Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-13 (2016) 059–064

An optimal centralized predictive control scheme applied to a Non-Square MIMO benchmark problem

Anuj Abraham*, N. Pappa*

*Department of Instrumentation Engineering, Madras Institute of Technology, Anna University Chennai-600044. India
anuj1986aei@gmail.com, npappa@rediffmail.com,

Abstract: This paper aims at the implementation of advanced control technique such as Generalized Predictive Control (GPC) for non-square Multi-Input-Multi-Output (MIMO) benchmark problem. The process considered is a coupled distillation column (3 input, 2 output) studied by Levein and Morari. The design approach for tuning controller parameters in conventional methods of a non-square system is a big challenge, as it involves computational complexities. In this work, predictive algorithm with constraints on the input and output control signals are developed and compared with the PID controller by retaining its non-minimum phase characteristics. GPC uses Controlled Autoregressive and Integrated Moving-Average (CARIMA) model. Simulation studies demonstrate the superiority of the constrained GPC over GA-PID controller for a non-square multivariable process. The effectiveness of the advance control structure ensures the reduction in computational complexities and fast convergences with better tracking capabilities.

Keywords: Non-square systems, multivariable, predictive control, distillation column.

1. INTRODUCTION

In many industrial applications, there are processes with unequal number of manipulated inputs and control outputs. These type of processes are termed as non-square system and generally has more number of inputs than the control outputs. The design of controller parameters for non-square system is a challenging task and conventional methods has its difficulties in properly tuning the parameters, incorporations of coupling effects and interactions. Padhi, R. et al, (2007) method was based on the addition of an extra output or deletion of some inputs to make it to a square system. But former method can lead to increase in the cost and later method requires a larger variation in control action and involves a large number of computations. Recently, an improvement to the above method, Ganesh, P et al., (2010) reported a multivariable PID controller design for non-square systems, which reduces the computational complexities by optimally tuning the parameters by Genetic Algorithm (GA).

In this proposed work, a Model Predictive Control (MPC) algorithm was implemented and tested for a coupled distillation column (non-square system) developed by Levein and Morari. The control of MIMO process has been extensively treated in literature, perhaps the most popular way of controlling MIMO process is by designing decoupler compensators to reduce the interaction and then design multiple SISO controllers (Sung, S. W. et al, 2009). But, this requires the knowledge of how to pair the input and output variables and for complex dynamics the decoupling design is very difficult to determine. One advantage of MPC is that multivariable process is handled in a straightforward manner with less cross effect (Scokaert, P. O. M, et al., 1994).

MPC is a specific control strategy, which makes an explicit use of a process model to obtain the control signal by minimizing an objective function to predict the process output at a future time instants or horizons (Farina, M et al., 2012). Generating a reliable measurement and accurate measurement for any industrial processes is challenging and depends on the factors like non-stationary dynamic mathematical models due to their time dependency, process nonlinearity, multivariable coupling, severe disturbances, etc. Linear controller design have practically the same structure and provide adequate degrees of freedom. The horizons of receding strategy at each instant are displaced towards the future, which involves the application of the initial control signal of the sequence generated at each step (Andrzej Pawlowski, et al., 2014).

The most widely used MPC control strategies include Extended Prediction Self-Adaptive Control (EPSAC), Dynamic Matrix Control (DMC), Model Algorithmic Control, Predictive Functional Control (PFC), GPC and Extended Horizon Adaptive Control (EHAC) (Camacho, F, 2007). The different MPC algorithms differ in the model used to represent the process and the cost function is to minimize the control action within the allowable limits and error minimizations. For output prediction, a process model is necessary for the plant behavior and a receding horizon concept is implemented to introduce the feedback. In this paper, the implemented predictive control design is based on GPC algorithm which uses a CARIMA model and has become one of the most popular MPC methods in industries (Patxi Alkorta et al., 2014). The capability of MPC algorithms shows simple and good performances in industry application to achieve highly efficient control to operate in a certain degree of robustness with time delays (Ogunnaike,

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.07.927

B.A. et al., 1994 and Dong, J.W.,1997). It can be used to control a great variety of processes with relatively simple dynamics to more complex processes, including systems with dead times or of non-minimum phase or unstable ones. To compensate for measurable disturbances, a feed forward control mechanism may be incorporated.

The regimes of operation of a multivariable process are determined to satisfy economic goals, and works in the constrained allowable limits. For a long range predictive control, the control system has to anticipate constraint violations and correct them in an appropriate way. GPC algorithm with constraints (input, output) focus on the minimization of an objective function subject to linear inequalities: Quadratic Programming (QP) – in MATLAB quadprog function from optimization toolbox (Tsang, T. T. C, 1998). Simulated responses show the effectiveness of the constrained GPC problem to that of a PID controller for a multivariable non-square benchmark system studied by Levein and Morari (Sarma, K. L. N. et al, 2005).

2. BENCHMARK PROBLEM DESCRIPTION

Levein and Morari benchmark example are considered for GPC control design which is a non-square multivariable system (Sarma, K. L. N. et al, 2005), given by the transfer function in Eq.1,

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} \dfrac{0.052\, e^{-8s}}{19.8s+1} & \dfrac{-0.03(1-15.8s)}{108s^2+63s+1} & \dfrac{0.012(1-47s)}{181s^2+29s+1} \\ \dfrac{0.0725}{890s^2+64s+1} & \dfrac{-0.0029(1-560s)}{293s^2+51s+1} & \dfrac{0.0078}{42.3s+1} \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} \quad (1)$$

The non-square system has 3 inputs and 2 outputs model, in which the manipulated variables are distillate flow rate (U_1), steam flow rate (U_2), product fraction of the side column (U_3) and the outputs are mole fraction of ethanol in distillate (Y_1) and mole fraction of water in the bottoms (Y_2). The chosen bench mark problem has a RHP zero, which describes the non-minimum phase characteristics (Levien, K. et al., 1987).

3. PREDICTIVE CONTROL SCHEMES

3.1 Model Predictive Controller

MPC is the family of controllers, makes the explicit use of model to obtain control signal and its structure is shown in Fig.1. The reason for its popularity in industry and academia is its capability of operating without expert interfering for long periods. There are various predictive control design schemes based on process model mainly state space model, step response model, impulse response models or CARIMA models. (Wilkinson, D. J et al., 1994 and Mihai Draganescu et al., 2015).

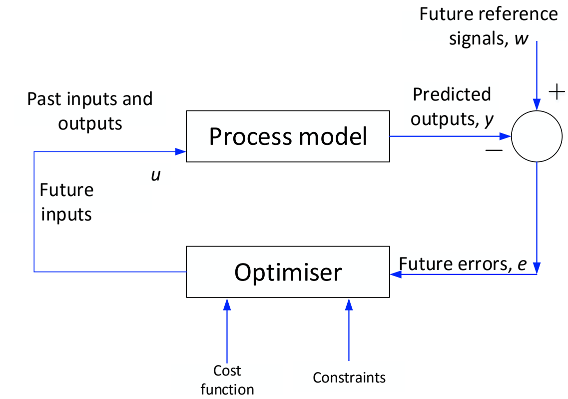

Fig. 1. Model predictive control structure

3.2 Generalized Predictive Controller

A predictive control algorithm developed by D. W. Clarke in 1987 is GPC and it caters for offsets, feed-forward signals, and multivariable plant without any previous information of structural indices. The basic principle of GPC is shown in Fig.2.

To minimize a cost function defined over a prediction horizon and optimization of future control signals, a CARIMA model is used for obtaining good output predictions. The predictive output depends on previous values of outputs and previous and future values of the control signal.

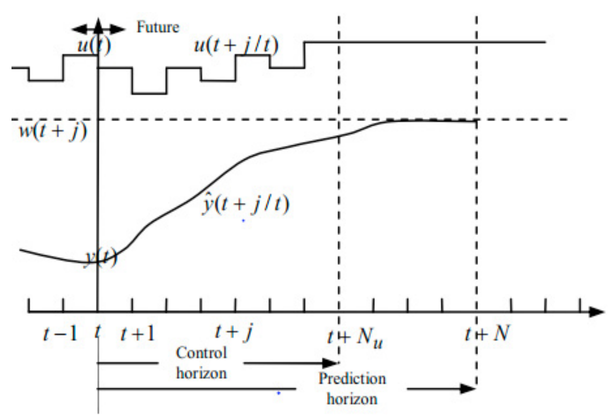

Fig. 2. Moving horizon strategy

At the current sampling instant, denoted by k, the output predictions of GPC for a Three-Input-Two-Output multivariable process is based upon a CARIMA model can be expressed as,

$$\begin{aligned} A_1(z^{-1})\, y_1(k) &= B_{11}(z^{-1})\, u_1(k-1) + B_{12}(z^{-1})\, u_2(k-1) + \\ &\quad B_{13}(z^{-1})\, u_3(k-1) + \frac{C(z^{-1})}{\Delta} e_1(k) \\ A_2(z^{-1})\, y_2(k) &= B_{21}(z^{-1})\, u_1(k-1) + B_{22}(z^{-1})\, u_2(k-1) + \\ &\quad B_{23}(z^{-1})\, u_3(k-1) + \frac{C(z^{-1})}{\Delta} e_2(k) \end{aligned} \quad (2)$$