RECENT ACHIEVEMENT AND PERSPECTIVE DIRECTIONS IN SLIDING MODE CONTROL

22ST IFAC World Congress

Yokohama, July 9-14, 2023

Open Invited Track

Leonid FRIDMAN

Abstract

September 18th, 2022 Professor Utkin one of the originators of Variable Structure and Sliding Mode Theory died. That is why now it is a correct moment to organize the open track memorizing the originators of Variable Structure and Sliding Mode Theory and to revisit the recent results in sliding mode control and to draw the next most perspective lines of development.

The following main lines of investigation are planned to be be reflected:

(i) homogeneous and bi -homogeneous sliding mode algorithms(continuous and discontinuous);

(ii) sliding mode based observation, identification, fault detection and fault tolerant control;

(iii) comparison of conventional and high-order sliding mode controllers,chattering analysis in both frequency domain and state-space ;

(iv) discrete sliding modes;

(v) adaptation of sliding mode control algoritms;

(vi) application of the sliding mode control: control of under actuated systems, aerospace applications, networked control, event triggered control, and others.

IFAC technical committee: 2.3 Non-linear Control Systems

Background

In control systems, Variable Structure and Sliding Mode Control(SMC), originated by Professors Emelyanov[1], [2] and Utkin[3] in the end of fifties-early sixties, is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal. Instead, such a system can switch from one continuous structure to another, basing on the current position in the state space. This explains why SMC stems from the so-called variable structure control method.

The main advantage of SMC strategy producing discontinuous control signal is a theoretically exact compensation of bounded matched perturbations [4]. Over the course of the development of the sliding modes theory during the past sixty five years, the range of both control problems and design methods to solve them has expanded significantly.

The conventional design procedure within the SMS is divided into two stages. In the first stage, it is necessary to choose the manifold in the state space of the system with the desired trajectories[4]. At the second stage, the control is selected to ensure the existence of a sliding mode on this preselected manifold. Both problem are of reduced order with the same dimensions of the state and control vectors, but the convergence to origin is just asymptotical.

The higher order SMC(HOSMC) originated by Levant [5],[6], [7] allow to control the r-th order chain of integrators without usage of the sliding surfaces, nullifiying the output and its derivatives till the order (r-1) in finite-time using ideas of homogeneity.

Introducing in the control law an integral of discontinuous function [6], Professor Levant proposed a Super-Twisting Algorithm(STA) ensurng for the system of relative degree one theoretically exact compensation of Lipschitz perturbaton nullifying in finite-time not only to the system output but also to it's derivative generating a continuous control signal.

Than STA was extended till arbitrary order in the recent works [8],[9], [10],[11],[12],[13] for the chain of integrtors of arbitrary order.

The principal disadvantages of HOSMC and STA is a chattering produced by usage of the terms requiring infinite control gain. This phenomenon needs to be analyzed and discussed.

The other disadvantage of SMC is that they need the knowledge of the upper estimation of perturbations (discontinuous controllers) or even its derivatives (STA). Such upper bounds are frequently unknown or overestimated, that's why the problem of adaptation of SMC algorithms will be every time actual because it can be reduced the chattering and energy consumption.

One of the most important advantage of SMC algorithms is their usage for observer design, because even for the system with unknown inputs it can ensure theoretically exact finite-time estimation for variables of strong observable systems [14].

The other crucial issue is the discretization of SMC algorithms and analysis of sliding modes in discrete control systems.

Objective

The main objective of the open track is to reflect the principal directions of modern SMC:

- Homogeneous and bi-homogeneous sliding mode algorithms(continuous and discontinuous); In this direction two main lines of investigation will be discussed. First, Lyapunov-based design for the classes of continuous and discontinuous HOSMC and calculation of the algorithm gains. Then, a new type of convergence provided by HOSMC: fixed-time and algorithms with two types of predefined upperbound of settling time: [15] combining proportional navigation functions based algorithm [16] and finite-time controllers [17].

- Sliding mode based observation, identification, fault detection and fault tolerant control; In this set of papers the principal property of HOSM-based Levant's differentiators [18] ensuring finite-time theoretically exact estimations of derivatives is used to construct different type of observers and applied to identification, fault detection and fault tolerant control.

- Comparison of conventional and HOSM controllers,chattering analysis, frequency domain and state-space; Tree approaches to Chattering analysis and adjustment will be discussed:
  - Analysis of chattering using frequency methods [19].
  - State-space approach using singular perturbations [20].
  - Filtering and bypass by observers [21].
- Discrete sliding mode; Two main types of discretization will be presented. Homogeneous discretization [22] and implicit discretization [23].
- Adaptation of sliding mode control algoritms; According to [24], four main frameworks for adaptive sliding-mode control (ASMC) were acknowledged by the community:
  - **Reconstruction of the equivalent control**[25]: The discontinuous control signal is filtered to approximate the equivalent control and use this approximation to compensate the disturbance.
  - **ASMCs with increasing gains** [26]: The ASMCs'gains are increased until the sliding-mode is reached. This level of gain is maintained until the disturbance grows once more.
  - **ASMCs with increasing and decreasing gains** [27]: The ASMC makes the gains increase and decrease to follow the perturbation as closely as possible, achieving an ultimate bound on the sliding-variable.
  - **Barrier function-based ASMC** [28]: The ASMCs' gains are increased until the sliding variable reaches a value of half of a prescribed ultimate bound. Then, by means of a barrier function, the trajectories of the sliding variable are forced to remain within the prescribed neighborhood of the origin.
- Application of the sliding mode control: networked control systems, control of under-actuated systems, aerospace applications, event triggered controllers, etc.

There is preliminary appointment with the scientists from at least 10 countries: Austria, Brazil, China, France, Germany, India, Italy, Israel, Japan, Mexico, UK to contribute in this track.

Short bio of organizer

Leonid M. Fridman obtained the M.S. degree in mathematics from Kuibyshev (Samara) State University, Samara, Russia, in 1976, the Ph.D. degree in applied mathematics from the Institute of Control Science, Moscow, Russia, in 1988, and the Dr. Sc. degree in control science from Moscow State University of Mathematics and Electronics, Moscow, Russia, in 1998.

In 2002, he joined the Division of Electrical Engineering of Engineering Faculty, Department of Control Engineering and Robotics, National Autonomous University of Mexico (UNAM), Mexico City, Mexico.

His research main interests are variable structure systems and sliding mode control. In 2014-2018 he served as a Chairman of IEEE TC on Variable Structure and Sliding Mode Control. He is a co-author and co-editor of 11 books and 20 special issues devoted to sliding-mode control.

Dr. Fridman is the recipient of the IFAC WC 2020 Harold Chestnut Control Engineering Textbook Prize for co-authored book «Sliding Mode Control and Observation», and winner of the UNAM Prize for exact sciences, in 2019 and Scopus Prize for the best cited Mexican Scientists in Mathematics and Engineering 2010. He was working as an invited Professor in 20 universities and research laboratories in Argentina, Australia, Austria, China, France, Germany, Italy, Israel, and Spain. He is an International Chair of INRIA, France, and a High-Level Foreign Expert of Ministry of Education of China.

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