cnrs GDR Groupement de recherche MACS Modélisation, analyse et conduite des systèmes dynamiques

Scientific Day

LCIS Laboratoire de Conception et d'Intégration des Systèmes

SAGIP Société d'Automatique, de Génie Industriel & de Productique

Thursday, 16 November 2023

Location: Room: D030, Esisar-Grenoble INP, Time: 10:00-17:30

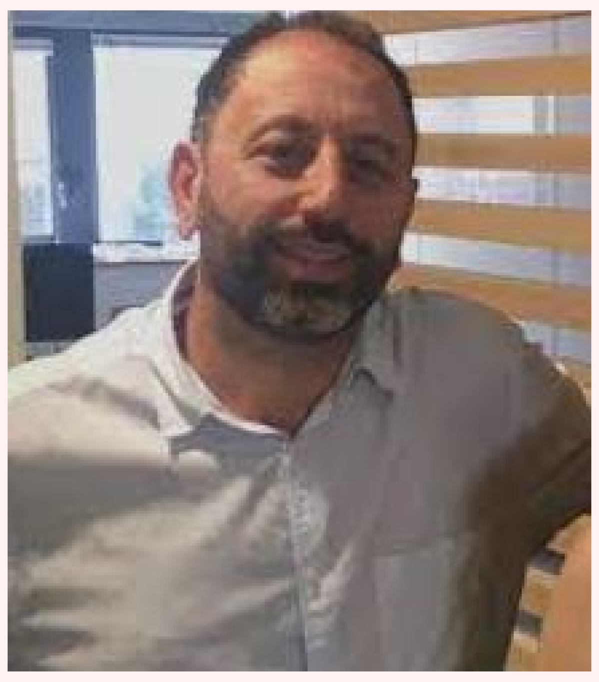
50, rue Barthélémy de Laffemas - 26000 Valence

Organizers: Ionela Prodan (LCIS, Grenoble INP, Valence)
Sylvain Bertrand (ONERA, Palaiseau)

ct-cpnl.fr

GRENOBLE INP UGA

Recent technological advances have enabled the development and design of Model Predictive Control (MPC) for complex systems with hard constraints, fast nonlinear dynamics, large uncertainties and perturbations, networked components, dynamic models learned from data, etc. These systems are naturally requiring hierarchical/distributed control architectures. A wide spectrum of applications has emerged from these developments, with model predictive controllers being nowadays applied to autonomous and robotic systems (aquatic/terrestrial/aerial/space), large-scale and multi-agent systems, power and energy systems, health, biology and neuroscience, etc.
This day is intended to bring together researchers from France (and outside France) and to shed light on efficient implementations and control architectures for NMPC. Two widely recognized researchers in the domain will give extended talks of 50 minutes (see Abstracts below). We warmly invite other PhDs, postdocs and researchers to join with short talks of 30 minutes.



Mazen Alamir
CNRS, GIPSAlab,
Grenoble INP, France

Title: A (small) step towards a systematic design of NMPC effective and implementable setting

Abstract: It is needless to say that Nonlinear Model Predictive Control is currently the most effective and widely used feedback design methodology in academic works that address the control of constrained nonlinear systems. The theoretical foundations of NMPC are now quite established. Moreover free and easy-to-use programming frameworks that embed multiple efficient and trustworthy dedicated solvers for the NMPC-underlying optimization problems are now available. Nevertheless, practitioners still lack a systematic design procedure for the NMPC components (such as the control updating period, down-sampling period for prediction, control parameterization, prediction horizon's length as well as the penalties on the terminal cost and the soft constraints) that enables the last step to be achieved, namely the real-time implementation on a specific computation target device. In this talk, the real-time implementation-related issues are first recalled. Then a framework that enables a systematic and rational design of NMPC design components is sketched. The rationale that underlines the design choices expresses real-time implementability, convergence and constraints satisfaction for a given computational device and a specific optimization algorithm. Finally, a freely available associated Python-based implementation is also proposed with a fully developed illustrative example before an overview of remaining-to-achieve tasks is proposed.

Alexandra Grancharova
UCTM, Bulgaria

Title: Distributed predictive control based on Gaussian process models

Abstract: A suboptimal approach to distributed NMPC is proposed based on Gaussian process models of the interconnected systems dynamics and taking into account the imposed constraints. The suggested method is based on a sequential linearization of the nonlinear system dynamics and finding a suboptimal solution of the resulting Quadratic Programming (QP) problem by using distributed iterations of the dual accelerated gradient method. The main advantages of the distributed approach are that it allows the computation of the suboptimal control inputs to be done autonomously by the subsystems without the need for centralized optimization and it has a simple software implementation. The proposed method is illustrated with simulations on the simplified model of a sewer system.

For more information about the organization and presentation proposals you can contact Sylvain Bertrand (sylvain.bertrand@onera.fr) and Ionela Prodan (ionela.prodan@lcis.grenoble-inp.fr). The registration is mandatory at the following link. The final program will be available at ct-cpnl.fr.

CT CPNL (Commande Prédictive Non Linéaire)

French Research Group on Nonlinear Model Predictive Control

Detailed program

[9:30-10:00] Welcoming coffee and organizers speech

[10:00-10:30] **Maintaining a relevant dataset for data-driven MPC using Willems' fundamental lemma extensions**
Alexandre Faye-Bédrin, Stanislav Aranovskiy, Paul Chauchat, Romain Bourdais.
IETR (Institut d'Electronique et des Technologies du numéRique), CentraleSupélec Rennes, France.

[10:30-11:00] **Nonlinear MPC for collision-avoidance trajectory tracking of a multi-UAV system in a mapping mission**
Dora Novak, Sihem Tebbani
Université Paris-Saclay, CNRS, CentraleSupélec, Laboratoire des Signaux et Systèmes, Gif-sur-Yvette, France.

[11:00-11:30] **Solving MPC problems using ramp functions**
Morten Hovd
Department of Engineering and Cybernetics, Norwegian University of Science and Technology, Trondheim, Norway.

[11:45-13:45] Lunch break and Esiarium platform visit (Esisarium - localisation and control of cyber-physical systems)

[13:50-14:20] **Distributed Moving Horizon Estimation with pre-estimation using Extended Kalman Filter for Nonlinear Measurements**
Matthieu Borelle[1,2], Sylvain Bertand[1], Cristina Stoica[2], Teodoro Alamo[3], Eduardo F. Camacho[3]
[1] Université Paris-Saclay, ONERA, Traitement de l'information et systèmes, Palaiseau, France.
[2] Université Paris-Saclay, CNRS, CentraleSupélec, Laboratoire des Signaux et Systèmes, Gif-sur-Yvette, France.
[3] Department of Ingeniería de Sistemas y Automática, Universidad de Sevilla, Sevilla, Spain.

[14:20-15:05] A (small) step towards a systematic design of NMPC effective and implementable setting
Mazen Alamir
CNRS, GIPSAlab, Grenoble INP, France.

[15:05-15:50] Distributed predictive control based on Gaussian process models
Alexandra Grancharova
University of Chemical Technology and Metallurgy, Bulgaria.

[15:50-16:00] Quick coffee break

[16:00-16:30] **Computer-generated Control Lyapunov Function via offline linear programming**
Huu-Thinh Do[1], Franco Blanchini[2], Stefano Miani[2], Ionela Prodan[1]
[1] Univ. Grenoble Alpes, Grenoble INP, LCIS, 26000 Valence, France.
[2] Dipartimento di Matematica e Informatica, Università di Udine, Italy.

[16:30-17:00] **Terminal region enlargement of a stabilizing NMPC design for a multicopter**
Huu Thien Nguyen[1], Ngoc Thinh Nguyen[2], Ionela Prodan[3]
[1] SYSTEC–ISR, University of Porto, Porto, Portugal
[2] Univ. of Luebeck, Institute for Robotics and Cognitive Systems, Luebeck, Germany
[3] Univ. Grenoble Alpes, Grenoble INP, LCIS, 26000 Valence, France.

[17:00-17:30] **Mixed-integer predictive control for a three-phase electric arc furnace producing Silico Manganese**
Minh Tuan Dinh[1,2], Ionela Prodan[1], Olivier Lesage[2], Eduardo Mendes[1]
[1] Univ. Grenoble Alpes, Grenoble INP, LCIS, 26000 Valence, France.
[2] Eramet Ideas, Trappes, France.

Abstracts

[10:00-10:30] **Maintaining a relevant dataset for data-driven MPC using Willems' fundamental lemma extensions**

Abstract: This work explores the recent formulation of non-linear Data-driven Model Predictive Control in the case of dynamic references. Indeed, the state-of-the-art methods rely on Willems fundamental lemma, and freeze the used dataset at some point. While this ensures consistent behavior, i.e., excitation and accuracy, for a given setpoint, this will likely fail when the reference, and thus the operating point, changes. To this end, we propose refined heuristics for dataset management. First, a singular value-based method induces regular dataset updates but still guarantees a minimum excitation level. Then, a double-dataset formulation aims at decoupling accuracy and excitation issues and leverages the singular value-based one. These heuristics are validated in real-time experiments on a heat-blower system.

[10:30-11:00] **Nonlinear MPC for collision-avoidance trajectory tracking of the multi-UAV system in a mapping mission**

Abstract: Using UAVs in the context of smart agriculture can optimize farming management and increase agricultural productivity while protecting the environment. In addition, a multi-UAV system can be employed to map the field to ensure increased mission efficiency and reduce the mapping duration, especially for large fields. In this case, coordination between the UAVs engaged in the same mission must also be considered. Ensuring minimal tracking error and keeping the safety distance between the UAVs in order to avoid collision are the main challenges for a well-conducted mapping mission with multiple UAVs. Nonlinear MPC has shown promising results for real-time trajectory tracking, primarily when implemented in the often irregular field shape that leads to a nonlinear flight path. The proposed nonlinear MPC approach successfully deals with trajectory tracking of multiple UAVs employed in the same mission while handling collision avoidance. The robustness of the proposed nonlinear MPC is seen in good performance in the presence of external disturbances and the model parameter uncertainties.

[11:00-11:30] **Solving MPC problems using ramp functions**

Abstract: Model Predictive Control (MPC) requires the fast online solution of an optimization problem. When using a linear system model in the MPC, the optimization problem is often formulated as a quadratic programming (QP) problem or as a linear programming (LP) problem. Such optimization problems can fairly effectively be solved with gradient based or interior point solvers. However, for implementations requiring very fast sampling times, or where resource constrained computing platforms are used, both calculation times and computer memory requirements may be relevant concerns. Also, complex computer code may make standard solvers inappropriate for safety-critical systems. The talk will describe a novel approach to solving strictly convex optimization problems, using ramp functions. The optimization problem involves solving an implicit equation involving the ramp functions. For QP problems, numerical experience shows that problems arising in MPC can be solved very fast, and with very simple computer code. The talk will describe the proposed solution strategy, demonstrate the efficiency for several benchmark problems. For LP problems, numerical results are less impressive when comparing Matlab code with state-of the-art solvers, but indicate computational advantages for problems of modest size. For both QP and LP solvers, significant speedups are expected from ongoing work to program the solution strategies in C/C++.

[13:50-14:20] **Distributed Moving Horizon Estimation with pre-estimation using Extended Kalman Filter for Nonlinear Measurements**

Abstract: In this work, a new Moving Horizon Estimation algorithm is developed for distributed state estimation using nonlinear measurements, by a multi-agent system connected through a communication network. The concept of pre-estimation, introduced in previous works for the linear framework, is extended here to account for nonlinearities using an Extended Kalman Filter. In a dual way to Model Predictive Control strategies, the estimate is computed by solving online an optimization problem considering a finite time horizon in the past and possibly incorporating constraints. The considered formulation of this problem is distributed, in the sense that it only depends on the information locally available at each agent (its own information and information sent by neighbor agents through the communication network). An example of collaborative localization of a fleet of drones is proposed to illustrate the performance of the approach in terms of computation time and estimation accuracy.

Abstracts

[14:20-15:05] **A (small) step towards a systematic design of NMPC effective and implementable setting**

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[15:05-15:50] **Distributed predictive control based on Gaussian process models**

Abstract: A suboptimal approach to distributed NMPC is proposed based on Gaussian process models of the interconnected systems dynamics and taking into account the imposed constraints. The suggested method is based on a sequential linearization of the nonlinear system dynamics and finding a suboptimal solution of the resulting Quadratic Programming (QP) problem by using distributed iterations of the dual accelerated gradient method. The main advantages of the distributed approach are that it allows the computation of the suboptimal control inputs to be done autonomously by the subsystems without the need for centralized optimization and it has a simple software implementation. The proposed method is illustrated with simulations on the simplified model of a sewer system.

[16:00-16:30] **Computer-generated Control Lyapunov Function via offline linear programming**

Abstract: We propose a technique of exploiting open-loop generated trajectories for a constrained control problem, using them to shape a suitable non-quadratic control Lyapunov function. These trajectories, generated off-line, allow detecting a suitable domain of attraction in which a candidate Lyapunov function has negative derivative. Given a suitably constructed basis function, our working machinery is based on linear programming, hence the technique can be applied to problems of non-trivial size in terms of number of basis functions and points in the state space. For linear systems, we seek convex Lyapunov functions which are homogeneous polynomial. The simulation and experimental results for autonomous aerial vehicles control are highlighting the contributions.

[16:30-17:00] **Terminal region enlargement of a stabilizing NMPC design for a multicopter**

Abstract: This work proposes an NMPC scheme for stabilizing multicopter dynamics with semi-globally asymptotic stability guarantees. Recurrent issues in the state of the art, such as the existence of a terminal invariant set and a decreasing terminal cost under a local controller are analyzed. Within this context, the novelty resides in the use of a nonlinear local controller with feedback linearization properties which allows for arbitrary enlargement of the ellipsoidal terminal region with respect to the initial conditions. The framework is completed through a detailed analysis of the NMPC parameters. Comparisons and simulations for a nanodrone system show the benefits of the approach

[17:00-17:30] **Mixed-integer predictive control for a three-phase electric arc furnace producing Silico Manganese**

Abstract: In the metallurgical industry, Electrical Arc Furnace are usually controlled through simple rules, without necessarily handling the coupling among their various components. In here, we concentrate on a particular model of a three-phase arc furnace producing Sillico-Manganese (SiMn). We first develop a mathematical model of the EAF that is able to capture the behavior of the three-phase electrical evolution in time. Next, we formulate a mixed-integer optimization problem in an MPC framework for the plant's linearized model. The goals are to control the power and intensity to track a priori given set-points, handle integer inputs, and limit tap switching frequency. The benefits of the proposed approach are validated over a SiMn furnace simulator developed by Eramet Ideas.