Application of Adaptive control In a Process control

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Abstract: **This paper presents the performance evaluation on the application of model reference adaptive control with various types of command inputs in a process plant. In the design of model reference adaptive control (MRAC) scheme, adaptive law have been developed based on Lyapunov stability theory .This paper deals with basic simulation studies on of the Continuous Stirred Tank Reactor (CSTR). The mathematical model is developed from material balances. Numerical mathematics is used for steady-state analysis and dynamic analysis which is usually represented by a set of differential equations. A simulation is carried out using Mat lab and Simulink to control the process system using the adaptive control algorithm. It is also utilized to show that the adaptive controller will be superior to the conventional controller even without parameters change in the process In a real world situation, these parameters could be estimated by using simulations or real execution of the system. It may possible to improve the performance of the adaptive controller by further modifying the adaptation law or by incorporating parameter identification in to the control.**

I. INTRODUCTION

In common sense, 'to adapt' means to change a behavior to conform to new circumstances. Intuitively, an adaptive controller is thus a controller that can modify its behavior in response to the changing dynamics of the process and the character of the disturbances. The core element of all the approaches is that they have the ability to adapt the controller to accommodate changes in the process. This permits the controller to maintain a required level of performance in spite of any noise or fluctuation in the process. An adaptive system has maximum application when the plant undergoes transitions or exhibits non-linear behavior and when the structure of the plant is not known. Adaptive is called a control system, which can adjust its parameter automatically in such a way as to compensate for variations in the characteristics of the process it control.

II. MODEL REFERENCE ADAPTIVE CONTROL

Model reference adaptive controller (MRAC) is a controller used to force the actual process to behave like idealized model process. MRAC systems adapt the parameters of a normal control system to achieve this match between model and process.

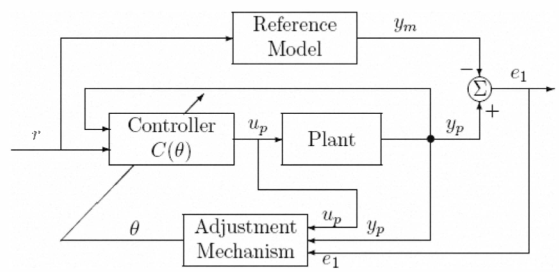

Fig. 1. Model reference adaptive control

The standard implementation of MRAC based systems contains the four key blocks shown above. The reference model defines the desired performance characteristics of the process being controlled. The adaptation law uses the error between the process and the model output, the process output and input signal to vary the parameters of the control system. These parameters are varied so as to minimize the error between the process and the reference model.

III. MATHEMATICAL MODELING

The examined reactor has real background and graphical diagram of the CSTR reactor is shown in Figure 2. The mathematical model of this reactor comes from balances inside the reactor. In this module we consider a perfect mixed continuously stirred tank reactor (CSTR) shown in figure 2. The case of a single, first-order exothermic irreversible reaction A_ B will be studied. In figure 2 we see that a fluid stream is continuously fed to the reactor and other fluid stream is continuously removed from the reactor. Notice that: a jacket surrounding the reactor also has feed and exit streams. The jacket is assumed to be perfectly mixed and at lower temperature than the reactor. Energy passes through the reactor walls into jacket, removing the heat generated by reaction.

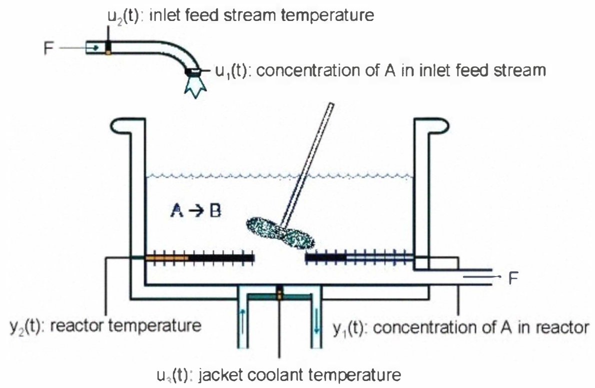

Figure 2 Continues stirred tank reactor with cooling jacket

Put together, the CSTR has three input signals:
u1(t) = C_{Af} Concentration of feed stream .
u2(t) = T_f Inlet feed stream temperature.
u3(t) = Tj Jacket coolant temperature .

and two output signals:
y1(t)=C_A Concentration of A in reactor tank .
y2(t) = T Reactor temperature.

3.1 Overall material balance

The CSTR system is modeled using basic accounting and energy conservation principles.

Rate of material accumulation = rate of material in – rate of material out

$$dV\rho/dt = F_{in}\rho_{in} - F_{OUT}\,\rho_{OUT}$$

Assuming constant volume and constant density

$F_{in}\rho_{in} = F_{OUT}\,\rho_{OUT}$

$F_{in} = F_{OUT}$ and $dV/dt=0$ .... (1.1)

$$V\, dC_A/dt = FC_{Af} - FC_A - rV \quad \text{... (1.2)}$$

Energy balance
Assuming constant Cp

$$V\rho C_P dT/dt = F\rho C_P(T_f - T) + (-\Delta H)Vr - UA(T - T_j) \quad ..(1.3)$$

3.2 State variable form of dynamic equation

We can write equation (1.2) and equation (1.3) as:

$f_1(C_A,T) = dC_A/dt = F/V(C_{Af} - C_A) - r$

$f_2(C_A,T) = dT/dt = F/V(Tf - T) + (-\Delta H/\rho Cp)r - UA/V\rho Cp(T - Tj)$

And r = KCA,
r= Koexp (-E/RT) CA

$$f_1(C_A,T) = dC_A/dt = F/V(C_{Af} - C_A) - K_O\, exp(-E/RT)C_A \quad ...(1.4)$$

$$f_2(C_A,T) = dT/dt = F/V(T_f - T) + (-\Delta H/\rho C_P)K_0 exp(-E/RT)C_A - UA/V\rho C_P(T - T_j) \quad ....(1.5)$$

3.3 Steady State Solution

The steady state solution is obtained when dCA/dt= 0 and dT/dt=0, that is

$$f_1(C_A,T) = dC_A/dt = 0 = F/V(C_{Af} - C_A) - Koexp(-E/RT)C_A \quad ....(1.6)$$

$$f_2(C_A,T) = dT/dt = 0 = F/V(T_f - T) + (-\Delta H/\rho C_P)K_0 exp(-E/RT)C_A) - UA/V\rho C_P(T - T_j) \quad ....(1.7)$$

To solve these two equations, all parameters and variables except for two (C_A and T) must be
Specified.

Table a. Reactor Parameter's value

Reactor parameters	Values
F/V,hr-1	4
Ko,hr-1	15e12
(-ΔH),BTU/lbmol	40000
E, BTU/lbmol	33500
ρCp, BTU/ft^3	54.65
Tf,'c	70
Caf, lbmol/ft^3	.132
UA/V	122.1
Tj,'c	60

3.4 Guess 1

High concentration (low conversion) and low temperature.
We consider an initial guess of CA=8 and T=300K.
X= ode45 (@reactor [0 10], [0.1;40],[],60);
X =
0.056
312
So the steady-state solution for guess 1 is C_{As}=0.056 and Ts=312

3.5 *Linearization of Dynamic Equation*

The stability of the non-linear equation can be determined by finding the following state space
form:
X' = AX + BU
And determine the eigen values of the A (state space) matrix.
The non-linear dynamic equation (1.8) and (1.9) are

$F_1(C_A, T) = dC_A/dt = F/V(C_{Af} - CA) - koexp(-E/RT)\, C_A$
$F_2(C_A, T) = dT/dt = F/V(T_f - T) + (-\Delta H/\rho Cp)\, koexp(-E/RT)\, C_A - UA/V\rho Cp\,(T - Tj)$

Let the state and input variables be defined in deviation variable form:

$$X = \begin{bmatrix} C_A - C_{AS} \\ T - T_S \end{bmatrix} \qquad U = \begin{bmatrix} F - F_S \\ T_J - T_{JS} \end{bmatrix}$$

3.6 *Stability Analysis*

Two-state (Jacket Temperature Input) Model .The steady-state operating p o i n t i s C_{As}, = 0.056, *Ts,* = 312k.

The state space model is (the time unit is hours), where the states are concentration and reactor temperature, and jacket temperature is the manipulated input performing the linearization, we obtain elements for A. The stability of particular operating point is determined by finding the A-matrix for that particular operating point and finding the Eigen values of the A-matrix Substituting the values for the lower temperature steady state point, we have

$$A= \begin{bmatrix} -7.3929 & -0.014674 \\ 2622.9 & 4.7534 \end{bmatrix}$$

Then to find the eigenvalues, In Mat lab command we write

```
>>
A= [7.3929, -0.014674; 2622.9, 4.7534];
>>Lambda = eig (A);
>>Lambda=
                    -1.3134
                    -1.3567
>>
```

Both of the eigenvalues are negative, indicating that the point is stable. similarly we find B matrix and Once we found the A, B the transfer function that relate the input to output is obtained by using the Mat lab command.

IV. ADAPTATION LAW

The adaptation law attempts to find a set of parameters that minimize the error between the plant and the model outputs. To do this, the parameters of the controller are incrementally adjusted until the error has reduced to zero. A number of adaptation laws have been developed to date. The two main types are the gradient and the Lyapunov approach and we have use lyapunov approach.

V. ADAPTIVE CONTROL DESIGN AND SIMULATION

This set provides the implementation of a basic adaptive controller using Simulink. The first item that must be defined is the plant that is to be controlled. We have got the transfer function for the two SISO systems (concentration and temperature of reaction control) as

a) Concentration control

The simplified transfer function model of the process given as:

$$G_P1(s) = \frac{1.478s + 11.02}{s^2+3.391s+3.34} \qquad (2.0)$$

The next step is to define the model that the plant must be matched to. To determine this model we must first define the characteristics that we want the system to have. Firstly we will arbitrary select the model to be a second order model of the form:

$$Gm(s) = \frac{\omega_n^2}{s^2+2\omega_n\xi s + \omega_n^2} \qquad (2.1))$$

We must then determine the damping ratio ξ and the natural frequency ω_n to give the required performance characteristics. For the concentration control a maximum overshoot (Mp) of 5% and a settling time (Ts) of less than 2 seconds are selected. We can use the equation below to determine the required damping ratio and natural frequency of the system.

$$\xi = \frac{\ln Mp/100}{-\pi} \sqrt{\frac{1}{1+\left[\frac{\ln Mp/100}{-\pi}\right]^2}} \qquad \text{.......(2.2)}$$

Equation 2.2.Damping ratio for Maximum Overshoot

$$\omega_n = \frac{3}{\xi\, Ts} \qquad \text{..... (2.3)}$$

Equation 2.3 .Natural frequency from settling time and damping ratio .Based upon these formulae we get ξ=0.71 and ω_n=2.1834 rad/s. The transfer function for the model is therefore.

$$Gm(s) = \frac{4.76}{S^2+ 3.1s + 4.76} \qquad \text{..... (2.4)}$$

Equation 2.4 Model transfer function

Note that we have defined the plant we need to develop a standard controller to compare with the adaptive controller. Controller setting is done using Ziegler-Nicholas technique and the best controller parameters are found to be Kc=10, tI=1 and td=1.

The following parameters are plotted on graph: plant output with adaptive and with conventional control, model output, error between plant and model outputs and the controller parameters.

5.1 Comparison without noise

Note that the model is complete; the first task we must perform is to compare the performance of the two controllers for a step input and no noise

a)concentration

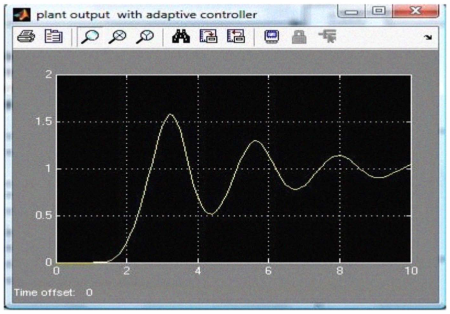

Figure 3. Plant output{concentration) with adaptive control (step input, no noise, Gamma=0.99

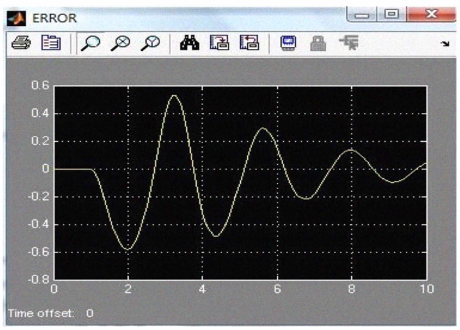

Figure 4. Error (step input, no noise, Gamma=0.99)

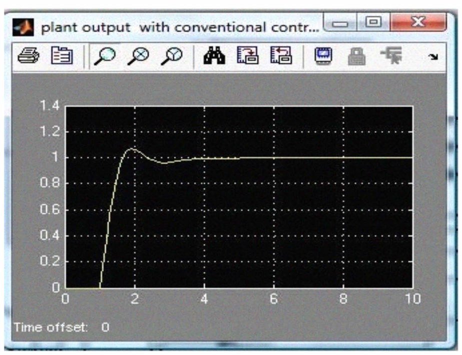

Figure 5. Plant output with conventional control (step input, no noise, Gamma=0.99)

Looking at figure 3 and figure 5, one of the major disadvantages of adaptive control is immediately apparent. It takes the adaptive controller nearly 20 seconds to match perfectly the output of the reference model. However the conventional controller is matched within 2 seconds. The overshoot of the adaptive controller is also excessive (of the order of 50%) while the conventional controller has an overshoot of below 3%. One method of addressing this problem is to increasing the adaptation gain (Gamma).

5.2. Comparison without noise and increasing adaption rate

a)concentration

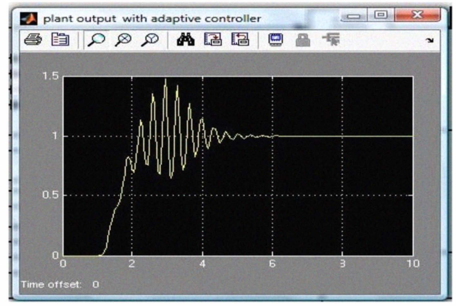

Figure 6.Plant output with adaptive control (step input, no noise, Gamma=100)

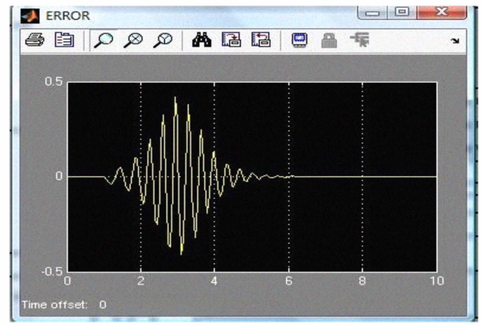

Figure 7.Error (step input, no noise, Gamma=100)

This has improved the overshoot to below 10% and the settling time is now less than 10 seconds.

5.3 Comparison with ramp noise

The next logical step is to compare the performance of the two controllers in the presence of noise in the form of ramp signal, (slope=1). The adaptation gain has been restored to 0.99.

a)concentration

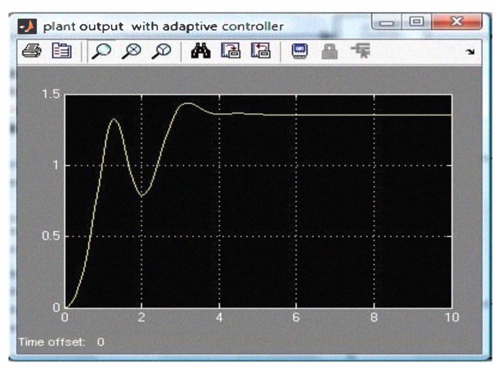

Figure 8. Plant output (concentration) with adaptive control (step input, ramp noise, Gamma=0.99)

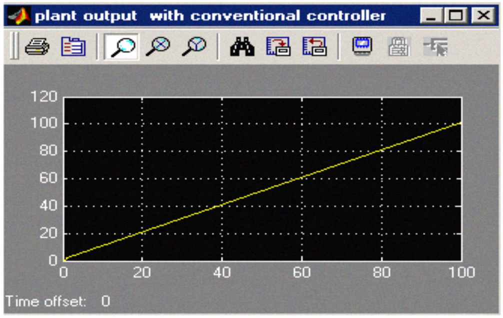

Figure 9. Plant output (concentration)with conventional control (step input, ramp noise, Gamma=0.99)

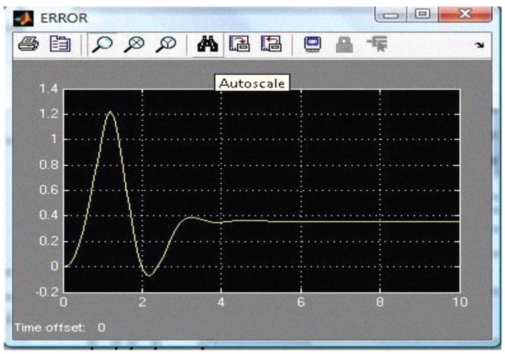

Figure 10.Error (concentration)(step input, ramp noise, Gamma=0.99)

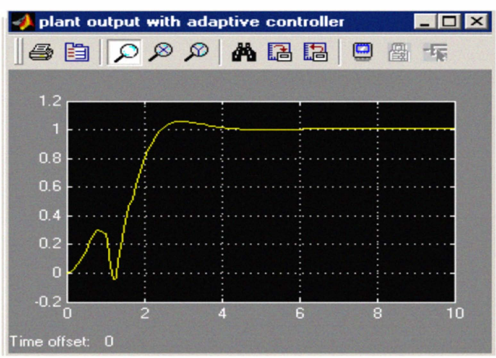

Figure 11.Plant output(concentration) with adaptive control (step input, ramp noise, Gamma=100)

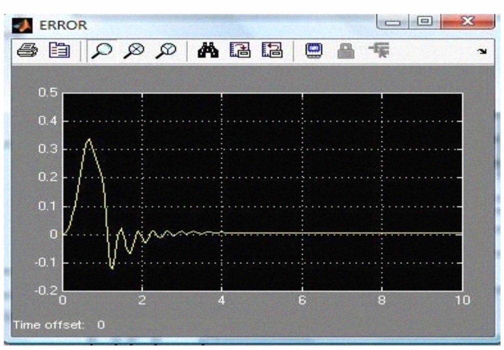

Figure 12.Error (concentration)(step input, ramp noise, Gamma=100)

The situation begins to show the actual advantages of adaptive control. In this case the conventional controller is incapable of maintaining even a stable system. On the other hand the adaptive control manages to maintain stability.

CONCLUSION

The proposed adaptive controller is tested by using Math lab Simulink program and its performance is compared to a conventional controller for a different situation. The paper demonstrated that while the adaptive controller exhibits superior performance in the presence of noise the convergence time is typically large and there is a large overshoot. To resolve these problems of adaptive controller, the proposed controller is redesigned by modifying the adaptation law. And the results show a significant improvement in the performance of the adaptive controller without excessive increase in the adaptation rate.

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