Journal of Process Control 21 (2011) 1345–1358

Contents lists available at ScienceDirect

Journal of Process Control

journal homepage: www.elsevier.com/locate/jprocont

Latent variable model predictive control for trajectory tracking in batch processes: Alternative modeling approaches

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ARTICLE INFO

Article history:
Received 8 November 2010
Received in revised form 13 June 2011
Accepted 14 June 2011
Available online 25 August 2011

Keywords:
Latent Variable Modeling (LVM)
Batch processes
Latent Variable MPC (LV-MPC)
Principal Component Analysis (PCA)

ABSTRACT

Several Latent Variable Model (LVM) structures for modeling the time histories of batch processes are investigated from the view point of their suitability for use in Latent Variable Model Predictive Control (LV-MPC) [1] for trajectory tracking and disturbance rejection in batch processes. The LVMs are based on Principal Component Analysis (PCA). Two previously proposed approaches (Batch-Wise Unfolding (BWU) and Observation-Wise with Time-lag Unfolding (OWTU)) for modeling of batch processes [2] are incorporated in the LV-MPC and the benefits and drawbacks of each are explored. Furthermore, a new modeling approach (Regularized Batch-Wise Unfolding (RBWU)) is proposed to overcome the shortcomings of each of the previous modeling approaches while keeping the major benefits of both. The performances of the three latent variable modeling approaches in the course of LV-MPC for trajectory tracking and disturbance rejection are illustrated using two simulated batch reactor case studies. It is seen that the RBWU approach models the nonlinearity and time-varying properties of the batch almost as accurately as BWU approach, but needs fewer observations (batches) for model identification and results in a smoother PCA model. Recommendations are then given on which modeling approach to use under different scenarios.

1. Introduction

The trajectory tracking control problem in batch processes involves control over the local batch behavior at every sample time throughout the duration of the batch to make key process variables follow their corresponding set-point trajectories. In industrial practice these trajectory tracking control problems are usually handled by simple PID controllers. However, when control is not uniformly acceptable over the entire batch, due to changing gains and dynamics or the need to track complex set-point trajectories, gain scheduled PID controllers are used [3] or feed-forward terms are added [4,5]. Nonlinear controller approaches based on mechanistic models have also been described in the literature. Differential geometric approaches [5,6] and various versions of nonlinear MPC have been proposed. Garcia et al. [7] first proposed a nonlinear MPC for batch processes based on a nonlinear prediction model and control using a linearization of the model. Fully nonlinear MPC, formulated in an optimization framework, has more recently been proposed [8–11]. However, due to the difficulties associated with the development of reliable mechanistic models for real batch processes, and significant computational effort required in implementation of the mechanistic models, empirical models are often more appealing for practical situations. Several studies have been performed on the application of LVMs for batch process modeling [12–14]. LVMs can model the batch process with much less effort as compared to mechanistic modeling. Furthermore, since LVMs significantly reduce the dimension of the process, they represent interesting modeling approaches for on-line applications. PCA is an approach to latent variable modeling that focuses on dimension reduction of the dataset by explanation of the major variations as well as quantification of the correlation structure in the dataset. The main idea behind the PCA is to extract new orthogonal latent variables, defined as linear combinations of the original variables, that capture the maximum amount of variation in the data using the smallest number of latent variables [15,16].

LVMs have been extensively studied for the purpose of the analysis of batch process data to understand the sources of variation among batches and for the monitoring and diagnosis of future batches [12,17–19]. Flores-Cerrillo and MacGregor [20] proposed the idea of Model Predictive Control over batch trajectories based on Latent Variable models. Alternative control and modeling methodologies for trajectory tracking MPC based on latent variable models are proposed by Golshan et al. [1]. The latent variable approaches mentioned above are based on using a Principal Component Analysis (PCA) model in the core of the prediction and

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doi:10.1016/j.jprocont.2011.06.007