ISA Transactions xxx (2018) 1–9

Contents lists available at ScienceDirect

ISA Transactions

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

Practice article

Experimental validation of predictor-corrector approach based control schemes on the laboratory scale non-linear system

S. Kapil Arasu, J. Prakash*

Department of Instrumentation Engineering, Madras Institute of Technology Campus, Anna University, Chennai-44, India

A R T I C L E I N F O

Article history:
Received 26 March 2017
Received in revised form
6 February 2018
Accepted 16 February 2018
Available online xxx

Keywords:
Model-based controller
Multiple-model based controller and
variable area tank system

A B S T R A C T

In this work, the authors have designed and implemented predictor-corrector approach based control schemes for a single input-single output nonlinear system. The controller output is computed in two steps. The first step explicitly uses a non-linear model or multiple-linear models weighted using fuzzy membership function to compute the value of the controller output. The second step is based on the measurement, where the value of the controller output computed in first step is updated. The extensive simulation studies show that the set-point tracking and disturbance rejection capability of the proposed control schemes are found to be satisfactory in the absence and presence of Model-plant mismatch. The performances of the proposed control schemes have been compared with that of a gain-scheduled PI controller. In addition, the control schemes are experimentally validated on the laboratory scale conical tank experimental setup.

1. Introduction

Plethora of design techniques for linear controller which takes into consideration either robustness specifications or performance requirements in the design stage have been reported in the control literature. Yet a single linear controller cannot guarantee the performance of the controller over a wide operating region. The model based control has gained widespread acceptance in the field of process system engineering to optimally control systems under various constraints. The accuracy of the model has a significant impact on the performance of model based control schemes. Hence adaptive control mechanism provides the way for the use of linear control schemes to control nonlinear process. The concept of multiple-linear model based approaches for controller design [1–3] has gained attention in the process control community. Also numerous multi-model based adaptive control schemes have been reported in literature [4–8]. Real-time implementation of multiple-linear model based control scheme on laboratory scale process has been reported in Ref. [9].

It should be noted that, variable-area tank process has been considered as a bench-mark system to demonstrate the efficacy of adaptive control schemes. Design of globally linearized control for the conical tank process using variable transformations is reported in Ref. [10]. Limitations of PI controller and the effectiveness of the gain scheduled controller for the conical tank process is reported in Ref. [11]. Neural network based dynamic programming is used for the design of adaptive time-optimal control of the conical tank process [12]. Use of adaptive neural networks for robust control of nonlinear system has been reported in Ref. [13]. A fuzzy scheduled controller based on robustness, tracking, disturbance rejection and overall aggressiveness (RTDA) to control nonlinear processes is reported in Ref. [14]. Use of fuzzy systems to implement adaptive control have been reported in Refs. [15,16]. The most widely used control scheme for the control of variable area tank process is the gain scheduled form of adaptive controller. However the performance of the standard gain scheduled controller reported in Ref. [17] is not optimal in all cases.

The main contribution of the paper is to design and implement simple model based control schemes, as an alternative to the existing gain scheduled controller, providing better performances for a SISO nonlinear system. The proposed prediction-correction type nonlinear feedback control scheme employs a process model directly within the controller. The model could be either a single nonlinear model or a nonlinear model consisting of multiple linear models weighted using fuzzy membership function. The controller output is computed in two steps. The first step explicitly uses the model of the plant to compute the value of the controller output. In the second step, based on the measurement, the computed value of

* Corresponding author.
E-mail address: prakaiit@gmail.com (J. Prakash).

https://doi.org/10.1016/j.isatra.2018.02.020
0019-0578/

Please cite this article in press as: Kapil Arasu S, Prakash J, Experimental validation of predictor-corrector approach based control schemes on the laboratory scale non-linear system, ISA Transactions (2018), https://doi.org/10.1016/j.isatra.2018.02.020

the controller output is updated. The efficacy of the proposed control schemes is validated via extensive simulation and experimental studies.

The organization of the paper is as follows: Section 2 discusses the evolution and design of proposed control schemes using predictor-corrector approach for a nonlinear system. Simulation results for the conical tank system are presented in section 3, and experimental validation is reported in section 4, followed by concluding remarks in section 5.

2. Control schemes using predictor-corrector approach for a SISO nonlinear system

2.1. Design of model based control scheme for a SISO linear system

The transfer function of the PI controller is given by:

$$\frac{u(s)}{e(s)} = K_c\left[1+\frac{1}{\tau_i(s)}\right]. \tag{1}$$

The above equation can be re-written as:

$$\left[1-\frac{1}{\tau_i(s)+1}\right]u(s) = K_c e(s). \tag{2}$$

[18] suggests the realization of integral action as a positive feedback around a lag. Also during practical implementation of a controller, it is necessary to restrict the controller output within desired limits. Hence to maintain the controller output within desired bounds, (2) should be practically implemented as Fig. 1

From Fig. 1, it can be inferred that a first order model with unity gain is used implicitly in a PI controller regardless of the order of the process to be controlled [19]. Model based design of PI control schemes such as Internal Model Control and Direct Synthesis method recommend that the integral time constant of the controller (τ_i) should be equal to the dominant time constant of the process (τ). If $\tau_i = \tau$, then the $\frac{1}{1+\tau_i s}$ present within the controller in Fig. 1 can be replaced with $\frac{1}{1+\tau s}$. Most of the chemical process can be approximated as a first order plus dead time process with process gain (K), time constant (τ) and dead time (L). PID controller with dead-time compensation allows the inclusion of process dead-time within the integral action [20]. For dead-time dominant process, the $\frac{e^{-Ls}}{1+\tau s}$can be used within the controller.

If the process model $G_p(s) = \frac{Ke^{-Ls}}{1+\tau s}$ is available, then the model based PI controller for a first order plus dead-time process can be realized as shown in Fig. 2.

From Fig. 2, it could be inferred that a model based controller, which employs model based prediction and measurement based correction with a single tuning parameter could be realized. The positive feedback around the controller helps the process variable to asymptotically approach the set point (zero steady state error).

2.2. Design of predictor-corrector approach based control scheme for the SISO non-linear system using the non-linear model and measurement

Let's assume that a deterministic non-linear system can be represented using the state and measurement equations as given below:

$$\left.\begin{aligned} \frac{dx}{dt} &= f[x(t),u(t),d(t)] \\ y(t) &= x(t) \end{aligned}\right\}. \tag{3}$$

Where, $x(t)\in R$ is the state variable, $u(t)\in R$ is the manipulated input variable, $d(t)\in R$ denotes the disturbance variables and $y(t)\in R$ is the measured output variable.

For the purpose of simulation, the model is discretized as follows:

$$\left.\begin{aligned} x(k) &= \left[x(k-1)+\int_{t_{k-1}=(k-1)T}^{t_k=kT} f[x(\tau),u(k-1),d(k-1)]\,d\tau\right] \\ &= [F(x(k-1),u(k-1),d(k-1))] \\ y(k) &= x(k) \end{aligned}\right\}. \tag{4}$$

where, T is the sampling time. In the above equation, the manipulated input (u) and disturbance variables (d) are modelled as piece-wise constants between the interval $(k-1)T \le t \le kT$.

The block diagram of the proposed predictor-corrector approach based control scheme using the nonlinear model, is shown in Fig. 3.

The computation of the controller output at each sampling instant is as follows:

Step-1 Computation of Controller Output using Non-linear Model.

Step-1a The model state ($x_m(k)$) is computed as follows:

$$x_m(k) = \left[x_m(k-1)+\int_{t_{k-1}=(k-1)T}^{t_k=kT} f\left[x_m(\tau),u(k-1),\bar{d}\right]d\tau\right]. \tag{5}$$

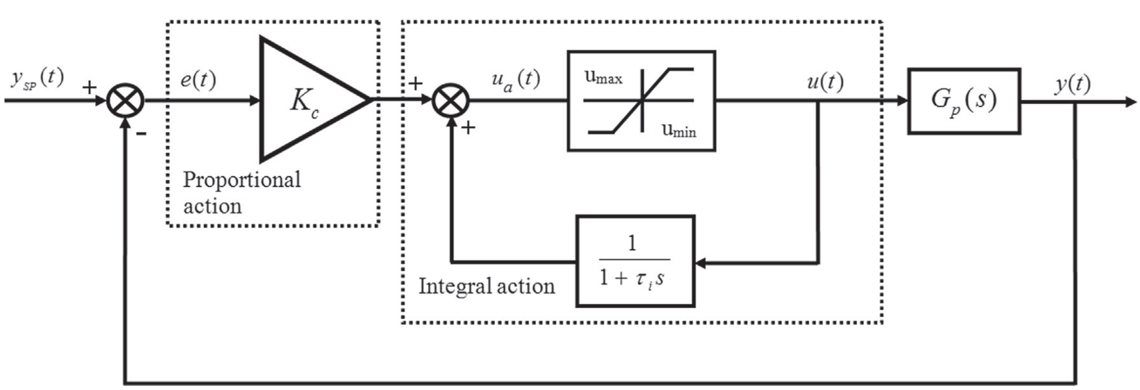

Fig. 1. Block diagram of PI controller in reset configuration with anti-reset windup.

Please cite this article in press as: Kapil Arasu S, Prakash J, Experimental validation of predictor-corrector approach based control schemes on the laboratory scale non-linear system, ISA Transactions (2018), https://doi.org/10.1016/j.isatra.2018.02.020