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High gain observer based extended generic model control with application to a reactive distillation column

Sudip Banerjee, Amiya K. Jana*

Energy and Process Engineering Laboratory, Department of Chemical Engineering, Indian Institute of Technology – Kharagpur, 721 302, India

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ABSTRACT

This article aims at synthesizing an estimator based hybrid control scheme that consists of a high gain nonlinear observer and the extended generic model controller (EGMC) that is developed by the application of differential geometry theory. The model-based EGMC control system demands the knowledge of some physical state variables of the process and therefore, the development of a suitable algorithm to perform the state estimation has captured the attention. Here, we design a high gain observer so that it estimates a limited number of states which are solely required for the controller simulation. As a consequence, there exists a significant structural discrepancy. Despite this large mismatch, the state observer performs satisfactorily in converging the estimation error for the case of an example ethylene glycol reactive distillation system. With the same reduced-order predictor model, a comparison is also made between the high gain observer and the extended Kalman filter (EKF). Finally, the high gain observer based EGMC control structure shows promising performance in regulating the ethylene glycol column.

1. Introduction

Most of the chemical processes are nonlinear in nature. Again, owing to the increasing level of global competitiveness, the chemical plants are pushed to operate into highly nonlinear regions in order to meet: (i) increased production capacity, (ii) increased product quality, and (iii) reduced environmental emissions [1]. It is true that the linear controllers are not efficient enough even to regulate the moderately nonlinear processes. Motivated by these facts, several advanced control schemes, importantly internal model control (IMC) [2,3], model predictive control (MPC) [4,5], globally linearizing control (GLC) [6,7], and generic model control (GMC) [8,9], have been proposed in literature.

The classical GMC control scheme proposed by Lee and Sullivan [8] is probably one of the simplest nonlinear control techniques. Most notable advantages offered by this control scheme include: any available process model can directly be used in the control structure, control parameters are easily tunable, measurable disturbances can be compensated effectively, its implementation requires minimal computational effort and it has strong robustness. It is interesting to note that the classical GMC law derived based on simple algebra is only applicable to the processes having relative order of 1. In order to broaden its acceptability, subsequently Wang et al. [10] have developed the *generalized* GMC by using the differential geometry theory. However, the application of this generalized control scheme is again restricted to the processes possessing relative order of 2 or more. Keeping this issue in mind, recently Jana [11] has developed a control system within the framework of differential geometry that can be employed to control the processes having any number of relative order, including 1. We call this control scheme here as the *extended* generic model controller (extended GMC or simply, EGMC).

In a model-based controller, there exist usually two types of model mismatch: structural and parametric mismatch. The former one occurs when the plant and the model have different mathematical representations, whereas the latter one exists if the numerical values of parameters in the model do not correspond with true values. Interestingly, both of these discrepancies lead to deterioration in control performance.

In developing the advanced model-based control systems, we usually prefer to employ a reduced-order/approximate model to avoid mathematical complexity as well as computational load. Besides, the perfect representation of a plant is also rarely possible. Hence, the

* Corresponding author. Tel.: +91 3222 283918; fax: +91 3222 282250.
E-mail address: akjana@che.iitkgp.ernet.in (A.K. Jana).

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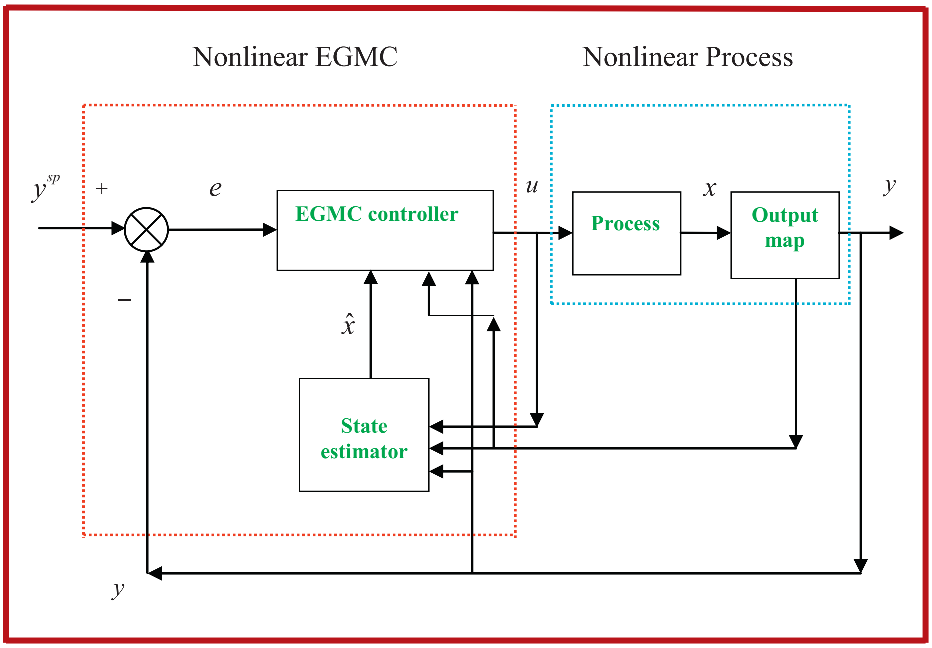

Fig. 1. State estimator based EGMC control structure [e = error signal, u = manipulated input, x = state variable, $\hat{x}$ = estimated state, y = controlled variable (measured state), y^{sp} = set point of y].

existence of structural mismatch is quite common in practice and it leads to a challenging control problem. However, there is a way to minimize the effect of structural discrepancy by continuously updating the model parameters. To cope with this, it is required to devise a state estimator/observer for online use.

There are a number of state estimators developed for nonlinear systems. Few of the important ones include Kalman filtering based observer [12,13], extended Luenberger observer [14,15], sliding nonlinear observer [16,17], particle filtering [18,19], etc. The current work focuses on the design of a high gain nonlinear state estimator [20] that is perhaps not applied so far on the distillation system.

Distillation is a well-known separation process in the chemical industries. Because of its inherent nonlinearity and complex dynamics, the distillation column is widely chosen [21,22] to illustrate the control schemes. Our main contribution consists in synthesizing a differential geometry based extended GMC controller coupled with a high gain closed-loop estimator with the application to a reactive distillation (RD) column. First we present the formulation of the key constituents of the model-based hybrid control scheme, namely the EGMC law and the high gain estimator along with an extended Kalman filter (EKF). Then we extend their design approach to an example reactive distillation column for the production of ethylene glycol. Since all the states of the example system are not truly measurable quantities, we need to design an efficient state estimator. In order to avoid the mathematical complexity as well as computational burden, instead of estimating the full state vector, we aim to compute a few states that are exclusively required for the EGMC controller simulation. Accordingly, we construct the predictor model for the observers that comprises of a single component balance equation around the reboiler-column base system of the representative RD column. Performing a comparative study between the high gain observer and the EKF, it is investigated that despite the large discrepancy, the proposed estimator based EGMC controller shows high quality performance over the classical proportional integral (PI) controller.

2. Nonlinear observer based extended generic model control

In this section, we develop a multivariable nonlinear control scheme that comprises of the extended GMC controller and a high gain state estimator. Additionally, we develop the EKF estimator for comparison in both the open-loop and closed-loop modes. First we aim to devise the GMC controller under the framework of differential geometry that can be used for any kinds of processes, irrespective of their relative order. Fig. 1 shows the hybrid closed-loop structure.

2.1. Extended GMC

2.1.1. Differential geometry

A brief review is presented of some concepts from differential geometry that are relevant to design the extended GMC. For additional details, the interested reader is referred to the book by Isidori [23].

The state space representation of a nonlinear multi-input/multi-output (MIMO) system is considered as:

$$\begin{aligned} \dot{x}(t) &= f(x, d, \theta) + g(x, d, \theta) \cdot u(t) \\ y(t) &= h(x) \end{aligned} \tag{1}$$

Here, the state vector $x(t) \in \Re^n$, the manipulated input vector $u \in \Re^m$, the output vector $y \in \Re^m$, $h \in \Re^m$, the process parameter vector $\theta \in \Re^q$ and the disturbance vector $d \in \Re^l$. There are three nonlinear functions involved, namely $f(\bullet)$, $g(\bullet)$ and $h(\bullet)$.