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REAL TIME EMOTIONAL CONTROL FOR ANTI-SWING AND POSITIONING CONTROL OF SIMO OVERHEAD TRAVELING CRANE

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Abstract. *Research in artificial intelligence and bioinspired algorithms is still being actively pursued in different fields of engineering. In this work, Brain Emotional Learning Based Intelligent Controller (BELBIC) is applied for real time positioning of laboratorial overhead travelling crane. This controller is based on biologically motivated algorithm originating from emotional processes in the limbic system of the mammalian brain. Simulations show that learning capability, adaptation, robustness and other control concerns of this controller are comparable with conventional techniques which lead to better performance in many cases. Two objectives, tracking desired position and keeping pendulum vertically, must be considered simultaneously. The bottom up strategy was utilized for designing the controllers. First separated BELBIC was designed for each control task. Next, in order to suppose the real coupling between control tasks, the objective of each control tasks was considered in the stress signal of the other one. Obtained results in real tracking applications are also comparable with other conventional and intelligent approaches such as hierarchical fuzzy control (HFLC) and confirm the simulation results. Learning capability, model free control algorithm, robustness and fast response are main characteristics of this controller and designer can define emotional stress signal based on control application objectives.*
Keywords: BELBIC, Model Free Control, HFLC, PID Controller

1. **Introduction.** Brain Emotional Learning Based Intelligent Controller (BELBIC) is an example of bioinspired control methods which is based on limbic system of mammalian brains. This controller is based on emotional behaviours in biological systems. Emotion is an emergent behaviour in biological systems for fast decision making in complex environments. The advantages of this behaviour cannot be neglected in creature surveillance.

Several attempts have been made to model the emotional behavior of human brain [1], [2], and [3]. In [2] the computational models of Amygdala and context processing were introduced. Based on the cognitively motivated open loop model, BELBIC was introduced in [4] and after that this controller was utilized in several applications. Applying BELBIC in Speed control of an interior permanent magnet synchronous motor was shown in [6]. In [5] a modified version of BELBIC was applied to heating, ventilating and air conditioning (HVAC) system which is multivariable, nonlinear and non minimum phase. In [7] this controller used for controlling identified washing machine and in [8] this controller was tuned for washing machine with multi objectives constraints based on evolutionary approaches. A trade-off between energy consummation and other control objectives should be considered by designer. Because of recurring applications of BELBIC in new contexts, describing the BELBIC in pattern format was done in [9]. Pattern describes a problem, which occurs over and over again in our environment, and then describes the core of the solution to that problem [10]. Reusability, extendibility and implementation concerns in different platforms were described in this pattern and designer can reuse the BELBIC framework easily in desired control applications.

All the above applications of BELBIC were done in software simulation environments. For the first time, the real-time implementation of the BELBIC for interior permanent magnet synchronous motor (IPMSM) drives was presented in [11]. The controller was successfully implemented in real-time using a digital signal processor board ds1102 for a laboratory 1-hp IPMSM. Results show superior control characteristics, especially very fast response, simple implementation and robustness with respect to disturbances and manufacturing imperfections. These features make the BELBIC useful in different tasks which fast tuning should be a necessity. In this paper this controller is implemented for real time and model free control of overhead travelling crane which is a laboratorial set and is a small model of bridge crane. The plant is nonlinear, one input-two output and multi objectives. The benefit of model free control is eliminating the identification task. However many methods are presented to identify and model the complex nonlinear systems and with respect to successful applications to model unknown nonlinear system by a set of fuzzy rules [12], these procedures are too costly and time consuming. Also when the identifying procedure leads to very complex system, it is hard to design controllers even define proper rule for fuzzy controllers [13]. Two BELBICs based on control strategy cooperate together for controlling the mentioned system. In emotional stress signal of each controller, the objective of the other one is employed and the emotional signal is the fusion of control objectives. In other words, each of these controllers controls an objective of whole system which firstly assumed to be decoupled and next the emotional stress signals play the role of coupling these two controllers. Unlike classic controllers, this controller has the learning capability and initial tuning of parameters is not very critical.

This paper consists of five sections: In section 2, mathematical description of BELBIC is demonstrated. Practical overhead crane is presented in section 3. Experimental result and comparison of this controller with other classical and intelligent methods is shown in section 4 and finally section 5 contains concluding remarks.

2. **Brain Emotional Learning Based Intelligent Controller.** BELBIC is a simple computational model of Amygdala and Orbitofrontal cortex of brain. In this section, a short description about each part of BELBIC is given. The structure of BELBIC is shown in Figure 1 [2].

Thalamus is a simple model of real thalamus in mammalians' brain. Some simple preprocessing on sensory input signals such as noise reduction or filtering can be done in this part. Sensory Cortex receives its inputs from thalamus, and it is assumed that this part is responsible for subdividing and discrimination of the coarse input from thalamus [2]. Orbitofrontal Cortex is supposed to inhibit inappropriate responses from Amygdala based on the context given by the hippocampus [2]. Amygdala is a small structure in the medial temporal lobe of brain that is thought to be responsible for the emotional

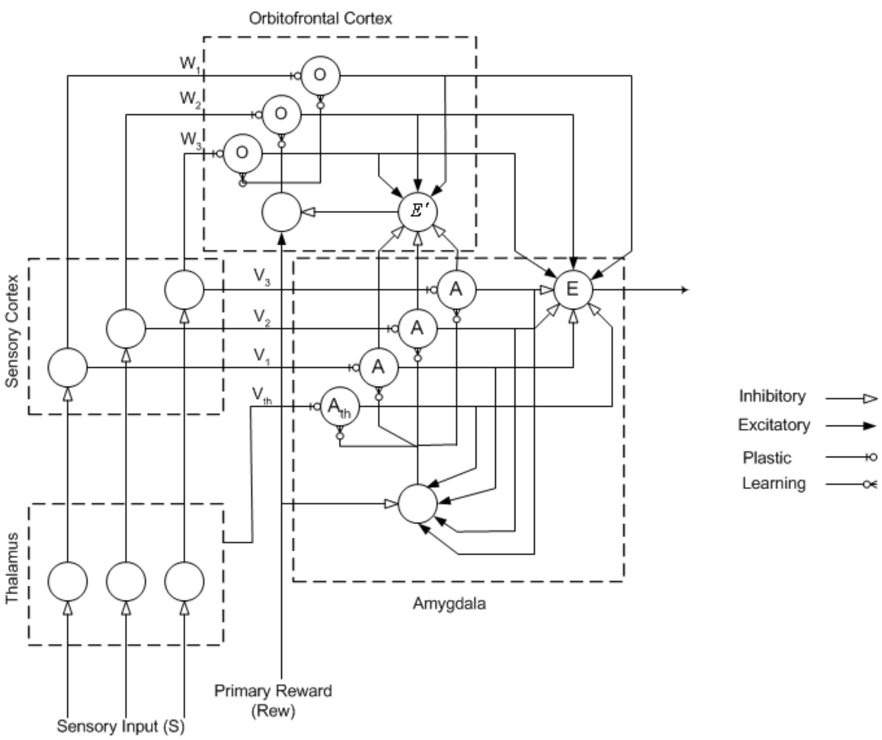

FIGURE 1. Structure of BELBIC [Moren00]

evaluation of stimuli [2]. This evaluation is in turn used as a basis for emotional states, emotional reactions and is used for attention signal and laying down long-term memories [2].

BELBIC receives Sensory Input signals via Thalamus. After pre-processing in Sensory Input, processed input signal will be sent to Amygdala and Sensory Cortex. Amygdala and Orbitofrontal compute their outputs based on Emotional Signal received from environment. Final output is calculated by subtracting Amygdala's output from Orbitofrontal Cortex's output. Through this section, functionality of these parts and learning algorithm is discussed based on [2].

The Thalamic connection is calculated as the maximum overall Sensory Input S and becomes another input to Amygdala as described in equation (1). Unlike other inputs to Amygdala, the thalamic input is not projected into the Orbitofrontal part and can not be inhibited by itself.

$$A_{th} = \max_i(S_i) \tag{1}$$

For each A node in Amygdala, there is a plastic connection weight V. Any input is multiplied by this weight to provide the output of the node. The O nodes behave analogously, with a connection weight W applied to the input signal to create an output. The connection weights V_i are adjusted proportionally to the difference between the emotional stress and the activation of the A nodes. The α term is a constant that is used to adjust the learning speed. In formula (2) Amygdala learning rule is presented. This is an instance of a simple associative learning system. The real difference between this system and similar associative learning systems is the fact that this weight-adjusting rule is monotonic, i.e., the weights V cannot decrease. At first glance, this may seems like a fairly substantial drawback; however, there are good reasons for this design choice. Once an emotional reaction has been learned, this should be permanent. It is the task of the Orbitofrontal part to inhibit this reaction when it is inappropriate [2].

$$\Delta V_i = \alpha(S_i \max(0, stress - \sum A_j)) \tag{2}$$

The reinforcement signal for the O nodes is calculated as the difference between the previous output E and the reinforcing signal $stress$. In other words, the O nodes compare the expected and received reinforcement signals; therefore, inhibiting the output of the model should be a mismatch. In (3), the learning rule in the Orbitofrontal Cortex is presented.

$$\Delta W_i = \beta(S_i \sum (O_j - stress)) \tag{3}$$

The Orbitofrontal learning rule is very similar to the Amygdala rule. The only difference is that the Orbitofrontal connection weight can either increase or decrease as needed to track the required inhibition. Parameter β is another learning rate constant. The A nodes produce their outputs proportionally to their contribution in predicting the reward or stress signal $stress$, while the O nodes inhibit the output of E when necessary.

$$\begin{array}{l} A_i = S_i V_i \\ O_i = S_i W_i \\ E = \sum A_i - \sum O_i \end{array} \tag{4}$$

Equation (4) presents the Model output expression.

3. **Practical Overhead Crane.** As it is shown in Figure 2, the overhead traveling crane consists of a trolley, a rope, and a load. The load is regarded as a material particle with a mass of m. The rope is considered as an inflexible rod with a length of l, which its mass is negligible in comparison with the load mass. Having a mass of M, the trolley moves on a straight rail. It is supposed that no friction exists in the system. Therefore the dynamic of the overhead traveling crane can be described by equations (5) and (6) [15].

With more detail these assumption can be made for simplifying the model: (a) The dynamics and nonlinearities of driving motor are neglected. (b) The trolley moves along the track without friction or slip. (c) The rope has no mass and elasticity. (d) There is no damping of pendulum. (e) The load is regarded as a point mass.

$$\cos(\theta)\ddot{x} + l\ddot{\theta} + g\sin(\theta) = 0 \tag{5}$$

$$(M+m)\ddot{x} + ml\cos(\theta) - ml(\dot{\theta})^2\sin(\theta) = F \tag{6}$$

As shown above, it is obvious that the state equations are nonlinear. The cart friction is a non-linear function of its velocity as shown in Figure3 [14].

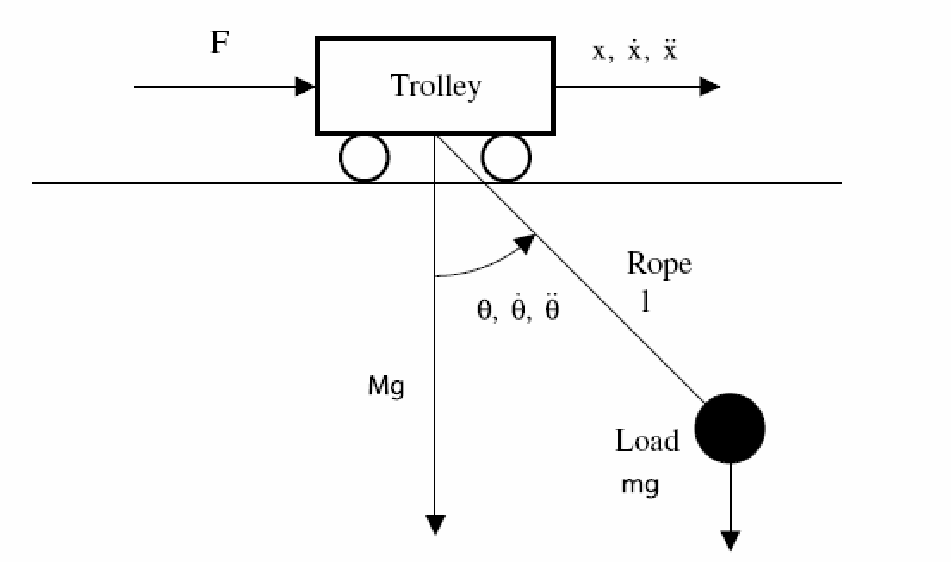

FIGURE 2. A simplified model for overhead crane

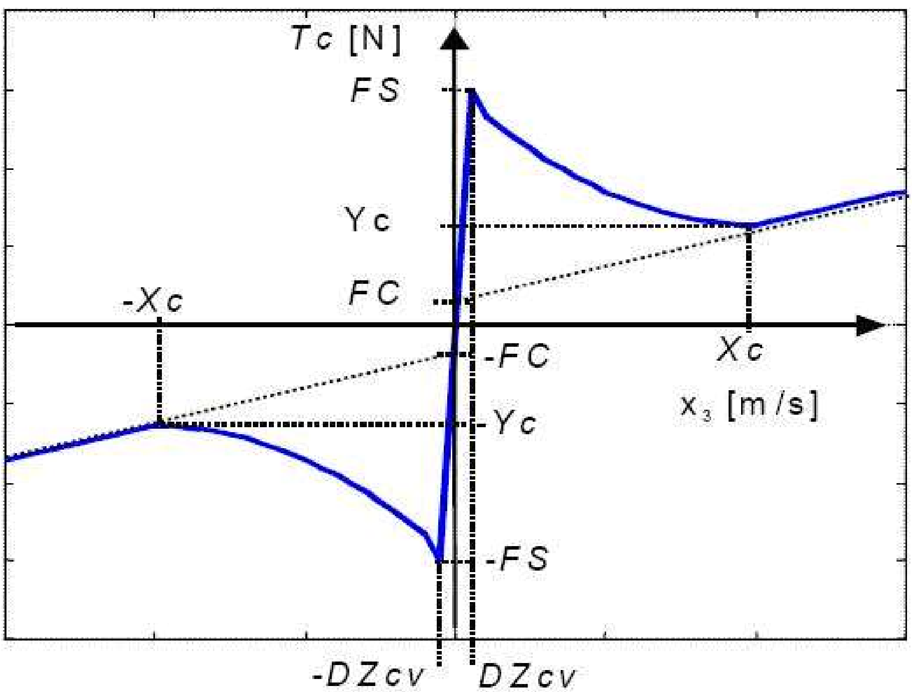

FIGURE 3. Friction model of crane [Feedback02]

The control task is tracking reference signal along with and avoiding of pendulum load swings. Block diagram of plant with BELBIC controllers is presented in Figure 4.

Figure 4 shows that two BELBICs work together to control the plant. Sensory input of the first one is position error and sensory input of the other one is angle error. The

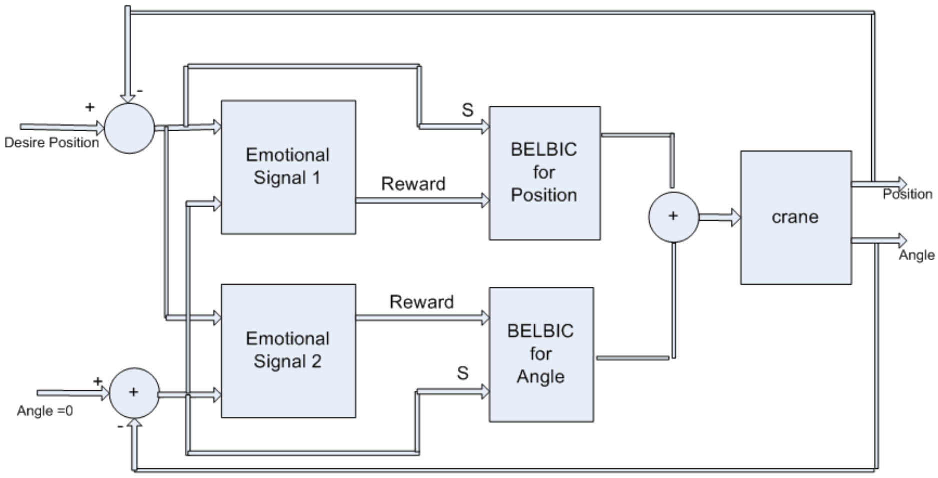

FIGURE 4. Block Diagram of Control System

emotional signals are created based on designer objectives. In addition, designer can fuse objectives of one controller by the other one. In the other words, decoupling of controllers is compensated by fusing the objectives in reward or stress functions. It must be noticed that any of above equation and knowledge about friction in procedure of proposed controller design is not used in this paper. The control strategy which is used in this paper is model free.

4. **Experimental Results.** In this section BELBIC performance is compared with other classic and intelligent controllers in controlling a crane laboratorial set.[1]

The first controller in this experiment is originally supplied sample controller, which consists of two PID controllers and a nonlinear friction compensator. This controller is a model based controller and designed by Feedback Instruments Corporation. It has to be said that double PID controller is designed to act on sinusoid reference signal and don't lead to desire response when the position reference signal is in different type for example step signals.

The second controller is a HFLC that was implemented on crane and it can track different type of reference signals with minimal dependency to the model. It is a model free controller which has been designed based on very simple knowledge about behaviour of system.

Finally the proposed BELBIC controller is implemented that have learning capability and works in completely model free manner. Reference signal is sinusoidal which could be assumed similar to real reference signal of industrial overhead crane. The experimental results are gathered without effect of external disturbance and in the presence of disturbance.

4.1. **Results without Effect of Disturbance.** This section demonstrates obtained results without effect of disturbance. Figure 5 shows the reference sinusoidal and tracked

[1]The Digital Pendulum Control System, crane system, manufactured by Feedback Instruments Limited, England.

signal for each controller. The reference is dashed line and the tracked signal is complete one.

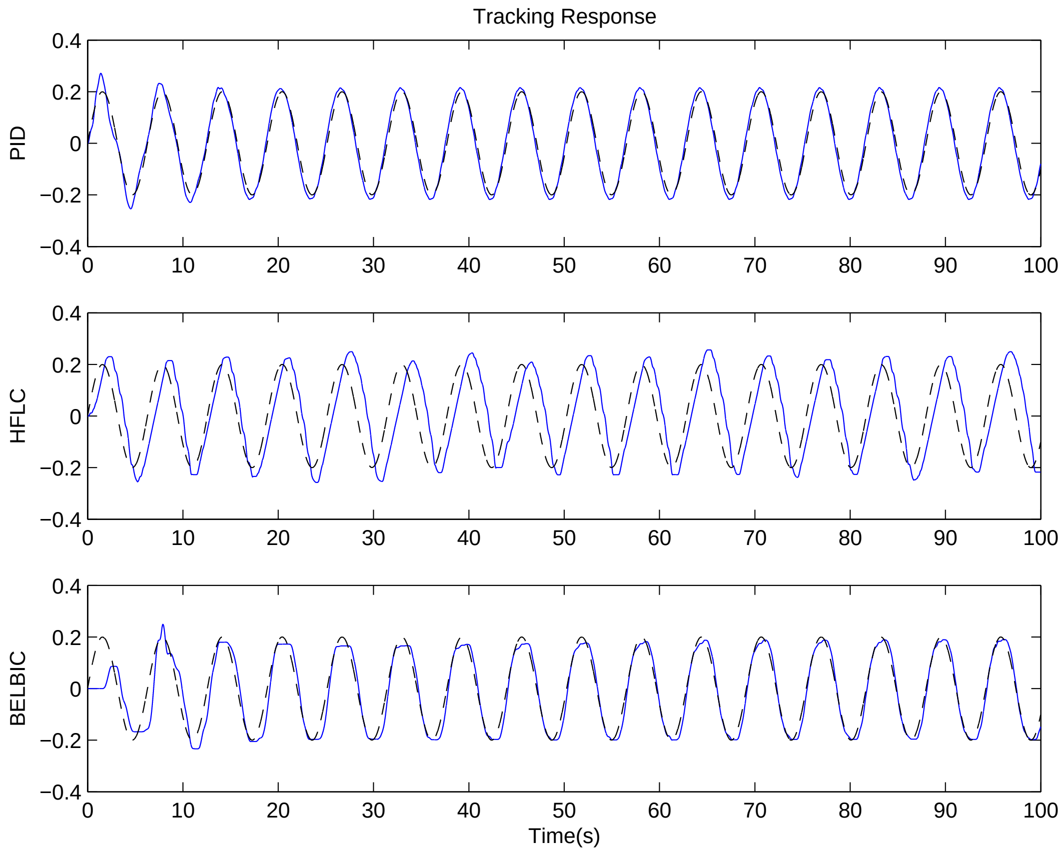

FIGURE 5. Tracking of sinusoid reference signal employing different controllers

It is obvious from Figure 5 that the BELBIC learning capability enables it to learn tracking task and its performance in comparison with double PID controller is admirable. The performance of proposed controller is dramatically better than HFLC in accurate tracking reference signal.

As mentioned before, the second control task is fixing the angle about zero degree during tracking. Figure 6 shows that the double PID controller does the control task better than others but the performance of BELBIC is still comparable with the HFLC.

In industrial applications, there is direct relation between energy consummation and control effort. In this experience, control signal of BELBIC is acceptable and better than other controllers as shown in Figure 7.

4.2. **Results in Presence of Disturbance.** Like the previous sub-section, the plant must track the sinusoidal reference signal but in the presence of disturbance between 30th and 75th seconds. The results are shown in Figures 8, 9 and, 10 for tracking, angle and control signal respectively.

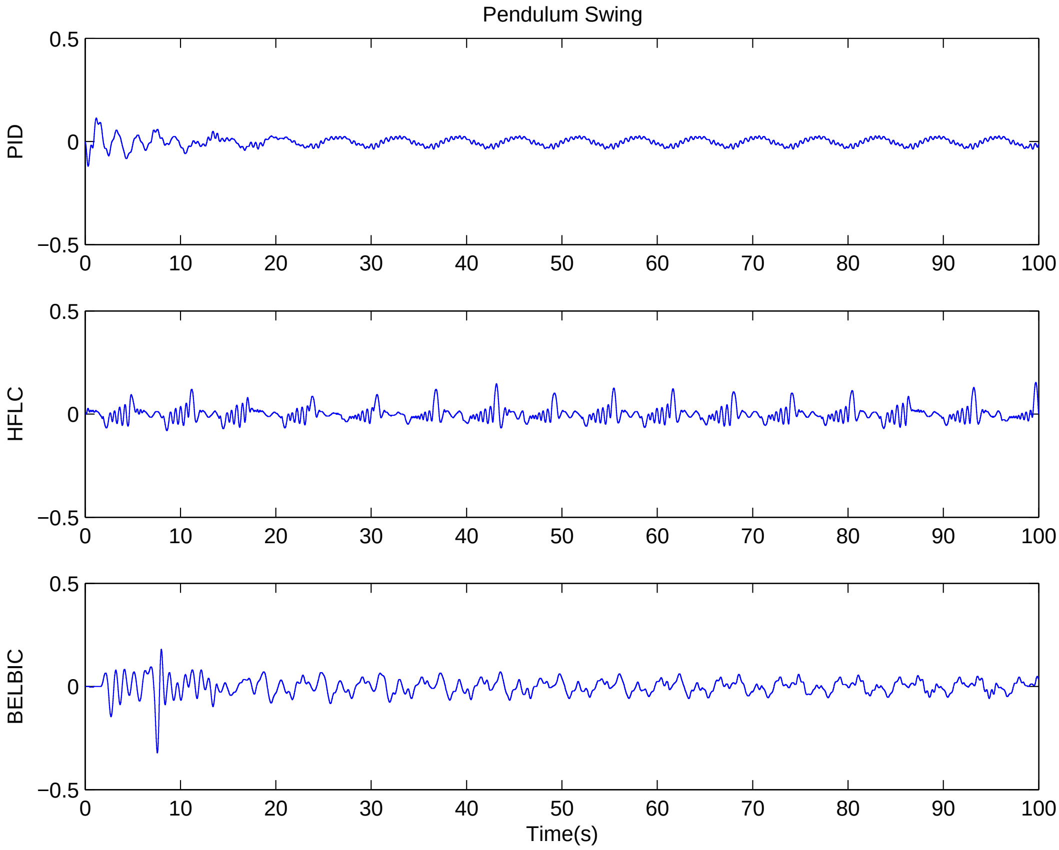

FIGURE 6. Pendulum angle using different controllers

As it is demonstrated in Figure 8, BELBIC controller is more robust than double PID and HFLC and it can compensate disturbance effect in an acceptable manner for tracking task.

In the presence of disturbance, the performance of BELBIC in fixing the pendulum is better than other controllers and it is because of the capability of proposed controller to reject the disturbances quickly as shown in Figure 9, however according to Figure 6, the performance of double PID controller was better than others in the absence of disturbance.

The control signal for each controller in presence of disturbance is presented in Figure 10.

In Table 1, Integral Squared Error(ISE) of pendulum angle in absence and presence of disturbance is demonstrated. Based on results which are depicted on Table 1, in absence of disturbances the BELBIC did not learn to damp pendulum swing properly. As demonstrated in Figure 6, at the beginning of learning procedure because of small emotional stresses, BELBIC learn to damp load swings slowly and some oscillation is observed at this period. After continuing learning procedure the result of BELBIC improved extremely. Due to above expression in the absence of disturbance,the ISE of pendulum angle in original sample controller and HFLC controllers are better than the BELBIC one. But when disturbance implies to the system, BELBIC learn faster and leads to better performance.

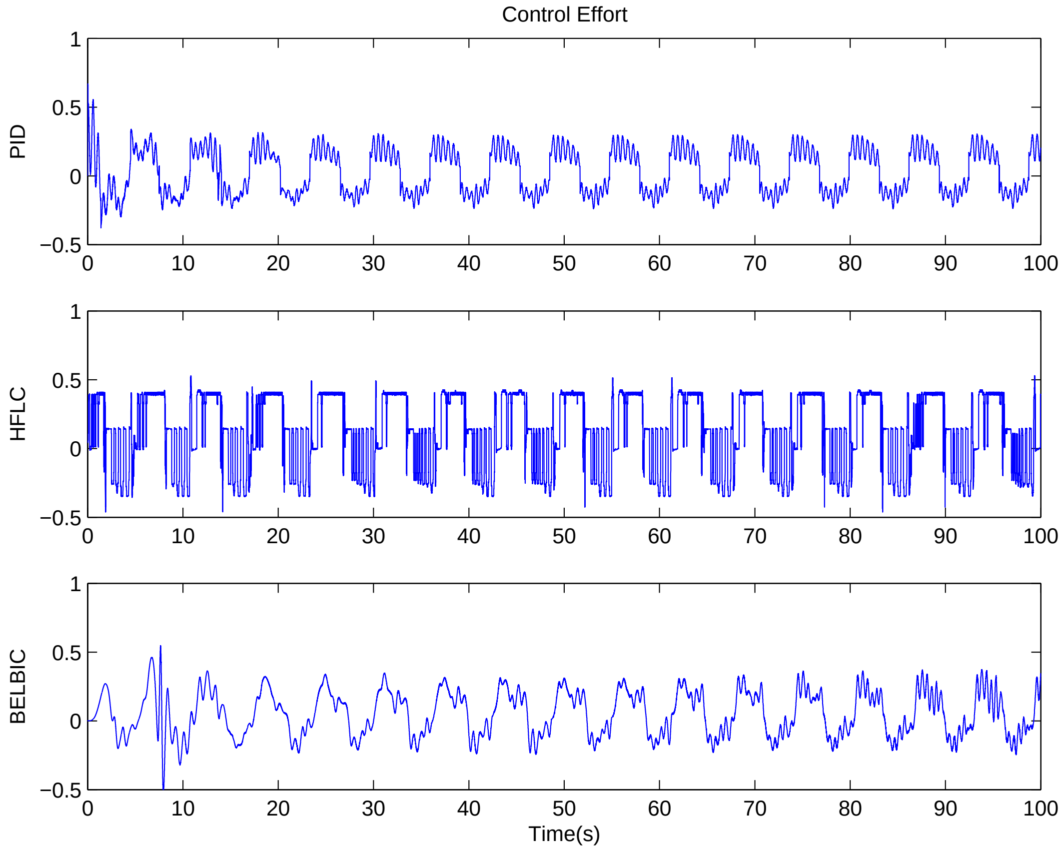

FIGURE 7. Control effort using different controllers

TABLE 1. Integral Squared Error of Angle

Applied Controller	Without Disturbance	In Presence of Disturbance
Original controller (PID)	0.0717 rad	0.1410 rad
HFLC	0.1084 rad	0.1493 rad
BELBIC	0.1221 rad	0.1236 rad

In Table 2 Integral Squared Error (ISE) of trolley position tracking in absence and presence of disturbance is presented. The indexes values are calculated considering the results from 20th second till 100th second. This consideration is rational because of eliminating delayed response arise from initial learning phase.

TABLE 2. Integral Squared Error of Position

Applied Controller	Without Disturbance	In Presence of Disturbance
Original controller (PID)	0.0465	0.1020
HFLC	1.0546	1.0232
BELBIC	0.0514	0.0774

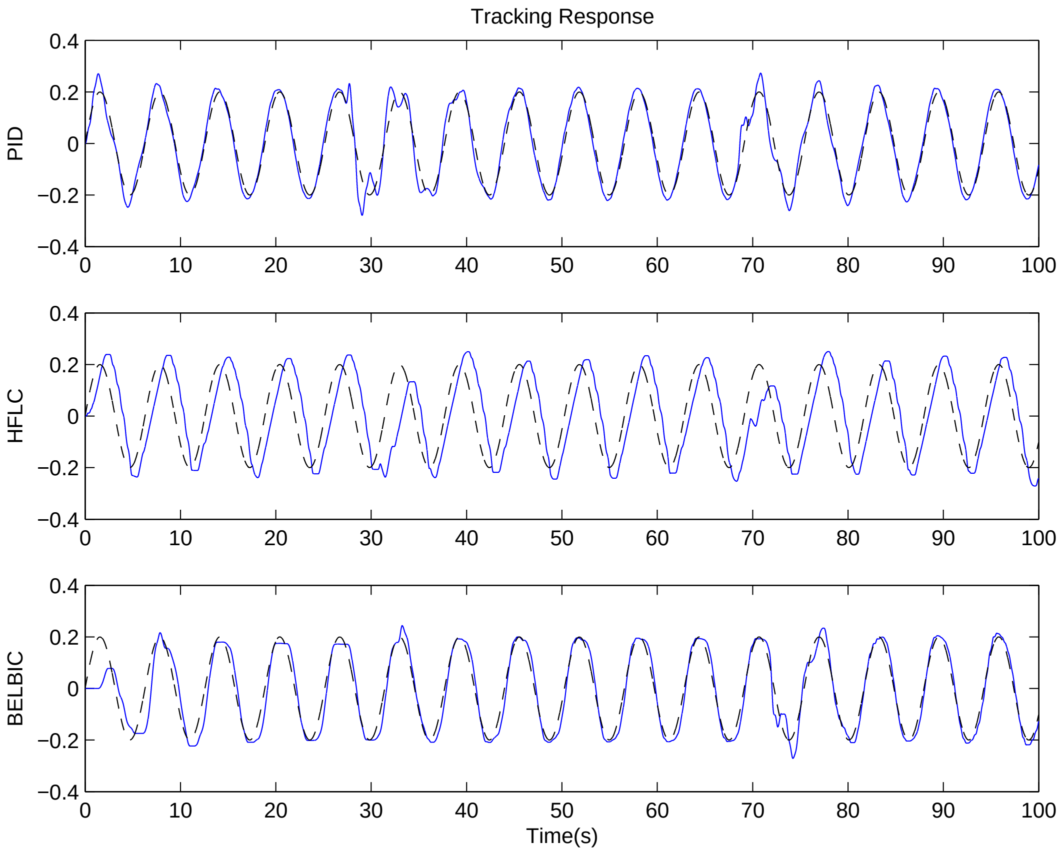

FIGURE 8. Tracking of sinusoid reference signal using PID, HFLC and BELBIC controllers in presence of disturbance in 30th and 75th seconds.

Based on Table 2, in absence of disturbance state, the result of original sample controller and BELBIC are approximately equal but employing double PID controller leads to slightly better result in tracking reference signal. BELBIC learn how to compensate the tracking error while system operation this capability represents itself particularly in presence of disturbance. In presence of disturbance comparing the results show the superiority of BELBIC.

In Figure 11, real execution of BELBIC on plant is shown.

5. **Coclusion.** Previous simulations show that brain emotional learning based controller (BELBIC) is comparable with classical controllers and even leads to better performance in some cases. The learning capability, robustness and fast response are the main features of this controller that has been reported in the previous simulation works. Also the initial parameters are not very critical and learning capability enables it to obtain reasonable gains. In this paper, BELBIC was applied to real overhead traveling crane and similar behaviour to previous simulation in robustness, fast response and learning capability is seen. Due to control objectives, the emotional signals could be defined properly and because of learning capability of this controller, the initial parameters are not important. Obtained results showed that this controller was comparable with double PID controller and disturbance rejection of this controller is better than classical approaches. Also results

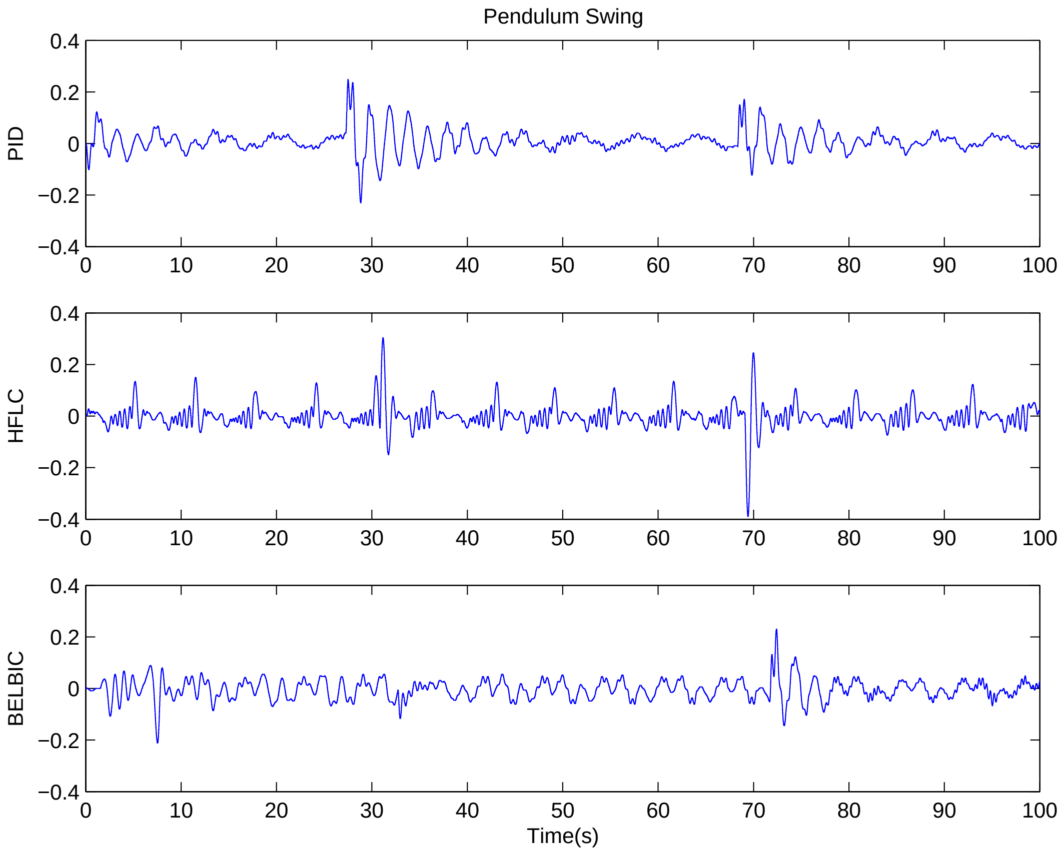

FIGURE 9. Pendulum angle using different controllers in presence of disturbance in 30th and 75th seconds.

of BELBIC were better than HFLC as an intelligent and model free method. This work is the essential step towards enclosing BELBIC to an appropriate industrial controller.

REFERENCES

[1] Balkenius, C. and J. Moren, A Computational Model of Emotional conditioning in the Brain, *workshop on Grounding Emotions in Adaptive Systems*, Zurich,Germany, 1998.

[2] Moren,J. and C. Balkenius, A Computational Modelof Emotional Learning in the Amygdala: From animals to animals , *6th International Conference on the Simulation of Adaptive Behavior*, Cambridge, MIT Press, pp.383-391, 2000.

[3] Moren, J.,*Emotion and Learning: A computational model of the amygdale*, PhD thesis, Lund university, Lund, Sweden, 2002.

[4] Lucas, C., D. Shahmirzadi, N. Sheikholeslami,Introducing BELBIC: Brain Emotional Learning Based Intelligent Controller, *International Journal of Intelligent Automation and Soft Computing*,pp. 11-22, 2004.

[5] Sheikholeslami,N., D. Shahmirzadi, E. Semsar, C. Lucas, and M. J. Yazdanpanah, Applying Brain Emotional Learning Algorithm for Multivariable Control of HVAC Systems,*International Journal of Intelligent and Fuzzy Systems*, 17 (1), pp 35- 46, 2006.

[6] Milasi, R. M., C. Lucas, and B. N. Araabi,Speed Control of an Interior Permanent Magnet Synchronous Motor Using BELBIC (Brain Emotional Learning Based Intelligent Controller), *Special Session on Emotional Learning and Decision Fusion in Satisficing Control and Information Processing, Minisymposium on Satisficing, Multiagent, and Cyberlearning Systems, 5th International Symposium on*

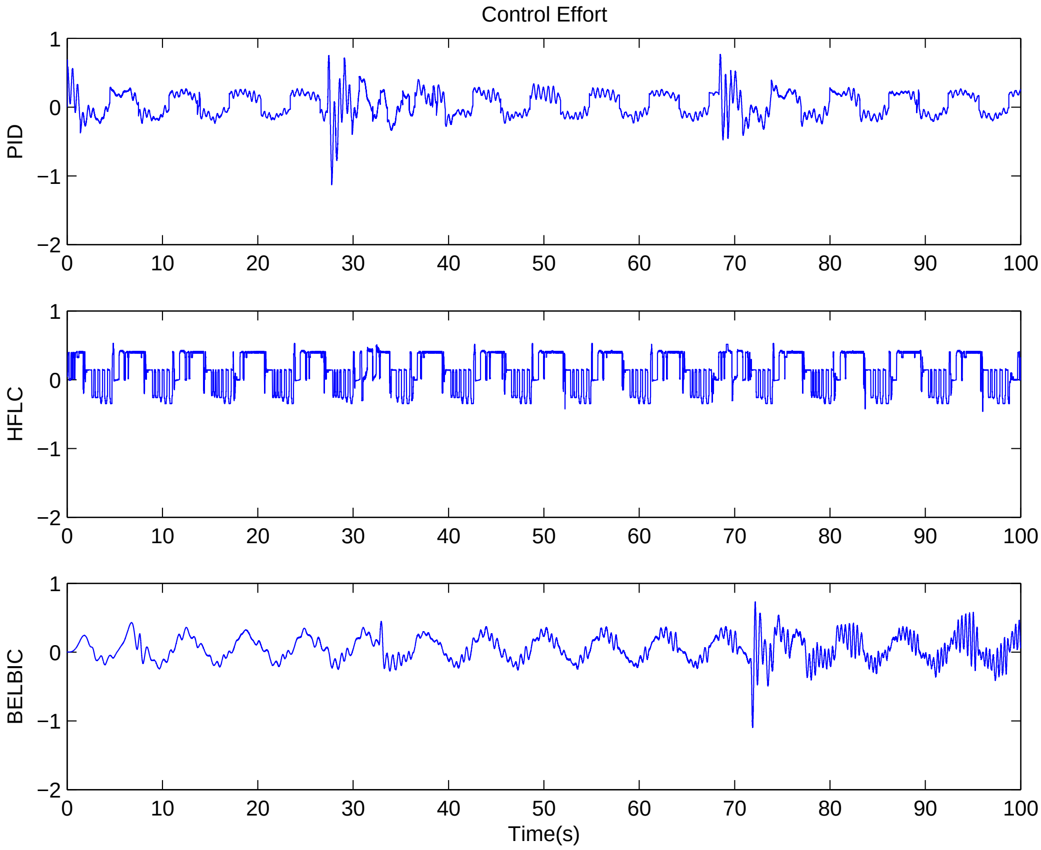

FIGURE 10. Control efforts belong to different controllers in presence of disturbance in 30th and 75th seconds.

Intelligent Automation and Control, World Automation Congress, WAC 2004, Seville, Spain, June 28- July1, ISIAC 116, 2004.

[7] Milasi, R. M., C. Lucas, and B. N. Araabi, Intelligent Modeling and Control of Washing Machine Using Locally Linear Neuro- Fuzzy (LLNF) Modeling and Modified Brain Emotional Learning Based Intelligent Controller (BELBIC), *SAsian Journal of Control*, 8 (4), 2005.

[8] Milasi, R. M., M. R. Jamali, and C. Lucas,Intelligent Washing Machine: A Bioinspired and Multi-Objective Approach, *Accepted in International Journal of Control, Automation, and Systems*, 2007.

[9] Jamali, M. R.,A. Pedram, M. R. Milasy, C. Lucas,Design and Implementation of BELBIC Pattern, *Proceeding of 14th Iranian Conference on Electrical Engineering,ICEE2006*,Tehran,Iran, 2006.

[10] Alexander, C., *The timeless way of building*, Oxford University Press, 1979.

[11] Milasi, R. M., C. Lucas, B. N. Arrabi, T. S. Radwan, and M. A. Rahman, Implementation of Emotional Controller for Interior Permanent Magnet Synchronous Motor Drive, *IEEE / IAS 41st Annual Meeting: Industry Applications*, Tampa, Florida, USA, October 8 - 12, 2006.

[12] Tong, S. and Y. Li ,"Direct Addaptive Fuzzy Backstepping control for a class of nonlinear systems, *International Journal of Innovative Computing, Information and Control*,Vol. 3, No. 4, 2007.

[13] Fujimoto, K., H. Sasaki, Y. Masaoka and R. Q. Yang,An implementation of the neuro-fuzzy inference circuit,*International Journal of Innovative Computing, Information and Control* ,Vol. 3, No. 4, 2007.

[14] Feedback Instrument Ltd, *Digital Pendulum Control Experiments*, Manual: 33-935/936-1V60, 2002.

[15] Yager,R. R., An alternative procedure for the calculation of fuzzy logic controller values,*IJ. Jpn. Soc. Fuzzy Technol, SOFT 3*,pp. 736-746, 1991.

FIGURE 11. Digital Pendulum Controller with BELBIC.