

Applying Modified BELBIC (Brain Emotional Learning Based Intelligent Controller) to Control of a Servo Motor with Backlash

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Abstract. In this paper, a biologically motivated algorithm originating in emotional processes in the limbic system of the mammalian brain -termed BEL- is used to speed control of a servo motor which suffers from internal backlash and defect. The proposed modified version of brain emotional learning based intelligent controller (BELBIC) is applied experimentally to servo motors of U of T omni-directional mobile robot. In spite of the highly nonlinear and uncertain nature of the system, the controller shows very robust and satisfactory performance including a fast response time and highly adaptation ability. The proposed strategy is very flexible and alternative performance specification can easily be enforced via defining proper emotional cues.

1 Introduction

Backlash is one of the most important non-linearities that limit the performance of speed and position control in robotics applications. The definition of backlash according to a Webster dictionary is “the play between adjacent movable parts (as in a series of gears)”. Backlash is present when a driving member (motor) is not directly connected with the driven member (load). This is the case in many, if not most driven mechanical systems, notably those with gears, e.g. the drive trains in cars, rolling mills, printing presses, and robots.

It is immediately clear that control of a load behind a backlash is complicated in particular if high precision is desired. There are instances when the backlash gaps opens, and the motor loses contact with the load. This may happen when a disturbance acts on the load, or when the motor has to take corrective action in the opposite direction to where the load is moving or is positioned at the moment. When the backlash gap is open, the movement of the load is autonomous, and in addition, the force or moment generated by the motor drives only the motor itself (and the parts of the transmission before the backlash) and not the load. Controlled systems with backlash often exhibit steady-state error or, even worse, limit cycles whereby the system oscillates, often in an irregular fashion, with a peak-peak amplitude that may exceed the total size of the backlash. The control of systems with backlash has been the subject of study since 1940s and various controllers such as linear, adaptive and fuzzy controllers have been investigated. In this paper, we apply a modified version of brain emotional learning based intelligent controller (BELBIC), which is biologically motivated, for this purpose. Our goal is to implement modified BELBIC to speed control of an omni-directional mobile robot's wheels, which suffers from backlash and defects.

2 U of T's Omni-directional Mobile Robot

Omni-directional vehicles are a class of mobile robots that provide superior maneuvering capability compared to the more common nonholonomic vehicles. The ability to move along any direction, irrespective

of the orientation of the vehicle, makes it an attractive option in dynamic environments. The annual RoboCup competition, where teams of fully autonomous robots engage in soccer matches, is an example of where omni-directional mobile robots have been used. The omni-directional mobile robots have been studied by using a variety of mechanisms. In other words, several omni-directional platforms have been known to be realized by developing a specialized wheel or mobile mechanism.



Fig. 1. The U of T omni-directional mobile robot

The *U of T* omni-directional robot consists of three omni-alpha wheels, driven separately by servo motors, to provide three *DOF*, as shown in Fig. 1.

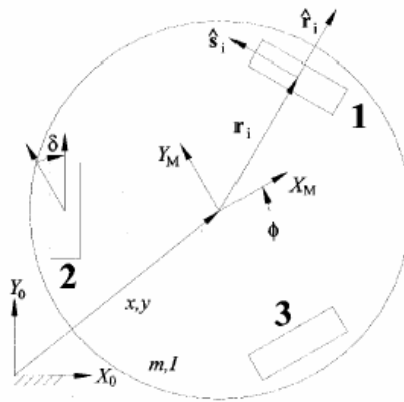


Fig. 1. The kinematic model of an Omni-directional mobile robot

The kinematic model of the robot is shown in Fig. 2 and its Jacobian matrix can be found as:

$$\dot{\theta} = \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix} = \frac{1}{r} \begin{bmatrix} -\sin(\delta + \phi) & \cos(\delta + \phi) & L \\ -\sin(\delta - \phi) & -\cos(\delta - \phi) & L \\ \cos\phi & \sin\phi & L \end{bmatrix} \begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \\ \dot{\phi} \end{bmatrix} = \mathbf{J}\dot{\mathbf{X}} \quad (1)$$

In which L is assumed to be the distance from the c.g. of the robot to the center of wheels along a radial path. Using (1), the velocities for the wheels are determined for desired robot's motion. Therefore, a

high-quality speed control for the motors is essential. Each driving unit consists of a servo motor, produced by Maxon Co., which is connected to the omni-alpha wheel via a gearbox in order to provide appropriate velocity and torque, as shown in Fig. 3.

The gearboxes suffer highly from backlash and some defects such as shaft misalignment, pitting, and corrosion. Consequently, they show bad performance which makes the control process extremely difficult.

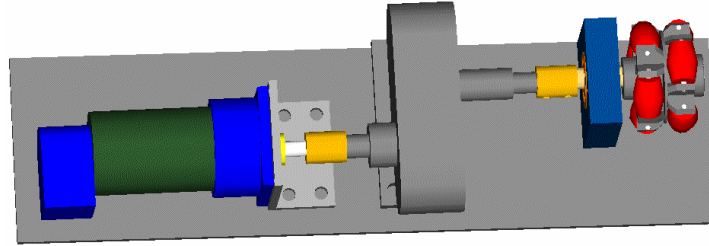


Fig. 3. The driving Pack of the robot

3 Data Acquisition System

In order to measure the wheels' velocity for close-loop control, tachometers are mounted to the servo motors. A first-order low-pass analog filter reduce the noise of the signals. Afterward, the filtered signals are converted to digital signals by means of an *A/D* converter, *ADC0809*. The desired motor voltages are generated by a PWM circuits and dual-bridge current drivers, *L298N*. Finally, a digital I/O card, *Advantech PCI-1753*, is employed to transfer the digital data between computer and the electronic circuit.

4 Modeling the Backlash and Defects

Backlash or gear play is a common non-linearity in mechanical systems. Depending on the mechanical surrounding of the backlash, and the operating conditions, different mathematical models must be utilized to model the behavior. A simple sketch of backlash, depicted in Fig. 4, is used to model it. θ_s is the twist of the shaft (not explicitly shown in the figure), $\theta_d = \theta_m - \theta_l$ (rad) is the displacement angle between the motor angle θ_m and the load angle θ_l , and $\theta_b = \theta_d - \theta_s$ (rad) is the backlash angle, with the restriction that $-\alpha \leq \theta_b \leq \alpha$. k_s , c_s are the elasticity and damping coefficients, respectively, of the shaft. The maximal backlash angle is denoted α .

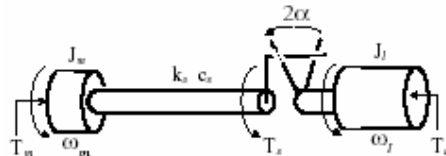


Fig. 4. Backlash or gear play in a two-mass system

An often proposed model, found in almost any basic control course, for analysis and simulations of an elastic shaft with backlash is the classical dead zone model, where the shaft torque, being proportional to the shaft twist θ_s (rad), is given by:

$$T_s = k_s \theta_s = k_s D_\alpha(\theta_d) \quad (2)$$

The dead zone function

$$D_\alpha(x) = \begin{cases} x - \alpha & x > \alpha, \\ 0 & |x| < \alpha, \\ x + \alpha & x < -\alpha \end{cases} \quad (3)$$

gives θ_s directly as a static function of the displacement θ_d . The effect of defects in gearbox can be modeled as uncertainty in system's stiffness or an external low frequency disturbance on the shaft. The second approach is used throughout this paper.

5 Modified BELBIC

BELBIC is the abbreviation for brain emotional learning based intelligent controller. Motivated by the success in functional modeling of emotions in control engineering applications, a structural model based on the limbic system of mammalian brain, for decision making and control engineering applications has been developed. The computational model of emotional learning in the amygdala, based on Moren and Balkenius model, is depicted in Fig. 5. The main parts that are responsible for performing the learning algorithms are orbitofrontal cortex and amygdala.

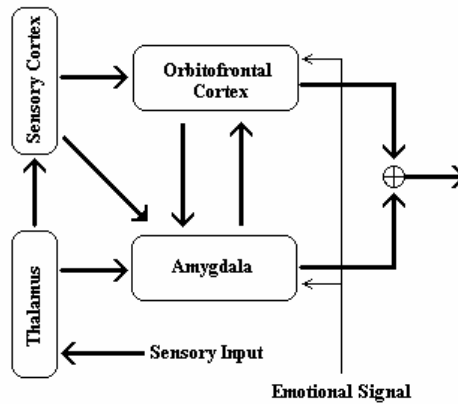


Fig. 5. Computational model of emotional learning in the Amygdala

There are two approaches to intelligent and cognitive control. In the indirect approach, the intelligent system is utilized for tuning the parameters of the controller. BELBIC is based on the second approach, called direct approach, in which the intelligent system is used as the controller block. This paper proposes a modified BELBIC structure, constructed based on Moren and Balkenius model, whose schematic diagram is illustrated in Fig. 6.

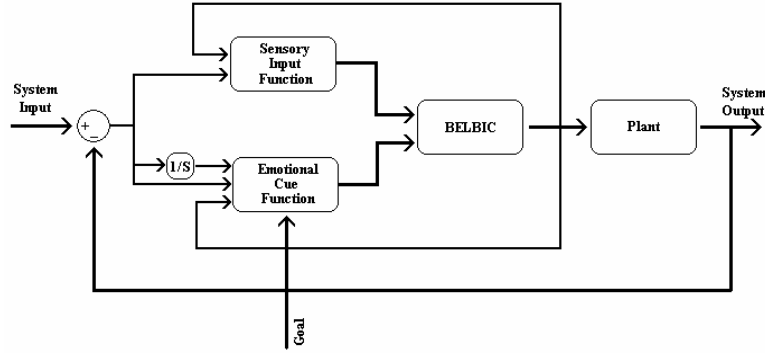


Fig. 6. Schematic structure of modified BELBIC

It is believed that the amygdalo-orbitofrontal system implements part of a two-process model of emotional learning. This approach separates learning into first a stimulus-emotional system that evaluates incoming stimuli, and a second learning system that uses this evaluation as a reinforcer for stimulus-response learning. Among the advantages of this approach is that the motivation to respond and the response itself are cleanly separated. Therefore, these two sub-systems are defined in this paper based on this fact.

BELBIC is essentially an action generation mechanism based on sensory inputs and emotional cues which are generally vector values. The emotional learning occurs mainly in the Amygdala and Orbitofrontal Cortex. The learning rule of the Amygdala and Orbitofrontal Cortex is given as:

$$\Delta G a_i = \max(0, \eta |S_i| \cdot Ec) \quad (4)$$

$$\Delta G o_i = \eta |S_i| \cdot \overline{Ec} \quad (5)$$

In which the sensory inputs and the emotional cues for the Amygdala and Orbitofrontal Cortex are defined as

$$S = \begin{Bmatrix} k_1 e \\ k_2 \int e \cdot dt \\ k_3 u \end{Bmatrix} \quad (6)$$

$$Ec = k_4 (k_5 |e| + k_6 |u|)^{k_7} \quad (7)$$

$$\overline{Ec} = \frac{1}{Ec + k_8} \quad (8)$$

In which e and u are error signal and control signal, respectively. k_i s are coefficients that should be tuned manually. The sensory input, proposed based on classic control, consists of error signal, error integral signal and control signal. Because of the highly noisy and uncertainty nature of the plant, we cannot use the differentiation of the error signal for control purpose.

The proposed emotional cue function is actually the stimulus-emotional system for control purpose that evaluates incoming stimuli. For an ideal control system, the error signals and control effort should be minimized; correspondingly, the emotional cue is defined as (7). The complementary emotional cue func-

tion is defined as (8) because it shows the mismatches between the system's actual performance and its ideal performance. The node value is then calculated as:

$$A_i = Ga_i \cdot S \quad (9)$$

$$O_i = Go_i \cdot S \quad (10)$$

and the output of the model is found as:

$$\overline{Ec} = \frac{1}{Ec + k_s} \quad (11)$$

The emotional learning system works at two levels: the amygdaloid part learns to predict and react to a given reinforcer. This sub-system can never unlearn a connection; once learned, it is permanent, giving the system the ability to retain emotional connections for as long as necessary. The orbitofrontal system tracks mismatches between the base system predictions and the actual signal and learns to inhibit the system output in proportion to the mismatch. Finally, the control signal is determined by applying a nonlinear saturation function on the output of the emotional model.

7 Experimental Results

The proposed modified BELBIC was implemented successfully on the U of T omni-directional mobile robot. It is used for speed control of servo motors with backlash and defect. The performance is verified by studying the step response of the system and the comparing it with that of the conventional *PID* controller. To show the learning ability of the modified BELBIC, we initially set the amygdaloid and orbitofrontal cortex gains to zero. By applying a step input to the system, controller learnt and adjusted its gain automatically.

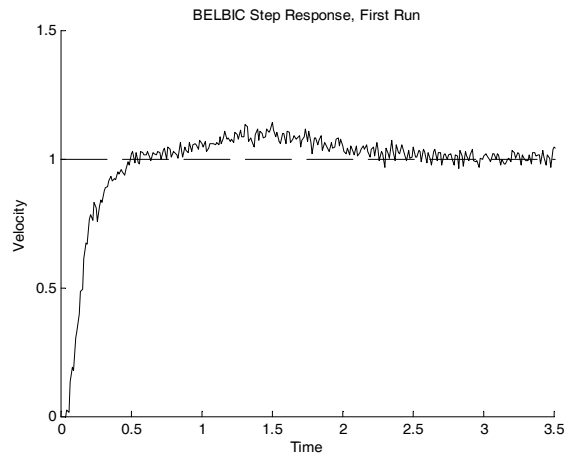


Fig. 7. BELBIC, step response, first run

Because the BELBIC had not been trained, it did not show a good performance. However, the interesting point about the BELBIC is its adaptive nature. The gains were automatically tuned during the first run. Fig. 8 shows the step response of the system using the BELBIC which is trained during the first run.

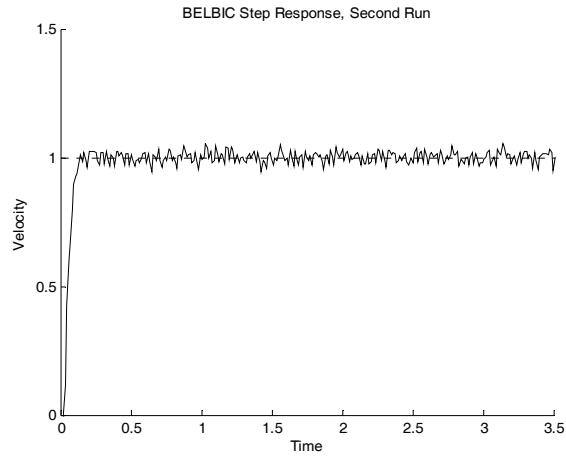


Fig. 8. BELBIC, step response, second run

The result is really considerable. Very fast responses without steady state error and noise reduction ability are noticeable. To make a comparison, the step response of the system controlled by a *PI*-controller is depicted in Fig. 9.

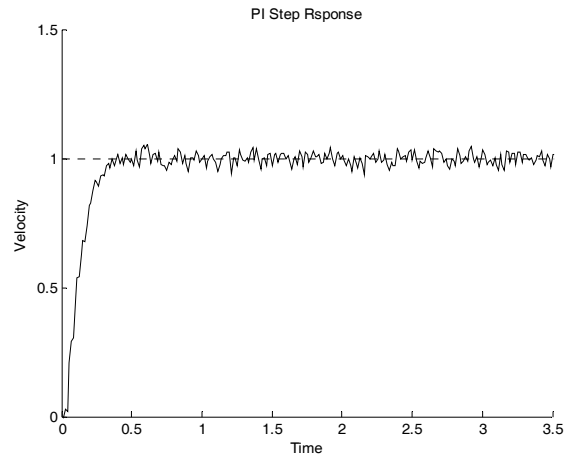


Fig. 9. PI-controller, step response

To illustrate the training process, the amygdala and orbitofrontal cortex gains are plotted versus time for the first run and the second run.

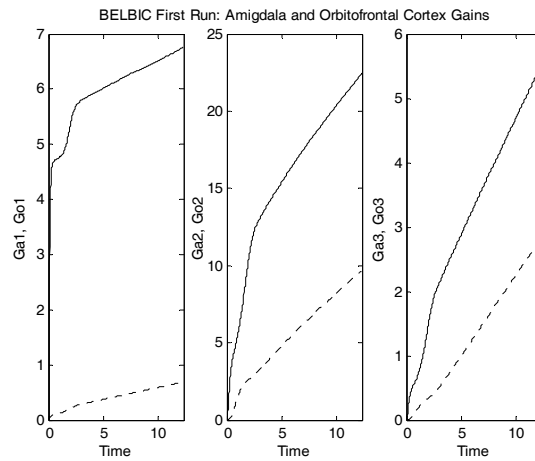


Fig. 10. Amigdala and Orbitofrontal Cortex gains, first run

It can be seen that after the training process, the trend of amygdala gains and that of the corresponding orbitofrontal gains becomes parallel. It means that the difference between them reaches a steady-state values which is the optimal trained gains of the controller.

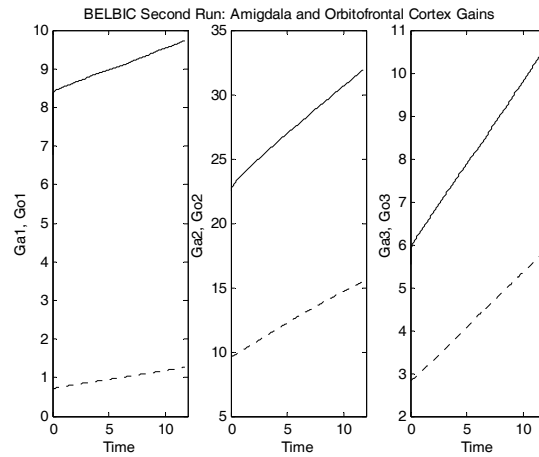


Fig. 11. Amigdala and Orbitofrontal Cortex gains, second run

Fig. 12 shows the control effort of the trained BELBIC for the step response.

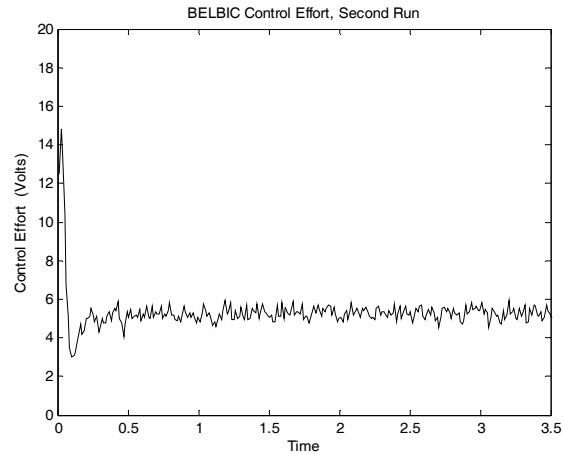


Fig. 12. Control effort for trained BELBIC

7 Conclusion

In this paper, a modified version of BELBIC is proposed based on Moren and Balkenius emotional model. The emotional cue function and sensory inputs are defined completely different with that of the conventional BELBIC. The modified controller was implemented experimentally on the U of T omnidirectional mobile robot's wheels which driving system suffers highly from backlash and defects. The system showed a considerable performance in speed control of the servo motors including very fast response, no steady-state error, significant adaptation and robustness.

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