SEVENTH FRAMEWORK PROGRAMME
THEME – ICT
[Information and Communication Technologies]

Contract Number:	223854
Project Title:	Hierarchical and Distributed Model Predictive Control Large-Scale Systems
Project Acronym:	HD-MPC

Deliverable Number:	D8.2.1
Deliverable Type:	Report
Contractual Date of Delivery:	01/03/2010
Actual Date of Delivery:	**20/02/2010**
Title of Deliverable:	**Report on or proceedings of a special session at an international conference**
Dissemination level:	Public
Workpackage contributing to the Deliverable:	WP8
WP Leader:	Moritz Diehl
Partners:	TUD, EDF, KUL, POLIMI, RWTH, USE, UNC, SUPELEC, INOCSA
Author(s):	Atilla Kozma, Carlo Savorgnan, Rudy Negenborn, Bart De Schutter

Table of contents

Project co-ordinator

Name: Bart De Schutter
Address: Delft Center for Systems and Control
Delft University of Technology
Mekelweg 2, 2628 Delft, The Netherlands
Phone Number: +31-15-2785113
Fax Number: +31-15-2786679
E-mail: b.deschutter@tudelft.nl

Project web site: `http://www.ict-hd-mpc.eu`

Executive Summary

In this deliverable we report on the two invited sessions on Hierarchical and Distributed Model Predictive Control at international conferences organized by the project partners:

- invited session on *"Optimization Methods for Hierarchical and Distributed Model Predictive Control"* at the 14th Belgian-French-German Conference on Optimization (BFG'09), Leuven, Belgium, September 14–18, 2009, and
- invited session on *"Hierarchical and Distributed Model Predictive Control"* at the 2010 American Control Conference (ACC 2010), Baltimore, Maryland, USA, June 30–July 2, 2010.

Chapter 1

Invited session at BFG'09

The BFG'09 conference was the 14th of the series of French-German meetings which started in Oberwolfach in 1980. In September 2009, it was organized jointly with the Belgian optimization community, and took place in Leuven, Belgium. The conference consisted of 12 invited plenary talks, parallel contributed sessions, mini-symposia, and a poster session. It addressed all aspects of optimization and its applications.

1.1 Invited session on "Optimization Methods for Hierarchical and Distributed Model Predictive Control"

Tamás Keviczky (TUD) and Rudy Negenborn (TUD) have organized an invited session on "Optimization Methods for Hierarchical and Distributed Model Predictive Control". The session consisted of the following contributions:

- Using adjoint variables for decomposition of MPC controllers

  A. Rantzer, Lund University
  P. Giselsson, Lund University
  K. Mårtensson, Lund University

- On distributed, optimization-based control of discrete-time nonlinear systems

  A. Jokic, Eindhoven Univ. of Tech.
  M. Lazar, Eindhoven Univ. of Tech.

- Hydro power valley control: Decomposition coordination methods

  J. Zarate Florez, INPG/Gipsa-Lab and EDF
  D. Faille, EDF
  G. Besancon, INPG/Gipsa-Lab
  J. M. Molina, INPG/Gipsa-Lab

- An iterative approach for distributed model predictive control of irrigation canals

  D. Doan, Delft Univ. of Tech.
  T. Keviczky, Delft Univ. of Tech.
  R. R. Negenborn, Delft Univ. of Tech.
  B. De Schutter, Delft Univ. of Tech.

1.2 Conference proceedings

The organizing committee of the conference agreed with Springer Verlag about the publication of an edited volume titled "Recent Advances in Optimization and its Applications in Engineering". The conference participants submitted their contributions which are currently under the review process. The edited volume with the conference proceedings is expected to appear by the end of 2010.

1.3 Abstracts of the presentations

Using adjoint variables for decomposition of MPC controllers

A. Rantzer, Lund University
P. Giselsson, Lund University
K. Mårtensson, Lund University

Introduction Dual decomposition has been used in large-scale optimization since the early 1960s. Decomposition was applied to linear quadratic optimal control in [4] and more general methods for decomposition and coordination of dynamic systems were introduced in [2,1]. The purpose of this paper is to investigate how the same methods can be used for analysis and synthesis of distributed feedback controllers.

In our previous paper [3], we used dual decomposition for distributed performance validation and synthesis of feedback controllers in a linear-quadratic setting. In this presentation, the same idea is applied in the context of Model Predictive Control.

Dynamic dual decomposition Consider an optimal control problem involving J nodes

$$\min_u \sum_{t=1}^{T} \sum_{i=1}^{J} l_i\left(x_i(t), u_i(t)\right) \tag{1.1}$$

with minimization over control sequences $u_i(t)$ and solutions $x_i(t)$ to the state equations

$$x_i(t+1) = \sum_{i=1}^{J} A_{ij} x_j(t) + B_i u_i(t) \tag{1.2}$$

where $i = 1, \dots, J$ The problem has an associated graph, with one node for every i and an edge connecting j and i if and only if A_{ij} and A_{ji} are not both zero.
To decompose this problem, we write the state equations as

$$x_i(t+1) = A_{ii} x_i(t) + B_i u_i(t) + v_i(t) \tag{1.3}$$

with additional constraints that $v_i(t) = \sum_{j \neq i} A_{ij} x_j(t)$.
The constraints are then relaxed by introduction of corresponding Lagrange multipliers in the cost function:

$$\max_p \min_{u,v} \sum_{t=1}^{T} \sum_{i=1}^{J} \left[l_i(x_i, u_i) + 2 p_i^T \left(v_i - \sum_{j \neq i} A_{ij} x_j \right) \right] \tag{1.4}$$

$$= \max_p \sum_i \min_{u_i, v_i} \sum_{t=1}^{T} \left[l_i(x_i, u_i) + 2 p_i^T v_i - 2 \left(\sum_{j \neq i} p_j^T A_{ji} \right) x_i \right] \tag{1.5}$$

The introduction of dual variables decomposes the optimization problem into separate criteria for every node in the graph. The objective of the agent in node i is to minimize

$$\sum_{t=1}^{T}\left[l_i(x_i,u_i)+2p_i^T v_i-2\left(\sum_{j\neq i}p_j^T A_{ji}\right)x_i\right] \tag{1.6}$$

It can be verified that the optimal prices $p_i(t)$ are must satisfy the adjoint equations of the discrete time Maximum Principle.

Decomposition of MPC controllers The basic idea of Model Predictive Control is to solve an optimal control problem repeatedly over a finite but moving time horizon. This gives a sequence of optimization problems, where the change from one to the next is relatively small. Hence the solution to one problem often gives a good starting point in the search for a solution of the next.
In this presentation, we will use dual decomposition in the context of MPC. Once the price variables p_i are fixed, the optimization of u_i and v_i can by done by each agent i separately. Furthermore, the price variables can be expected to be similar from oneMPC iteration to the next. Hence, prices are updated by a gradient step in each iteration.
The presentation will include examples as well as some theoretical analysis.

References

[1] G. Cohen. Auxiliary problem principle and decomposition of optimization problems. Journal of Optimization Theory and Applications, 32(3), November 1980.

[2] M. D. Mesarovic, D. Macko, and Y. Takahara. Theory of Hierarchical Multilevel Systems. Academic Press, New York, 1970.

[3] A. Rantzer. Dynamic dual decomposition for distributed control. In Proceedings of American Control Conference, St. Louis, June 2009.

[4] Y. Takahara. Multilevel approach to dynamic optimization. Technical Report SRC-50-C-64-18, Case Western Reserve, Cleveland, Ohio, 1964.

On distributed, optimization-based control of discrete-time nonlinear systems

A. Jokic, Eindhoven Univ. of Tech.
M. Lazar, Eindhoven Univ. of Tech.

Abstract Over the past few years there has been a rapidly growing interest in the systems and control community in the study of networked dynamical systems. Examples of such systems include electrical power networks, formation flight of unmanned aerial vehicles, automated highways, control of communication networks and smart structures, to name just a few. The fundamental characteristics of these systems, such as coupling between local system dynamics or performance objectives, uncertainties and communication constraints, require a theory for synthesizing control laws able to cope with predefined physical and information constraints. In this context, prominent examples of constraints on the structure of control algorithms are the ones arising from decentralized and distributed implementation structures. The term decentralized is commonly used to denote a set of controllers which operate with no mutual exchange of information, while the term distributed assumes that the controllers share information over a specific communication network with a predefined and usually sparse structure.

In this talk we present a new approach to stabilization and optimal control of interconnected discrete-time nonlinear systems under given, arbitrary information constraints on the controller structure. The central ingredient of the developed results is the concept of a set of structured control Lyapunov functions (CLFs), which was recently introduced in [1]. Structured CLFs are closely related to the theory of dissipative dynamical systems and are suited to accommodate stabilizing controller synthesis under various information constraints. A set of structured CLFs is defined as a set of positive definite functions, with each of these functions depending only of the state vector of its corresponding local system and satisfying certain coupling conditions. Although neither of these functions is required to be a CLF for its corresponding local system, it is proven that the coupling conditions guarantee a global CLF, i.e. a CLF for the overall interconnected system.

Based on the notion of structured CLFs, we show how to construct a convex optimization problem such that any of its feasible solutions provides a stabilizing control action for the interconnected system. By including a convex performance criterion, optimal control problem is formulated in terms of a structured convex optimization problem. This optimization problem is characterized with one scalar valued global inequality constraint, and a set of local objective functions and local constraints. When the global inequality constraint is omitted, the optimization problem is separable and can be solved in a completely decentralized way. The global constraint originates from the definition of structured CLFs and is instrumental in ensuring overall system stability. We present how using dual decomposition techniques, the corresponding structured optimization problem can be solved under various information constraints. As a consequence, we present optimization-based control algorithms which accommodate decentralized control, decentralized control with global coordination, and distributed control over communication network with an arbitrary, possibly time varying, interconnection graph.

References

[1] A. Jokic, M. Lazar, “On Decentralized Stabilization of Discrete-Time Nonlinear Systems,” American Control Conference, St. Louis, USA, June 2009.

Hydro power valley control: Decomposition/Coordination methods

J. Zarate Florez, INPG/Gipsa-Lab and EDF
D. Faille, EDF
G. Besancon, INPG/Gipsa-Lab
J. M. Molina, INPG/Gipsa-Lab

Introduction Hydro-power valleys can be considered as (large scale) plants that provide CO_2-free power with good manoeuvrability capabilities. These plants are however submitted to the other ecological or process constraints, and they are made of various interconnected hydroelectric production units.
In view of the institutional and society evolution, hydroelectric production recovers consideration for its flexibility, and the EDF French group gradually engages the improvement of hydroelectric plants it manages, by taking into account the overall optimization problem. Today indeed, most of the plants are controlled by decentralized power and level PID control with references determined by off-line optimization.
In order to improve the efficiency of the whole hydro-power valley instead, an on-line optimal control with HD-MPC solution is studied. In the present work, some corresponding optimization problem formulation as well as possible use of so-called decomposition/coordination methods [1] will be discussed.
More precisely, those formulation and discussion will be based on a case study chosen to be relevant to a real application. This case study is briefly depicted in next section, while the decomposition methods under study are recalled in the section after.

Case study description We are interested in a hydro power valley that globally consists of a cascade run-of-river plants and storage lakes. For the present work, a simplified version of this hydro power valley with few reaches and lakes [4, 5] will be considered. This system is controlled by a hierarchical control, with local (PLC) controllers used to regulate the level and power of each plants. Our purpose is to propose and develop a higher level strategy to be implemented in the control center (DCS) that controls the whole valley.

Decomposition Decomposition/coordination methods consist in dividing an optimization problem into several subproblems, which are to be coordinated so as to get the overall optimization. Various approaches can be considered [1]:

Price decomposition: The coordination sends a price vector (associated to the constraints) to the plants, and each of these subsystems minimizes a cost function that depends on those prices [2].

Quantity decomposition: The coordination manages the constraints and sends the production set-points to the subsystems. Each subsystem minimizes its production cost and sends a price to the coordination. This approach is dual of the price one.

Prediction decomposition: Each subsystem deals with part of the coupling constraints and sends to the other ones a price associated with these constraints, and every subsystem takes into account the prices associated with the constraints that it does not treat [3].

Cascade decomposition: Two loop levels can be considered, a fast loop that regulates the variables around the set-points and manages the physical constraints, and an optimization loop that computes the set-points.

The purpose of the present work is to discuss the possible formulation of a global control optimization problem in the considered case of hydro power valley, in the spirit of the decomposition methods here above recalled.

References

[1] G. Cohen. Optimization with an auxiliary constraint and decomposition. SIAM Journal on control and optimization, 28(1):137-157, January 1990.

[2] A. Rantzer. Dynamic Dual decomposition for Distributed Control. To appear at American Control Conference. 2009.

[3] M. Jamshidi. Large-Scale Systems: Modeling and Control. Elsevier Science Ltd. 1983.

[4] M. v. Siebenthal and G. Glanzmann. Supervisory water level control for cascaded river power plants. Masters thesis, Automatic Control Laboratory, ETH Zurich,2004.

[5] C. Setz, A. Heinrich, P. Rostalski, G. Papafotiou, M. Morari. Application of Model Predictive Control to a cascade of river power plants. Proceedings of the 17th World Congress. The International Federation of Automatic Control. Seoul, Korea, July 6–11, 2008.

An Iterative Approach for Distributed Model Predictive Control of Irrigation Canals

D. Doan, Delft Univ. of Tech.
T. Keviczky, Delft Univ. of Tech.
R. R. Negenborn, Delft Univ. of Tech.
B. De Schutter, Delft Univ. of Tech.

Introduction Optimization techniques have played a fundamental role in designing automatic control systems for the most part of the past half century. This dependence is ever more obvious in todays wide-spread use of online optimization-based control methods, such as Model Predictive Control (MPC) [1]. The ability to capture process constraints and characterize comprehensive economic objective functions has made MPC the industry standard for controlling complex systems.
However, the growing size and geographical spread of these systems is reaching unprecedented levels, which makes the traditional centralized control paradigm inefficient and sometimes even infeasible. Cost-effective and reliable operation of such systems requires a more pragmatic control approach relying on distributed control techniques. These methods strive for a division of the optimization task into problems of smaller size, which involve only a subset of the global variables in order to tackle the computational complexity and respect operational constraints in a large-scale optimal control problem. This is achieved by a trade-off between information exchange among local controllers and the complexity of their local computations.

Distributed version of Han's method In order to address the challenges raised by distributed control using online optimization-based approaches, we have recently developed a distributed version of Hans parallel method for convex optimization [2]. This method aims to define local controllers for dynamically coupled subsystems that share coupling constraints and minimize a separable objective function. Relying on the decomposition of the dual optimization problem such that local problems have analytical solutions, the algorithm uses an iterative update procedure that converges asymptotically to the global optimizer of the primal problem. The solution approach allows each controller to work in parallel and exchange information only with a small number of other controllers. The control solution obtained in a distributed way converges to a globally optimal control sequence. Repeating the iterative solution procedure based on new measurements leads to a Distributed Model Predictive Control (DMPC) approach.

DMPC of irrigation canals In this paperwe illustrate the application of the novelDMPC approach on the control of a system of irrigation canals. Irrigation channels are large systems, consisting of many interacting components, and spanning vast geographical areas. For the most safe and efficient operation of these channels, maintaining the levels of the water flows close to prespecified reference values is crucial, both under normal operating conditions as well as in extreme situations. Manipulation of the water flows in irrigation channels is done using devices such as pumps and gates.
The distributed optimization-based control approach is demonstrated on theWest-Mirrigation system [3] composed of 8 canal reaches and on an artificial irrigation network involving 34 reaches to illustrate the scalability of the method. In both simulations, the control objective is to regulate water levels at downstream ends of all reaches, with respect to operational constraints including control input limitations, upper and lower bounds and rates of change of the water levels. The results confirm that the DMPC scheme obtains asymptotic global optimality in a distributed way.

References

[1] J. Maciejowski, Predictive Control with Constraints, Prentice Hall, 2000.

[2] D. Doan, T. Keviczky, I. Necoara, M. Diehl, and B. De Schutter, “A Distributed Version of Hans Method for DMPC of Dynamically Coupled Systems with Coupled Constraints,” submitted to NecSys09 conference, 2009.

[3] A.J. Clemmens, T.F. Kacerek, B. Grawitz, and W. Schuurmans, “Test cases for canal control algorithms,” Journal of Irrigation and Drainage Engineering, vol. 124, no. 1, pp. 23–30, January 1998.

Chapter 2

Invited session at ACC 2010

The ACC is the annual conference of the American Automatic Control Council (AACC). AACC is the U.S. national member organization of the International Federation for Automatic Control (IFAC). The 2010 ACC, held in cooperation with IFAC, will present a technical program consisting of new developments in theory and practice in the area of automatic control. The technical program will consist of papers in regular technical sessions, invited sessions, special sessions, and pre-conference tutorial/workshop sessions. The 2010 ACC will be held in Baltimore (Maryland), June 30–July 2, 2010.

2.1 Invited session on "Hierarchical and Distributed Model Predictive Control"

Bart De Schutter (TUD), Rudy Negenborn (TUD), and Moritz Diehl (KUL) have organized an invited session on "Hierarchical and Distributed Model Predictive Control". In this invited session new approaches for hierarchical and distributed model predictive control of large-scale systems are proposed. These include not only decomposition and coordination schemes for control of large-scale linear and nonlinear systems, but also novel results to the distributed state estimation problem. Applications to control problems from the domains of the process industry, water networks, and power grids illustrate the potential of such approaches. The accepted papers that will be presented during the session are:

- Almost decentralized Lyapunov-based nonlinear model predictive control

  R.M. Hermans, Eindhoven Univ. of Tech.
  M. Lazar, Eindhoven Univ. of Tech.
  A. Jokic, Eindhoven Univ. of Tech.

- Decentralized robust control invariance for a network of integrators

  M. Baric, Univ. of California at Berkeley
  F. Borrelli, Univ. of California at Berkeley

- Distributed hierarchical MPC for conflict resolution in air traffic control

  G. Chaloulos, ETH Zurich
  P. Hokayem, ETH Zurich
  J. Lygeros, ETH Zurich

- Model predictive control of drinking water networks: A hierarchical and decentralized approach

C. Ocampo-Martinez,	Inst. de Robotica i Informatica Industrial (CSIC-UPC)
V. Fambrini,	Univ. of Siena
D. Barcelli,	Univ. of Siena
V. Puig,	UPC

- Coordination in urban water supply networks using distributed model predictive control

S. Leirens,	Univ. de Los Andes
C. Zamora,	Electrical Engineering
R. Negenborn,	Delft Univ. of Tech.
B. De Schutter,	Delft Univ. of Tech.

- Hierarchical cooperative distributed model predictive control

B.T. Stewart,	Univ.of Wisconsin-Madison
J.B. Rawlings,	Univ. of Wisconsin-Madison
S.J. Wright,	Univ. of Wisconsin-Madison

In addition to the papers above we also organized a second special session that was unfortunately not accepted in its totality. The accepted papers of this second special session are:

- State estimation for large-scale partitioned systems: a moving horizon approach

M. Farina,	Pol. di Milano
G. Ferrari-Trecate,	Univ. degli Studi di Pavia
R. Scattolini,	Pol. di Milano

- Nonlinear distributed dynamic optimization based on first order sensitivities

H. Scheu,	RWTH Aachen
J. Busch,	BTS
W. Marquardt,	RWTH Aachen

2.2 Conference proceedings

The papers presented at the 2010 American Control Conference will be included in the electronic conference proceedings and in the IEEE database IEEE-XPLORE (`http://ieeexplore.ieee.org`).

2.3 Abstracts of the presentations

Almost decentralized Lyapunov-based nonlinear model predictive control

R.M. Hermans, Eindhoven Univ. of Tech.
M. Lazar, Eindhoven Univ. of Tech.
A. Jokic, Eindhoven Univ. of Tech.

This paper proposes a novel “almost decentralized” solution to the problem of stabilization of a network of discrete-time nonlinear systems with coupled dynamics that are subject to local state/input constraints. By “almost decentralized” we mean that each local controller is allowed to use the states of neighboring systems for feedback, but it is not permitted to employ iterations between the systems in the network to compute the control action. The controller synthesis method used in this work is Lyapunov-based model predictive control (MPC). The stabilization conditions are decentralized via a set of structured control Lyapunov functions (CLFs) for which the maximum over all the functions in the set is a CLF for the global network of systems. However, this does not necessarily imply that each function is a local CLF for its corresponding system. Additionally, we provide a solution for relaxing the temporal monotonicity of the global CLF. For structured CLFs defined using the infinity norm, we show that the decentralized MPC algorithm can be implemented by solving a single linear program in each network node. A non-trivial example illustrates the effectiveness of the developed theory and shows that our method can perform as well as more complex distributed, iteration-based MPC algorithms.

Decentralized robust control invariance for a network of integrators

M. Baric, Univ. of California at Berkeley
F. Borrelli, Univ. of California at Berkeley

Robust control of networked storage devices is considered. Each storage device is modeled as single-state, discrete time integrator with bounded control input and subject to additive bounded disturbance. Nodes exchange matter through links of limited capacity. We characterize the maximal robust control invariant set and consider a decentralized solution to the robust feasibility problem. We show how to compute the set of link capacities ensuring the feasibility of the proposed decentralized design by using convex optimization. The results allow to ensure persistent feasibility when a decentralized Model Predictive Control scheme is used to robustly control the network flow while satisfying input and state constraints.

Distributed hierarchical MPC for conflict resolution in air traffic control

G. Chaloulos, ETH Zurich
P. Hokayem, ETH Zurich
J. Lygeros, ETH Zurich

We present a decentralized Model Predictive Control scheme for hierarchical systems to tackle the collision avoidance problem for autonomous aircraft in an air traffic control setting. Using a low level controller, the aircraft dynamic equations are abstracted to simpler unicycle kinematic equations. The navigation function methodology is then used to generate conflict free trajectories for all aircraft. To ensure that the resulting trajectories respect the aerodynamic constraints of the aircraft, a decentralized model predictive controller is added at a higher level, to provide preview to the otherwise myopic navigation functions. The overall hierarchical, distributed control scheme has the same feasibility properties as the corresponding centralized problem. Its performance is demonstrated by simulations of dense air traffic scenarios.

Model predictive control of drinking water networks: A hierarchical and decentralized approach

C. Ocampo-Martinez, Inst. de Robotica i Informatica Industrial (CSIC-UPC)
V. Fambrini, Univ. of Siena
D. Barcelli, Univ. of Siena
V. Puig, UPC

In this paper, a decentralized model predictive control (DMPC) strategy for drinking water networks (DWN) is proposed. The DWN is partitioned in a set of subnetworks using a partitioning algorithm that makes use of the topology of the network, the information about the actuator usage and heuristics. A suboptimal DMPC strategy was derived that allows the hierarchical solution of the set of MPC controllers used to control each partition. A comparative study between the CMPC and DMPC approaches is developed on the case study, which consists in an aggregate version of the Barcelona DWN. Results have shown the effectiveness of the proposed DMPC approach in terms of the computation time while an admissible level of suboptimality is obtained in all the considered scenarios.

Coordination in urban water supply networks using distributed model predictive control

S. Leirens, Univ. de Los Andes
C. Zamora, Electrical Engineering
R. Negenborn, Delft Univ. of Tech.
B. De Schutter, Delft Univ. of Tech.

Urban water supply networks are large-scale systems that transport potable water over vast geographical areas to millions of consumers. A safe and efficient operation of these networks is crucial, as without it living in today's cities would be impossible. To achieve an adequate operation, these networks are equipped with actuators like pumps and valves, which are used to maintain water pressures and flows within safe margins. Currently, these actuators are controlled in a decentralized way using local controllers that only use local information and do not take into account the presence of other controllers. As a result, water supply networks experience pressure drops and interruptions of water supply when there is an unexpected increase in water demand. To improve performance the actions of the local controllers should be coordinated. Implementing a centralized control scheme is not tractable due to the large-scale nature of these networks. Therefore, this paper proposes the application of a distributed control scheme for control of urban water supply networks. The scheme is based on local model predictive control (MPC) strategies and a parallel coordination scheme that implements cooperation among the local MPC controllers. A simulation study based on a part of the urban water supply network of Bogotá, the capital of Colombia, illustrates the potential of the approach.

Hierarchical cooperative distributed model predictive control

B.T. Stewart, Univ.̇of Wisconsin-Madison
J.B. Rawlings, Univ. of Wisconsin-Madison

S.J. Wright, Univ. of Wisconsin-Madison

Cooperative distributed model predictive control has recently been shown to provide stabilizing feedback for plants composed of any finite number of dynamically coupled subsystems. The only assumptions made about the plant is that it is stabilizable and does not contain coupling constraints. In particular, no assumption is made about the strength of the coupling between the subsystems. This control scheme provides optimal feedback in the limit of infinite optimization iterates. Yet it can be terminated before convergence of the iterates and guarantee feasibility and stability. These properties, however, require communication between all subsystems in the plant at every iterate. In this paper, we weaken this requirement and propose an extension in which the subsystems are grouped in a hierarchy. The subsystems communicate with their neighbors at every iterate, but communicate with subsystems outside their neighborhood on a slower and asynchronous time schedule. We show that this extension is plantwide stabilizing. We introduce a method to modify the information sent between neighborhoods in order to reduce the volume of communication and to hide input trajectories between neighborhoods. To achieve these properties, the leader of each subsystem performs a minor additional calculation at each plantwide information exchange. We conclude with an example demonstrating control performance in a chemical plant.

State estimation for large-scale partitioned systems: a moving horizon approach

M. Farina, Pol. di Milano
G. Ferrari-Trecate, Univ. degli Studi di Pavia
R. Scattolini, Pol. di Milano

In this paper we propose novel state estimation methods for large-scale discrete-time constrained linear systems that are partitioned, i.e. made by coupled subsystems with non-overlapping states. We focus on Moving Horizon Estimation (MHE) schemes due to their capability of exploiting physical constraints on states and noise in the estimation process. We propose three different Partition-based MHE (PMHE) algorithms where each subsystem solves reduced-order MHE problems to estimate its own state. Different estimators have different computational complexity, accuracy and transmission requirements among subsystems. Numerical simulations demonstrate the viability of our approach.

Nonlinear distributed dynamic optimization based on first order sensitivities

H. Scheu, RWTH Aachen
J. Busch, BTS
W. Marquardt, RWTH Aachen

A method for the distributed optimization of dynamic nonlinear systems is presented. The method is based on partial goal-interaction operators. Partial goal-interaction operators provide gradient information of non-local objective functions. Hence, these operators are used to modify the objective functions of infimal optimization problems in order to take non-local information into account and to achieve an optimum for the overall objective, i.e. the objective of the entire process. However, that optimum is achieved by a decentralized but cooperative optimization, while communication between the different infimal optimization units is limited. An important part of the method is the decentralized calculation of sensitivities. The method is applied to a nonlinear differential-algebraic simple-toy system and compared to the dual-optimization method as well as to the solutions of fully centralized and fully decentralized optimizations.