Computer Engineering and Intelligent Systems
ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online)
Vol.4, No.5, 2013
www.iiste.org

Brain Emotional Learning Based Intelligent Controller And Its Application To Continuous Stirred Tank Reactor

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Abstract

This paper investigates an intelligent control approach towards Continuous Stirred Tank Reactor in chemical engineering. CSTR is a well known in process control and it offers a diverse range of research in chemical and control engineering. Brain emotional learning based intelligent controller (BELBIC) is an intelligent controller based on the model of Limbic system of brain. Our objective is to implement Computational Model of Brain Emotional Learning Based Intelligence Controller(BELBIC) and its Application To CSTR . Model design and simulations are done in MATLAB™ SIMULINK® software.

Keywords: CSTR, BELBIC, Limbic system, Amygdala, Orbitofrontal cortex

1. Introduction

Emotional behavior of humans and animals play an important role in determining their intelligence, an intelligent system with a fast learning ability can thus be created by modeling a Brain Emotional Learning system. J. Moren and C. Balkenius [1], [2] evaluated the learning of the brain limbic system by constructing a computational model of emotional learning and processing inspired by neurological findings. Biologically inspired method such as the evolutionary algorithm has been employed to solve complex computational problems in the past. They developed the role of the amygdala and orbitofrontal cortex and reproduced a model to mimic the characteristics of the biological systems and simulated the same proving the associative learning ability of the model.

Caro Lucas et al [3] introduced the “Brain Emotional Learning Based Intelligent Controller” – BELBIC: a controller based on the computational model of limbic system of mammalian brain. The controller was applied to some Single Input Single Output, Multiple Input Multiple Output and non-linear systems, the results gives excellent control action, disturbance handling and system parameter robustness. Farzan Rashidi et al [4] proposed several effective speed regulation controllers for DC motors which included: Fuzzy auto tuning, GA based PID controller, GA based fuzzy PID controller, Fuzzy PID controller using Neural network and BELBIC. Simulation results showed that fuzzy PID controller and BELBIC controller gave better results than others. Ali Mehhrabian et al [5] applied BEL controller to some non-linear uncertain systems such as: Van Der Pol oscillator, Duffing forced oscillator and Automatic self balancing scale. Simulation results showed the robustness and adaptability of BEL controllers for uncertain systems giving a satisfactory performance. Caro Lucas et al [6] compared the performance of locally linear Neuro-fuzzy (LLNF) model tree system and BEL controller to control a washing machine. Simulation results illustrated the control parameters for BEL controller was better than the LLMF. Also when compared for energy consumption BEL controller proved to be more efficient. Hossein Rouhnai et al. [7] evaluated the performance of BEL controller for an electrically heated micro-heat exchanger using locally linear model tree (LoLiMoT) for system dynamics identification. The closed loop system performance using BELBIC was compared with that of PID controller. Results show that BELBIC controller had better settling time, overshoot and better stability as compared to PID controller. Guoyong Huang et al [8] investigated the applicability of BELBIC to control an Unmanned Aerial Vehicle (UAV). They applied BELBIC to attitude stability control loop under the conditions of UAV with wind disturbance in flat flight process. Simulation results illustrate that the BELBIC showed good adaptability and robustness. Naghmeh Garmsiri and Farid Najafi [9] proposed a Sugeno Fuzzy inference system (FIS) to tune the parameters of BEL controller dynamically during the control procedure. They applied the system to a 2 degree of freedom rehabilitation robot while tracking different reference trajectories. Simulated results revealed that dynamically changing parameters provide better performance in different conditions of a particular control trend as compared to rigid setting of BELBIC parameters. Hassen T. Dorrah et al [10] used particle Swarm Optimization – BEL

(PSO-BEL) controller to control a two-coupled distillation column with 4 input/4 output process. They compared the PSO-BEL controller with PSO-PID controller and found PSO-BELBIC to be more useful. Although PSO-BELBIC had overdamped response but overall performance for PSO-BELBIC was more stable. ISE (integral square error) and e_{ss} (steady state error) both were less for PSO-BELBIC

2. CSTR

The continuous stirred-tank reactor (CSTR), also known as vat- or backmix reactor is a common ideal reactor type in chemical engineering. A CSTR often refers to a model used to estimate the key unit operation variables when using a continuous agitated-tank reactor to reach a specified output. The mathematical model works for all fluids: liquids, gases, and slurries.

The behavior of a CSTR is often approximated by presuming perfect mixing. In a perfectly mixed reactor, the output composition is identical to composition of the material inside the reactor, which is a function of residence time and rate of reaction. If the residence time is 5-10 times the mixing time, this approximation is valid for engineering purposes. The CSTR model is often used to simplify engineering calculations and can be used to illustrate complex reactors.

CSTR has a wide variety of uses, including: anti freeze applications, aircraft de-icing; a solvent for a number of drugs, moisturizers and as artificial smoke of fog, for fire-fighting training or theoretical productions. For Example: It has been used for the production of propylene glycol by hydrolysis of propylene oxide with sulphuric acid being the catalyst[11]. The reaction involved is[11]:

$CH_2 – O – CH - CH_3 + H_2O \rightarrow CH_2OH – CH_2O – CH_3$

Water is supplied in excess, so the reaction is first order in propylene oxide concentration. The rate of reaction of propylene oxide is first order

$r_A = -k_0 \exp(-E_a/RT)\, C_A$

2.1 Mathematical Modelling

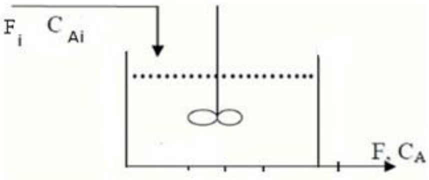

Figure1: Continuous Stirred Tank Reactor [11]

Ethylene oxide (A) is reacted with water (B) in a continuously stirred tank(CSTR) to form ethylene glycol (P). Assume that the CSTR is maintained at a constant temperature and that the water is in large excess. The stoichiometric equation is

A+B= P

The overall mass balance is [11]

$$\frac{\partial V\rho}{dt} = F_i \rho_i - F\rho$$

Assumption : The liquid phase density p is not a function of concentration. The vessel liquid (and outlet) density is than equal to the inlet steam density so

$$\rho_i = \rho$$

And we can write it as [11]

$$\frac{dV}{dt} = F_i - F$$

Let C_A and C_p represent molar concentrations of A and P (moles/volume). The component material balance equations are [11]

$$\frac{dVC_A}{dt} = F_i C_{Ai} - FC_A + V_{rA}$$

$$\frac{dVC_p}{dt} = -FC_{pi} + V_{rP}$$

Where r_A and r_p represents the rate of generation of species A and P per unit volume, and C_{Ai} represents the inlet concentrations of species A. Since the water is in large excess its concentration does not change significantly, and the reaction rate is in first order with respect to the concentration of ethylene oxide,

$r_A = -kC_A$

Where k is the reaction rate constant and the minus sign indicates that A is consumed in the reaction. Each mole of A reacts with a mole of B and produces a mole of P, so the rate of generation of p is,

$r_p = kC_A$

Energy balances on the vessel and fluids result in the following equations [11]:-

$$x_1 = \frac{dx_1}{dt} = u_1 - u_2 = f_1(x,u,p)$$

$$x_2 = \frac{dx_2}{dt} = \frac{u_1}{x_1} = (u_3 - x_2) - p_1 x_2 = f_2(x,u,p)$$

$$x_3 = \frac{dx_3}{dt} = -\frac{u_1}{x_1} x_3 + p_1 x_3 = f_3(x,u,p)$$

The state, input and parameter vectors are [11]

$$X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} V \\ C_A \\ C_p \end{bmatrix}$$

$$U = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} = \begin{bmatrix} F_i \\ F \\ C_{Ai} \end{bmatrix}$$

2.2 Parameters

The parameter values for the CSTR are as follows:

This system has the following activation energy, frequency factor and heat of reaction values:-[12]

Table 1

E_0	75.3624 Kj/Kg mol
K_0	47 * 10^8 sec^{-1}
-ΔH	90714 Kj/mol PO
U	425.8725W/ m^2 K
ρc_p	992.02 W/m^3 K
R	4.621Kj/Kg mol ^{o}F

Assume that the reactor is to be operated with the following residence time, feed concentration, and feed temperature [12]:-

Table 2

V/F	900 sec
C_M	0.644 Kgmol/m^2
T_f	288.706 K

Also assume the reactor is designed as a vertical cylinder with a height/diameter ratio of 2:1,that complete heat transfer area coverage occurs when the reactor is 75% full, and that the reactor is operated at 85% of the design volume.

Now at Reactor scale:

Table 3

PARAMETERS	**VALUE**
Reactor volume (nominal)	82.831 m^3
Heat transfer Area	8.175 m^2
Diameter	1.2192 m
Operating volume, V	2.406 m^3
Operating Flow rate, F	2.67*10^{-3} m^3/sec

3. Problem Formulation

The objective of the linearization is to find the transfer function is CSTR [12] :-

$$X' = Ax + Bu$$

$$y = Cx + Du$$

Where the states, inputs and output are in deviation variable

$$A = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{\partial f_1}{\partial u_1} \\ \frac{\partial f_2}{\partial u_1} \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

The linear transfer function of CSTR is

$$G_p = \frac{0.4099s+3.275}{0.2811s^2+0.9664s+1}$$

4. Brain Emotional Learning Based Intelligent Controller

BELBIC [14] is based on the architecture of the "Limbic System" of human brain. Limbic system is responsible for the emotional learning in human beings.

BELBIC is one such nonlinear controller – a neuromorphic controller based on the computational learning model shown above to produce the control action. This model is employed much like an algorithm in these control engineering applications. In these new approaches, intelligence is not given to the system from the outside but is actually acquired by the system itself.

The major components of the limbic system which cooperate with Amygdala in emotional processes. The input rudiments of the limbic system, and its connected cortical and subcortical areas, which are well thought-out for the model are the Amygdala, the Orbitofrontal Cortex, the Sensory Cortex and the Thalamus. These rudiments and their interactions with additional components of the limbic system. Besides, from the abovementioned components, the first two engage in recreation a input position in the dispensation of emotions even as they have a rest mainly (though not entirely) purpose the same as preprocessors of sensory input.

Following figure shows the block diagram of BELBIC controller:

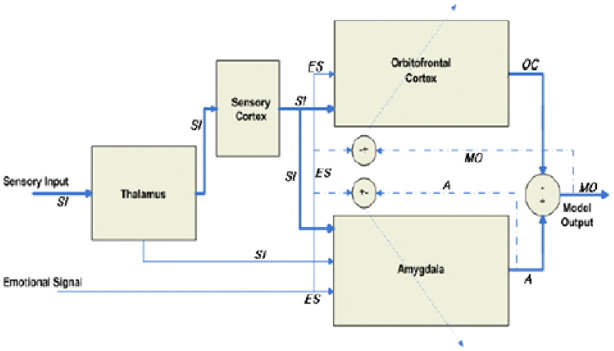

Figure 2: Block diagram of simplified Limbic Model[2]

Mathematically the linear model of BEL controller is represented by following simplified equations [2]:

$A = G_A.SI$

$OC = G_{OC}.SI$

$$\frac{dG_A}{dt} = \alpha . SI\,(ES - A)$$

$$\frac{dG_{OC}}{dt} = \beta . SI\,(A - OC - ES)$$

MO = A – OC

Where,

MO = Model Output

SI = Sensory Input

ES = Emotional Sensor

A = Amygdala Output

OC = Orbitofrontal Cortex

α = Learning rate of Amygdala

β = Learning rate of Orbitofrontal cortex

G_A = Gain for Amygdala

G_{OC} = Gain for Orbitofrontal Cortex

5. Control Action Mathematics

In feedback control, a setpoint is given and the variable that has to controlled and measured is compared with the setpoint. The error is taken into account by the controller and then the controller decides what action should be taken by the manipulated variable to compensate for and hence remove the error.

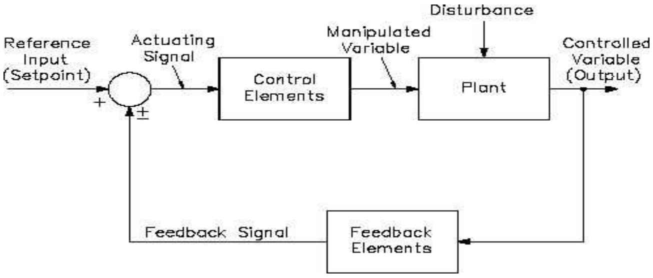

Figure 3: Feedback Control Loop [12]

There are two types of feedback control: negative and positive. Negative feedback is the most useful control type since it typically helps a system converge toward an equilibrium state. On the other hand, positive feedback can lead a system away from an equilibrium state thus rendering it unstable, even potentially producing unexpected results. Unless stated explicitly, the term feedback control most often refers to negative feedback.

6. Result and Conclusion

In this paper, we have presented the application of Brain Emotion Learning Based Intelligent Controller in CSTR. The main issue that arises while applying the BEL model to an application is defining the emotional and the sensory signals in such a way so as to approximately represent the state and objective of the system. At last, BELBIC is more efficient than any other controller (PID etc) as it has minimum error and high response time.

The input parameters are compared with Brain emotional learning based intelligent controller and its application to jacketed Continous stirred tank reactor [14], taking both x axis and y axis same in both the systems.

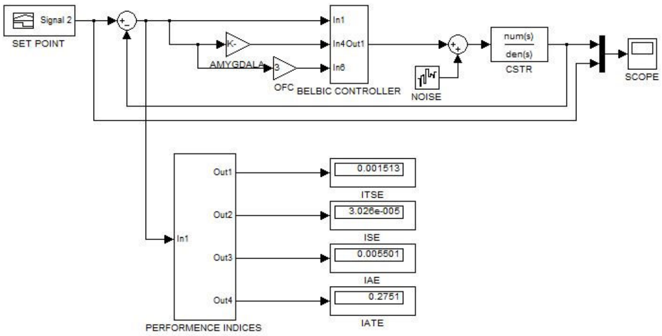

Figure 4: BELBIC with CSTR (Noise present)

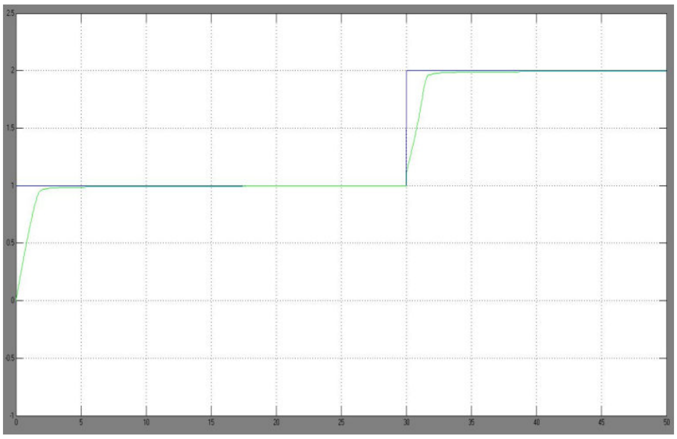

Figure 5: Output response of the system

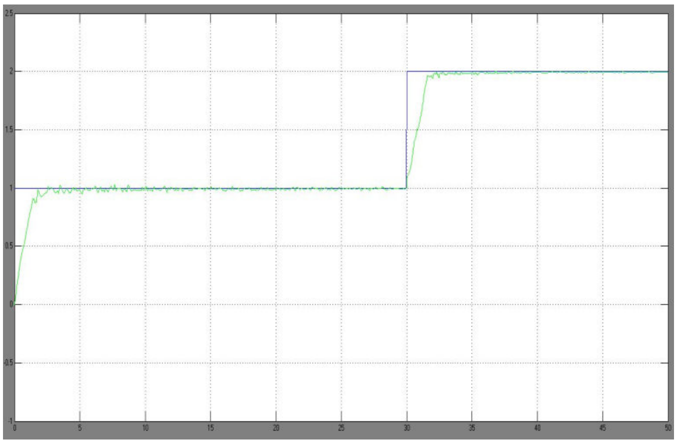

Figure 6: Output response of the system (with noise)

6.1 Performance Indices

Table 4: Error Parameters

Error parameters	With noise	Without noise
ITSE	0.001427	0.001062
ISE	2.854e-005	2.124e-005
IAE	0.005342	0.005342
IATE	0.2671	0.2304

Table 5: Error Parameters [14]

Error Parameters	Without Noise	With Noise
ISE	1.165	1.189
ITSE	5.281	5.358
IAE	2.31	2.375

On comparison with [14], it can be concluded the performance indices for our system shows improvement

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Arpit Jain, Deep Tayal, Neha Sehgal, "Brain emotional learning based intelligent controller and its application to jacketed Continous stirred tank reactor", International journal of Electrical and Electronics Engineering Research, 2013, Volume 3, Issue 1, ISSN: 2250-155X

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