# Preface

There are many problems of engineering interest for which an optimal operating point or condition exists, but this point or condition are not necessarily well known or easy to find. Extremum seeking control is a family of control design methods whose purpose is to autonomously find an optimal system behavior (e.g., set point or trajectory to be tracked) for the closed-loop system, while at the same time maintaining stability and boundedness of signals. Extremum seeking control is therefore mainly used to realize real-time optimization for dynamic systems. It has been applied to engineering problems in the automotive industry, process control, thermal fluids, flow control, semiconductor industry, energy conversion and many other areas. The motivation for the research on extremum seeking control arises from its practical interest, since even small improvements in performance can lead to cost and energy savings. This book reviews existing extremum seeking techniques, and proposes a new numerical optimization based extremum seeking control approach. Several applications are presented, including problems from the automotive industry, autonomous robotics and the semiconductor industry. This book will be of benefit to students and professionals in all areas of engineering, especially on system control and optimization. The book contains many figures (block diagrams, plots, simulation and experimental results) that will help the reader to understand the material. The reader (researcher, Ph.D or M.S level graduate student, R&D engineer) will become familiar with step-by-step algorithms that can be readily applied to a variety of control problems in engineering practice. The reader will also acquire a deep understanding of extremum seeking control and its mathematical foundations. The application examples included in the book will help the reader understand the concepts and how they can be applied.

## Overview of the Book

Tracking a varying maximum or minimum of a performance (output, cost) function is called extremum seeking control. For example, problems where finding such an extremum may be of interest include maximizing the yield of bioreactors, minimizing the power demand in formation control, minimizing reflected power, or even producing a better tuning of the PID coefficients in a control system. All of these are problems of practical interest in engineering, some of which have ad-hoc solutions, and some of which are yet unresolved. It is for these types of problems that extremum seeking control can be of great value. Extremum seeking attempts to determine the optimal performance of a control system as it operates, thereby potentially eliminating or reducing the need for down time and for doing system analysis.

In the first part of the book, we begin with a comprehensive review of the state-of-the-art in the extremum seeking control literature, and provide the reader with an understanding of what the different "flavors" of extremum seeking control are, and how they relate to each other. We review the existing analog optimization based extremum seeking control methods, which include gradient based design, perturbation based design and sliding mode based design. Then, we present a novel numerical optimization based extremum seeking control method that makes use of numerical optimization algorithms and state regulation, starting from simple linear time invariant systems and extending to a class of feedback linearizable nonlinear systems. We also analyze the robustness of two main optimization algorithms as they apply to extremum seeking: line search methods and trust region methods. For linear systems, a finite time state regulator is proposed and an asymptotic state regulator is used for nonlinear systems. Further design flexibility is achieved via the robustness results of the optimization algorithms and the asymptotic state regulator, where existing nonlinear adaptive control techniques can be introduced for robust design.

The second part of the book deals with the application aspects of extremum seeking control. We perform a comparative study of antilock braking system design via different extremum seeking control schemes. An industrial application of extremum seeking control methods to RF impedance matching is also presented, including experimental results obtained by one of the authors (Zhang) at Applied Materials. Finally, an interesting and promising application studied here is the autonomous agent source seeking problem. We use extremum seeking control and artificial potentials to achieve source seeking, formation control, collision avoidance and obstacle avoidance of a group of autonomous agents. Within this context, we present a practical application of source seeking via extremum seeking control to mobile radar sensor networks.

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Santa Clara, CA, USA — Chunlei Zhang
Dayton, OH, USA — Raúl Ordóñez

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