

Studies in Systems, Decision and Control 271

Martin Steinberger
Martin Horn
Leonid Fridman *Editors*

Variable-Structure Systems and Sliding-Mode Control

From Theory to Practice

 Springer

Studies in Systems, Decision and Control

Volume 271

Series Editor

Janusz Kacprzyk, Systems Research Institute, Polish Academy of Sciences,
Warsaw, Poland

The series “Studies in Systems, Decision and Control” (SSDC) covers both new developments and advances, as well as the state of the art, in the various areas of broadly perceived systems, decision making and control—quickly, up to date and with a high quality. The intent is to cover the theory, applications, and perspectives on the state of the art and future developments relevant to systems, decision making, control, complex processes and related areas, as embedded in the fields of engineering, computer science, physics, economics, social and life sciences, as well as the paradigms and methodologies behind them. The series contains monographs, textbooks, lecture notes and edited volumes in systems, decision making and control spanning the areas of Cyber-Physical Systems, Autonomous Systems, Sensor Networks, Control Systems, Energy Systems, Automotive Systems, Biological Systems, Vehicular Networking and Connected Vehicles, Aerospace Systems, Automation, Manufacturing, Smart Grids, Nonlinear Systems, Power Systems, Robotics, Social Systems, Economic Systems and other. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution and exposure which enable both a wide and rapid dissemination of research output.

** Indexing: The books of this series are submitted to ISI, SCOPUS, DBLP, Ulrichs, MathSciNet, Current Mathematical Publications, Mathematical Reviews, Zentralblatt Math: MetaPress and Springerlink.

More information about this series at <http://www.springer.com/series/13304>

Martin Steinberger · Martin Horn ·
Leonid Fridman
Editors

Variable-Structure Systems and Sliding-Mode Control


From Theory to Practice

 Springer

Editors

Martin Steinberger 
Institute of Automation and Control
Graz University of Technology
Graz, Austria

Martin Horn 
Institute of Automation and Control
Graz University of Technology
Graz, Austria

Leonid Fridman 
Control Engineering and Robotics
Department
National Autonomous University of Mexico
Mexico City, Distrito Federal, Mexico

ISSN 2198-4182 ISSN 2198-4190 (electronic)
Studies in Systems, Decision and Control
ISBN 978-3-030-36620-9 ISBN 978-3-030-36621-6 (eBook)
<https://doi.org/10.1007/978-3-030-36621-6>

MATLAB[®], Simulink[®], Stateflow[®] and Simscape Electrical[™] (formerly SimPowerSystems[™] and SimElectronics[®]) are registered trademarks or trademarks of The MathWorks, Inc. For more information and a list of additional trademarks visit mathworks.com/.

© Springer Nature Switzerland AG 2020

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*Dedicated to
Stefanie, Georg and Klemens
Astrid, Ilona and Lorenz
and Millie*

Preface

Variable-structure systems (VSS) and sliding-mode control (SMC) and observation are known to be one of the most efficient robust control and observer design techniques. Especially the ability to completely reject matched perturbations, i.e., perturbations that act in the input channels, is a stand-alone feature of these approaches compared to other robust methods.

In the last years, research was pushed further leading to new algorithms and important extensions of existing methods and more and more applications exploit the nice properties of sliding-mode techniques. This was also evident at the 15th International Workshop on Variable Structure Systems and Sliding Mode Control (VSS 2018) which was held at Graz University of Technology, Austria. The conference featured five sessions focusing on sliding-mode theory and four sessions on applications based on submissions from 30 countries.

The present book covers theoretical and practical aspects related to VSS and SMC. It is divided into four parts comprising 14 self-contained chapters that allow separate reading in any preferred order.

The first part introduces *New HOSM Algorithms*. New homogeneous controllers obtained by means of a recursive procedure for any relative degree of the system are proposed. The controllers are accompanied by new filtering sliding-mode-based differentiators. In addition, discontinuous integral control for systems with arbitrary relative degree capable of tracking smooth but unknown reference signals under the presence of Lipschitz continuous perturbations is presented.

Part II addresses *Properties of Continuous Sliding-Mode Algorithms* such as the computation and estimation of the reaching time of the super-twisting algorithm and two chapters dealing with the issue of constrained sliding-mode control, which is inevitable for real-world implementations. Also, an analysis of the orbital stability of self-excited periodic motions in a Lure system as well as a comparison of the chattering using continuous and discontinuous sliding-mode controllers is treated.

Part III covers the *Usage of VSS Controllers for Solving Other Control Problems*. Sliding-mode stabilization of SISO bilinear systems with delays is considered where Volterra operator theory is exploited to perform stability and robustness analysis. After that, a comparison of classical results and recent methods

using integral and HOSM is carried out in the next chapter in order to investigate their ability to compensate for unmatched disturbances.

The last part of the book is dedicated to *Applications of VSS*. Three chapters related to power electronics show the capability of sliding-mode techniques in this field. First, a grid-connected shunt active LCL control via continuous SMC and HOSM control techniques is presented. After that, the robust distributed secondary control of islanded inverter-based microgrids as well as local and wide-area sliding-mode observers in power systems is investigated.

The last two chapters deal with the application of sliding-mode-based methods for vehicle platooning, i.e., the task to form tight vehicle formations on one lane on a highway, and an application to a single-loop integrated guidance and control intercept strategy that makes use of HOSM control.

Enjoy reading!

Graz, Austria
Graz, Austria
Mexico City, Mexico
July 2019

Martin Steinberger
Martin Horn
Leonid Fridman

Acknowledgements

We gratefully acknowledge the financial support of (i) the Christian Doppler Research Association, the Austrian Federal Ministry for Digital and Economic Affairs and the National Foundation for Research, Technology and Development; (ii) CONACYT (Consejo Nacional de Ciencia y Tecnología) grant 282013; PAPIIT-UNAM (Programa de Apoyo a Proyectos de Investigación e Innovación Tecnológica) grant IN 115419; and (iii) the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 734832.

Graz, Austria
Graz, Austria
Mexico City, Mexico

Martin Steinberger
Martin Horn
Leonid Fridman

Contents

Part I New HOSM Algorithms

- 1 **New Homogeneous Controllers and Differentiators** 3
Avi Hanan, Adam Jbara and Arie Levant
- 2 **Discontinuous Integral Control for Systems with Arbitrary Relative Degree** 29
Jaime A. Moreno, Emmanuel Cruz-Zavala and Ángel Mercado-Uribe

Part II Properties of Continuous Sliding-Mode Algorithms

- 3 **Computing and Estimating the Reaching Time of the Super-Twisting Algorithm** 73
Richard Seeber
- 4 **Saturated Feedback Control Using Different Higher-Order Sliding-Mode Algorithms** 125
Mohammad Ali Golkani, Stefan Koch, Markus Reichhartinger, Martin Horn and Leonid Fridman
- 5 **Constrained Sliding-Mode Control: A Survey** 149
Massimo Zambelli and Antonella Ferrara
- 6 **Analysis of Orbital Stability of Self-excited Periodic Motions in Lure System** 177
Igor Boiko
- 7 **Chattering Comparison Between Continuous and Discontinuous Sliding-Mode Controllers** 197
Ulises Pérez-Ventura and Leonid Fridman