Abstracts and titles for Colloquium on Predictive Control

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A convex and tractable formulation for robust predictive control

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The problem of finding optimal control laws for constrained linear systems without disturbances or model uncertainty is relatively well understood. However, existing results, which allow for the explicit incorporation of disturbances or model mismatch in the optimal control problem, are either too conservative or computationally intractable. Much of current research in optimal control is therefore aimed at finding non-conservative and computationally efficient methods for the optimal control of uncertain systems with constraints on the state and input.

This talk will consider the problem of finding, at each sample instant, a sequence of affine state feedback control laws that guarantees the satisfaction of input and state constraints over a finite horizon, despite the presence of a bounded disturbance on the state. We will assume that the system is linear and discrete-time, and that the constraints on the state, input and disturbance are described by linear inequalities. It is well known that this control problem is non-convex in the space of decision variables, which implies that it is very difficult to find a solution. However, we will show that this control problem can be solved in a tractable fashion by re-parameterising the control problem and formulating it as a convex optimisation problem. We will also outline how this alternative parameterisation can be used to efficiently compute receding horizon controllers with robust stability guarantees.

Nonlinear Model Predictive Control using Automatic Differentiation

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The computational burden, which obstacles Nonlinear Model Predictive Control techniques to be widely adopted, is mainly associated with the requirement to solve a set of nonlinear differentiation equations and a nonlinear dynamic optimisation problem in real-time online. In this work, an efficient algorithm has been developed to alleviate the computational burden. The new approach uses the automatic differentiation techniques to solve the set of nonlinear differentiation equations, at the same time to produce the differential sensitivity of the solution against input variables. Using the differential sensitivity, the gradient of the cost function against control moves is accurately obtained so that the online nonlinear dynamic optimisation can be efficiently solved. The new algorithm has been applied to an evaporation process with satisfactory results to cope with large setpoint changes, unmeasured severe disturbances and process-model mismatches.

IQC analysis of linear constrained MPC

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It is well known that linear constrained model predictive control has a nonlinearity that is continuous and piecewise affine. Under certain feasibility conditions the nonlinearity may be sector bounded and shown to satisfy sufficient conditions for the existence of Zames-Falb multipliers. Thus the nonlinearity satisfies a wide class of integral quadratic constraint (IQC). Standard analysis then allows a closed-loop robust stability test for infinity-norm bounded model uncertainty. We illustrate the results for output feedback MPC with integral action.

Feasibility, uncertainty and interpolation

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One major aim of researchers is to maximise feasible regions without recourse to demanding optimisations. This issue is particular important in the uncertain case where guarantees of convergence further complicate analysis and computation. This talk gives an overview of some of the uses of polyhedral and ellipsoidal sets in this context and discusses how interpolation can give far more benefit than published to date. Specifically, it will also be shown that interpolating between two control laws can give feasible regions far larger than the convex union of the underlying maximal admissible sets.

Robust Model Predictive Control

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The difficulties in achieving robust model predictive control are briefly discussed. `Nominal' model predictive control is robust only in special circumstances; even then its degree of robustness is limited, motivating the development of new forms of model predictive control. A novel solution to the problem of robust model predictive control of constrained, linear, discrete-time systems in the presence of bounded disturbances is then presented. The optimal control problem that is solved online includes, uniquely, the initial state of the model employed in the problem as a decision variable. The associated value function is zero in a disturbance invariant set that serves as the

`origin' when bounded disturbances are present, and permits a strong stability result, namely robust exponential stability of the disturbance invariant set for the controlled system with bounded disturbances, to be obtained. The resultant online algorithm is a quadratic program of similar complexity to that required in conventional model predictive control.

Optimized Robust Control Invariance and its applications in Robust Model Predictive Control

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In this talk we introduce the concept of optimized robust control invariance for a discrete-time, linear, time-invariant system subject to additive state disturbances. This concept improves and extends some of the existing results in the set invariance theory. A novel characterization of a family of the robust control invariant sets is given. The existence of a constraint admissible member of this family can be checked by solving a single linear programming problem. Application of the results to robust model predictive control is also briefly discussed.

Keywords: Set Invariance, Optimized Robust Control Invariance, Optimized Robust Control Invariant Tubes, Robust Model Predictive Control.

New Developments In Predictive Control For Nonlinear Systems

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Predictive control has been very successful in the process industries where the system has a very slow speed of response and where the multivariable nature of the problem dominates. The predictive control methods have not been so successful in the high-speed machinery controls area and one reason is the severe nonlinearities encountered in such systems. The presentation will include an overview of two different approaches to nonlinear predictive control. The first might be considered an extension of traditional GPC and LQG related predictive control methods. The system is represented in a state equation form and the nonlinear control algorithms reduced to their linear counterparts in the special case when the system is linear.

The second approach to predictive control is based on nonlinear generalized minimum variance ideas and the use of future set point information. This is a new approach to the control of nonlinear systems which has the virtue of simplicity. The presentation will include a brief summary of both of these different approaches and a multivariable control example will be provided.

The Explicit Non-Linear Optimal Control Law for Continuous Time Dynamic Systems via Parametric Programming

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In this work an algorithmic framework is presented for the derivation of the explicit optimal control policy for continuous-time dynamic systems that involve constraints on process inputs and outputs. The control actions are usually computed by solving regularly an on-line optimization problem in the discrete-time space based on a set of measurements that specify the current process state. The novel approach presented in this paper derives the optimal control law off-line as an explicit function of the state of the continuous-time dynamic plant representation. The control law is proved to be nonlinear with respect to the system state even for linear plant description, but does not require the repetitive solution of on-line optimization problems. Hence, the on-line implementation is reduced to a sequence of function evaluations. The key advantageous features of the algorithm are demonstrated via two illustrative examples on a linear and a non-linear system.

Multiplexed Model Predictive Control

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Most academic control schemes for MIMO systems assume all the control variables are updated simultaneously. MPC outperforms other control strategies through its ability to deal with constraints. This requires on-line optimization, hence computational complexity can become an issue when applying MPC to complex systems with fast response times. The multiplexed MPC scheme described in this talk solves the MPC problem for each subsystem sequentially, and updates subsystem controls as soon as the solution is available, thus distributing the control moves over a complete update cycle. The resulting computational speed-up allows faster response to disturbances, and hence improved performance, despite finding sub-optimal solutions to the original problem. The multiplexed MPC scheme is also closer to industrial practice in many cases. This paper presents initial stability results for two variants of multiplexed MPC, and illustrates the performance benefit by an example.