus of variations, 97 covariance filter, 178 Cayley-Hamilton theorem, 18, 46 curse of dimensionality, 461 curve fitting, 92 central limit theorem, 62 Chandrasekhar algorithm, 178, 238, 242, 261 linear, 92

quadratic, 93

Chapman-Kolmogorov equation, 54

D	Gaussian sum filter, 420–421
D	giants, shoulders of, 485
decentralized filtering, 317	Givens transformation, 163, 171
decision theory, 490	GPS, 223, 386, 490
delayed measurement, 317, 320	Gram-Schmidt transformation, 163, 171, 219
digital signal processing, 491	modified, 163, 171–172, 180
discretization, 26, 379	grid-based filter, 422
duality, 258, 487, 490-491	gyroscope, 240, 261–262
E	Н
e-mail address, xxiii	H_{∞} filter, 336, 367
Earth, dimensions of, 485	a posteriori, 365
ecology, 480	a priori, 365
error function, 220	combined with Kalman, 374, 376–377
estimation	comparison with Kalman, 354, 361, 368
a posteriori, 124	constrained, 381
a priori, 125	continuous, 361
covariance, 85	limitations, 360, 368
frequency domain, 94	model uncertainties, 377
gain matrix, 84	nonlinear, 368
least squares, 79	optimality, 374
	performance bound, 344, 365
alternate forms, 86	philosophy, 343
history, 485–486	polynomial systems approach, 368
recursive, 84	sensitivity to design parameters, 368
weighted, 82	stability, 357
maximum likelihood, 481, 486	steady state, 354
mean based, 103, 481	system identification, 368
median based, 103	transfer function, 357, 364–365
minimax based, 104, 481	weighting matrices, 344
minimum mean square, 481	Hamiltonian function, 341, 345
mode based, 103	Hamiltonian matrix, 205, 226, 366, 370
of a constant, 80	Householder transformation, 163, 171
of the mean, 103	hypersphere, 473, 482
of the variance, 103 predicted, 125	I
smoothed, 125	•
unbiased, 84	image processing, 480
unblased, 64	impulse function, 72
F	sifting property, 112, 119, 231
f - Clt 2 Clt	infimum, 383
f - g filter, see α - β filter	information filter, 156, 178
f - g - h filter, see α - β - γ filter	backward, 282
fading-memory filter, 140, 143, 208	information matrix, 334
falling body, 405, 417, 427, 451, 456, 471, 477, 479	input matrix, 19
	interacting particles, see particle filter
fault detection, 480	inverted pendulum, 459
feedback control, xxii	investments, 12
finite precision arithmetic, 140 first order hold, 111	J
•	-
fish, 145	j (complex variable), 4
Fourier transform, 71	Jacobian, 457
Fourier transform, 71	Johns Hopkins University, 229, 486
FPGA, 481	Jordan form, 18, 20, 43, 74, 153, 205, 219
free lunch, 462 fuzzy logic, 463	Jupiter, 485
	K
G	Kalman-Bucy filter, 229, 400
G g - h filter, see α - β filter	Kalman-Bucy filter, 229, 400 Kalman-Schmidt filter, 487
G g - h filter, see α - β filter g - h - k filter, see α - β - γ filter	Kalman-Bucy filter, 229, 400 Kalman-Schmidt filter, 487 Kalman filter
G g - h filter, see α - β filter	Kalman-Bucy filter, 229, 400 Kalman-Schmidt filter, 487

batch, 154 combined with H_{∞} , 374, 376-377 comparison with H_{∞} , 354, 361, 368 comparison with Wiener filter, 490	triangular, 483 uniform, 483 Krein space, 369, 491 Kronecker delta function, 72, 124
continuous, 229	
alternate form, 238	L
gain, 236	Lagrange multiplier, 214-215, 337-338, 345
innovations, 301, 326	linearization, 22, 397, 434
steady state, 252	covariance approximation, 446
decentralized, 491	mean approximation, 444
decoupled, 490	operating point, 23
discrete, 123	Lyapunov equation
alternate form, 135, 149, 265, 318, 334	continuous, 39, 41, 115
closed form, 138	discrete, 39, 42, 108
gain, 128	M
innovations, 130, 298, 300, 326	IVI
Joseph stabilized version, 145	MATLAB, xxiii, 491
measurement update, 127	functions
offline calculation, 129	CARE, 253, 256, 262
one-step equations, 131	CHOL, 160, 441
steady state, 137, 193	COND, 159
time update, 126-127	DARE, 194, 225, 355
divergence, 140	DLYAP, 110
extended, 400, 416, 462	EXP, 19
continuous, 400–401 difficulties, 433, 439, 462	EXPM, 19
discrete, 407, 409	LYAP, 119
hybrid, 403, 405	QP, 217
iterated, 410–411	RESIDUE, 99
second order, 413, 419	matrix, 4
steady state, 404	matrix inversion lemma, 11 matrix
fictitious process noise, 140, 142	algebra, 6
history, 485, 490–491	calculus, 14
initialization, 140	characteristic roots, 9
Joseph stabilized version, 129	condition number, 159, 328
limitations, 336	degenerate, 4
linearized, 397, 399	determinant, 7
multiple model, 301	product rules, 14
optimality, 336, 374, 465, 480	diagonalization, 153
philosophy, 343	dimension, 4
properties, 129, 145	eigendata, 9
proportional integral, 326 reduced order, 305	eigenvalues, 8-9
Anderson's approach, 306	eigenvectors, 9
covariance approximation, 305	exponential, 19
decoupled, 305	hermitian, 5
model reduction, 305	hermitian transpose, 5 history, 17–18
Schmidt's approach, 309	identity, 7
robust, 312	indefinite, 10
sequential, 150	infinity-norm, 359
square root, 140	inverse, 8, 10
stability, 196, 254, 297, 308, 317	derivative, 14
symmetrization, 140	trace, 294
transition matrix approach, 238	Laplace expansion, 7
verification, 298	latent roots, 9
kernel	latent vectors, 9
bandwidth, 472, 483	negative definite, 10
biweight, 483	negative semidefinite, 10
density, 472 Epanechnikov, 473, 483	noninvertible, 8
Gaussian, 483	nonnegative definite, 10
, 200	nonpositive definite, 10

nullity, 5 positive definite, 10 positive semidefinite, 10 product, 9 proper numbers, 9 proper vectors, 9 rank, 4–5 singular, 8 singular values, 10, 159, 180 square root, 160, 246, 441, 458, 473 symmetric, 5, 10 symplectic, 205, 226, 370 trace, 9	observability matrix, 41–42 Occam's razor, 498 Ohm's Law, 395 open research areas, xxv, 224, 317, 377, 388, 396, 457, 480 optimal control, 258 optimization constrained, 214 order statistics, 467 output matrix, 19 output vector, 19
inverse, 294	P
transpose, 5	parameter estimation, 422, 428, 487
triangular, 261	parsimony, 498
triangularization, 169	particle filter, 466, 468
MCMC resampling, 470, 476	auxiliary, 470, 476
meaning of life, 493	comparison with unscented filter, 480
measurement residual, 80 Metropolis–Hastings acceptance, 476	difficulties, 462, 467
minimax filter, 336, 367	extended, 477
see also H _∞ filter	H_{∞} , 478
missile tracking, 486	implementation issues, 469
MIT, 486	prior editing, 470, 472
model errors, 140	regularized, 470, 472
model uncertainties, 377	resampling, 466–468
modified matrices formula, 12 monotonic function, 59	roughening, 470
Monte Carlo filter, see particle filter	sample impoverishment, 469
moon, 485, 487	unscented, 477
motor, 20, 25, 47, 379, 401, 429, 457	pattern recognition, 480
N	perfection, 497
	persistent excitation, 496
NASA, xiii, 158, 165, 246, 486–487	perturbation estimator, 326
neural networks, 480 noise	pleasure, 494
artificial, 423	poker, 51
bandlimited, 252	population, 109, 327
biased, 369, 398, 426	prerequisites, xxiii, xxv
colored, 71, 183, 188, 247, 249, 309	primal-dual interior-point method, 341 prior editing, 470
simulation, 73	probability density function, 53
control, 398, 426	conditional, 54
correlated, 184, 247–248 nonlinear, 450	joint, 61
power spectrum, 252	marginal, 62
white, 71, 112, 230–231	multimodal, 463, 473
zero measurement, 190, 214, 250	probability distribution function, 53
nominal operating point, 23, 397	conditional, 54
nonlinear filter, 395, 425, 490	joint, 61
benchmark problem, 469	marginal, 61
stability, 425 tradeoffs, 396, 480	probability
notation, xxiii, xxv	a posteriori, 51
nuisance state, 311	a priori, 51
nuisance variable, 311	conditional, 51
numerical difficulties, 158, 246	definition, 50
0	independence, 52
	joint, 51
objective function, 80	
and the second s	proportional integral Kalman filter, 326 pseudo inverse, 81

	DI C simouit 20 40 47 110 140 101
Q	RLC circuit, 39, 42, 47, 119, 148, 181 rocket, 48
	roughening, 470
Q-function, 54	running average, 90
quadratic programming, 216 quaternions, 18	
	S
R	saddle point, 351, 383
radar, 104	satellite, 264, 274, 309, 428, 486
radioactivity, 145, 179, 370	Saturn, 485
RAND, 486	scalar, 4
random process, 68	sequential filter, 178
random sequence	sequential importance, see particle filter Sherman-Morrison formula, 12
continuous, 68	sigma point, 441, 449, 452
discrete, 68	signal, two-norm, 358
random variable, 49, 53	simulation, 27, 232
average, 54 Cauchy, 76	colored noise, 73
central moment, 56	Euler integration, 29
continuous, 53	rectangular integration, 29
correlation coefficient, 62	Runge Kutta integration, 31
covariance, 62	trapezoidal integration, 29
definition, 53	slot machine, rigged, 63
discrete, 53	smoother
expectation, 54	constant states, 274 fixed-interval, 264, 279
expected value, 54	forward-backward, 280, 285
exponential, 75	RTS, 286
function, 55, 59, 67 Gaussian, 57	fixed-lag, 264, 274
independence, 62	fixed-point, 264, 267
Laplace, 57	Gaussian sum, 422
mean, 54	improvement, 270
moment, 56	stability, 295
multivariable, 65	solution manual, xxiv
normal, 57	spacecraft, 400, 489
orthogonal, 63	speech recognition, 480
realization, 53	square root filter, 158, 178, 238, 246, 490–491 Potter's algorithm, 158, 165
skew, 56 skewness, 56	triangularization, 169
standard deviation, 56	state, xxi
transformation, 59	state space models, 18
uncorrelated, 62	state transition matrix, 19, 109, 111, 114, 320
uniform, 56	invertibility, 282, 320, 377
variance, 55	state vector, 19
vector, 65	stationary point, 81, 351
autocorrelation, 66	steel production, 105
autocovariance, 66 correlation, 66	Stein equation, 39, 42, 108 stochastic process, 68
covariance, 66	autocorrelation, 69
Gaussian, 67	autocovariance, 69
recursion, see recursion	colored, 71
regularized particle filter, 470	continuous, 68
research funding, 144	cross correlation, 71
residual sampling, 467	cross covariance, 71
retrodiction, 322	cross power spectrum, 72
retrodiction filter, 294	discrete, 68
return function, 80 Riccati equation	ergodic, 70
continuous, 235, 248, 253, 259, 361	power, 72 power density, 72
discrete, 131, 158, 194, 196, 314, 355, 374,	power density, 72 power density spectrum, 72
378, 389	power density spectrum, 72 power spectral density, 72
RL circuit, 112	power spectrum, 71
	- · · · · · · · · · · · · · · · · · · ·

systematic resampling, 467
T
target maneuvering index, 201, 203
target tracking index, 201
Taylor series, 23, 337, 397, 407, 413, 439
tire tread, 328–329
toast, 343
tracking, 317, 480, 491
U
O
U-D filter, 174, 178, 180, 490
unscented filter, 447
comparison with particle filter, 480
difficulties, 462
simplex, 454
spherical, 455
square root, 457
weighting coefficient, 442, 444, 453
unscented transformation, 441, 446, 452
covariance approximation, 446
mean approximation, 444
V
variable structure filter, 326
vector, 4
calculus, 14
column, 4
Euclidean norm, 9
quadratic form, 10
row, 4
two-norm, 9-10, 358
vehicle navigation, 223, 370, 386, 430, 459
W
weather forecasting, 305
Web site, xxiii
Wiener–Hopf equation, 100, 259 Wiener–Kalman filter, 489
Wiener-Kaman inter, 469 Wiener-Khintchine relations, 71
Wiener filter, 94, 257, 486
causal, 100
comparison to Kalman filter, 490
noncausal, 98
parametric, 96
wombat, 147
Woodbury's identity, 12
workhorse of state estimation, xxiv
World War II, 94
Y