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Real-Time Level Plant Control Using Improved BELBIC

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Abstract: Brain emotional learning based intelligent controller (BELBIC) is based on computational model of limbic system in the mammalian brain. In recent years, this model was applied in many linear and nonlinear control applications. Previous studies show that this controller has fast response, simple implementation and robustness with respect to disturbances. It is also possible to define emotional signal based on control application objectives. But in the previous studies, internal instability of this controller was not considered and control task were done in limited time period. In this article mathematical description of BELBIC is investigated and improved to avoid internal instability. Simulation and implementation of improved model was done on level plant. The obtained results showed that instability of model has been solved in the new model without loss of performance by using Integral Anti Windup (IAW).

1. INTRODUCTION

In recent years, applications of intelligent controllers are increasing complex control systems. In the past years, emotion was assumed as a problem in decision-making and rational behaviours but new studies shows that emotion has main role in the human decision making process and emotional system is supposed as an expert system (Moren 2002). In engineering applications, the simple computation model of some parts of brain is utilized. Making models for emotional behaviour of brain is very interesting field for cognitive scientist (Balkenius-Moren 1998a).

In the computational models of brain, emotions are signals that describe external environment. Several attempts have been made to model the emotional behaviour of human brain by Moren and Balkenius (Balkenius-Moren 1998b). In (Moren-Balkenius 2000) the computational models of amygdala and context processing were introduced.

Based on the cognitively motivated open loop model, BELBIC was introduced for the first time in (Lucas-Shahmirzadi 2004) by Lucas and Shahmirzadi and after that this controller was utilized in several application and control purposes. Applying this controller for eliminating stator oscillations through fin placement was done in (Lucas-Shahmirzadi 2002). Application of BELBIC in Speed control of an interior permanent magnet synchronous motor was shown in (Milasi-Lucas-Araabi 2004) and in (Sheikholeslami 2006) a modified version of BELBIC was utilized in heating, ventilating and air conditioning (HVAC) control problem that is multivariable, nonlinear and non-minimum phase. In (Milasi 2005), this controller used for controlling an identified model of a washing machine and in (Milasi 2007) this controller with multi objectives constraints was tuned for washing machine with evolutionary algorithms where it is possible to have a trade-off between energy consummation and other control objectives. Also in (Pouladzadeh 2007) this controller was applied to automotive suspension system and the results are compared with classical controllers.

Although this controller was applied in many simulation and real control tasks but the internal stability of this controller has not been considered in these studies and the simulation and implementation were done in limited simulation or real time. In this article the instability phenomena in BELBIC controller is analysed and an improved version of this controller, without internal instability, is introduced and applied to control a level plant.

The structure of the paper is as following, In Section 2 the limbic model of mammalian brain and original model of BELBIC is presented. Section 3 present the level control plant and in Section 4 implementation of the original BELBIC on level plant system is demonstrated. In this section internal instability of controller in simulation plant model and real plant are shown. The improved model of BELBIC and experimental results are shown in Section 5 and finally in Section 6 the conclusion part is discussed.

2. LIMBIC MODEL OF MAMMALIAN BRAIN

The limbic system in brain has an important role in emotional behaviour of mammalians. Fig. 1 shows a simple graphical of limbic system in human brain. Fig. 2 presents a structural engineering model of this System.

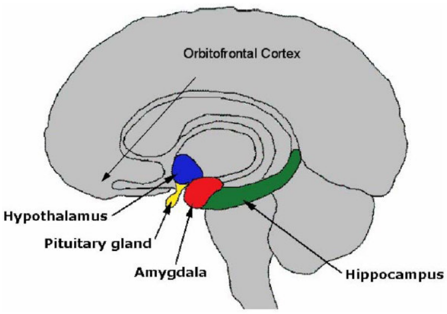


Fig. 1. Limbic system of human brain (Shahmirzadi 2005)

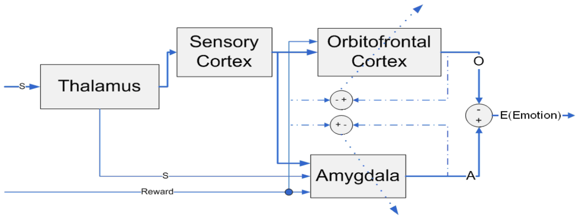


Fig. 2. Block diagram of structure model of limbic system (Masoudinejad-Khorsandi 2007)

Output of system E is the difference of two learning part, amygdala and orbitofrontal cortex that is presented in equation (1)

$$E = A - O \quad (1)$$

In the above equation, A is the output of amygdala part and O is the output of orbitofrontal cortex.

For simplification of modelling, Thalamus and sensory cortex are modelled with simple identity function. In real biological models, these parts perform simple pre-processing and signal routing (Moren 2002). The mathematical description of amygdala and orbitofrontal cortex will be presented in the next parts.

2.1 AMYGDALA

Amygdala is the basic part of limbic system for conditioning process and it only can learn emotional reaction and can not forget the learned reaction. The computing rules of this part are presented in equations (2), (3) and (4).

$$A = \sum_i a_i \quad (2)$$

$$a_i = S_i V_i \quad (3)$$

$$\Delta V_i = \alpha S_i MAX(R - A, 0) \quad (4)$$

In the above relations, S_i and V_i are the i_{th} sensory input and the weight of i_{th} amygdala node respectively and R is the reward signal. a_i is the output of i_{th} amygdala node output and α is a constant learning rate.

2.2 ORBITOFRONTAL CORTEX

The orbitofrontal learning rule is very similar to the amygdala rule. The only difference is that the orbitofrontal connection weight can both increase and decrease as needed to track the required inhibition. The parameter β is another learning rate constant:

$$O = \sum_i o_i \quad (5)$$

$$o_i = S_i W_i \quad (6)$$

$$\Delta W_i = \beta S_i (R - O) \quad (7)$$

In the above equations the parameter W_i is the weight of i_{th} orbitofrontal node. Also the o_i is the output of the i_{th} orbitofrontal node.

3. LEVEL PLANT SYSTEM

The test plant used in this paper is a level control set called RT512 which is produced by GUNT Company (GUNT 2003) for engineering education. Fig. 3 and 4 illustrate the RT512 and its P&ID diagram. So far, some advanced control methods have been implemented on this plant such as STR (Self Tuning Regulator), GPC (Generalized Predictive Control), and MARS (Model Reference Autoregressive system) (Maghoul 2005), (Kouhi 2006).

4. APPLYING BELBIC ON LEVEL PLANT SYSTEM

In this section, experimental results of applying original BELBIC on level plant system are presented. Reward and sensory inputs of BELBIC are as follows:

$$R = K_1 e + K_2 u \quad (8)$$

$$S = F(e) \quad (9)$$

The reward formula is based on designer objectives. BELBIC tries to minimize the reward signal. The sensory input signal is a function of error. Integral and/or derivation of error can also be utilized in this formula.

The output level of the plant with original BELBIC is illustrated in Fig. 5. As it is shown in this figure, in the primary steps, the controller behaviour will improve and this behaviour is expected based on learning capability of this intelligent controller. But this controller did not stop learning and the result in the next steps will be worse than previous steps. This phenomenon is the result of competition between

Amygdale and orbitofrontal cortex. Outputs of both parts ultimately increase. Growing amygdala and orbitofrontal Cortex output cause the internal instability in BELBIC. However the control signal is difference between amygdala and orbitofrontal cortex does not grow that fast and in some examples stay bounded.

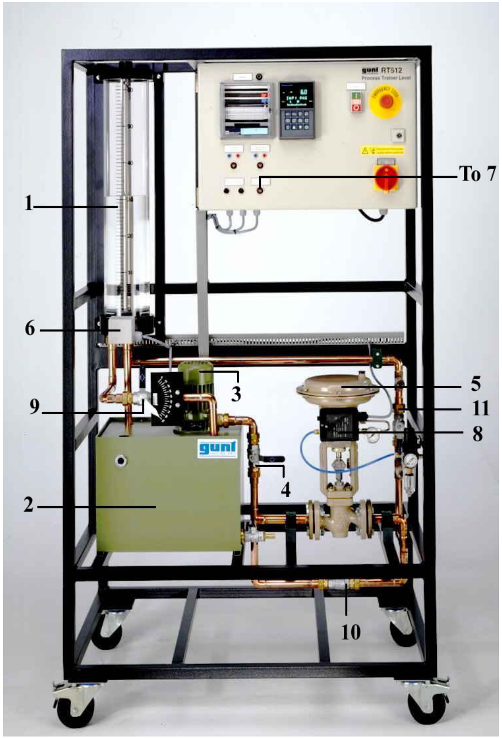
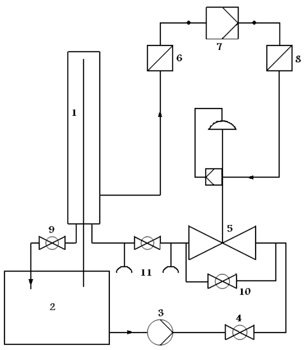


Fig. 3. Plant level system (GUNT web)



1.	Level cylinder	7.	External controller
2.	Water tank	8.	Current/pressure transducer
3.	Pump	9.	Outlet cock
4.	Inlet cock	10.	By-pass
5.	Control valve	11.	Hose connections for cascade control
6.	Pressure transducers		

Fig. 4. P& ID of level plant system (GUNT 2003)

For better discussion, the simulation result for the model of the plant level with BELBIC controller is shown in Fig. 6. The simulation time is about 14000^s. The weight W of the orbitofrontal in this simulation is shown in Fig. 7. This parameter does not saturate and does not tend to infinity. The similar behaviour is seen for amygdala weights. This means that although the output of the BELBIC is suitable to control the plant, but each of its two parts, amygdala and orbitofrontal cortex, continue to increase according to their inputs.

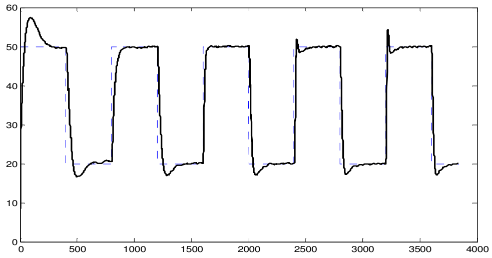


Fig. 5. Implementation result of applying the original model of BELBIC on level plant system

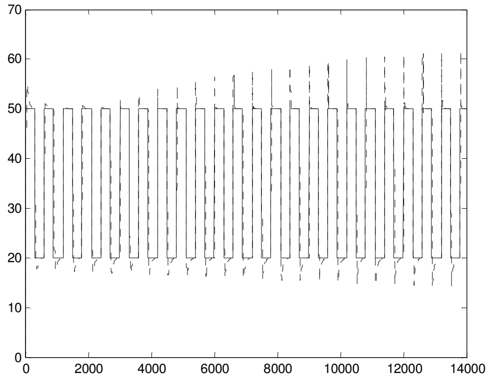


Fig. 6. Simulation results of applying the original model of BELBIC on level plant model

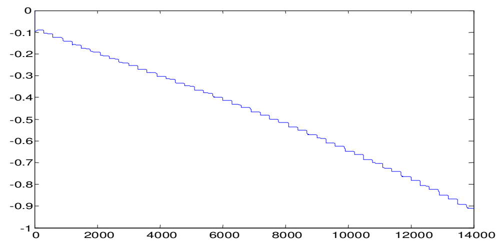


Fig. 7. The W parameter in orbitofrontal cortex simulation result

5. MODEL IMPROVEMENT

As it was shown in the previous section, the original BELBIC has internal instability. To avoid this instability, it is necessary to limit them to some reasonable value. The popular method for avoiding this kind of instability in control engineering is Integral Anti Windup (IAW) technique (Fatehi 2007), (Astrom 1995). In this paper, the same technique is utilized to limit the weights of amygdala and orbitofrontal cortex and stabilizing BELBIC. For example, the IAW structure for amygdala part is demonstrated in Fig. 8.

If the weight V in equation (4) passes the saturation level limit, the negative signal will be added to integral part and the weight will decrease smoothly. The similar method is applied to orbitofrontal cortex weights, W in equation (7).

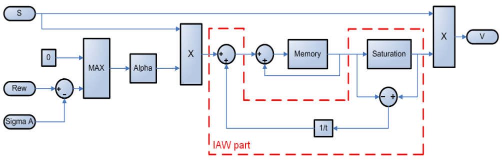


Fig. 8. Improved model of amygdala with IAW

6. APPLYING IMPROVED BELBIC ON LEVEL PLANT SYSTEM

As discussed in the previous section, the IAW technique can stabilize BELBIC. However the saturation bound must be determined. The saturation parameters depend on the parameters of the controller system.

Fig. 9, illustrates the final controller result using the improved BELBIC.

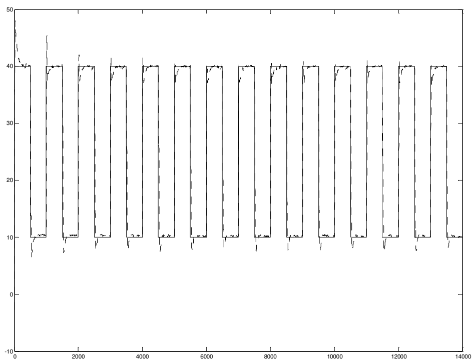


Fig. 9. Implementation result of applying the improved model of BELBIC on level plant system without changing parameters of original BELBIC

Fig. 9 shows that operation is both fine and stable. Internal parameters V and W and their difference, adaptive nonlinear gain ($2V$-W), are shown in Fig. 10. Parameters V and W are both stable. Difference of them has main role in obtaining suitable response.

Fig. 11 shows output of level plant RT 512 with tuned parameters of S and R.

7. CONCLUSION

The brain emotional learning based intelligent controller (BELBIC) was implemented on a level plant. It is shown that original BELBIC suffered from internal instability. Improved BELBIC with integral anti-wind up (IAW) is introduced for this problem. Simulation and implementation result show that the system is stable and obtained results are reasonable. One can define emotional signal based on control application objectives. Learning capability, model free control algorithm, and fast response time are main characteristics of this controller.

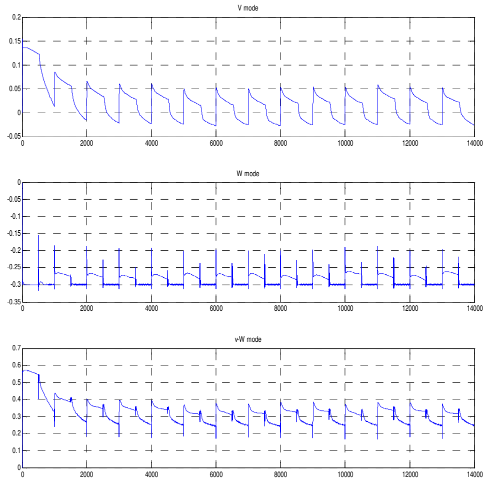


Fig. 10. A) V parameter in amygdala, B) W parameter in orbitofrontal cortex, C) Nonlinear gain = $2V$-W

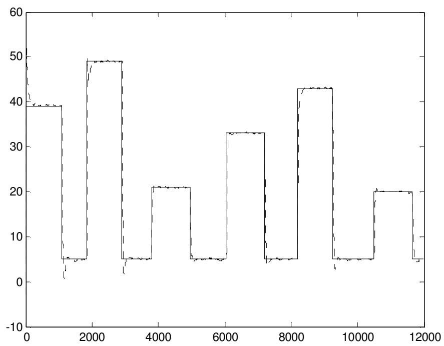


Fig. 11. Output result on level plant with tuned parameters

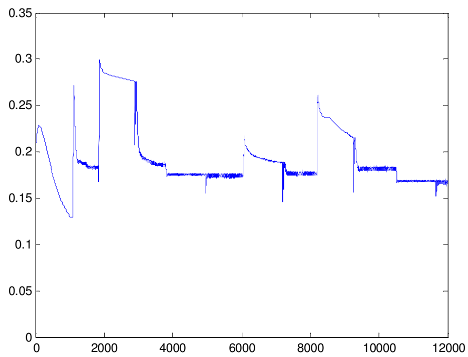


Fig. 12. Nonlinear gain = $2V$-W

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