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Self-tuning regulator for an interacting CSTR process

Niraj Rajendra Mungale, Akshay Upadhyay and B Jaganatha Pandian

School of Electrical Engineering, VIT University, Vellore - 632014, Tamil Nadu, India.

E-mail: jaganathapandian@vit.ac.in

Abstract: In the paper we have laid emphasis on STR that is Self Tuning Regulator and its application for an interacting process. CSTR has a great importance in Chemical Process when we deal with controlling different parameters of a process using CSTR. Basically CSTR is used to maintain a constant liquid temperature in the process. The proposed method called self-tuning regulator, is a different scheme where process parameters are updated and the controller parameters are obtained from the solution of a design problem. The paper deals with STR and methods associated with it.

1. Introduction

Mostly the chemical process is non-linear by nature. A description of various Continuous Stirred Tank Reactor Control schemes is shown below:

1.1. Gain Scheduling:

Here in this process the gain is measured then it schedules the controller for compensating process gain changes. Following is the block diagram of the above scheme:

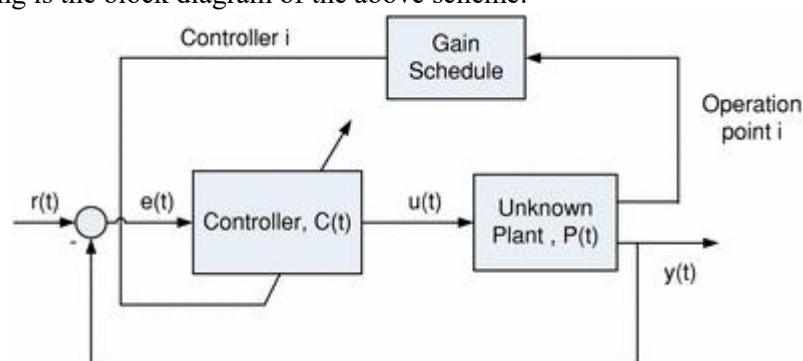


Figure 1. Gain Scheduling

Inner loop is made up of process & controller and the outer one is used to update the controller parameters on the basis of the process working conditions [5].

1.2. Model Reference Adaptive System:

In this scheme a closed loop controller is constructed with various parameters which can be modified to get the desired response of the system [5]. The output is then compared with the reference model desired output and an ERROR is generated.

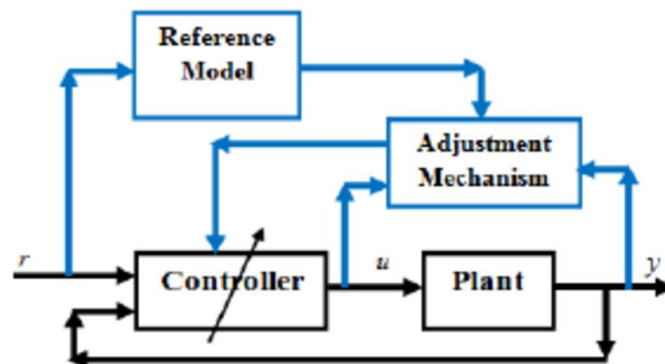


Figure 2. MRAC

1.3. Self Tuning Regulator

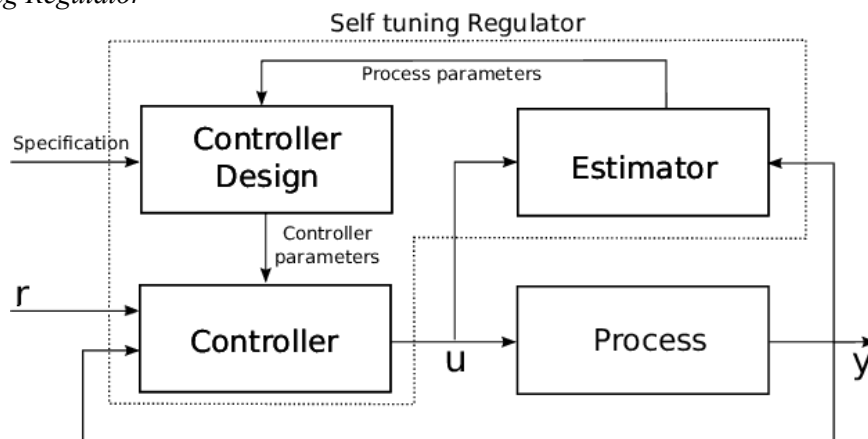


Figure 3. STR

STR is an indirect method of controlling process. In many processes the dynamics of the process and disturbances are unknown & so it becomes difficult to find the controller parameters. Therefore we need to estimate the process parameters [4]. Such a controller can tune the parameters on its own to get the requirements of a closed loop system.

1.4. Adaptive Control:

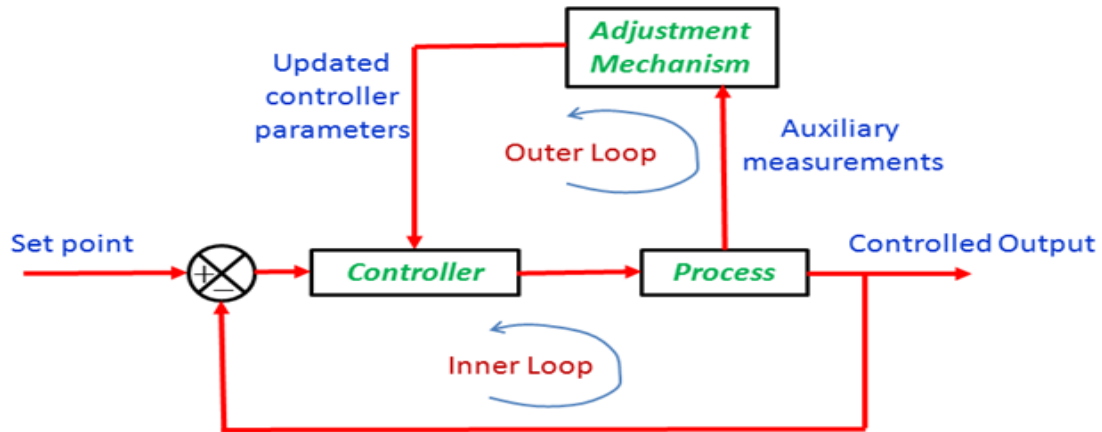


Figure 4. Adaptive Control

We must know what happens if the process fluctuates from the point of operation. It may lead to efficiency issues of the controllers. Thus we need to update and tune the parameters of the controller again to overcome such a drawback [1]. For this we use an automatic tuning/updating scheme and hence the controller is termed as Adaptive Controller.

The objective of our project is to validate a Self-Tuning-Regulator approach for controlling a high dimensional control problem.

2. Methodology

2.1. System Description

System under consideration here is Interacting CONTINUOUSLY STIRRED TANK REACTOR (CSTR). Schematic representation of CSTR system can be shown in the diagram below.

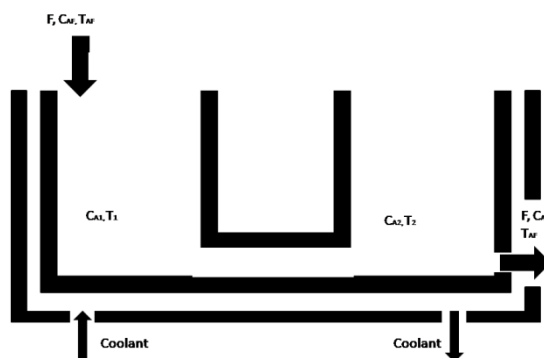


Figure 5. Interacting CSTR schematic

Since Self Tuning Regulator is to be considered, there is no need for linearization of model. Thus, direct differential equation model for interacting CSTR system can be used. Ordinary Differential Equation (ODE) model is used for CSTR system. It has following differential equations governing the system:

$$\frac{dC_{A1}}{dt} = \frac{q(C_{Af} - C_{A1})}{V_1} - K_0 C_{A1} e^{-\frac{E}{RT_1}} \quad \{eqn. 1\}$$

$$\frac{dT_1}{dt} = \frac{q(T_f - T_1)}{V_1} + \left(\frac{dHK_0}{\rho C_p}\right) C_{A1} e^{-\frac{E}{RT_1}} + \frac{\rho_c C_{pc}}{\rho C_p V_1} \times q_c \left(1 - e^{-\frac{-U_{A1}}{q_c \rho_c C_{pc}}}\right) \times (T_{cf} - T_1) \quad \{eqn. 2\}$$

$$\frac{dC_{A2}}{dt} = \frac{q(C_{A1} - C_{A2})}{V_2} - K_0 C_{A2} e^{-\frac{E}{RT_2}} \quad \{eqn. 3\}$$

$$\begin{aligned} \frac{dT_2}{dt} = & \frac{q(T_1 - T_2)}{V_2} + \left(\frac{dHK_0}{\rho C_p}\right) C_{A2} e^{-\frac{E}{RT_2}} + \frac{\rho_c C_{pc}}{\rho C_p V_2} \times q_c \left(1 - e^{-\frac{-U_{A2}}{q_c \rho_c C_{pc}}}\right) \\ & \times \left(T_1 - T_2 + e^{-\frac{-U_{A2}}{q_c \rho_c C_{pc}}} \times (T_{cf} - T_1)\right) \quad \{eqn. 4\} \end{aligned}$$

Input in this case is Coolant flow rate. For model considered in this paper, it is 100 L/min. However, since simulation is to be done on MATLAB, random white Gaussian noise is added in the input, so as to get random input and random output data for estimation process. System considered here is higher dimensional, hence linearizing it is a difficult task which cannot give sufficient performance satisfaction [2]. Thus, direct estimating system parameters from given input output data, makes it faster and reliable.

Assuming numerator order 1 and denominator order 4 for given system, we run Recursive Least Square algorithm for obtained I/O data to get system parameter. i.e. Transfer function of unknown system. Parameter to be controlled here is temperature in Tank 2 for disturbances in input. Thus transfer function obtained is with respect to temperature in tank two.

2.2. Controller Design

Controller used here is Self Tuning Regulator (STR). Main block diagram of system with STR can be shown as,

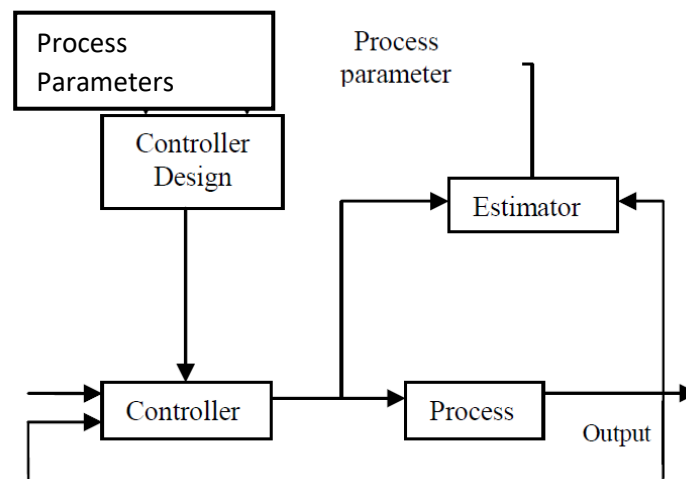


Figure 6. Block diagram of system with STR

First part of any STR is an estimator. Estimator is a system which treats entire process as a black box and tries to identify the system parameters with the help of input output data. As system parameters are very much important part of STR, main emphasis should be on estimation of process parameters/ system parameters.

Estimator used here is Recursive Least Square Estimator (RLS Estimator). Main feature of RLS estimator is it minimizes sum of error squares. It takes input and output data as input, and also takes desired system model as an input. It gives system parameters, in terms of numerator polynomial, denominator polynomial and transportation delay [3]. Thus we can construct process transfer function from RLS estimator output. As the process involved here is higher dimensional and not linearized, we use numerator order as 1 and denominator order as 4. This gives almost exact performance for system around current operating point.

Next stage of STR is controller design. We assume model structure which system needs to follow. Let that model structure be G_m . From estimator model received is G_p . With the help of controller, we can make system to follow G_m even though original transfer function is G_p . By using Minimum Degree Pole Placement (MDPP) technique, controller can be designed as follow:

System Structure for MDPP is-

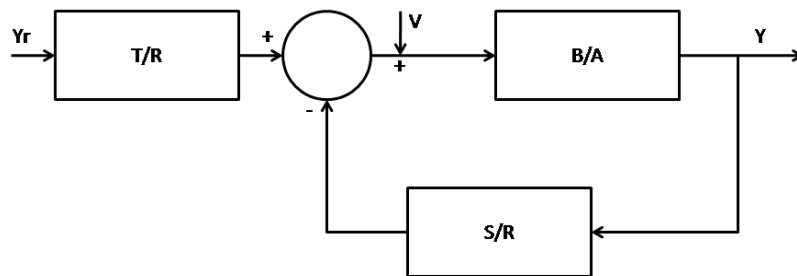


Figure 7. Block Diagram for MDPP

Using MDPP, R, S, T is designed which provide main function of controller. Then next stage is developing control law for STR. As it can be seen from above block diagram, control law for STR becomes,

$$R \times u(t) = T \times y_r(t) - S \times y(t)$$

Thus main part is designing R, S and T vectors, which will give controller a proper structure.

After designing R, S, T, we repeat steps from estimation up to building control law, for each sampling instance.

3. Results

Input output data is used for estimation of process parameters. As, the process is considered to be 4th order, expected transfer function is in the form of

$$\frac{b_0 + b_1 z^{-1}}{1 + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3} + a_4 z^{-4}}$$

And estimated results from RLS algorithm are

$$\frac{3.032 - 0.1961z^{-1}}{1 - 0.1563z^{-1} - 0.12z^{-2} + 0.09623z^{-3} - 0.02653z^{-4}}$$

To verify whether estimated model gives satisfactory performance, same input was given to estimated model but without noise added. Results for that simulation are as following-

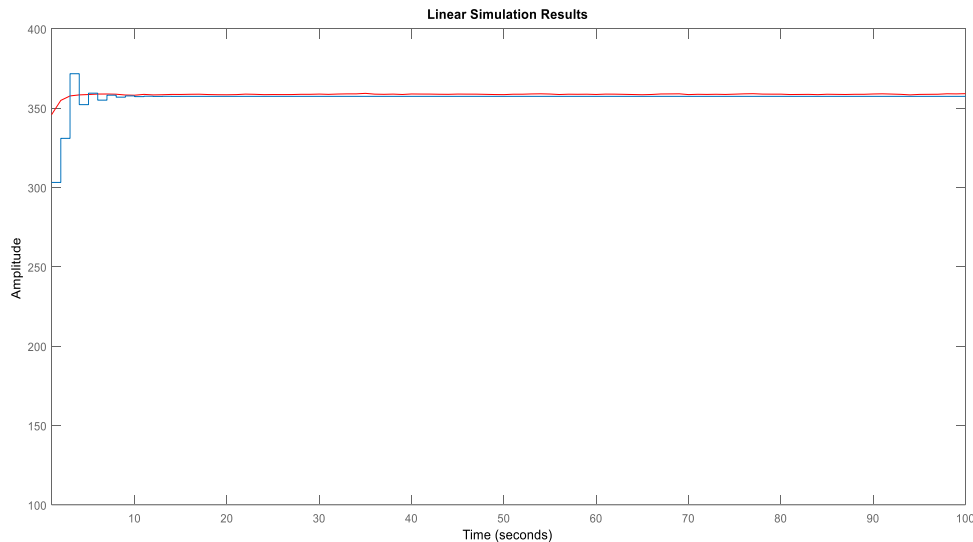


Fig8. Simulation results for both, actual process and estimated transfer function.

As it can be observed, red graph is for original process, for coolant flow rate of 100 L/min. same input was fed to estimated transfer function, and simulated in MATLAB. That result is in blue graph. It can be observed that, both systems give almost identical performance, showing accuracy of RLS algorithm used.

References:

- [1] Åström K J, Borisson U, Ljung L and Wittenmark B 1977 Theory and applications of self-tuning regulators *Automatica* **13(5)** 457-476
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