Network of Excellence

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HYCON

Hybrid Control: Taming Heterogeneity and Complexity of Networked Embedded Systems

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Author(s)	**Andrea Balluchi** balluchi@parades.rm.cnr.it **Alberto Sangiovanni Vincentelli** alberto@parades.rm.cnr.it
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HYCON Partner [1]	UNISI
WP4c leader [2]	Alberto Bemporad
Research team [3]	A. Alessio, A. Bemporad, S. Di Cairano, D. Hrovat, I. Kolmanovsky, F. Maggi, M. Piliego, G. Ripaccioli, E. Tseng

Research topic

Title

Hybrid and Explicit Model Predictive Control of Automotive Systems

Short description [4]

The research group of UNISI, in collaboration with Ford Research Laboratories (Dearborn, MI) is carrying out a few case studies of automotive control problems addressed through hybrid modeling, model predictive control (MPC) design, and code generation via multiparametric programming (explicit MPC). In particular, the following case studies are currently under investigation:

- Control of an electromagnetic actuators
- Control of a direct-injection-stratified-charge (DISC) engine
- Control of suspension systems

Expected impact of hybrid system approach

All automotive control problems tackled by UNISI in this workpackage have features that can be quite naturally and systematically approached by hybrid models. By modeling the open-loop system + constraints as a hybrid model, MPC techniques provide a very versatile and direct model-based design approach, that results in excellent closed-loop performance under complex specification scenarios.

Industrial collaborations [5]

Ford Research Laboratories, Dearborn (MI), USA

Description of the control problem specification [1]

1) Electromagnetic actuator: position control under joint position-velocity "soft-landing" constraints, maximum force constraints, maximum current constraints.

2) DISC engine: simultaneously actuate several command inputs (fuel flow, air flow, spark-advance, combustion regime) to track several reference signals (torque, air-to-fuel ratio, intake manifold pressure, etc.) under several mode-dependent constraints on air-to-fuel ratio and spark advance.

3) Semiactive suspensions: regulate vertical acceleration of the chassis, tire deflection, and suspension deflection by adjusting the damping force, under saturation, passivity, and maximum dissipation constraints.

Description of the adopted hybrid design methodology [(2)]

Hybrid Model Predictive Control based on HYSDEL models. Models are converted to MLD form for evaluation of the closed-loop performance in simulation, and to PWA form for deployment as a lookup table of linear feedback gains. The Hybrid Toolbox for Matlab, developed at UNISI, has been extensively used for analysis, design, and code generation.

Improvements with respect to non-hybrid control algorithms [(3)]

1) performances

As good as nonlinear control algorithms. Definitely better than linear control design.

2) robustness

Non yet investigated.

3) number of calibration parameters and complexity of the calibration process

Easily tunable by changing MPC weights, without struggling with constraint satisfaction issues.

4) implementation requirements (memory, computation resources, sampling frequency, etc)

Heavily depends on the complexity of the chosen hybrid models. The simplest designs, with satisfactory performance, obtained in the three case studies can be deployed on standard microcontrollers with <=64kb, with sampling times in the millisecond order.

Feedback from the industrial partner

Very positive. Especially impressed by the reduced time to achieve a satisfactory controller design.

Additional comments on experimental results (if carried out)

A large-scale laboratory prototype of the electromagnetic actuator is under development at the Automatic Control Laboratory of UNISI.

Reports and papers

N. Giorgetti, A. Bemporad, H. E. Tseng, and D. Hrovat, ``Hybrid model predictive control application towards optimal semi-active suspension,'' in Proc. IEEE Int. Symp. on Industrial Electronics, Dubrovnik, Croatia, 2005, pp. 391-398.

N. Giorgetti, A. Bemporad, I.V. Kolmanovsky, and D. Hrovat, ``Explicit hybrid optimal control of direct injection stratified charge engines,'' in Proc. IEEE Int. Symp. on Industrial Electronics, Dubrovnik, Croatia, 2005, pp. 247-252.

N. Giorgetti, A. Bemporad, H. E. Tseng, and D. Hrovat, ``Hybrid model predictive control application towards optimal semi-active suspension,'' International Journal of Control, 2005, Conditionally accepted for publication.

S. Di Cairano, A. Bemporad, I.V. Kolmanovsky and D. Hrovat, ``Model predictive control of mechatronic systems: an appplication to a magnetically actuated mass pring damper'', 2nd IFAC Conference on Analysis and Design of Hybrid Systems, 2006, Alghero, Italy (accepted).

Hybrid model predictive control for automotive applications

HYCON Partner [(1)]	TUD (partner 19)
WP4c leader [(2)]	Bart De Schutter
Research team [(3)]	Bart De Schutter, Ton van den Boom, Daniele Corona, Ion Necoara

Research topic

Title	Hybrid model predictive control for automotive applications
Short description [(4)]	We consider the use of hybrid control design techniques, in particular, Model Predictive Control (MPC), for automotive applications. More specifically, we will use a hybrid model of a Smart with an advanced cruise control system to develop a controller using various hybrid MPC techniques, and to compare the performance of the resulting controllers among themselves and also with that of the currently used controllers such as, e.g., sliding mode controllers.

Expected impact of hybrid system approach

The use of hybrid models and hybrid control design should allow us to get a better performance than existing non-hybrid models and controllers. Furthermore, the hybrid MPC control design techniques are structured and generic, in contrast to many of the currently used control design techniques in the field which are often ad-hoc or heuristics-based.

Industrial collaborations [(5)]

TNO Automotive, Helmond (The Netherlands)

Description of the control problem specification [1]

We consider adaptive cruise control with speed tracking and distance keeping as the control objectives. The control objective also contains a penalty term on the input energy (related to e.g. fuel consumption) and on the changes in the input signal (related to a.o. passenger and driver comfort and reduction of wear). Additional constraints are e.g. maximal acceleration or deceleration.

Description of the adopted hybrid design methodology [2]

We apply various model predictive control (MPC) techniques designed for piecewise affine (PWA), mixed logical dynamic (MLD), and max-min-plus-scaling (MMPS) systems. We consider both on-line and explicit MPC. In the latter approach part of the work is already done on beforehand using off-line computations.

Improvements with respect to non-hybrid control algorithms [3]

1) performances

Better than or comparable to conventional approaches. Main advantage is that hybrid MPC approach offers a structured and generic control design approach.

2) robustness

Still under investigation. Note that for this topic robust hybrid MPC approaches have to be used.

3) number of calibration parameters and complexity of the calibration process

In principle the same as in conventional MPC. However, due to complexity issues the control and prediction horizons should not be chosen too large.

4) implementation requirements (memory, computation resources, sampling frequency, etc)

The implicit, on-line approach suffers from combinatorial explosion if larger control and prediction horizons are used. Off-line approach addresses this issue partly (at the cost of increased memory usage) and is currently being assessed.

Reports and papers

I. Necoara, B. De Schutter, T.J.J. van den Boom, and J. Hellendoorn, “Robustly stabilizing MPC for perturbed PWL systems,” in Proceedings of the 44th IEEE Conference on Decision and Control, and the European Control Conference 2005 (CDC-ECC'05), Seville, Spain, pp. 3759-3764, Dec. 2005.

D. Corona, M. Lazar, B. De Schutter, and M. Heemels, "A hybrid MPC approach to the design of a Smart adaptive cruise controller,” Tech. rep., Delft Center for Systems and Control, Delft University of Technology, Feb. 2006. Submitted to a conference.

D. Corona, I. Necoara, B. De Schutter, and T.J.J. van den Boom, "Robust hybrid MPC applied to the design of an adaptive cruise controller for a road vehicle," Tech. rep., Delft Center for Systems and Control, Delft University of Technology, Mar. 2006. Submitted to a conference.