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System Identification Using Regular and Quantized Observations

Applications of Large Deviations Principles

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To my parents, Guozhen Cao and Qiumin He

Qi He

To my wife, Hong, and daughters, Jackie and Abby, for always believing, without evidence, that what I am doing might be interesting and useful

Le Yi Wang

To Meimei for her support and understanding

George Yin

Preface

This monograph develops large deviations estimates for system identification. It treats observations of systems with regular sensors and quantized sensors. Traditional system identification, taking noisy measurements or observations into consideration, concentrates on convergence and convergence rates of estimates in suitable senses (such as in mean square, in distribution, or with probability one). Such asymptotic analysis is inadequate in applications that require a probabilistic characterization of identification errors. This is especially true for system diagnosis and prognosis, and their related complexity analysis, in which it is essential to understand probabilities of identification errors. Although such probability bounds can be derived from standard inequalities such as Chebyshev and Markov inequalities, they are of polynomial type and conservative. The large deviations principle provides an asymptotically accurate characterization of identification errors in an exponential form and is appealing in many applications.

The large deviations principle is a well-studied subject with a vast literature. There are many important treatises on this subject in probability, statistics, and applications. This brief monograph adds new contributions from the point of view of system identification, with emphasis on the features that are strongly motivated by applications. Three chapters are devoted to case studies on battery diagnosis, signal processing for medical diagnosis of patients with lung or heart diseases, and speed estimation for permanent magnet direct current (PMDC) motors with binary-valued sensors. The basic methods and estimates obtained can of course be applied to a much wider range of applications.

This book has been written for researchers and practitioners working in system identification, control theory, signal processing, and applied probability. Some of its contents may also be used in a special-topics course for graduate students.

Having worked on system identification over a time horizon of more than twenty years, we thank many of our colleagues who have worked with us on related problems and topics. During these years, our work has been supported by (not at the same time) the National Science Foundation, the Department of Energy, the Air Force Office of Scientific Research, the Army Research Office, the Michigan Economic Development Council, and many industry gifts and contracts. Their support and encouragement are gratefully acknowledged. We would like to thank the reviewers for providing us with insightful comments and suggestions. Our thanks also go to Donna Chernyk for her great effort and expert assistance in bringing this volume into being. Finally, we thank the many Springer professionals who assisted in many logistic steps to bring this book to its final form.

Contents

Notation and Abbreviations

$\|A\|$ and $\|x\|$	Euclidean norms
$\overline{B}$	Closure of set B
B°	Interior of set B
$C_0([0,T];\mathbb{R}^n)$	Space of continuous functions
$C^2(\mathbb{R}^n)$	Class of real-valued C^2 function on $\mathbb{R}^n$
$D_N(t_0)$	$= (d(t_0), \ldots, d(t_0+N-1))'$
$H(\cdot)$	H functional
$H(v\|u)$	Relative entropy of probability vector v with respect to u
$I(\cdot)$	Rate function
$I^b(\cdot)$	Rate function for binary sensor
$I^q(\cdot)$	Rate function for quantized sensor
$I^r(\cdot)$	Rate function for regular sensor
K	Positive constant
LDP	Large deviations principle
$Y_N(t_0)$	$= (y(t_0), \ldots, y(t_0+N-1))'$
$d(\cdot,\cdot)$	Metric in a Euclidean space or a function space
$d(t)$	Noise
∇h	Gradient of h
$u(t)$	Input sequence
v'	Transpose of $v \in \mathbb{R}^{l_1 \times l_2}$ with l_1, $l_2 \geq 1$
$y(t)$	Output or observation
i.i.d.	Independent and identically distributed
w.p.1.	With probability one