Probabilistic and Randomized Methods for Design under Uncertainty

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With 21 Figures

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Preface

Solum certum nihil esse certi
Plinius, *Naturalis Historia*

A central issue in many engineering design endeavors is the presence of *uncertainty* in the problem description. Different application fields employ different characterizations of the uncertainty (for instance, deterministic unknown-but-bounded description *vs* stochastic description) and correspondingly adopt different techniques to devise 'designs' that are in some way insensitive, or *robust*, with respect to uncertainty.

The classes of problems considered in this book refer to uncertain control systems, as well as to generic decision or optimization problems in which the data are not exactly known.

In the area of robust control, the approach relying on a purely deterministic unknown-but-bounded description of the uncertainty spawned researches that yielded significant results in the last thirty years. However, this deterministic, or worst-case, approach also showed some inherent limitations that can be resumed in the fundamental tradeoff between computational complexity and 'conservatism'.

From a more philosophical perspective, a worst-case design, even if it could come at a cheap computational cost, may not be a desirable design in practice, since it contemplates *all* possible uncertainty scenarios, including those that are extremely unlikely to happen. On the other hand, one might think that a worst-case approach is necessary in situations where even rare events may lead to disastrous consequences. It should nevertheless be noticed that a design based on an unknown-but-bounded description of the uncertainty may lead to a 'false' belief of safety, since it provides no guarantees for uncertainty outcomes that, for some unforeseen reason, happen to fall outside the *a-priori* assumed uncertainty set. In this respect, an alternative approach based on a stochastic description of the uncertainty makes it clear right from the outset that, in reality, no statement can be given with absolute certainty.

In the field of optimization, the stochastic approach is indeed a classical one, dating back to the late fifties with the work of Dantzig [96] on linear programming under uncertainty and Charnes and Cooper [80] on chance-constrained optimization. In the robust control area, instead, the stochas-

tic approach still enjoys limited attention, since this area has been dominated lately by the worst-case deterministic viewpoint; early exceptions include [192, 195, 342] and later [207, 290, 347, 402]. From an historical point of view, we notice that the two areas of optimization and control followed two different routes: the optimization area has always been dominated by the stochastic paradigm, and only recently the works of El Ghaoui and Lebret [121] and Ben-Tal and Nemirovski [35] brought the worst-case approach into this area. Conversely, since the early eighties robust control has been mainly based on the worst-case paradigm; see the seminal works of Zames [407] on $\mathcal{H}_\infty$ control, of Kharitonov [183] on parametric uncertainty, and the structured singular value theory of Doyle [114] and Safonov [316]. Lately, however, the probabilistic paradigm gained new interest among control researchers, see, *e.g.*, [24, 74, 252, 359, 381] and the many references therein.

Book Scope and Structure

This book brings together leading researchers from both the optimization and control areas, with the intent of highlighting the interactions between the two fields, and with a focus on randomized and probabilistic techniques for solving design problems in the presence of stochastic uncertainty.

The book is divided into three parts. The first part presents three contributions dealing with the general theory and solution methodologies for probability-constrained and stochastic optimization problems and a contribution on the theory of risk measures. The second part of the book contains five chapters devoted to explicit robust design methods based on uncertainty randomization and sampling. The first chapter of the third part of the book presents a novel statistical learning theory framework for system identification, whereas the other six chapters in this part focus on applications of randomized methods for analysis and design of robust control systems.

Acknowledgments

We sincerely thank all the outstanding researchers and friends that made this project possible with their contributions. The financial support of the Italian Ministry of University and Research through an FIRB grant is gratefully acknowledged.

This book goal will be attained if it will stimulate further exchange and dialogue among scientists from the control and the optimization areas, and if it will foster further interest and attract new researchers to these fields.

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