Agenda for Workshop/Training Course 20th to 22nd May 2025

Fundamentals of Predictive Control

Practical Application and Implementation of Predictive Controls

1. Motivation for the Course

Model Predictive Control (MPC) is the most successful advanced multivariable control technique, which is used in applications across industrial sectors, particularly where high performance is required. It is valuable for complex systems that are difficult to control because of difficult dynamics, interactions and the multivariable nature, noise and disturbances, transport delays or because of constraints and nonlinearities.

The training course is aimed at engineers in industry that are interested in the Practical Application of Predictive Controls. They will need the design procedures and enhancements that can make practical implementation faster and more effective. The event therefore focuses on the basic ideas, design stages and the steps in implementation that can avoid difficulties in commissioning or normal operation.

The basic principles and concepts of MPC will be introduced but the full mathematical background is not needed to use an MPC algorithm. Nevertheless, it is important to have an instinctive understanding of the various stages in the MPC design stages and computations. An intuitive introduction to the solution of MPC problems will therefore be provided. It will detail the various aspects of model choice, cost-function definition, type of optimization method, and the form of optimal control solution that is obtained.

The MPC algorithm has the advantage that it is suitable for multivariable systems and can handle hard constraint conditions on inputs and outputs. The "predictive capability" employs the expected or known behaviour of reference or disturbance signals, over a future time horizon, to improve the accuracy and performance of industrial processes or electromechanical control systems.

AGENDA

2. Day One: Introduction and Modelling and Estimation for MPC Design

09.00 **Welcome to the Workshop/course**: Overview of Agenda.

09.15 **Introduction to MPC:** Motivational introduction to MPC methods and the solution approach, and why it is so successful, where it has advantages, and briefly overviews competing methods that are options such as classical, LQG, H_∞ robust and nonlinear control design methods

10.15 *Coffee Break*

10.30 **Physical System Modelling and Model Structures and Early MPC Designs**: Modelling by Step Response methods and simple early predictive control strategies.

11.30 Hands-on simulation on modelling systems for use in MPC applications.

12.30 *Lunch*

13.30 **Specification for a Model Predictive Control Problem:** involving cost-function definitions, constraint specifications, choice of stochastic and/or deterministic system models, and when the optimality of an MPC solution is important.

14.15 **System Identification and Testing Methods**: obtaining models and parameters when the physical equations/system description are only partially known.

15.00 *Coffee Break*

15.15 **Need for a State-Estimator or Observer:** When can state feedback be used and when is a linear or nonlinear estimator needed. Role of the state-estimator and intuitive introduction linear observers and Kalman filtering methods, digital implementation.

16.15 Hands-on Kalman Filtering/Observers for MPC applications. Reducing the effects of measurement noise using optimal filters or observers.

17.00 *Close*

3. Day Two: MPC Solution and Control Design Problem Difficulties

09.00 **Intuitive Solution for Predictive Controllers:** introduction to modern optimal linear predictive control-based solution methods. Intuitive understanding of the main solution method used for linear MPC based controls. Features of the control laws obtained and tuning variables available.

10.00 *Coffee Break*

10.15 **Overview of the Optimization Methods:** used in unconstrained and constrained MPC including details of the solvers and benefits of different QP algorithms. Choice of quadratic programming solvers, commercially available, free to use. Including convergence conditions, feasibility questions and the inclusion of constraints on inputs and outputs.

11.15 **Modifying Basic MPC for Systems with Mild Nonlinearities:** including use of nonlinear compensation, scheduling methods and Extended Kalman Filters. Also use of state-dependant models or the very successful linear parameter varying models for approximating non-linear system behaviour.

12.15 *Lunch*

13.15 Hands-on linear MPC design example to illustrate the types of results obtained and a comparison of benefits with classical control methods.

14.15 **Robust MPC Control:** Natural robustness, enhanced robustness and situations where the stability of an MPC design may be a concern. Dealing with uncertainties by improving robustness, practical ways of allowing for uncertainty and improving robustness, dealing with bias and unmodelled dynamics, tuning dynamic cost function weighting terms, recent advances in robust MPC solutions.

15.00 *Coffee Break*

15.15 **Recommended MPC Design Procedure**: for linear or nonlinear systems, unconstrained and constrained systems with linear models, linear parameter varying models or state-dependent nonlinear models. Compensation of disturbances that may be unknown or measurable in part. Choice of terms in a cost-function to match physical problem needs and to allow simple tuning rules.

16.00 Hands-on MPC control using LPV models for linear and nonlinear systems.

17.00 *Close*

4. Day Three: Practical Issues of MPC Tuning and Implementation

09.00 **Model Predictive Control for Applications:** multi-variable systems: interaction in systems, types of cost function for tracking or regulation problems, natural feed forward action, MPC for supervisory control, hierarchical structures, upper-level optimisation, integrated condition modelling. Covers MPC development tools/products available to reduce engineering effort.

10.00 *Coffee Break*

10.15 **Lessons in the application of MPC**: Particularly to automotive spark ignition engine controls regulating emissions and fuel, and to EV/HEV vehicle energy optimisation controls, and Hydrogen fuelled road vehicles and marine vessels.

10.45 **Possible MPC Application Examples:** Based on published ISC project experience and can be selected depending on relevance to attending delegate needs:

- Combined cycle power plant control - John Brown Engineering and Scottish Power.
- Nonlinear spark ignition engine control or variable displacement engine control - GM.
- Underwater vehicle tracking and positioning controls - Mitsubishi.
- Reheat furnace energy optimisation and control and results – British Steel/TATA.
- Shell Oil benchmark problem.
- Control of autonomous vehicles, obstacle/collision avoidance, lane merging and changing, joining highways, road junctions, T-Junctions, safety – Ford, Dearborn.
- High accuracy stabilised platform servo applications – BAE Systems.
- MATLAB/Simulink Demonstrations/Hands-on selected MPC examples.

12.30 *Lunch*

13.30 **Improvements to MPC to solve common problems in implementation:** including choice of weightings, choice of cost horizons, dealing with different transport delays in different channels, improving robustness, poorly known disturbance models and the implications of disturbances that must be rejected and those whose effects must be ignored for reduced maintenance and actuator health.

14.15 **Impact of AI and Machine Learning on MPC:** Artificial Intelligence Inspired MPC methods to enhance model-based MPC controls, black-box and data driven methods, use of neural networks or SVM methods, potential advantages and difficulties.

15.15 *Coffee Break*

15.30 **Calibration of MPC Controllers and Tuning Variables:** tuning MPC controllers and guidelines, how system description choices affect design, model-based and AI-based optimization and data driven calibration methods.

16.15 **Recent and Future Developments**: likely impact of new MPC technology, including the effect of new processors and the software tools that will simplify implementation and provide much greater capabilities for fast systems and complex plants. ISC's perspective on the adoption of MPC as a company's main advanced control package.

17.00 *Final questions and close of workshop/course.*

5. Explanation of the Course Structure

Early presentations will motivate the use of MPC and introduce the physical system modelling methods or system identification techniques that may be needed. The great majority of predictive control laws are obtained by optimizing a criterion that is representative of the form of control needed. This may be motivated by the physical system problem that could involve energy minimization, or it could be a general criterion where the cost-function weightings act rather like the tuning parameters in PID controls.

Optimization methods will therefore be introduced that are applicable to both constrained and unconstrained MPC system problems. Most physical processes do of course have hard constraints of some type and the way in which these are described and implemented in the optimization algorithms will be introduced.

After the basic modelling, optimization and optimal control algorithms have been presented attention will then turn to the design of such systems to satisfy industrial requirements and specifications. Care is needed when specifying the type of system model and the noise and disturbance models. The specification of the form and parameterization of the cost function that should embody the requirements of the physical problem is also important.

The design stage will therefore consider how to choose the cost-function, and the weighting terms involved. After an MPC controller is designed, it can of course be assessed using simulation. However, the implementation of MPC in real systems may involve many additional problems since the system model will have inaccuracies, uncertainties, and robustness issues that may arise. Fortunately, there are various engineering enhancements to basic MPC that can mitigate problems with uncertainties. There are also changes to the standard MPC problem that allow practical improvements to be made such as introducing integral action, allowing for different transport delays in input/output channels and ways to deal with unknown disturbances that may be present.

It is also recognized that artificial intelligence and machine learning will have a significant impact on the future use and implementation of MPC controllers. There are already significant advances in the use of adaptive AI based predictive controls and there are also simple additions to existing MPC designs that take advantage of data driven methods. The AI predictors can for example provide longer range prediction capabilities than is used in the MPC's own cost-function prediction horizon. The way in which the basic MPC algorithms can be enhanced to provide improved performance by using data driven methods, such as neural networks or support vector machines will be covered. The final presentation is a look to the future of AI Enhanced MPC to indicate the developments that companies should be aware of to maintain a competitive edge.

To ensure the ideas on modelling and on optimization are fully understood hands-on Simulink exercises will be provided throughout the course, so that delegates can assess the methods and solution methods. A servosystem will be used for all the hands-on examples from initial modelling to final implementation, although different application options can be offered through tailored versions of the course.

Venue: Scottish Engineering, 105 West George Street, Glasgow G2 1QL