

RUSSIAN ACADEMY OF SCIENCE

O.N.Granichin, B.T.Polyak
**RANDOMIZED
ALGORITHMS
OF ESTIMATION
AND OPTIMIZATION
UNDER
ALMOST ARBITRARY
NOISE**

MOSCOW "NAUKA" 2003

UDK 621.391

BKK 32.811

G 77

Editor
A.V. NAZIN

Reviewers:
A.I. KIBZUN
S.M. ERMAKOV

Granichin O.N.

Randomized algorithms of estimation and optimization under almost arbitrary noise / O.N. Granichin, B.T. Polyak. Editor A.V. Nazin. – M.: Nauka, 2003. – 291 p.

ISBN 5-02-006525-0 .

The book is devoted to the theory of effective recursive algorithms of multidimensional optimization and estimation which achieve a good performance without standard assumptions on observation noise as zero-mean and independence. The new approach is based on randomized simultaneous perturbations. The offered algorithms are widely used in an identification, recognition, control theory and economics.

This book is useful for practical engineers in developing and programming the devices of telecommunication, measurement or control. It is also interesting for a student and post graduate student which specialize in cybernetics.

TII-2003-1-81

ISBN 5-02-006525-0

© Russian Academy of Science, 2003

© Publisher "Nauka"
(design) 2003

Contents

Preface	vii
Notation	ix
Introduction	xiii
1 Problems and methods	27
1.1 Preview examples	27
1.1.1 Estimation of constant signal, which is available with noise	27
1.1.2 Problem of the signal detecting	31
1.1.3 Randomized algorithms	33
1.1.4 Mean risk function	34
1.1.5 Filtering	36
1.2 Regression analysis, LMS	36
1.2.1 Regression of one random element by another	37
1.2.2 Estimation under finite number of observations	39
1.2.3 Recursive modifications of LMS	45
1.3 Optimal filtering	48
1.3.1 Weiner-Kolmogorov filter	49
1.3.2 Kalman-Busy filter	54
1.4 Stochastic approximation	60
1.4.1 Finding the root of function. Robbins-Monro algorithm	61
1.4.2 Mean risk function minimization	63
1.4.3 Kiefer-Wolfowitz procedure	64
1.4.4 Randomized algorithms of stochastic approximation .	65
1.4.5 Passive stochastic approximation	66
1.4.6 Modification of SA algorithms	67

1.5	Random search	73
1.6	Elements of the estimation theory	74
1.6.1	Empirical function method	74
1.6.2	Baesyan estimates	76
1.6.3	Maximum likelihood method	79
1.6.4	Lower limit of the estimation accuracy	82
1.7	Estimation under bounded noise	85
1.7.1	Random signal which is available with bounded noise .	86
1.7.2	Recursive goal inequalities. Finite-convergence algorithms	87
1.7.3	"Strip" algorithm	90
1.7.4	Algorithm "modified strip" which stabilizes linear plant	91
1.7.5	Ellipsoids method	95
2	Linear problems	97
2.1	Linear regression	97
2.1.1	Problem statement and main assumptions	99
2.1.2	Randomized algorithm of stochastic approximation .	101
2.1.3	Randomized least mean squared estimator	104
2.2	Autoregression and moving averages models	105
2.2.1	Autoregression parameters estimation	106
2.2.2	Moving averages parameters estimation	109
2.2.3	Identification of the dynamical plant	111
2.2.4	The exciting signal	113
2.2.5	Reparameterization of ARMAX model	114
2.2.6	Randomized algorithm of identification	118
2.3	Linear filtering	120
2.3.1	Prediction of random signal which is available under arbitrary bounded noise	120
2.3.2	Tracking	123
2.3.3	Necessary and sufficient conditions for stability of LMS	124
2.3.4	Performance of adaptive tracking	126
2.4	Experimental results	132
2.4.1	Signal detecting under "unknown but bounded" non-random noises	132
2.4.2	Filtering	136
2.4.3	Tracking	139
2.5	Proofs of Theorems 2.1–2.6	141

3 Randomized algorithms of stochastic optimization	155
3.1 Formulations and main results	157
3.1.1 Problem statement and main assumptions	162
3.1.2 Simultaneous perturbation and randomized algorithms	164
3.1.3 Convergence with probability one and in the mean squared sense	165
3.1.4 Smoothed kernels and distribution of exciting simulta- neous perturbation	168
3.1.5 Rate of convergence	170
3.2 Optimal orders of accuracy	173
3.2.1 Minimax order of accuracy	173
3.2.2 Lower limit of the convergence rate	174
3.3 Experimental results	175
3.3.1 Compared simulation of KW and SPSA	175
3.3.2 Step-by-step implementation	178
3.4 Proofs of Theorems 3.1 и 3.2	179
4 Applications of randomized algorithms	187
4.1 Chemical inspection of a target	191
4.2 Adaptive control under "unknown but bounded" noise	194
4.2.1 Randomized algorithm of an identification	197
4.2.2 Adaptive ℓ_1 optimization	200
4.2.3 Adaptive optimal control for the nonminimal-phase plant of second order	206
4.3 Learning systems	212
4.3.1 Approximation of one function by a linear combina- tions of another	212
4.3.2 Model of learning system. Neurons network	214
4.3.3 Selflearning	219
4.3.4 Signal timing for vehicle traffic control	223
4.3.5 Optimal targeting of weapon systems	224
4.3.6 Locating buried objects via electrical conductivity	225
4.3.7 Investigation of poems rhythmic structures	226
4.4 Real-time systems optimization	228
4.4.1 Minimum point tracking of a nonstationary loss function	228
4.4.2 Optimization of a network router	229
4.4.3 Optimization of G/I/1 server	233
4.4.4 Options price estimation	234
4.5 Quantum computing and randomized algorithms	240
4.6 Proofs of Lemmas 4.1–4.3.	242

Appendix. Mathematical background	249
A.1 Theory of probabilities	249
A.1.1 Random elements	249
A.1.2 Important inequalities for random variables	251
A.1.3 Strong law of large number for independent random variables	251
A.1.4 Stationary random processes	252
A.1.5 Semi-supermartingal sequences of random variables . .	254
A.2 Facts from different fields	255
A.2.1 Convergence of some numerical sequences	255
A.2.2 Some matrix relations	256
A.2.3 Matrix functions factorization	258
A.3 Convergence of recursive algorithms	259
A.3.1 Linear case	259
A.3.2 Stochastic Lyapunov's function method	260
A.3.3 ODE method	263
Conclusion	271
Bibliography	271
Index	289