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Brain Emotional Learning Based Intelligent Controller for Velocity Control of an Electro Hydraulic Servo System

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Abstract: *In this paper, a biologically motivated controller based on mammalian limbic system called Brain Emotional Learning Based Intelligent Controller (BELBIC) is used for velocity control of an Electro Hydraulic Servo System (EHSS) in presence of flow nonlinearities, internal friction and noise. It is shown that this technique can be successfully used to stabilize any chosen operating point of the system with noise and without noise. All derived results are validated by computer simulation of a nonlinear mathematical model of the system. The controllers which introduced have big range for control the system. We compare BELBIC controller results with feedbacks linearization, backstepping and PID controller.*

Keywords: *BELBIC, EHSS, Intelligent Control, Velocity Control*

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I. Introduction

Electro Hydraulic Servo Systems (EHSS) are widely used in many kinds of industrial applications because of their ability to handle large torque loads fast responses. For instance, typical applications include active suspension systems, control of industrial robots, satellites, flight simulators, turbine control. Other credits are given because it yields quick and precise answers [1, 2].

Depending on the desired control objective, an EHSS can be classified as either a position, velocity or force/torque EHSS. In the past, lots of studies have been carried out regarding different ways of handling methods of electro hydraulic servo system (EHSS). Reference [3] gives more information in this regard. An intelligent CMAC, FNN neural controller that utilizes feedback error learning approach appears in [4, 5] which is highly complicated and [3] explain ways based on feedbacks linearization and backstepping, However, it is not easy, nor is it simple to design such controllers. Neural-adaptive control based on backstepping and feedback linearization presented in [6]. Other control methods will appear in [7, 8, 9, 10 and 11].

Emotional Learning is mathematically modeled by Moren and Balkenius in [12]. Based on emotional learning computational model, Brain Emotional Learning Based Intelligent Controller (BELBIC) was introduced by Lucas et al [13]. Brain Emotional Learning Based Intelligent Controller (BELBIC) is an intelligent controller which is employed to several applications and control problems such as Attitude Control of a Quadrotor [14], Intelligent Control of a Launch Vehicle [15], Motion Control of Omni-Directional Three-Wheel Robots[16]. Also, Intelligent Autopilot Control Design for a 2- Dof Helicopter Model is addressed in [17] and Target and Path Tracking Control of a Mobile Robot are presented in [18] and [19] respectively. Recently, it has been applied to flocking control of multi-agent system in [20].

Additionally, BELBIC has been successfully experimentally utilized in real-time by using a DSP-board for a laboratory 1 [hp] Interior Permanent Magnet Synchronous Motor drive [21]. Furthermore, it was implemented on Field-Programmable Gate Arrays (FPGA), and applied to control a laboratory Overhead Traveling Crane [22]. Also, it was practically applied for speed control of a Digital Servo System via MATLAB external mode [23]. Comparing Applying BELBIC to those plants to other controllers, BELBIC shows very acceptable results. This controller has two important inputs: Sensory Input (SI) and Primary Reward (Rew) and the flexibility in defining SI and Rew makes BELBIC a popular controller in multi objective problems. Since BELBIC has ability of learning, it shows the response like Robust Adaptive methods. One of the important parts of applying BELBIC to properly control a system is assigning the appropriate parameter for both Rew and SI. There are several methods for tuning the parameters of BELBIC such Particle-swarm-based Approach [24], Lyapunov Based Algorithm [25], Fuzzy Tuning [26], CLONAL Selection Algorithm [27] and trial and error method. Here, we intend to study and suggest a BELBIC controller for the EHSS system. The rest of the paper is organized as follows. Section II, contains the mathematical model of the EHSS system. Section III BELBIC controller in detail. Section IV discusses the simulation results of the proposed control schemes. Finally, the conclusion is given in Section V.

II. MATHEMATICAL MODEL OF THE SYSTEM

A scheme of an electrohydraulic velocity servo system is shown in Fig. 1.

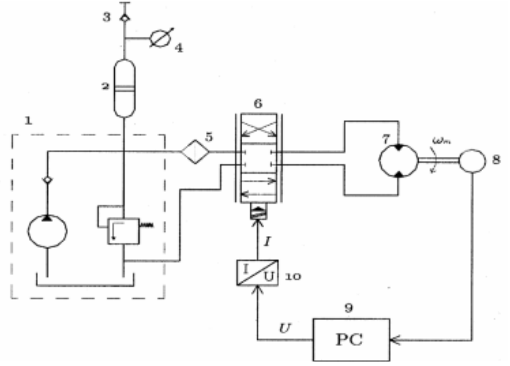

Figure 1. Electrohydraulic velocity servo system

The basic parts of this system are: 1. hydraulic power supply, 2. accumulator, 3. charge valve, 4. pressure gauge device, 5. filter, 6. two-stage electrohydraulic servo valve, 7. hydraulic motor, 8. measurement device, 9. personal computer, and 10.Voltage - to- current converter.

A mathematical representation of the system is derived using Newton’s Second Law for the rotational motion of the motor shaft. It is assumed that the motor shaft does not change its direction of rotation, $x_1>0$. This is a practical assumption and in order to be satisfied, the servo valve displacement $x_3$does not have to move in both directions. This assumption restricts the entire problem to the region where $x_3>0$.

If the state variables are denoted by:
x_1-hydro motor angular velocity
x_2-load pressure differential
x_3-valve displacement
Then the model of the EHSS is given by:

$$\begin{aligned}
\dot{x}_1 &= \frac{1}{j_t}\left\{-B_m x_1 + q_m x_2 - q_m c_f p_s\right\} \\
\dot{x}_2 &= \frac{2B_e}{v_o}\left\{-q_m x_1 - c_{im} x_2 - c_d w x_3 \sqrt{\frac{1}{\rho}(p_s - x_2)}\right\} \\
\dot{x}_3 &= \frac{1}{T_r}\left\{-x_3 + \frac{k_r}{k_q} u\right\} \\
y &= x_1
\end{aligned} \tag{1}$$

Where the nominal values of parameters are: $j_t = 0.03$ kgm^2- Total inertia of the motor and load referred to the motor shaft, $q_m = 7.96\times10^{-7}$ m^3/rad– volumetric displacement of the motor, $B_m=1.1\times10^{-3}$ Nms– viscous damping coefficient, $C_f = 0.104$-dimensionless internal friction coefficient, $V_O = 1.2\times10^{-4}$ m^3- average contained volume of each motor chamber, $B_e = 1.391\times10^9$ pa-effective bulk modulus, $C_d=0.61$– discharge coefficient, $C_{im}=1.69\times10^{-11}$ m^3/pa.s- internal or cross-port leakage coefficient of the motor, $P_S=10^7$ pa- supply pressure, $\rho=850$ kg/m^3- oil density, $T_r=0.1$ s - valve time constant, $-k_r=1.4\times10^{-4}$ m^3/s.v- valve gain,$k_a=1.66^{-4}$ m^2/s- valve flowgain, $w= 8\pi\times10^{-3}$ m - surface gradient.

The control objective is stabilization of any chosen operating point of the system. It is readily shown that equilibrium points of system are given by:

X_{1N}: Arbitrary constant value of our choice

$$\begin{aligned}
X_{2N} &= \frac{1}{q_m}\left\{B_m x_{1N} + q_m c_f p_s\right\} \\
X_{3N} &= \frac{q_m x_{1N} + c_{im} x_{2N}}{c_d w \sqrt{\frac{1}{\rho}(p_s - x_{2N})}}
\end{aligned} \tag{2}$$

With very simple linearization we can find out that the system is minimum phase which allows application of many different design tools. In [28], Alleyne and Liu developed a control strategy that guarantees global stability of nonlinear, minimum phase single-input single-output (SISO) systems in the strict feedback form by using a passivity approach and they later used this strategy to control the pressure of an EHSS.

III. Belbic Controller

In this section, the structure of BELBIC is introduced. A brief structure of this controller is shown in Fig. 2 [13]. BELBIC is a simple composition of Amygdala and Orbitofrontal cortex in the brain.

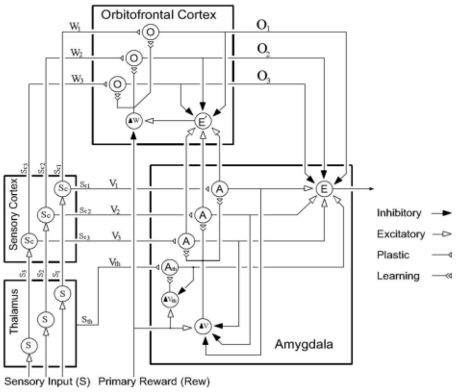

Figure 2. Graphical depiction of computational model of emotional learning in amygdala [12]

In Thalamus, some poor pre-processing on sensory input signals such as noise reduction or filtering can be done in this part. As a matter of fact, Thalamus is a simple model of brain real thalamus. The Thalamus part prepares Sensory Cortex needed inputs which to be subdivided and distinguished [13]. Based on the context given by the hippocampus, the Orbitofrontal Cortex part is supposed to inhibit the inappropriate responses from the Amygdala, [13].The emotional evaluation of stimuli signal is carrying out through the Amygdala, which is a small part in the medial temporal lobe in the brain. As result, this emotional mechanism is utilized as a basis of emotional states and reactions. [13].

At first, Sensory Input signals are going into Thalamus for pre-processing on them. Then Amygdala and Sensory Cortex will receive their processed form and their outputs will be computed by Amygdala and Orbitofrontal based on the Emotional Signal received from environment. Final output is subtraction of Amygdala and Orbitofrontal Cortex [13].One of Amygdala's inputs is called Thalamic connection and calculated as the maximum overall Sensory Input S as in (3). This specific input is not projected into the Orbitofrontal part and cannot by itself be inhibited and therefore it differs from other Amygdala's inputs.

$$A_{th} = \max(s_i) \qquad (3)$$

Every input is multiplied by a soft weight V in each A node in Amygdala to give the output of the node. The O nodes behaviors produce their outputs signal by applying a weight Wto the input signals as well as A nodes. To adjust theV_i, difference between the reinforcement signal and the activation of the Anodes is been made use. For tuning the learning rate the parameter αis used and it sets to a constant value. As shown in (4) Amygdala learning rule is an example of simple associative learning system, although this weight adjusting rule is almost monotonic. For instance, $V_i$can just be increased.

$$\Delta V_i = \alpha(s_i \max(0, rew - \sum A_i)) \qquad (4)$$

The reason of this adjusting limitation is that after training of emotional reaction, the result of this training should be permanent, and it is handled through of the Orbitofrontal part when it is inappropriate [12]. Subtraction of reinforcing signalrew from previous output E makes the signal of reinforcement for O nodes. To put it another way, comparison of desired and actual reinforcement signals in nodes Oinhibits the model output.The learning equation of the Orbitofrontal Cortex is drawn in (5).

$$\Delta W_i = \beta(s_i \sum(O_j - rew)) \qquad (5)$$

Amygdala and Orbitofrontal learning rules are much alike, but the Orbitofrontal weight Wcan be changed in both ways of increase and decrease as needed to track the proper inhibition. And rule of βin this formula is similar to the α ones.

$$\begin{aligned} O_i &= s_i w_i \\ E &= \sum A_i - \sum o_i \end{aligned} \qquad (7)$$

As presented in (7) the difference between A nodes and O nodes computes output E. The A nodes outputs are produced according to their rule in prediction of rewsignal (reward orstress), though the responsibility of O nodes are inhibition of output Ein while it is necessary. Fig. 3 demonstrates a typical feedback control block diagram including BELBIC Controller.

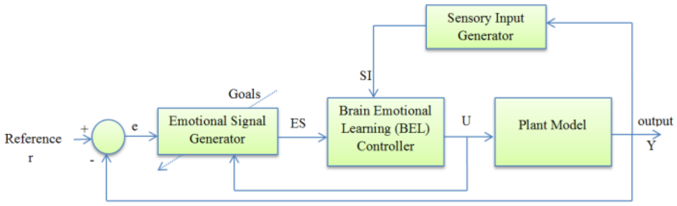

Figure 3. Typical feedback control block diagram

Due to simplicity of implementing proposed controller, the following functions used as Primary Reward (Emotional Signal) and Sensory Input signals for BELBIC control scheme respectively.

$$rew = k_1.e + k_2.\int e.dt + k_3.\frac{de}{dt} \qquad (8)$$

$$SI = k_4.\frac{de}{dt}$$

The BELBIC parameters as shown in table I.

TABLE I. BELBIC PARAMETERS

K_1	K_2	K_3	K_4	α	β
0.0317	0.04048	4.052e-04	0.001	0.000010	1e-07

IV. Simulation Results

In this section, the results of simulation are shown. The BELBIC controller has been compared with feedback linearization controller, back-stepping and PID controller. Figs. 4-7 show the system output, the signal controller and the system states without the presence of output noise.

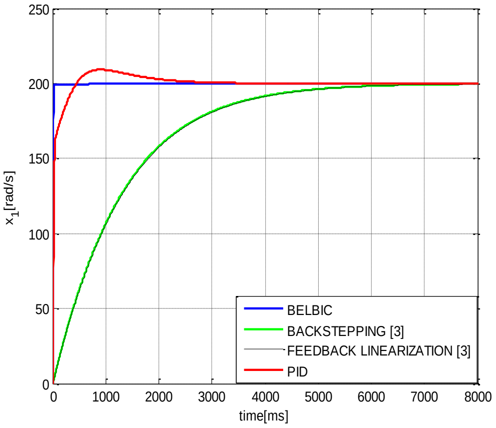

Figure 4. Simulation result X_1 without output noise for X_{1N}=200rad/s

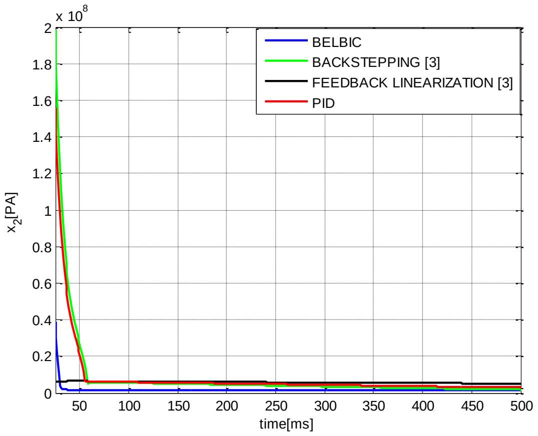

Figure 5. Simulation result X_2 without output noise for $X_{2N}=1.3 \times 10^6$Pa

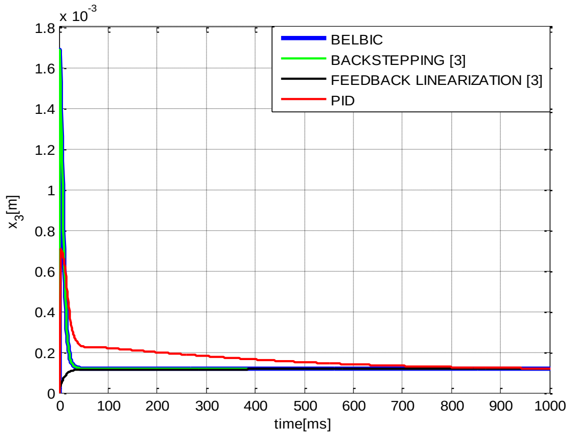

Figure 6. Simulation result X_3 without output noise for $X_{2N}=1.17\times 10^{-4}$m

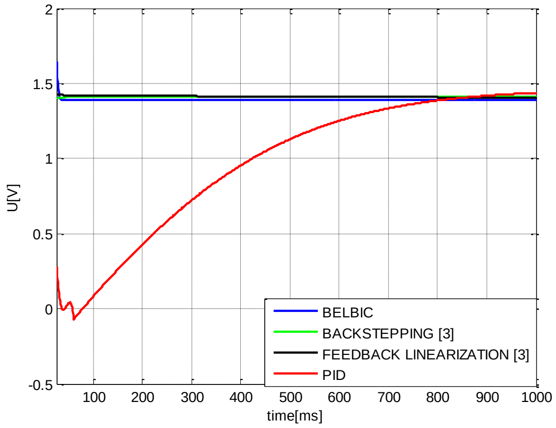

Figure 7. Simulation result u[v]

To show the capabilities of the controller introduced in this paper, Gaussian noises with follow property have been applied to the aimed system.

0.01× N(0,1): amp:0.01 vae:1 avr:0
0.1× N(0,1): amp:0. 1 vae:1 avr:0
1× N(0,1): amp: 1 vae:1 avr:0

Figs. 8, 9, and 10 show the results of the experiment with the presence of output Gaussian noise.

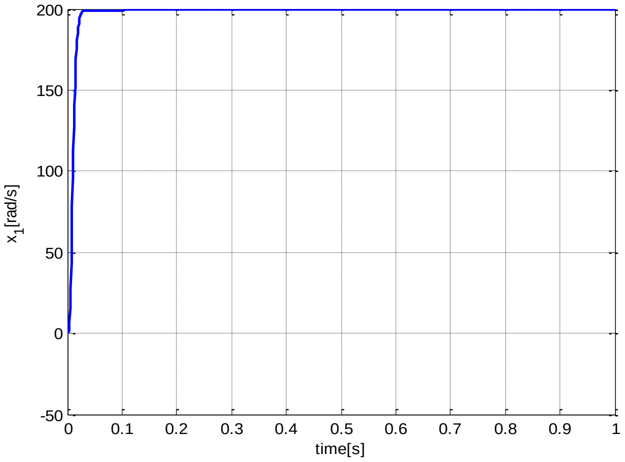

Figure 8. Simulation result X_1 without output noise for X_{1N}=200rad/s amp:0.01 vae:1 avr:0

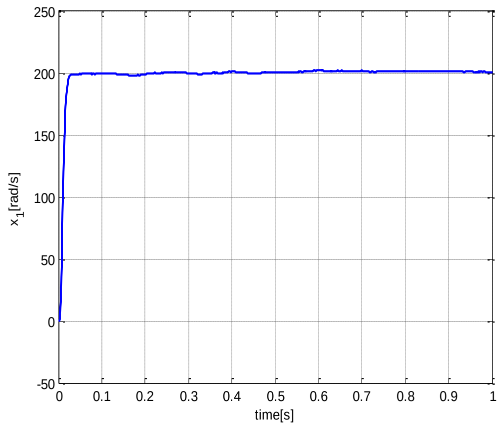

Figure 9. Simulation result X_1 without output noise for X_{1N}=200rad/s amp:0. 1 vae:1 avr:0

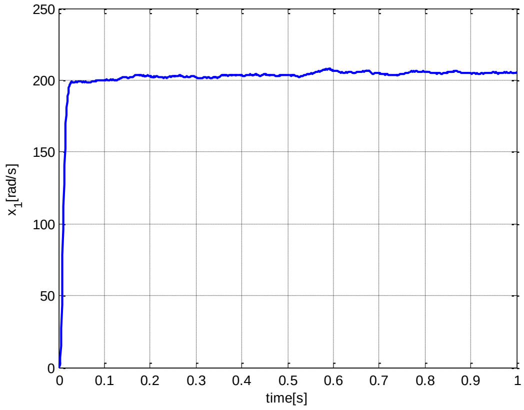

Figure 10.Simulation result X_1 without output noise for X_{1N}=200rad/s amp:1 vae:1 avr:0

Results show that BELBIC controller delivers the Hydro motor angular velocity to the desired velocity much more quickly than feedbacks linearization, back-stepping and PID controllers and has shorter settling time than other controllers also show that in presence output noise BELBIC controller is robust controller.

V. Conclusions

A new emotional controller based on BELBIC model is presented in this paper for control of the velocity of the electrohydraulic servo system which has practical uses in many industrial systems. In this paper, a BELBIC controller is designed for stabilization of EHSS system to the desired point in the state space. Results obtained from the simulation show the superiority of the control system suggested in this paper. BELBIC controller has shorter settling time than other controllers also it is robust in presence of output noiseapplied to the aimed system.

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