HD-MPC

Hierarchical and Distributed Model Predictive Control of Large-Scale Systems

A World of Large Interconnected Systems

Much of the modern world is characterized by large interconnected systems, such as the internet, traffic, electricity, or river networks, and large industrial manufacturing sites. These systems are composed of multiple subsystems that mutually influence each other, such that local decisions may have long-range effects throughout the entire system. But how can these large interconnected systems be operated in an optimal way? Controlling each subsystem independently, in a decentralized way, is rarely optimal and might even lead to instability. With standard techniques, controlling the whole system in a centralized fashion is not possible either, due to the tremendous computational complexity of the centralized control task. What can be done?

FP7 STREP project

HD-MPC - Hierarchical and distributed model predictive control of large-scale systems

Contract number

INFSO-ICT-223854

Project website

www.ict-hd-mpc.eu

Community contribution to the project

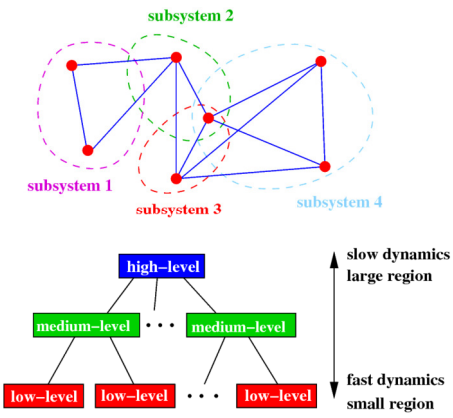
2000000 Euro

Period

Sept. 1, 2008-Dec. 31, 2011

Approach of the HD-MPC Project

The HD-MPC project has developed new methods for control of large-scale systems that are based on the principle of model-based predictive control (MPC). MPC uses a mathematical model of the system in order to predict and to optimize its future behavior. MPC is a well-known control technique for constrained systems with multiple inputs and multiple outputs and ideally solves a centralized optimization problem in each sampling time. For large interconnected systems the solution of this centralized MPC problem has not been possible with standard methods. The idea of the HD-MPC project has been to exploit both hierarchical as well as distributed algorithmic approaches to address the large MPC problem and render its solution possible even for extremely large interconnected systems. The building blocks of the HD-MPC architecture are optimization, control, and estimation methods that are highly parallelizable, keep calculations and decisions on a local level as much as possible, and scale well with the system.



A collection of new methods and results that are based on the HD-MPC approach have has been published in the special issue of the *Journal of Process Control* on HD-MPC (vol. 21, no. 5, June 2011).

Main Results

The HD-MPC project has focused on distributed control, hierarchical control, and distributed estimation.

New *distributed control methods* have been rigorously developed and successfully tested at the industrial benchmark problems as well as in a number of real world and simulation examples. They guarantee strong theoretical convergence properties and are based on two complementary principles:

- distribution of the optimization task among multiple subsystems to allow for an efficient decomposition of large-scale optimal control problems; these algorithms have been developed according to sensitivity-based coordination and distributed multiple shooting approaches;
- design of a set of local controllers requiring only limited inter-communication and relying on the predicted future evolution of the neighbors; the underlying approaches are based on game-theoretical formulations and robust control results.

Hierarchical control has been considered to deal with typical industrial control situations where multi-level structures are used with different goals (local low-level control of actuators, control of the process units, overall plant optimization). Within the framework of hierarchical control, a number of structures and design algorithms with strong theoretical basis have been developed and applied to road traffic networks and baggage handling systems. The possibility to resort to flexible control structures, where actuators can be added, removed or replaced has also been investigated and significant results have been achieved.

New *distributed state estimation methods* based on the moving horizon approach and with guaranteed convergence properties have also been developed. They can incorporate constraints on the values of the variables to be estimated. These algorithms deal with the following problems:

- estimation of the whole state of the system made by a number of sensors that can communicate with their neighbors in order to reach a global consensus on their state estimate. This problem arises in large sensor networks where communications among the sensors are limited by energy constraints;
- design of a set of local estimators, each one in charge of estimating the state of a subsystem and communicating it to its neighbors. This is the case of large plants where the state of each process unit can be locally estimated also based on the estimated states of the units connected to it.

Demonstration on Three Benchmark Problems

In addition to performing fundamental research on hierarchical and distributed control of large-scale systems the HD-MPC project concentrated on three applications that were formulated by the industrial partners in the consortium: combined cycle power plants, hydro-power valley operations, both operated by EdF, and water capture systems, operated by INOCSA. Moreover, the HD-MPC methods have also been applied to freeway and urban traffic networks, surface water networks, and baggage handling systems.



Impact and Benefits

The HD-MPC project has considerably widened the domain, in terms of system size, of large-scale control problems that can be addressed with Model Predictive Control (MPC) techniques by developing new methods and algorithms for distributed estimation, optimization, and control. All methods have been rigorously and successfully tested at the industrial benchmark problems.

Dissemination

The HD-MPC project has resulted in a special issue of the *Journal of Process Control* on HD-MPC (vol. 21, no. 5, June 2011), as well as more than 35 international journal papers, 7 contributions to books, and about 100 international conference papers. In addition, two dedicated HD-MPC workshops have been organized in Leuven, Belgium (June 2011) and in Milano, Italy (August 2011). More details on these activities can be found at the project's web site: http://www.ict-hd-mpc.eu.

Main achievements

We have developed several new approaches for hierarchical and distributed model predictive control (MPC) for large-scale systems, as well as novel distributed optimization and estimation methods for MPC. The effectiveness of the methods has been demonstrated on a four-tank set-up and a hydropower valley case study, as well as three industrial applications: combined cycle power plants, hydro-power valley operations, and water capture systems.

Project partners	Country
Delft University of Technology	NL
Electricité de France SA	FR
Katholieke Universiteit Leuven	BE
Politecnico di Milano	IT
RWTH Aachen	DE
Universidad de Sevilla	ES
Universidad Nacional de Colombia	CO
Ecole Supérieure d'Electricité	FR
Inocsa Ingeniería S.L.	ES
University of Wisconsin-Madison (cooperation partner)	USA