Module Announcement

PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

Module Title: New robust control methodologies for a broad class of nonlinear uncertain engineering systems

Lecturers:

Professor Michael Basin
Autonomous University of Nuevo Leon, Mexico
ITMO University, St. Petersburg, Russia
mbasin@fcfm.uanl.mx; mbasin2007@gmail.com

CV: **Michael V. Basin** received his Ph.D. degree in Physical and Mathematical Sciences with major in Automatic Control and System Analysis from the Moscow Aviation University (MAI) in 1992. He is currently Full Professor with the Autonomous University of Nuevo Leon, Mexico, and Leading Researcher with ITMO University, St. Petersburg, Russia. Starting from 1992, Dr. Basin published more than 300 research papers in international referred journals and conference proceedings. He is the author of the monograph "New Trends in Optimal Filtering and Control for Polynomial and Time-Delay Systems," published by Springer. His works are cited more than 3000 times (h index = 32). Dr. Basin has supervised 14 doctoral and 7 master's theses. He has served as the Editor-in-Chief and serves as the Senior Editor in Control of Journal of The Franklin Institute, a Technical Editor of IEEE/ASME Transactions on Mechatronics, an Associate Editor of Automatica, IEEE Transactions on Systems, Man and Cybernetics: Systems, IET-Control Theory and Applications, International Journal of Systems Science, Neural Networks. Dr. Basin was awarded a title of Highly Cited Researcher by Thomson Reuters, the publisher of Science Citation Index, in 2009; he is a regular member of the Mexican Academy of Sciences. His research interests include optimal filtering and control problems, stochastic systems, time-delay systems, identification, sliding mode control and variable structure systems.

Dr. Ph.D. Laura Celentano
Department of Electrical Engineering and Information Technology
University of Naples Federico II
laura.celentano@unina.it; lacelent@gmail.com

CV: **Laura Celentano** received the Ph.D. degree in automation and computer science engineering (with major in automatic control and system analysis) from the University of Naples Federico II, Naples, Italy, in 2006.

She has been an Assistant Professor of Automation and Control with the University of Naples Federico II, and a Professor of Fundamentals of Dynamical Systems, Modeling and Simulation, and Automation of Navigation Systems, since 2006. She has also taught classes at the Italian Air Force Academy, Naples (Fundamentals of Dynamical Systems).
She is a science journalist and has cooperated with radio programs and journals on the popularization of scientific matters. She has taken an active part in activities co-funded by the European Union, the Italian Ministry of University and Research and the Economic Development, Region Campania, and public and/or private corporations and industries.
She is an author/reviewer for IEEE, ASME, ELSEVIER and AIP journals and conferences.
Dr. Celentano has also been the Chair and an Organizer for conference sessions.
She has authored and co-authored scientific and educational books, presented by the IEEE Control Systems Society and international experts.
Her current research interests include the design of versatile, fast, precise, and robust control systems of linear and nonlinear uncertain systems; methods for the analysis of stability and for the stabilization of linear and nonlinear uncertain systems (as well as MIMO and discrete-time systems); modeling and control of rigid and flexible mechanical systems; multivalued control design methodologies; modeling and control of aeronautical, naval, and structural systems; rescue and security robotics; and telemonitoring and/or telecontrol systems.

Dates and Locations (rooms are in Ed.1, via Claudio 21, Napoli)

Date	Hours	Room
9 July 2018	11.00-14.00	Aula T3 Biennio Via Claudio 21, Napoli
11 July 2018	11:00-13:00	Aula T3 Biennio Via Claudio 21, Napoli
13 July 2018	11:00-13:00	Aula T3 Biennio Via Claudio 21, Napoli

Contents

I Lesson – Introduction: Main control problems for transportation and manufacturing systems (Laura Celentano): Since a kilovatt-hour of electrical energy transformed into mechanical energy can produce an impressive amount of human work, current and future well-being depend primarily on automatic systems concerning many key areas for humanity, including the transportation and manufacturing systems.
Hence, developing control algorithms that can be easily implemented using modern digital and wireless technologies to force electromechanical systems (e.g., AGVs, cars, trains, ships, airplanes, drones, and robots) to behave like skilled workers who work quickly, accurately, and cheaply despite parametric variations, nonlinearities, and persistent disturbances is of great importance. In particular, special attention has been paid to solving robust tracking control problems. However, in the literature many results have been obtained under the following simplified hypotheses, which are not always realistic and feasible: 1) exact knowledge of the controlled system is assumed, 2) actuators are considered ideal, and 3) signals are assumed measurable without noises; therefore, ideal or almost ideal derivative actions can be used in such cases. These simplified hypotheses, taking also into account the non-negligible computation time for feedback linearization or control signal generation by the inverse model technique or MPC techniques, make the inverse model, feedback linearization and MPC techniques not always reliable. In some cases, the control system can even be unstable, as can be verified from simple counterexamples. To avoid the aforementioned problems, various modifications of the inverse model and feedback linearization techniques have been proposed. Unfortunately, control techniques using high-frequency and high-amplitude control signals, in the presence of real actuators, real power amplifiers, measurement noises and computational delays, do not yield satisfactory performance or can result in unstable closed-loop systems.

To exceed the main aforementioned disadvantages, some new significant results will be presented in this and next lessons.
Moreover, the problem of a robust and performing controller is a significant issue also for structures and robots with flexible links having varying cross sections, under the hypothesis of large link deformations and of time-varying geometrical and/or physical parameters of both the robot and the end-effector.
Indeed in order to reduce the disadvantages due to flexibility (oscillations and/or vibrations, breaking and the spillover phenomenon when the structure is controlled by a closed-loop controller), it is necessary to design advanced control systems based on reliable and efficient models.
The above mentioned problems are of great relevance in several multidisciplinary engineering fields, such as robotics, mechanical, civil, aeronautical, and naval.
In practice, till now no satisfactory solutions have also been provided.

Continuous Finite- and Fixed-Time High-Order Regulators (Michael Basin):
It is well known that a state of a controllable linear system of an arbitrary dimension can be asymptotically driven as close to zero as necessary by means of a linear scalar feedback control. Using a continuous nonlinear scalar control law, a chain of integrators of an arbitrary dimension can be driven to the origin in finite time. Given that an arbitrary minimum phase linear system can be transformed into a chain of integrators form by using an appropriate change of variables, finite-time high-order regulators are applicable to an arbitrary minimum phase multi-dimensional linear system. A relevant problem consists in estimating the convergence (settling) time for the finite-time convergent control laws. Another challenging problem is to design a fixed-time continuous control law such that a system state converges to the origin for a pre-established or fixed settling time, independently of a magnitude of initial conditions.
The contribution of this study is twofold. First, an upper estimate of the convergence (settling) time is calculated for the finite-time convergent control algorithm that drives the state of a series of integrators to the origin. To the best of the authors' knowledge, such an estimate is obtained for the first time. Second, a novel fixed-time continuous control law is proposed for a chain of integrators of an arbitrary dimension. Its fixed-time convergence is established and the uniform upper bound of the settling time is computed. The theoretical developments are applied to a case study of controlling a DC motor. It is shown that stabilization time for the DC motor shaft rotation angle, its angular velocity, and armature current is independent of initial conditions of the state variables.
Finally, an extension of the developed approach to design fixed-time observers for integrator chain systems (differentiators) is discussed and compared to a built-in Simulink differentiation technique.

II Lesson - An Approach to Design Robust Tracking Controllers for a Class of Nonlinear Uncertain Engineering Systems (Laura Celentano, Michael Basin):

An approach to design robust smooth controllers that allow a plant belonging to a broad class of nonlinear uncertain systems is proposed. These systems are with possible real actuators and subject to bounded or rate-bounded disturbances, and the goal is to track a sufficiently smooth reference signal with an error norm smaller than a prescribed value. The considered class of systems includes electromechanical systems (AGVs, cars, trains, ships, airplanes, drones, robots, etc.). The proposed control laws are based on the concept of majorant systems and allow one to establish asymptotic bounds for the tracking error and its first and second derivatives. The proposed controller design is based on two parameters: the first is related to the minimum eigenvalue of an appropriate matrix, which the practical stability depends on, and the second is determined by the desired maximum norm of the tracking error and its convergence velocity. If the trajectories to be tracked are not sufficiently smooth, suitable filtering laws are proposed to facilitate implementation of the control laws and reduce the control magnitude, especially, during the transient phase. The obtained theoretical results are validated in two case studies. The first one presents a tracking control design for an industrial robot, both in

the joint space and workspace, with and without real actuators or velocity measurement noise. The second one deals with tracking control design for a complex uncertain nonlinear system.
Other simulation results illustrating the effectiveness of the presented methodology will be presented; they mainly concern control of the safety distance between three vehicles; a ship complex manoeuvre; a drone in a rescue mission; industrial robots for manufacturing; an application of "robotic surgery"; an antenna scanning system controlled with a new designed and constructed controller.

New Results on Robust Stability Analysis and Synthesis for MIMO Uncertain Systems (Laura Celentano, Michael Basin): Some theoretical preliminary results are provided and a first methodology is developed, that allows one to efficiently estimate the maximum time constant of a dynamic matrix of an uncertain system with rational multi-affine structure with respect to parameters, and a second one to find a majorant system of a multi-input multi-output (MIMO) system with rational multi-affine structure with respect to parameters. The developed methodologies are used to estimate the evolution of an uncertain linear time-invariant (LTI) system with additional bounded nonlinearities and/or additional bounded input signals. Moreover, the above results are also used to design a robust controller for an uncertain MIMO system with unmeasurable states and subject to a rate-bounded disturbance in order to track a rate-bounded reference signal. The obtained theoretical results are illustrated by three examples. The first two examples deal with the analysis of a LTI system with bounded disturbances and measurement noise, and additional bounded and not bounded nonlinearities, respectively; in the second example a new control law with saturation is also designed. In the last example, a robust controller for an uncertain electro-mechanical system with unmeasurable state is designed to track a rate-bounded reference signal in the presence of a disturbance with bounded derivative.

III lesson - Continuous Fixed-Time Control for Cart Inverted Pendulum Stabilization (Michael Basin):

Since the inverted pendulum problem was initially considered in the beginning of 1950s, its numerous modifications have been actively studied: rotational single-arm pendulum, cart inverted pendulum, double inverted pendulum, rotational two-link pendulum, parallel-type dual inverted pendulum, triple inverted pendulum, quadruple inverted pendulum, 3D or spherical pendulum, and many others. An inverted pendulum system is a typical nonlinear dynamic system assuming a stable equilibrium point with the pendulum at the pending position and an unstable equilibrium point with the pendulum at the upright position. A classical benchmark problem consists in stabilizing the cart inverted pendulum, which involves a DC motor, a pendant-type pendulum, a cart, and a driving mechanism. The principal control task here is to swing up the pendulum from any arbitrary initial condition to the unstable equilibrium point, balance the pendulum at the upright position, and further move the cart to a specified position by driving it forth and back. Furthermore, stabilization of cart inverted pendulum has been employed in solving related problems, such as straight motion design for the conventional two-wheeled inverted pendulum mechanism, omnidirectional mobile platform design for balance analysis, finite-time consensus tracking control for multi-robot systems, and many others. Recently, much attention have been paid to designing finite- and fixed-time convergent control laws and estimating their convergence (settling) times.
This study deals with a novel continuous fixed-time convergent control algorithm applied to the cart inverted pendulum stabilization problem in the presence of Lipschitzian disturbances. A continuous fixed-time convergent control is designed to drive the cart inverted pendulum states to the origin for a finite pre-established (fixed) time using a scalar input. The initial conditions for the cart inverted pendulum are assumed unknown, therefore, the settling time remains indefinite or even infinite if conventional control algorithms, such as linear feedback or higher-mode sliding mode, are applied. To guarantee a finite pre-established (fixed) convergence time, it is proposed to employ the fixed-time convergent continuous control algorithm that is insensitive to initial conditions and external Lipschitzian disturbances. The fixed-time convergence of the designed control algorithm is established and the uniform upper bound of the settling time is computed. Conducted numerical simulations confirmed validity of the theoretical results. In particular, the actual finite convergence times observed via simulations are only 5--11 times less than the convergence time upper estimate obtained theoretically.

Module Announcement

ECTS Credits: 1.4

Info: **Dr. LAURA CELENTANO -** tel. 081 7683860-3394275878 – laura.celentano@unina.it