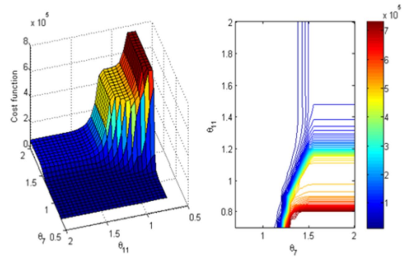

Comparative Analysis of MPC and Advanced Controls

Model Predictive Control (MPC) is a family of controllers that have found wide acceptance in industrial applications and have been studied in depth in academia. In this whitepaper, the reasons for its popularity are analyzed in comparison with other advanced control methodologies. The advances in Nonlinear MPC (NMPC) provide particular advantages with respect to most other Advanced Process Controls, including Dynamic Matrix Control (DMC).

Model Predictive Control

Model Predictive Control (MPC) is an advanced method of process control for multivariable systems that can control a process while satisfying a set of constraints. It has been used in the process industries in chemical plants and oil refineries since the 1980s. In recent years it has been applied in other industrial sectors very successfully. Model predictive controllers depend on the dynamic models of the process, and these may be linear models obtained using system identification. The main advantage of MPC is the fact that it allows the current control to be optimized, while taking account of future predicted behavior. This is achieved by optimizing over a finite time-horizon, but only implementing the current computed control, and then optimizing again, repeatedly. This is different to the Linear-Quadratic Regulator (LQR). The MPC has the ability to anticipate future events whereas PID controllers and most others do not have this ability. It is nearly always implemented as a digital control law and it is often applied on very large systems.

Limits of Related Control Policies

MPC is a modern generalization of many predictive control techniques such as Dynamic Matrix Control (DMC). Early DMC was based on two main assumptions that limit the closed-loop performance of such an algorithm. The first assumption is that a stable step response model can be used to represent a linear plant. The second assumption is to model any difference between the measured and predicted output signals as an external disturbance acting on the “output” variable. Due to these assumptions, different limitations affect DCM policies: (1) good control performance may require an excessive number of step response coefficients; (2) poor performance may be observed from disturbances affecting the plant input; (3) poor robustness may result for multivariable plants with strong interactions.

Points (1) and (2) affect plants with open-loop time constants that are much larger than the required closed-loop time-constant, whereas point (3) is due to gain uncertainty on the input signals. There are different methods to mitigate some problems. For example, reducing truncation errors in the design model development can be considered for the issue in point (1), whereas (2) can involve ad-hoc controller calibration, and (3) can be addressed by increasing controller gains related to disturbance frequencies.

The nonlinear extension of MPC (NMPC) deals with many problems of uncertainty directly, by avoiding some modelling errors. It also now includes further cost-function generalizations and features.

Industrial Systems and Control Ltd.

ISC Ltd. works across industrial sectors and has gained wide experience in a range of applications. It is this peripheral vision which is valuable for automotive companies, which have a complete understanding of current advances in the automotive industry. ISC Ltd. has particular expertise and experience on the following areas and methodologies:

- Physical system modelling and simulation, including training simulators.
- Developing tailored optimal or predictive control solutions for real-world applications.
- Production of bespoke estimation and filtering algorithms for nonlinear control.
- Use of stochastic or robust controls for different industries like wind energy and marine.
- Design of Machine Learning algorithms for industrial and embedded domains.
- Training courses mostly for the manufacturing industries based in the US.

ISC Expertise

- **In-depth understanding of control technologies**
- **Extensive experience in diverse industrial applications**
- **High-fidelity modelling of system behaviour**
- **Expert analysis of complex problems**
- **Proven project management and research skills**

Core Competencies

- **Dynamic modelling & simulation**
- **Control strategy design and implementation**
- **Optimization**
- **Algorithm development**
- **Benefits analysis and technology review**
- **Research & Development**
- **Troubleshooting**
- **Training**

Philosophy

- **Approaching problems with an open mind**
- **Dedicated to identify practical and innovative solutions without compromising performance**
- **Imparting understanding and empowering clients to drive improvements themselves**

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applied control technology consortium

- modelling and simulation
- control design
- system troubleshooting
- technology transfer and training
- energy efficiency investigation
- software tools

industrial systems and control

Modern Model Predictive Control: Features and Recent Developments

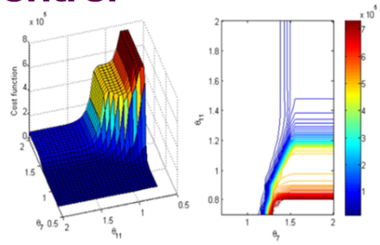
The MPC paradigm is based on the idea that a design model can be used to represent the relationships among system input, state and output variables (the dynamics of the system to be controlled). According to such a model, constraints are defined for limiting input and state variables within logical or physical bounds, and the required performance is expressed according to cost-function to be minimized with respect to control input, control-rate, magnitude, and controlled outputs. A constrained optimal control problem, is solved at each sample time, using a receding horizon approach, over a future prediction horizon.

Recent advances in MPC consider solutions addressing the original problems and exploiting recent technological methods. A common MPC limitation is due to the computational burden. Nowadays, different solutions are available such as the Explicit MPC (E-MPC) methods. Initially presented for Linear Time-Invariant (LTI) models, E-MPC can now be used for controlling linear parameter varying, hybrid or nonlinear and time-varying systems using multi-parametric programming techniques.

In recent years, the MPC framework has been successfully integrated with other design philosophies. Among recent developments, the most interesting is the integration of MPC with modern Machine Learning (ML) techniques, the development of advanced distributed economics MPC policies and the design of computationally efficient solutions proposed for avoiding the suboptimal E-MPC approach. The integration of Artificial Intelligence (AI) and ML methods with MPC can increase the standard MPC performance by adapting the prediction model, changing the controller calibration automatically, or providing estimates of future disturbances acting on the plant.

The recent development of efficient economic MPC designed according to a distributed control approach represents a solution involving the Internet-of-Things (IoT) for the monitoring and control of large sets of subsystems that are hard to manage by a centralized control policy. Distributed economic MPC can split the centralized control problem into several smaller MPC problems to be solved locally, and operating in parallel for minimizing the economic cost of the overall distributed system. This approach can define a distributed controller that is easily customized to changes in the system, such that changes in the plant can be accommodated by the controller with the changes affecting only the local MPC.

The development of efficient MPC solutions, able to reduce the computational complexity has recently considered advanced optimization algorithms (solvers). These methods exploit advanced mathematical concepts to compute the MPC optimization problem solution. This can avoid the use of E-MPC, neglecting the loss of performance related to the off-line computation of the explicit control law, increasing disturbance rejection capabilities and accommodating common MPC features (e.g. anticipative action or on-line tuning). The most significant advances have probably been in nonlinear MPC that tackles the nonlinearities in the system directly that can provide a significant performance benefit.



Service Examples

Modelling and Simulation

- Main Oil Line Pump Instability
- CHP Steam Pressure Improvement
- Nuclear Power Plant Modelling

System Troubleshooting

- Compressor Train Frequent Trips
- Steam Raising Boilers Operational Issues
- Evaporation Tower Level Instability

Control Design

- Paper Mill pH Control
- Automotive Energy Control
- Offshore Oil Processing
- Ship Stabilization and Control
- Heave Compensation on Survey Vessel

Technology

- Review of Valve Technologies for Offshore Oil Applications
- Multivariable and Model-Based Mill Controls
- Bespoke Nonlinear Sensor Compensation
- Offshore Wind Farm Strategies
- Control Performance Assessment

Training

- Control Fundamentals
- Introduction to Process Control
- Predictive Control
- Optimization and System Identification
- Process Control Academy

"Approaching a problem with an open mind is an important aspect of ISC philosophy, as is using the simplest, most cost-effective solution"

ISC Expertise in Control and Optimization

Over the last 2 decades ISC Ltd has been involved in a number of research and development projects with both universities and companies. The development of advanced control systems represents the main services provided by ISC able to study and design ad-hoc solutions for optimizing the behavior of any system to be controller.

The collaboration between ISC and automotive field companies has been consolidated by a multitude of projects, activities and training courses, permitting to establish partnership during last 20 years. ISC expertise covers strong knowledge on techniques for modelling and controlling automotive systems and sub-parts, considering vehicle's dynamics control and the development of models/controllers for any type of vehicle subsystem, e.g. engines.

ISC has large expertise in the development of MPC and other optimal control systems for a variety of applications and industries, including autonomous and non-autonomous vehicles. Various advanced modelling and control techniques have been considered and their potential exploited and customized – these include nonlinear optimization methods, computationally efficient modelling, advanced data-driven and model-based control techniques.

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