Attitude Control of a Quadrotor Using Brain Emotional Learning Based Intelligent Controller

Mohammad Jafari
Department of Mechatronics
Qazvin Branch, Islamic Azad University
Qazvin, Iran
mohamadj@gmail.com

Alireza Mohammad Shahri
Department of Electrical Engineering
Iran University of Science and Technology
Tehran, Iran
shahri@iust.ac.ir

Saeed Bagheri Shouraki
Department of Electrical Engineering
Sharif University of Technology
Tehran, Iran
bagheri-s@sharif.edu

***Abstract*—For the first time in this paper, Brain Emotional Learning Based Intelligent Controller (BELBIC) is applied to attitude control of a Quadrotor. BELBIC controller is designed based on the computational model of emotional learning process in mammalian brain limbic system. Proposed control algorithm is employed because of the learning ability and independency to system model and also satisfactory performances dealing with disturbances and changing in system parameters. Quadrotor is an Unmanned Aerial Vehicle (UAV) which has the capability of Vertical Take-Off and Landing (VTOL). Simulation results of controlling Quadrotor with BELBIC are addressed. Also pitch angle disturbance is applied due to examine system performances.**

Keywords— BELBIC; Quadrotor; VTOL; Emotional Learning; Intelligent Control.

I. INTRODUCTION

In the industries, we always deal with plants which have no information about their model. So designing controllers with less dependency to system model and no need to exact knowledge of system information is so vital. In Emotional Learning concept in control, we suppose that equations of system are unknown and the only available information are states of system and a feedback of measured controller performance in form of win or lose signal. Despite of this lack of knowledge, control system must have the capability of conveying this unknown system from present situation to desired one which expects to be better [13]. Brain Emotional Learning Based Intelligent Controller (BELBIC) is a model free controller which utilized to control several systems. In [9] BELBIC is used for controlling Two-Coupled Distillation Column Process, Intelligent Autopilot Control Design for a 2-Dof Helicopter Model is addressed in [10], Motion Control of Omni-Directional Three-Wheel Robots and Target Tracking Control of a Mobile Robot are presented in [11] and [12] respectively.

In recent years, a wide area of researches is focus on Unmanned Aerial Vehicles (UAVs). Among them, flights which have the capability of Vertical Take-Off and Landing (VTOL) are more important. Various control methods have been employed for stabilizing and controlling of Quadrotors. Most of them need detailed information of system dynamic and system parameters. Benallegue et al designed a High-Order Sliding-Mode Observer for a Quadrotor in [4], Neural Network Control Based on Adaptive Observer is employed by Boudjedir et al for Quadrotor Helicopter [6], Bou-Ammar et al Designed a Controller for Quadrotor UAVs Using Reinforcement Learning [7] and Nicol et al utilized Adaptive Fuzzy Control for a Quadrotor Helicopter.

For the first time in this paper, BELBIC controller is applied to attitude control of a Quadrotor. The results are compared with a well-tuned conventional PID controller. The proposed controller shows faster response, lower overshoot, smaller settling time and it is robust with respect to disturbances.

This paper is organized as follows. Section II describes the BELBIC controller. Mathematical model of Quadrotor is presented in section III. Simulation results are provided in section IV and finally some conclusions are presented in section V.

II. BELBIC Controller

Moren et al developed a computational model of those parts of limbic system thought responsible for processing emotions [1]. Fig.1 plots a graphical depiction of the emotional learning in amygdala.

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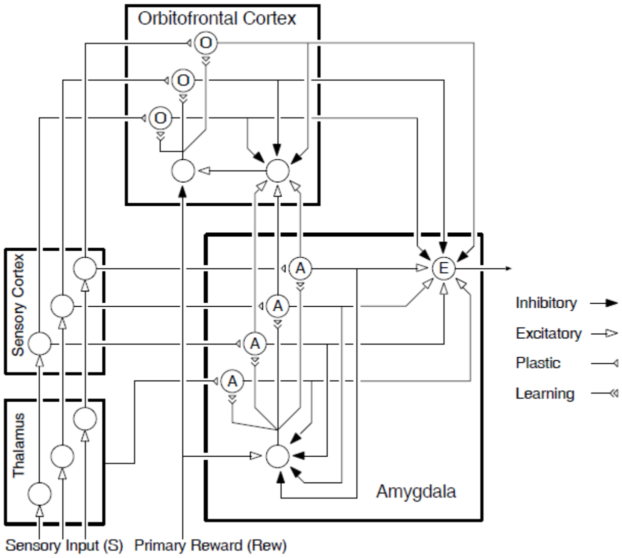

Fig. 1. Computational model of Emotional Learning in Amygdala [1].

The Amygdala and The Orbitofrontal Cortex (OFC) are two important parts of this model.

The vector S and Rew show the stimuli inputs to the system and the Primary Reward input respectively. As it is clearly seen in (3), the output of each node in Amygdala (Ai) and OFC (Oi) could be attained by multiplying any input (Si) with the weights Vi and Wi respectively.

$$A_i = S_i V_i$$
$$O_i = S_i W_i \tag{1}$$

The Ath is another node which is obtained from the maximum of stimuli inputs (S) input directly come to the Amygdala part from thalamus.

$$A_{th} = \max(S_i) \tag{2}$$

Equation (3) shows how the weights Vi and Wi could be updated.

$$\Delta V_i = \alpha\left(S_i \max\left(0, \mathrm{Re}\,w - \sum_j A_j\right)\right)$$
$$\Delta W_i = \beta S_i\left(\sum_j A_j - \sum_j O_j - \mathrm{Re}\,w\right) \tag{3}$$

The learning changes in amygdala are monotonic (i.e. the weights V cannot decrease), because once an emotional reaction is learned, this should be permanent. Since amygdala does not have the capability to unlearn any emotional response that it has ever learned, it is the task of OFC to inhibit any inappropriate response [1].

According to the Moren model, BELBIC was introduced by Lucas et al [2]. Fig. 2 demonstrates a feedback control block diagram consisting BELBIC Controller.

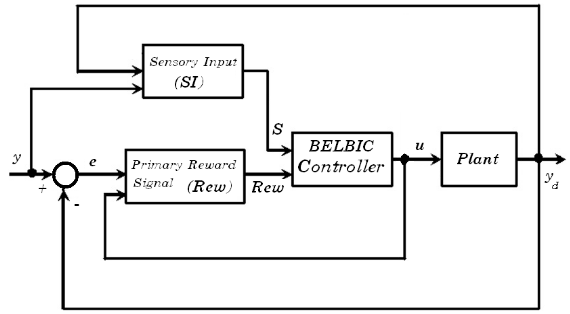

Fig. 2. BELBIC controller.

Sensory Input and Primary Reward (Emotional Signal) of BELBIC Controller are described as follow:

$$\mathrm{Re}\,w = f(e,u,r)$$
$$SI = g(y,e) \tag{4}$$

Where

e	error
r	reference input
u	control effort
y	plant output

In this study an intelligent controller including four BELBIC blocks is designed. Each BELBIC is responsible for one basic movement control. Fig. 3 demonstrates the proposed control scheme.

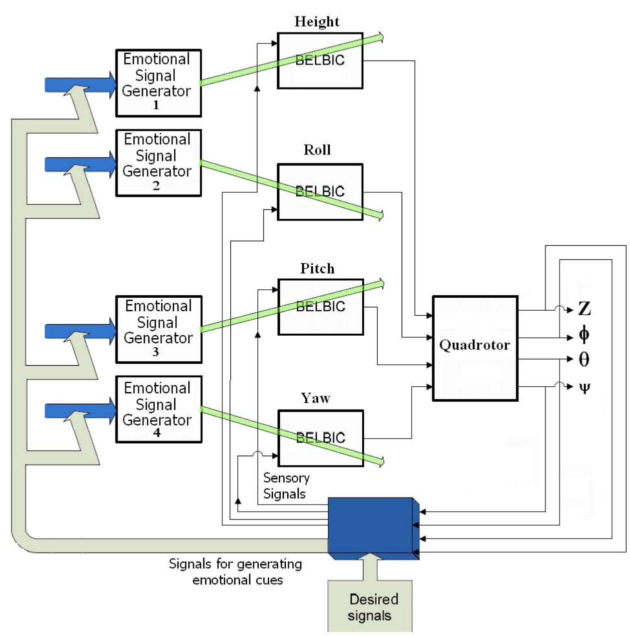

Fig. 3. Proposed control scheme.

The proposed controller consist of four different Emotional Signal Generator (Primary Reward) and four distinctive Sensory Inputs. In this paper simple PID is utilized for all emotional signals. To obtain Sensory Inputs error signals are used.

The Quadrotor dynamics which is employed for simulation is presented in following section.

III. Quadrotor Dynamics

Fig. 4 illustrated a sample Quadrotor. A hybrid frame consisting of E-frame and B-frame is used as the Quadrotor model.

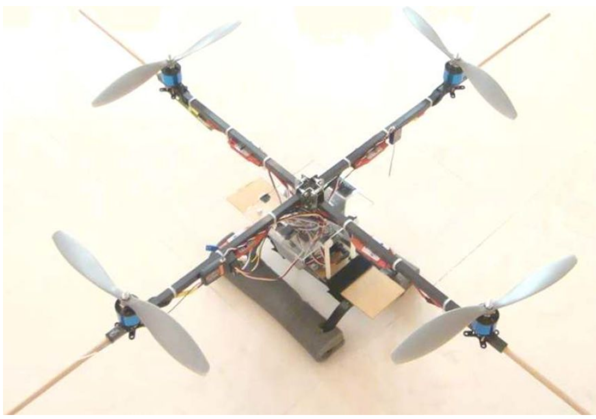

Fig. 4. Charotor, a sample Quadrotor [5].

The four basic movements which allow the Quadrotor to reach a certain height and attitude are described in the following. Throttle (U1) movement vertically raises or lowers the Quadrotor, Roll (U2), Pitch (U3) and Yaw (U4) movements make the Quadrotor turn around the x-axis, y-axis and z-axis respectively.

The equations in H-frame (which is a hybrid system composed of linear equations with respect to E-frame and angular equations with respect to B-frame) could be stated as follow [3].

$$\begin{cases} \ddot{X} = (\sin\psi \sin\phi + \cos\psi \sin\theta \cos\phi)\dfrac{U_1}{m} \\ \ddot{Y} = (-\cos\psi \sin\phi + \sin\psi \sin\theta \cos\phi)\dfrac{U_1}{m} \\ \ddot{Z} = -g + (\cos\theta \cos\phi)\dfrac{U_1}{m} \\ \dot{p} = \dfrac{I_{YY} - I_{ZZ}}{I_{XX}} qr - \dfrac{J_{TP}}{I_{XX}} q\Omega + \dfrac{U_2}{I_{XX}} \\ \dot{q} = \dfrac{I_{ZZ} - I_{XX}}{I_{YY}} pr - \dfrac{J_{TP}}{I_{YY}} p\Omega + \dfrac{U_3}{I_{YY}} \\ \dot{r} = \dfrac{I_{XX} - I_{YY}}{I_{ZZ}} pq + \dfrac{U_4}{I_{ZZ}} \end{cases} \tag{5}$$

Where

ψ	Yaw angle
ϕ	Roll angle
θ	Pitch angle

Relations between Basic movements and the propellers' speed are described in (6).

$$\begin{cases} U_1 = b\left(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2\right) \\ U_2 = bl\left(-\Omega_2^2 + \Omega_4^2\right) \\ U_3 = bl\left(-\Omega_1^2 + \Omega_3^2\right) \\ U_4 = d\left(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2\right) \\ \Omega = -\Omega_1 + \Omega_2 - \Omega_3 + \Omega_4 \end{cases} \tag{6}$$

Where

Ω_1	Front propeller speed
Ω_2	Right propeller speed
Ω_3	Rear propeller speed
Ω_4	Left propeller speed

Equation (7) shows the nonlinear dynamics of the Quadrotor motors (i.e. the relation between propellers' speed and motors' voltage).

$$\begin{aligned} J_{TP}\dot{\Omega} &= -\frac{K_E K_M}{R}\eta N^2 \Omega - d\Omega^2 + \frac{K_M}{R}\eta N v \\ J_{TP} &= \left(J_P + \eta N^2 J_M\right) \end{aligned} \tag{7}$$

Where

N	Reduction ratio of gear box
η	Conversion efficiency of gear box
v	Motor voltage

Table I shows the Quadrotor parameters which used in simulation in section IV. In this paper parameters of the mentioned model are selected identical to the real model due to the actualizing simulation.

TABLE I. QUADROTOR PARAMETERS[5]

Symbol	Description	Value
b	Trust factor	11×10^{-6} [NS^2]
d	Drag factor	1.1×10^{-6} [NmS^2]
m	Quadrotor mass	1.3 [Kg]
I_{xx}	Body moment of inertia around x-axis	8.1×10^{-3} [NmS^2]
I_{yy}	Body moment of inertia around y-axis	8.1×10^{-3} [NmS^2]
I_{zz}	Body moment of inertia around z-axis	14.2×10^{-3} [NmS^2]
l	Distance between the center of the quadrotor and the center of a propeller	0.27 [m]
J_{TP}	Total rotational moment of inertia around the propeller axis	7.33×10^{-5} [NmS^2]
K_E	Electric motor constant	6.3×10^{-3} [VSrad^{-1}]
K_M	Mechanic motor constant	6.3×10^{-3} [NmA^{-1}]
R	Motor resistance	0.6 [Ω]
g	Acceleration due to gravity	9.81 [mS^{-2}]

IV. SIMULATION RESULTS

This section presents numerical simulations of Quadrotor control. Two experiments are designed to examine the performance of proposed controller.

In first examination, Vertical Take off of the Quadrotor is investigated. The flight should reach to the 1 meter heights. Figs. 5-8 show the proposed controller and the PID applied to the model without any disturbance.

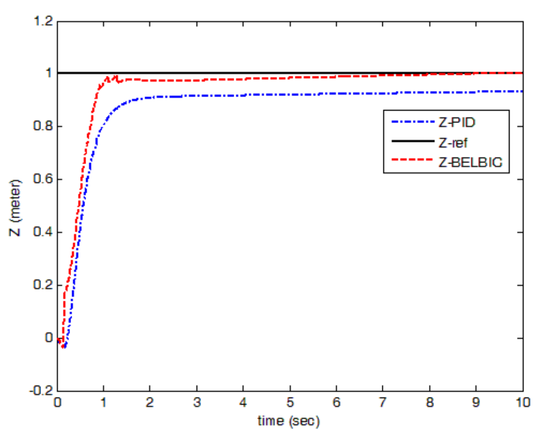

Fig. 5. Output of controlled system, PID (Blue), BELBIC (Red), Height

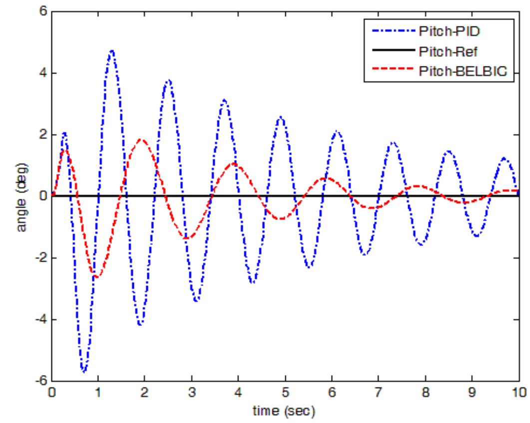

Fig. 6. Output of controlled system, PID (Blue), BELBIC (Red), Pitch

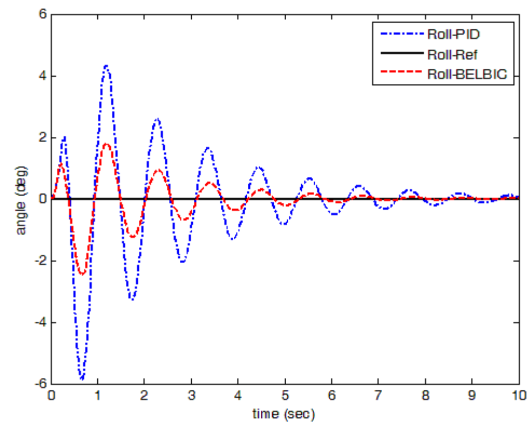

Fig. 7. Output of controlled system, PID (Blue), BELBIC (Red), Roll

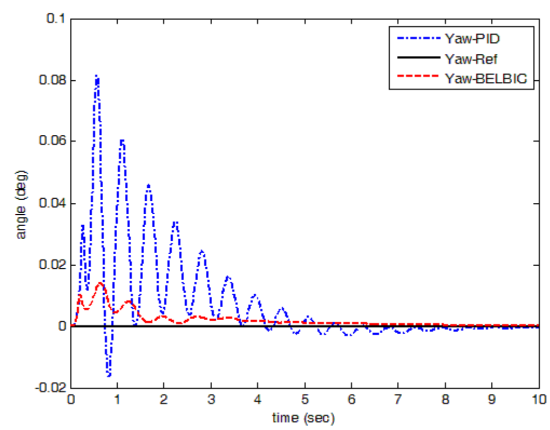

Fig. 8. Output of controlled system, PID (Blue), BELBIC (Red), Yaw

In second investigation, a force of 2 (N.m) is applied to pitch angle due to examine system performances dealing with disturbance. Fig. 9 plots the pitch angle of Quadrotor controlled by both PID and BELBIC. As it is clearly seen, proposed controller could handle the disturbance at least 10 times better than the conventional controller.

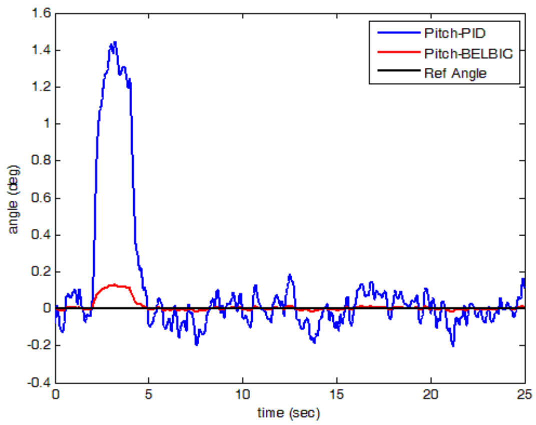

Fig. 9. Pitch angle of the Quadrotor, PID (Blue), BELBIC (Red).

V. CONCLUSION

For the first time, in this paper Brain Emotional Learning Based Intelligent Controller is utilized to attitude control of a Quadrotor. The simulation result of controlling the Quadrotor with proposed controller is compared to a well tuned PID. Also an effect of disturbance applied to pitch angle is addressed. The results show the satisfactory performances of applying BELBIC to the Quadrotor.

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