A BRIEF OVERVIEW OF MODEL PREDICTIVE CONTROL

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Model Predictive Control Strategy

Model Predictive Control, MPC, usually contains the following three ideas (Camacho and Bordons, 1995):-

(i) Explicit use of a model to predict the process output along a future time horizon.

(ii) Calculation of a control sequence to optimise a performance index.

(ii) A receding horizon strategy, so that at each instant the horizon is moved towards the future, which involves the application of the first control signal of the sequence calculated at each step.

The strategy is illustrated as shown in Figure 1 and described as follows (Camacho and Bordons, 1995):-

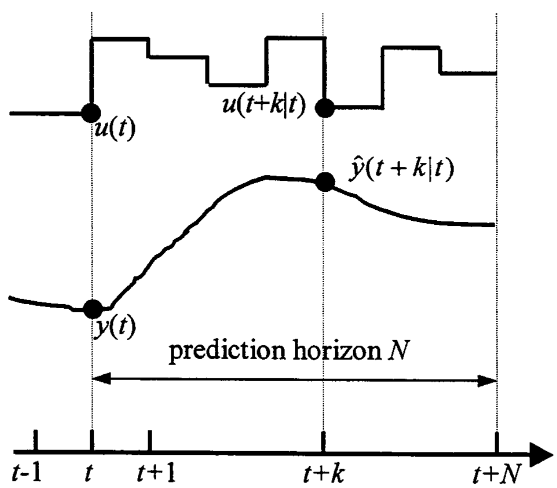

Fig. 1 MPC Strategy

1. The predicted future outputs $\hat{y}(t+k|t)$, $k = 1 \cdots N$ for the prediction horizon N are calculated at each instant t using the process model. These depend upon the known values up to instance t (past inputs and outputs), including the current output (initial condition) $y(t)$ and on the future control signals $u(t+k|t)$, $k = 0 \cdots N-1$, to be calculated. (*Note* - the notation $x(t+k|t)$ indicates the value of x at time instant $t+k$ calculated at time instant t).

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2. The sequence of future control signals is computed to optimise a performance criterion, often to minimise the error between a reference trajectory and the predicted process output. Usually the control effort is included in the performance criterion.

3. Only the current control signal $u(t|t)$ is transmitted to the process. At the next sampling instant $y(t+1)$ is measured and step 1 is repeated and all sequences brought up to date. Thus $u(t+1|t+1)$ is then calculated using the receding horizon concept.

Advantages and Disadvantages of MPC

Some of the main advantages are:-

- Concepts are intuitive and attractive to industry.
- Can be used to control a great variety of processes, including those with non-minimum phase, long time delay or open-loop unstable characteristics.
- Can deal with multivariable, multi-input multi-output as well as single-input single-output processes.
- Process constraints can readily be treated within the optimisation process.
- Readily applicable to batch processes where the future reference signals are known.
- An open technology which allows for future extensions.

A significant disadvantage is:-

- Requirement of an appropriate model of the process.

MPC Algorithms

Several reviews and comparative studies of the main MPC algorithms have been published, for example by De Keyser, Van de Welde and Dumortier (1988), Garcia, Prett and Morari (1989) Kramer and Ubehauen (1991) and Qin and Badgwell (1996). Their application particular to the chemical process industry has been described by Eaton and Rawlings (1992). Industrial applications have also been described by Richalet (1993). There are several textbooks on MPC, for instance those by Prett and Garcia (1988), Soeterboek (1992), Morari, Garcia, Prett and Lee (1993), Camacho and Bordons (1995), Camacho and Bordons (1999) and Maciejowski (1999).

The various techniques are differentiated by different types of model and performance function employed. Presented from an historical perspective, some of the main algorithms are:-

- Model Algorithmic Control, MAC, initially called Model Predictive Heuristic Control, MPHC, (Richalet, Rault, Testud and Papon, 1976, 1978). This uses an impulse response model, which is valid only for open-loop stable processes, and minimises the variance of the error between the output and a reference trajectory computed as a first-order system.
- Dynamic Matrix Control, DMC, (Cutler and Ramaker, 1980). This is similar to MAC but uses a step response model instead of an impulse response model. This technique was originally applied in Shell Oil as early as 1973. The method was extended to include input and output constraint handling using quadratic programming to solve the constrained optimisation problem, giving rise to Quadratic Dynamic Matrix Control,

QDMC, (Cutler Morshedi and Haydel, 1983). The DMC algorithm can also be derived for a general discrete state-space model (Prett and Garcia, 1988).

- Extended Prediction Self Adaptive Control, EPSAC, (De Keyser and Van Cuawenberghe, 1985) uses a discrete (z-transform) transfer function to model the process and a simple control law structure calculated analytically using a quadratic performance function assuming $u(t)$ stays constant from instant t. The process model also includes measurable disturbances.
- Generalised Predictive Control, GPC, (Clarke, Mohtadi and Tuffs, 1987), using a quadratic performance function, with weighting of control effort, and a auto - regressive moving average with exogenous variables model (ARMAX). It also provides an analytic solution for the optimal control in the absence of constraints.

DMC and GPC are perhaps the most popular techniques. There are several extensions to GPC including techniques with guarantee stability through end-point equality constraints (Clarke and Scattolini, 1992; Mosca and Zhang, 1992), and by stabilising the process prior to the objective function optimisation (Kouvaritakis, Rossiter and Chang, 1992). The GPC technique, using a method known as Constrained Stable Generalised Predictive Control, CSGPC, (Rossiter and Kouvaritakis, 1993) has also been extended to guarantee feasibility and stability when there are input constraints as well as terminal constraints (Rossiter, Kouvaritakis and Gossner, 1996; Rossiter, Gossner and Kouvaritakis, 1997). Although most of the work has been performed in discrete time GPC has also been formulated in continuous time (Demircioglu and Gawthrop; 1991, 1992). A state space model description for GPC controllers has also been developed (Ordys and Clarke, 1993; Gawthrop, Demircioglu and Siller-Alcala, 1998).

Nonlinear model predictive control based on state space models and the receding horizon concept has also been developed, for example by Mayne and Michalska (1990), who perform a stability analysis, and Balchen, Ljungquist and Strand (1992). Integration of economic objectives within the performance function has also been performed, (Becerra, Roberts and Griffiths, 1998).

Several commercial companies offer software products for implementation of model predictive control, for example MDC (SMOC), Predictive Control (CONNOISSEUR), AspenTech (DMCplus) and Honeywell (RMPCT).

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