Model Predictive Control: Ideas for the Next Generation

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[Based on work jointly with Alberto Bemporad, Domenico Mignone and Giancarlo Ferrari Trecate]

EXTENDED ABSTRACT

Over the last decade Model Predictive Control (MPC) has emerged as the standard for multivariable control in the process industries. Its ability to handle large complex systems involving hundreds of controlled and manipulated variables, dynamic interactions, time delays and constraints make it an attractive tool for many challenging control tasks.

In this presentation we will point out several clearly discernible trends which point toward an extended need for new techniques to design control and supervisory schemes. We will show how this need can be met by a new generation of Model Predictive Controllers.

First, there has been the trend for Programmable Logic Controllers (PLC) and Digital Control Systems (DCS) to approach each other in terms of functionality and the underlying hardware. In the 1970s the microprocessor based PLCs started to replace panels of fixed wired relays as a means to implement sequence control. Somewhat later DCSs pushed out fixed wired analog control panels for continuous control tasks, e.g. PID control and its advanced variants. With the cost of computing power falling rapidly, the hardware capabilities of DCSs and PLCs are expected to become indistinguishable in the next decade. To take full advantage of this confluence, tools are needed to tackle the combination of sequence, logic and continuous control tasks in a transparent and efficient manner.

Second, the traditional layers of the control hierarchy (measurements, regulatory control, supervisory control / real time optimization, scheduling and planning) have shown a tendency to merge and the clear boundaries which once existed have disappeared. As an example for this trend note that the historically separate functions of single loop control, anti-windup to deal with constraints, decoupling to remove multivariable interactions, time-delay compensation, and finally supervisory optimization have all been merged into the MPC layer which is closely coupled to the real time optimization functions. The historical reasons for this hierarchy were the different types of information and models used to arrive at the decisions in the various layers and the enormous complexity of the overall task. These reasons are becoming obsolete because of the explosion of computing power and the revolution in information technology.

The declared aim of the control system vendors is to push into the upper layers of the control hierarchy and to provide an integrated solution to Enterprise Resource Planning (ERP) by optimizing the complete supply chain. As a consequence of the integration and the tighter coupling of the various layers the effects of feedback are becoming noticeable in the higher scheduling and planning layers and can no longer be neglected. On the other hand, as the lower regulatory layers take on some of the higher level scheduling and planning tasks, they need to make discrete decisions based on criteria involving logical statements and qualitative knowledge. To make this confluence of the different layers possible new modelling tools are needed which can describe such systems in a unified manner and thus provide the information to allow the control system to make appropriate decisions for such "hybrid" systems.

In summary, the rapid advances in computer and information technology are enabling the closer integration of the various decision and control tasks which were traditionally distributed among a broad set of decision makers ranging from PLCs at the lowest level to planning and scheduling departments at the highest level. This integration should eventually lead to a smoother, more responsive and more competitive functioning of the entire organization. It requires the development of new modelling tools for such large complex systems involving continuous and discrete states whose behavior is governed by dynamics, logical statements and constraints. The models should facilitate the analysis of such systems and the efficient determination of optimal operating strategies.

At the center of this new framework we envision the class of Mixed Logical Dynamical (MLD) systems. These MLD systems are described by discrete time linear dynamic equations subject to linear inequalities involving real and integer variables. The justification for the MLD form is that it is capable to model a broad class of systems arising in many applications, in particular constrained linear systems, finite state machines, some classes of discrete event systems, and nonlinear systems which can be approximated by piecewise linear functions. More importantly, the MLD form leads to the formulation of various verification, control and estimation problems in terms of Mixed Integer Quadratic Programs (MIQPs), for which efficient algorithms are available. These problems have not been successfully addressed by other tools or only with a much higher computational effort. Specifically, a predictive control scheme is proposed which is able to stabilize MLD systems on desired reference trajectories while fulfilling operating constraints, and possibly take into account previous qualitative knowledge in the form of heuristic rules. Many examples from a variety of fields are used to illustrate the concepts.

In 1994 Manfred Morari was appointed head of the Automatic Control Laboratory at the Swiss Federal Institute of Technology (ETH) in Zurich. Before that he was the McCollum-Corcoran Professor of Chemical Engineering and Executive Officer for Control and Dynamical Systems at the California Institute of Technology. He obtained the diploma from ETH Zurich and the Ph.D. from the University of Minnesota, both in chemical engineering. His interests are in the areas of process control and design. In recognition of his research contributions, he received numerous awards among them, the Donald P. Eckman Award of the Automatic Control Council, the Allan P. Colburn Award and the Professional Progress Award of the AIChE, the Curtis W. McGraw Research Award of the ASEE and was elected to the National Academy of Engineering (U.S.). Professor Morari has held appointments with Exxon R & E and ICI and has consulted internationally for a number of major corporations.

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