An Adaptive Neuro PID for Controlling the Altitude of Quadcopter Robot

Mehdi Fatan[1]; Bahram Lavi Sefidgari[2]; Ali Vatankhah Barenji[3]
[1]Islamic Azad university of Qazvin, Qazvin, Iran
[2]Department of Computer Engineering, Eastern Mediterranean University, Cyprus,
[3]Department of Mechanical Engineering, Eastern Mediterranean University, Cyprus
Bahram.lavi@emu.edu.tr

***Abstract*- Controlling the altitude of flying robots is one of the challenging issues in robotics. In this regard, this paper tries to investigate an adaptive PID controller which can adaptively result proper coefficients for controlling the altitude of flying robot. The structure of this PID controller is similar to Artificial Neuron used in many of artificial neural networks. Control of the robot's altitude by this controller was shown in a sinusoidal path and eliminating the incoming disturbance by adaptive neuro PID controller was investigated too. The primary coefficients were obtained by genetic algorithm for improving the performance of controller and it was demonstrated. A PID controller that the coefficients of which was improved by genetic algorithm was used for better studying the controller in eliminating the disturbances' effect which the results show the advantages of adaptive neuro PID controller with proper primary coefficients.**

Keywords: adaptive neuro pid, controller, quadcopter, altitude, flying robot, genetic algorithm.

I. INTRODUCTION

Quadcopter, also known as quadrotor, is a helicopter with four rotors. The rotors are directed upwards and they are placed in a square formation with equal distance from the center of mass of the quadcopter. The quadcopter is controlled by adjusting the angular velocities of the rotors which are spun by electric motors. Quadcopter is a typical design for small unmanned aerial vehicles (UAV) because of the simple structure. Quadcopters are used in surveillance, search and rescue, construction inspections and several other applications.

Regarding their complicate structure, the quadcopter is nowadays taken into consideration by many of the robotics researches and its complication causes special abilities which can be used in extensive range of usages [1,2]. Quadcopter's dynamics is considered as a starting point for all studies in this area but several cases are defined for increasing the complexity of its aerodynamics. The different controlling methods are studying and we can mention some such as PID controller [3, 4, 5], LQR controller [6], Back Stepping [7,8] and other nonlinear controllers.

Although Several studies have been done for controlling the quadcopter's status, controlling the altitude of quadcopters like other flying robots is very important, since changing the weather conditions may cause some problems for altitude control system of flying robots [9,10,11,12,13]. Recently, many studies are being done for providing a proper controlling method which can control the robot in different conditions with high efficiency. Four produced forces by four robot's rotors shall be controlled for controlling the altitude of quadcopter which was shown in Fig. 1 which is whole structure of a quadcopter.

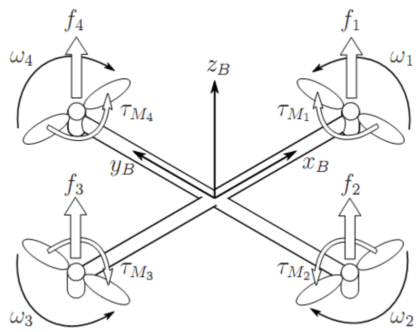

Fig. 1: whole structure of quadcopter robot and inbound forces on robot

In this research, it was trying to propose an adaptive controlling method for controlling the robot's altitude which can assurance the proper operation of robot in different conditions. System's stimulation was done in Matlab Simulink and The quadcopter is assumed to be rigid body and thus Newton-Euler equations can be used to describe its dynamics. Model of the quad rotor robot in [1] was used the dynamics equation of quad rotor based Neuton-Euler's method and equation 1 expresses the total equation of this method.

$$m\dot{V}_B + v \times (mV_B) = R^T G + T_B \qquad (1)$$

m : robot's mass

VB : linear speed

V : angular speed

R : rotation matrix

G : gravity acceleration

TB : sum of engines' forces

II. ADAPTIVE NEURO PID CONTROLLER (ANP)

PID controller is one the well-known and mostly-used controlling methods which is used for many years in many applications such as robotics. Although this controlling method is suggested for controlling the linear systems, it was used successfully for controlling many of nonlinear systems too. PID controller tuning is one of the important issues in using this controlling method which is schematically shown in Fig. 2 in Laplace form. In linear systems or systems in which there are good linear approximations, we can use the methods in linear control theory such as Ziegler Nichols for tuning of PID controller [14]. Meanwhile, optimum control is very effective in determining these gains or to use evolutionary and meta heuristic optimizing algorithms such as genetic algorithm, particle swarm optimization and etc. to reach efficient ones [15,16]. One of the other methods for tuning coefficients of controllers such as PID is, self tuning by adaptive interaction. The advantage of which is no need for complicated mathematical analysis for tuning controller because proper coefficients are achieved during the time by using an adaptive method. Some systems are changing during the time, therefore, the controller's parameters used in controlling the system may be not suitable as time passes or for example, assume a robotic system which is put in different environmental conditions and needs different coefficients in different conditions for proper function. The other advantage of adaptive methods is that they can adjust their parameters based on favorable system's behavior as online. In recent years, Adaptive PID controller is proposed and is used in several applications and in this research, it is trying to use a specific form of this controller for controlling the altitude of flying robot. The used method is similar to the method used in [17] and the only difference is that it is similar to neuron structure used in several artificial neural network structures such as multilayer perceptron. Each of the controller's gains are multiplied in a ratio (w_1, w_2, w_3) and the controller's output is limited by Sigmund function and equation 2 gives the details of desired controller's structure and Fig. 3 shows the whole structure of ANP controller.

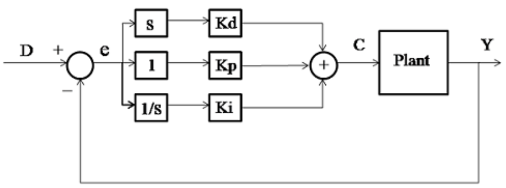

Fig.2 : Scheme of PID Controller

For updating w_1, w_2, w_3, it is trying to minimize an equation which describes the performance criterion of controlling system based error which equation 3 shows detail of that. It was used gradient values for updating online controller's coefficients in each time steps by a recursive equation which is the same as the Steepest Descent Algorithm (SD) and equations 4 and 5 show its details. According to use online learning method, some inputs like steps because of high error value feeding to controller can make the system unstable. Although controller's output is a value between [0,1], we can change the controller's output in a custom range by multiplying in an arbitrary number.

$$C = T(N) \tag{2}$$

$$,\quad N = (e^{\cdot} * k_d * w_1) + (e * k_p * w_2) + \left(\int e * k_i * w_3\right)$$

Where $C = \text{control signal}$, $e = \text{error}$, $T(N) = \dfrac{1}{1 + e^{-N}}$

$$F = \frac{1}{2}(D - Y)^2 \tag{3}$$

Where $D = \text{Desigerd Value of plant}$, $Y = \text{Output of Plant}$

and $F = \text{Performance Criterion}$

$$W(t+1) = W(t) - \gamma \frac{\partial F}{\partial W} \tag{4}$$

Where W is (w_1 or w_2 or w_3) and γ is a value in $(0,1)$

$$\frac{\partial F}{\partial W} = \frac{\partial F}{\partial Y}\frac{\partial Y}{\partial C}\frac{\partial C}{\partial N}\frac{\partial N}{\partial W} \tag{5}$$

Where $\dfrac{\partial Y}{\partial C} = 1$, $\dfrac{\partial F}{\partial Y} = -1$, $\dfrac{\partial C}{\partial N} = \dfrac{1}{1+e^{-N}}\left(1 - \dfrac{1}{1+e^{-N}}\right)$, $\dfrac{\partial N}{\partial w_1} = e^{\cdot} * k_d$, $\dfrac{\partial N}{\partial w_2} = e * k_p$, $\dfrac{\partial N}{\partial w_3} = \int e * k_i$

For optimizing ANP controller coefficients(w_1, w_2, w_3), performance criterion should be minimized then using equation 4 and in each time step, coefficients are updated. It was supposed to have a very fast processor and tuning algorithm applies to system without time delay.

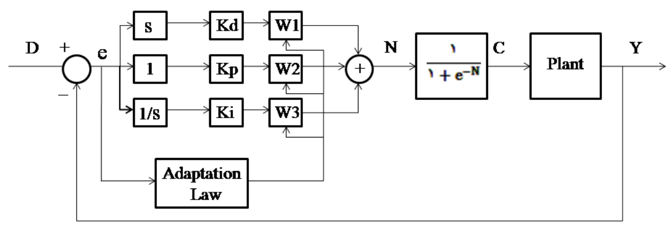

Fig.3 : structure of ANP Controller

III. EXPERIMENTS AND RESULTS

For appraising the proposed method for controlling the altitude of flying robot, in Matlab Simulink, the desired controlling method is investigated in two states. The primary values of w_1, w_2, w_3 coefficients are considered as zero for controlling the system which results in proper coefficients during time adaptively. In the first state, the primary gains of controller (k_p, k_d, k_i) is considered as random values and the result of desired control system toward sinusoidal input with frequency=1(rad/sec) and magnitude=1(m), is investigated. Having used trial and error, 0.3 is being considered for γ which is a same value for changing each of the three w_1 , w_2 , w_3 coefficients and Fig. 4 shows the result of this simulation. For better investigating the controller's behavior, 5-Newton disturbance is input as a square signal with a width of 0.5 unit of time which is shown in Fig. 5 of system's behavior. But disturbance more than 6 (N) makes system unstable and hard to control. In second state, the system's response toward sinusoidal input but with proper primary values for controller gains are obtained by genetic algorithm and learning rate of γ is being investigated and Fig. 6 and 7 show the control result in two states of with disturbance and without disturbance. The adaptively of ANP controller's coefficients can lead to improving the controller's function in eliminating the input disturbance to the system, for studying this issue, the controller's function with a PID controller, the gains of which is obtained by a genetic algorithm was being compared. Like previous experiments, the controller's function was investigated in two states of with disturbance and without and Fig. 8 & 9 show the results of this estimate. The last part of experiments is about of controlling of the system in a noisy situation then the three used controller were tested to control of altitude of robot for tracking the sinusoidal path in a suddenly started uniform random number as incoming noise with period of 0.01(Sec) in range [-2,2] that superimposed to the input of plant. Fig 10&11&12 illustrate the result of this experiment.

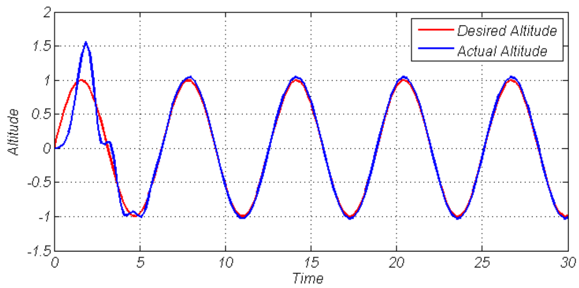

Fig. 4: ANP controller's behavior in controlling the robot's altitude toward sinusoidal input with random gains and without disturbance.

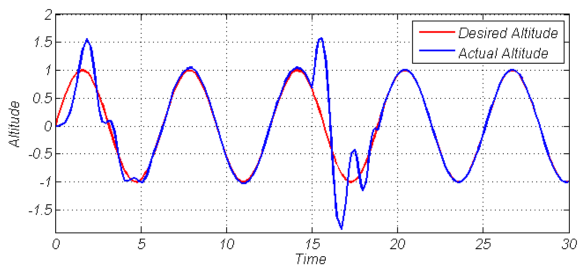

Fig. 5: ANP controller's behavior in controlling the robot's altitude toward sinusoidal input with random gains and with disturbance.

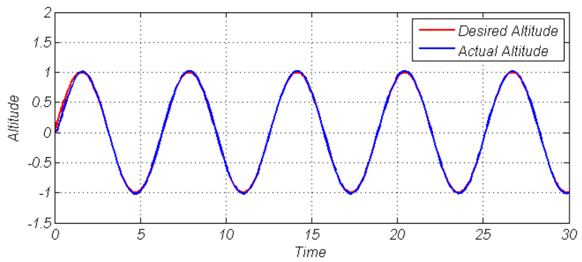

Fig. 6: ANP controller's behavior in controlling the robot's altitude toward sinusoidal input with gains improved by genetic algorithm and without disturbance.

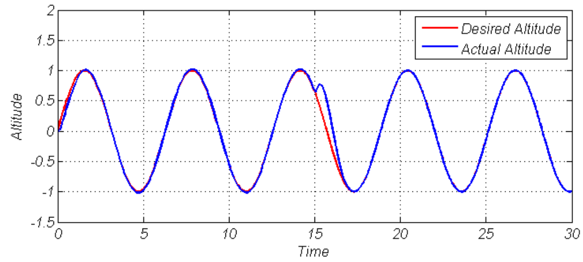

Fig. 7: ANP controller's behavior in controlling the robot's altitude toward sinusoidal input with gains improved by genetic algorithm and with disturbance.

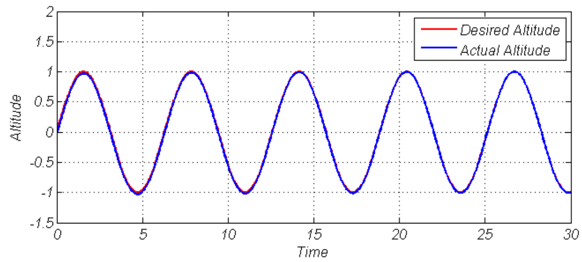

Fig. 8: PID controller's behavior in controlling the robot's altitude toward sinusoidal input with gains improved by genetic algorithm and without disturbance.

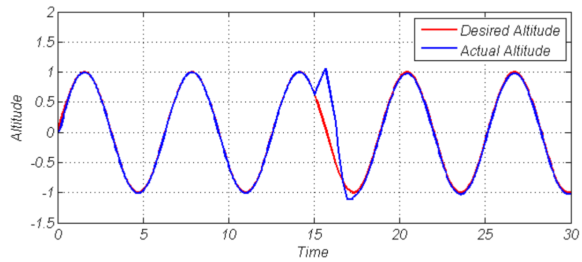

Fig. 9: PID controller's behavior in controlling the robot's altitude toward sinusoidal input with gains improved by genetic algorithm and with disturbance.

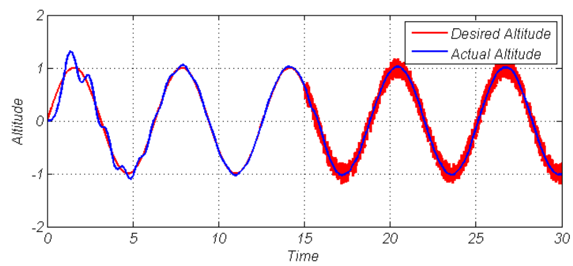

Fig. 10: ANP controller's behavior in controlling the robot's altitude toward sinusoidal input and in presence of noise.

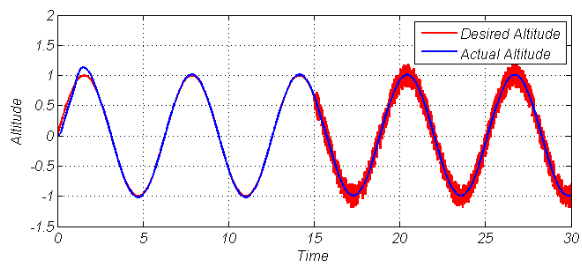

Fig. 11: ANP controller's behavior in controlling the robot's altitude toward sinusoidal input with gains improved by genetic algorithm and in presence of noise.

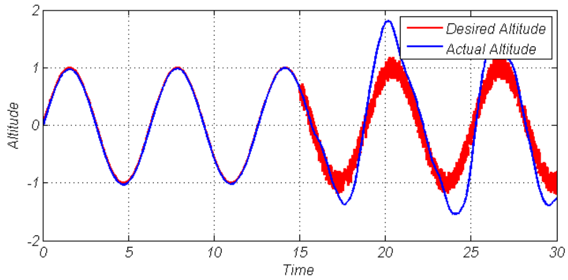

Fig. 12: PID controller's behavior in controlling the robot's altitude toward sinusoidal input with gains improved by genetic algorithm and in presence of noise.

CONCLUSION

In this research, an ANP controller was used for controlling the altitude of a flying robot in which the controller could obtain proper coefficients adaptively and based on existing conditions for controlling the desired system. The important advantage of this method is no need for different mathematical analysis for defining proper coefficients, adapting with new conditions and variations in system dynamics. On the other hand, it is not guarantee for reaching proper coefficients. The other problem is that the value of learning rate is an important challenge because low learning rate slows moving to proper coefficients and the controller cannot adapt it with conditions quickly and high learning rate may lead to inconstant. A primary gain of ANP controller is a very important issue and controller's function is largely depends on it which the results show of this problem. Meanwhile, adaptively can lead to improving the controller's function in eliminating the input disturbances to system . As Fig 10&11 ANP controller can control the system in presence of noise that a PID controller with improved gains couldn't do well.

REFERENCES

[1] Teppo Luukkonen, "Modelling and control of quadcopter," Independent research project in applied mathematics, Espoo, August 22, 2011.

[2] H. Huang, G. M. Hoffmann, S. L. Waslander, and C. J. Tomlin, "Aerodynamics and control of autonomous quadrotor helicopters in aggressive maneuvering," IEEE International Conference on Robotics and Automation, pp. 3277–3282, May 2009.

[3] A. Tayebi and S. McGilvray, "Attitude stabilization of a four-rotor aerial robot," 43rd IEEE Conference on Decision and Control, vol. 2, pp. 1216–1221,2004.

[4] I. C. Dikmen, A. Arısoy, and H. Temelta¸s, "Attitude control of a quadrotor," 4th International Conference on Recent Advances in Space Technologies, pp. 722–727, 2009.

[5] Z. Zuo, "Trajectory tracking control design with command-filtered compensa-tion for a quadrotor," IET Control Theory Appl., vol. 4, no. 11, pp. 2343–2355,2010.

[6] S. Bouabdallah, A. Noth, and R. Siegwart, "PID vs LQ control techniques applied to an indoor micro quadrotor," IEEE/RSJ International Conference on Intelligent Robots and Systems, vol. 3, pp. 2451–2456, 2004.

[7] T. Madani and A. Benallegue, "Backstepping control for a quadrotor heli- copter," IEEE/RSJ International Conference on Intelligent Robots and Sys- tems, pp. 3255–3260, 2006.

[8] K. M. Zemalache, L. Beji, and H. Marref, "Control of an under-actuated system: Application to a four rotors rotorcraft," IEEE International Conference on Robotic and Biomimetics, pp. 404–409, 2005.

[9] Pines, D. and Bohorquez, F., "Challenges facing future micro air vehicle development," AIAA Journal of Aircraft,Vol. 43, (2), 2006, pp. 290–305.

[10] Gurdan, D., Stumpf, J., Achtelik, M., Doth, K., Hirzinger, G., and Rus, D., "Energy-efficient Autonomous Four-rotor Flying Robot Controlled at 1 kHz," Proc. of the IEEE Int. Conf. on Robotics and Automation, April 2007.

[11] Bouabdallah, S., Design and Control of Quadrotors with Application to Autonomous Flying, Ph.D. thesis, Ecole Polytechnique Federale de Lausanne, 2007.

[12] Hoffmann, G., Waslander, S., and Tomlin, C., "Quadro- tor Helicopter Trajectory Tracking Control," AIAA Guid- ance, Navigation and Control Conference and Exhibit, April 2008.

[13] Feng Lin. , Robert D. Brandt , and George Saikalis , "Self-Tunung of PID Controllers by Adaptive Interaction" , Proceedings of the American Control Conference , Chicago , Illinois , June 2000.

[14] Ziegler, J.G and Nichols, N. B. (1942).Optimum setting for automatic controllers ,Transactions of the ASME. 64. pp. 759–768.

[15] Zwe-Lee Gaing, A Particle Swarm Optimization Approach for Optimum Design of PID Controller in AVR System, IEEE Transactions on energy conversation,Vol. 19, No. 2, June 2004.

[16] Hashim Ali, IkramUllah , et al, Genetic Algorithm Based PID tuning for Controlling Paraplegic Humanoid Walking Movement

[17] Feng Lin. , Robert D. Brandt , and George Saikalis , "Self-Tunung of PID Controllers by Adaptive Interaction" , Proceedings of the American Control Conference , Chicago , Illinois , June 2000.

[18] Tu Diep Cong Thanh and Duong Chi Thien, Hybrid Neuro - PID Controller of Pneumatic Artificial Muscle Manipulator for Knee Rehabilitation , International Symposium on Electrical & Electronics Engineering 2007 - Oct 24, 25 2007 - HCM City, Vietnam.