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Experimental validation of a Nonlinear Model based Control scheme on the Variable area tank process

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Abstract: In this paper, the authors have proposed a simple non-linear model based control scheme for the variable area tank process. The proposed control scheme relies on the nonlinear model of the conical tank process. The parameters of the nonlinear model have been determined using empirical approach. The proposed control algorithm has been implemented on pilot scale conical tank experimental setup. The performance of the proposed control scheme is compared with that of a gain scheduled PI controller.

Keywords: Nonlinear process, Conical Tank, Model-based controller.

1. INTRODUCTION

The model based control has gained widespread acceptance in the field of process system engineering to optimally control systems under various constraints. Among various model based control schemes, MPC is considered to be popular for plant-wide control, because at each sampling instant the present and future control moves are determined by solving a finite horizon open-loop optimal control problem from the current system state or from its estimate based on output measurements. The current control move is only applied to the plant. Then the calculations are repeated starting from the current state, yielding a new control sequence, Morari and Lee, (1999).

Equally IMC is deployed for the control of nonlinear systems and it may be noted that several non-linear internal model control schemes (NIMC) have appeared in the process control literature (Economou et al, 1986; Parrish & Brosilow 1988, Henson & Seborg 1991, Nahas et al. 1992, Doyle at al. 1995, Coulibaly et al. 1995, Kravaris et al. 199, Hu and Rangaiah, 1999, Niemieca et al, 2003, Deng et al, 2009).

The main contribution of the paper is to experimentally validate a simple non-linear model based control scheme for the variable area tank process. The proposed control scheme employs a non-linear process model directly within the controller. It should be noted that the control law is a function of both model state and measured output variables. The process model is simulated on-line to generate the model state, for open-loop stable processes. In spite of several model based control schemes available in the process control literature, the proposed control schemes remain an attractive control strategy, because it offer advantages such as simple design and low computational complexity and the performance is found to be satisfactory.

The organization of the paper is as follows: Section 2 discusses the design of a nonlinear model based controller for a nonlinear system. The real-time implementation of the proposed model based control scheme for the conical tank is reported in section 3. Experimental results for the nonlinear model based control of the variable area tank are presented in section 4, followed by concluding remarks in section 5.

2. DESIGN OF NONLINEAR MODEL BASED CONTROLLER (NMBC)

Arasu and Prakash, (2015) had proposed a multiple linear model based controller realized in reset configuration for a nonlinear MIMO system. The steps involved in designing the multi-model based control scheme are as follows:

- Divide the whole nonlinear model into n -local linear models corresponding to each operating region.
- For each operating point, the system is stabilized using a state feedback approach.
- Determine the gain of the stabilized model (K_m) for the nonlinear system at each operating point.
- Determine the model state (x_m) by solving the stabilized model.
- Determine the input (u_m) corresponding to the model state (x_m) using inverse of the model gain (K_m^{-1}).

This would result in an offset free response for step like changes in the set point. In order to satisfy either desired performance or robustness specification an additional tuning parameter (K_C) could be used. The controller gain (K_C) is determined using appropriate optimization technique.

The proposed work extends the design of model based control scheme for a non-linear system using a nonlinear model rather than multiple linear models. The schematic of the proposed control scheme is shown in figure 1.

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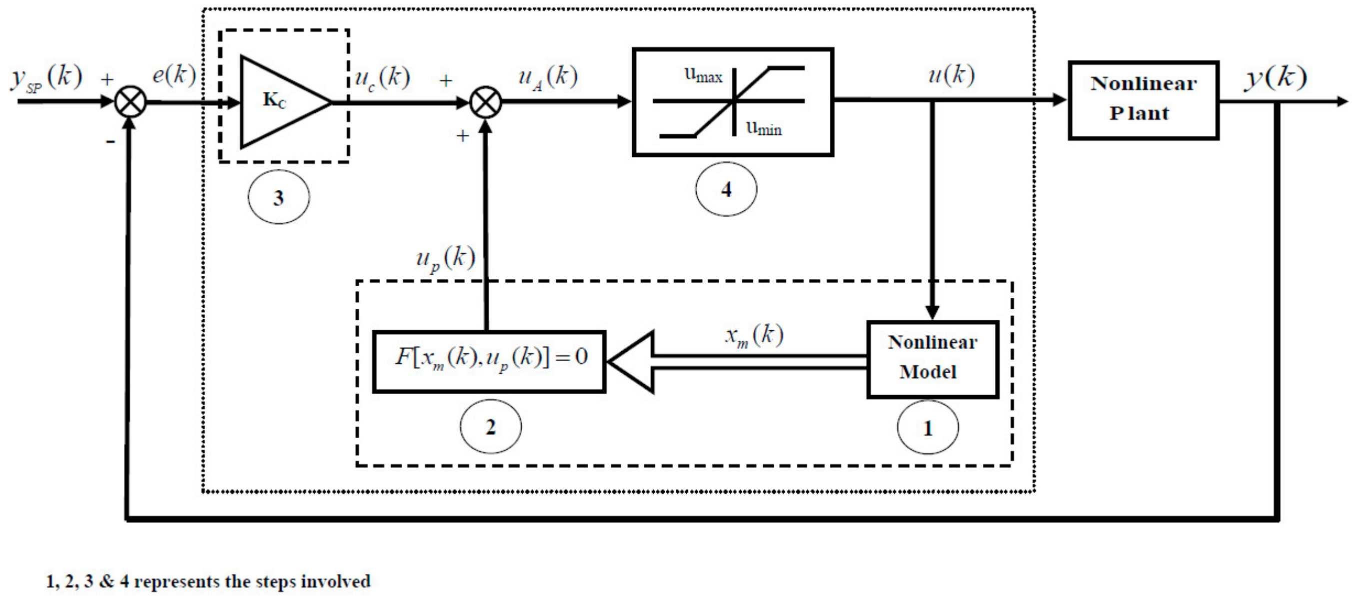

Fig. 1. Schematic diagram of the proposed nonlinear model based control scheme.

2.1 Model based controller for a nonlinear SISO system.

Consider the deterministic non-linear system been represented using the state and measurement equations as given below:

$$x(k)=\left[x(k-1)+\int_{(k-1)T}^{kT}F[x(\tau),u(k-1))]d\tau\right] \quad (1)$$

$$y(k)=Cx(k) \quad (2)$$

where, $x(k)\in R^n$ is the state variables, $u(k)\in R$ is the manipulated input variable $y(k)\in R$ is the measured output variable.

The computation of the controller output at each sampling instant by the proposed non-linear model based control scheme for the open-loop stable SISO processes is as follows:

Step-1: Determine the model state (x_m) by solving the non-linear state equation

$$x_m(k)=\left[x_m(k-1)+\int_{k-1}^{k}F[x_m(\tau),u(k-1)]d\tau\right] \quad (3)$$

Step-2: Determine the value of $u_p(k)$ by solving the non-linear algebraic equations

$$F[x_m(k),u_p(k)]=0 \quad (4)$$

Step-3: Compute the value of $u_c(k)$ as given in (5).

$$u_c(k)=K_ce(k)=K_c\left[y_{sp}(k)-y(k)\right] \quad (5)$$

where, K_c is the controller gain, which can be optimally determined by minimizing a suitable performance measure. It may be noted that y_{sp} is the set point and y is the measured process variable. The value of $u_A(k)$ is computed as follows:

$$\begin{aligned}u_A(k)&=u_p(k)+u_c(k)\\&=u_p(k)+K_c\left[y_{sp}(k)-y(k)\right]\end{aligned} \quad (6)$$

Step-4: If the computed value of $u_A(k)$ is outside the feasible region, then it is projected to the boundary to obtain the constrained value of the controller output $u(k)$ as given below:

$$u(k)=u_{min}\le u_A(k)\le u_{max} \quad (7)$$

where, u_{max} and u_{min} are the upper and lower bounds associated with the manipulated variable. It should be noted that $u(k)$ is applied as an input to the non-linear system.

3. NMBC OF VARIABLE AREA TANK PROCESS

The process considered is the tank, conical in shape in which the liquid level is to be maintained at desired value. This is achieved by controlling the liquid inflow into the tank. The governing equation of the conical tank is as follows.

$$A(h)\frac{dh}{dt}=F_{in}-F_{out} \quad (8)$$

where F_{in} is inflow rate expressed in cm^3/s , F_{out} is the outflow rate expressed in cm^3/s and h is the liquid level expressed in *cm*. $A(h)$ is the cross-sectional area of the tank corresponding to the liquid level h .

$$A(h)=\frac{\pi R^2h^2}{H^2} \quad (9)$$

where H is the maximum height of the tank and R is the maximum radius of the tank.