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Gain-Adaptive PID Control for a 2 DOF Helicopter (TRMS System-33-949S)

Boudia assam*, Messalti sabir *, * bouguerra abderrahmen, *Harrag abdelghani

* Electric engineering department, LGE Laboratory, M'sila University, Algeria.
* Electric engineering department, M'sila University, Algeria.
* Electric engineering department, LGE Laboratory, M'sila University, Algeria.
* Electronics Department, CCNS Laborator, University of Ferhat Abbas Setif 1, Algeria.

E-mail: assam_boudia@univ-msila, sabir.messalti@univ-msila.dz, a.b.harrag@gmail.com

Abstract

In this paper, control of 2 DOF Helicopter (TRMS System) Based on Gain-Adaptive PID using two methods the approach from the theory of Lyapunov and fuzzy-PID. In particular, the PID controller with fixed parameters may fail to provide acceptable control performance. To improve the PID control effect, new designs of the Lyapunov gain Scheduled PID controller and fuzzy-PID were presented in this paper. The proposed techniques were applied to the TRMS, The parameters of PID controller were adjusted by an adaptation algorithm gradient type, used to tune in real-time the controller gain, the proposed adaptive PID controllers were compared with the conventional PID. The obtained results confirm the effectiveness of the proposed method.

Keywords TRMS, PID, fuzzy, lyaponov, Gain-adaptive.

1. Introduction

Aeronautical systems have become so difficult and complex today that they cannot be controlled by conventional techniques. Indeed, automatic control researchers have looked into these control problems, for this several prototypes have been produced in order to test new control techniques. The helicopter simulator (Twin Rotor MIMO System: TRMS) is one of these prototypes that we will work on[1].

TRMS is an aerodynamic physical system designed for the development and implementation of new control laws. This includes, modeling the dynamics of the system, identifying, analyzing and designing various controllers using classic and modern methods. Its behavior resembles that of a helicopter, from a control point of view; it presents a higher order nonlinear system with significant couplings [2].

The TRMS is made up of figure 1:

• A beam which can pivot on its base so that it can rotate freely in the vertical and horizontal plane.

• Two thrusters (main and secondary) fixed at the two ends of the beam, they are formed by a propeller, a DC motor as well as a shield for safety reasons

• A counterweight fixed on the rod to its pivot, its role is to reduce the vibrations (oscillations) of the beam

• A tower to hold the beam

• A base including electronic circuits for the adaptation, synchronization and filtering of incoming and outgoing signals

• A motor start / stop box

Fig .01. The TRMS helicopter simulator.

In industrial applications, the PID command by its simplicity of design is the most used command. The synthesis of a PID command consists in determining three parameters, namely: the proportional gain Kp, the integration gain Ki and the bypass gain Kd. For linear systems, the Ziegler-Nichols method [3] is the most used method to determine the gains Kp, Ki and Kd. On the other hand, for nonlinear systems there are no systematic methods to find these three gains. For this class of systems, the current trend is towards adaptive PID control [4], [5], and robust PID control [6], especially for the case of uncertain or disturbed nonlinear systems. In [4] and [5], the authors develop adaptive PID control approaches for single-variable non-linear systems with a control gain assumed to be known.

To improve the disadvantages of conventional PID such as peak and response time, an adaptive gain PID controller will be used to best approach the unknown ideal command. The three gains of this PID controller, i.e., the gain Kp, Ki and the Kd will be considered here as the adjustable parameters. To do this, an adaptation mechanism will be developed to minimize a quadratic criterion of the error between the unknown ideal command u* and the supplied command upid, from the PID controller [7].

A new PID scheme is proposed in which the controller gains were scheduled by the theory of Lyapunov and fuzzy-PID. Many method and research works in this domain in [8-12]. A particle group optimization method is used in [10] to design membership functions of fuzzy PID controller. In [13], an accumulated genetic algorithm is proposed which learns the parameters and number of fuzzy rules in the fuzzy PID controller

A Gain-Scheduled PID (GS-PID) is designed for the angle control of the TRMS. The remainder of this paper is organized as follows. The model of the TRMS is described in Section II. The FTC strategy is designed in Section III. Theory of Lyapunov in section VI, Section V presents the simulation results to demonstrate the effectiveness of the Controllers. Concluding remarks are provided in Section VI.

2.Model Description of the TRMS

Figure 3 shows an aero-dynamical system similar to a helicopter. At both ends of a beam, pivoting on its base, there are two propellers driven by DC-motors. The articulated joint allows the beam to rotate in such a way that its ends move on spherical surfaces. There is a counter-weight fixed to the beam and it determines a stable equilibrium position. The system is balanced in such a way, that when the motors are switched off, the main rotor end of beam is lowered.

The controls of the system are the motors supply voltages. The measured signals are: position of the beam in the space, that is, two position angles, and angular velocities of the rotors. [14].

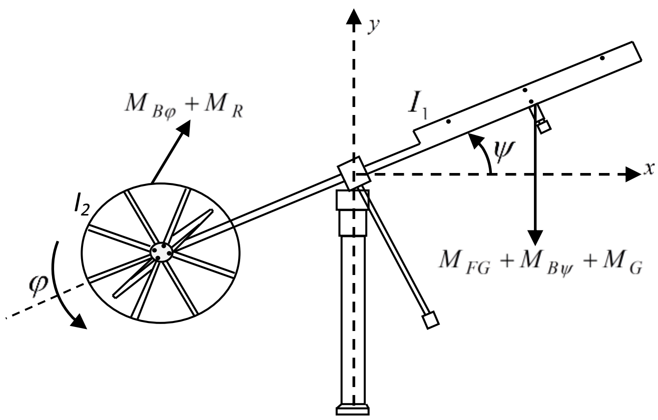

Fig.2. The twin rotor multi-input multi-output system (TRMS).

The two rotors are controlled by variable speed electric motors enabling the helicopter to rotate in a vertical and horizontal plane (pitch and yaw).

Usually, phenomenological models are nonlinear, that means at least one of the states (i – rotor current, θ – position) is an argument of a nonlinear function. The non-linear model equations can be derived. As far as the mechanical unit is concerned the following momentum equations can be derived for the vertical movement [14]:

$$I_1.\ddot{\Psi} = M_1 - M_{FG} - M_{B\Psi} - M_G \tag{1}$$

Where

$$M_1 = a_1.\tau_1^2 + b_1.\tau_1 \quad - \text{nonlinear static characteristic} \tag{2}$$

$$M_{FG} = M_g.\sin(\Psi) \quad - \text{gravity momentum} \tag{3}$$

$$M_{B\Psi} = B_{1\Psi}.\dot{\Psi} + B_{2\Psi}.\text{sign}(\dot{\Psi}) \quad - \text{frictionforces momentum} \tag{4}$$

$$M_G = K_{gy}.M_1.\dot{\varphi}.\cos(\Psi) \quad - \text{gyroscopic momentum} \tag{5}$$

The motor and the electrical control circuit are approximated by a first order transfer function thus in Laplace domain the motor momentum is described by:

$$\tau_1 = \frac{k_1}{T_{11}s + T_{10}}.u_1 \tag{6}$$

Similar equations refer to the horizontal plane motion:

$$I_2.\ddot{\varphi} = M_2 - M_{B\varphi} - M_r \tag{7}$$

Where

$$M_2 = a_2.\tau_2^2 + b_2.\tau_2 \quad - \text{nonlinear static characteristic} \tag{8}$$

$$M_{B\Psi} = B_{1\varphi}.\dot{\Psi} + B_{2\varphi}.\text{sign}(\dot{\varphi}) \quad - \text{frictionforces momentum} \tag{9}$$

M_R is the cross reaction momentum approximated by:

$$M_R = \frac{k_c(T_0 s + 1)}{T_p s + 1}.\tau_1 \tag{10}$$

Again the DC motor with the electrical circuit is given by:

$$\tau_2 = \frac{k_2}{T_{21}s + T_{20}}.u_2 \tag{11}$$

The phenomenological model parameters have been chosen more or less experimentally, which actually makes the TRMS nonlinear models a semi phenomenological model. The following table gives their approximate values.

Table 1. The parameters of the TRMS [14]

Definition	Symbol	Value
Moment of inertia of vertical rotor	I_1	0.068 kgm2
Moment of inertia of horizontal rotor	I_2	0.02 kgm2
Static characteristic parameter	a_1	0.0135
Static characteristic parameter	b_1	0.0924
Static characteristic parameter	a_2	0.02
Static characteristic parameter	b_2	0.09
Gravity momentum	M_g	0.32 N.m
Friction momentum function parameter	$B_{1\Psi}$	0.006 N.m.s/rad
Friction momentum function parameter	$B_{2\Psi}$	0.001 N.m.s2/rad
Friction momentum function parameter	$B_{1\varphi}$	0.1 N.m.s/rad

Friction momentum function parameter	$B_{2\varphi}$	0.01 N.m.s2/rad
Gyroscopic momentum parameter	K_{gy}	0.05 s/rad
Motor 1 gain	K_1	1.1
Motor 2 gain	K_2	0.8
Motor 1 denominator parameter	T_{11}	1.1
Motor 1 denominator parameter	T_{10}	1
Motor 2 denominator parameter	T_{21}	1
Motor 2 denominator parameter	T_{10}	1
Cross reaction momentum parameter	T_p	2
Cross reaction momentum parameter	T_0	3.5
Cross reaction momentum gain	k_c	-0.2

The bound for the control signal is set to [–2.5V; +2.5V].

The TRMS is a MIMO plant – multiple input multiple outputs. Figure 2 presents a simplified schematic of the TRMS.

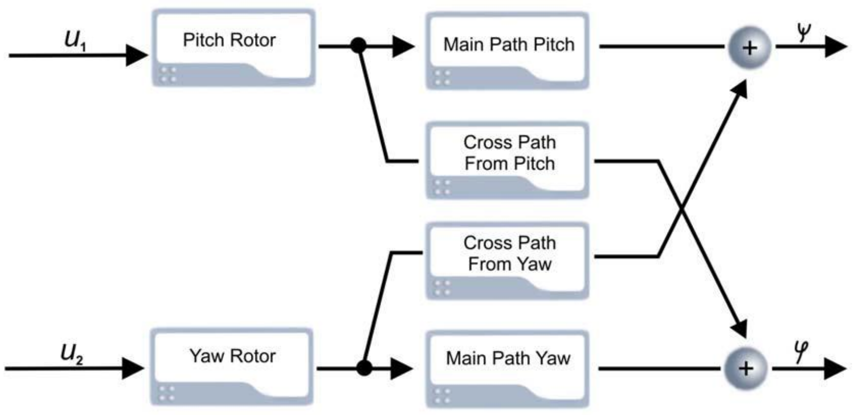

Fig.3. TRMS simplified system schematic.

The TRMS is controlled with two inputs the U_1 and U_2. The dynamics cross couplings are one of the key features of the TRMS (Figure 3). The position of the eams is measured with the means of incremental encoders, which provide a relative position signal. Thus every time the Real-Time TRMS simulation is run one must remember that setting proper initial conditions is important.

3.fuzzy-PID strategy.

A set of linguistic rules in the form of (12) is used in the FLC structure to determine PID gains:

$$\text{if } e(k) \text{is } A_i \text{ and } \Delta e(k) \text{ is } B_i \text{ then } K_p \text{ is } C_i \text{ , } K_i \text{ is } D_i \text{ and } K_d \text{ is } E_i \quad (12)$$

Where A_i, B_i, C_i, D_i and E_i are fuzzy sets corresponding to $e(k)$, $\Delta e(k)$, K_p, K_i and K_d respectively. 3 sets of 49 rules are used to determine controller gains. The membership functions for input variables are defined with Gaussian shapes and those for output variables are singleton (Figures 4 and 5). All the fuzzy sets for input and output values are normalized for convenience.

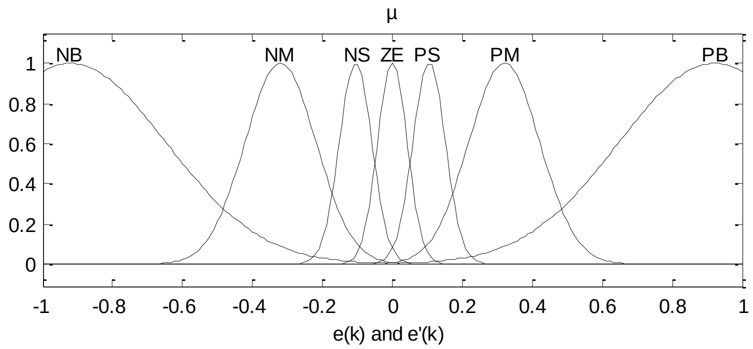

Fig.4. Membership function for e(k) and Δe(k).

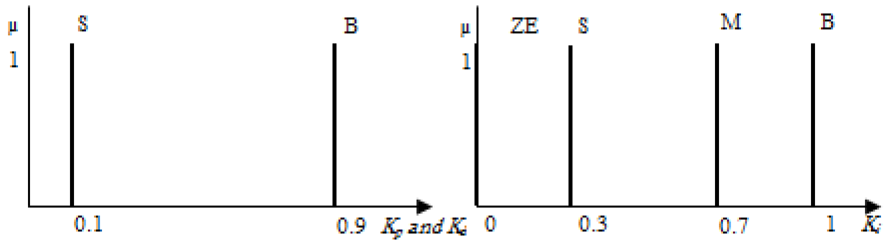

Fig.5. Membership functions for Kp, Ki and Kd.

Table 2 and table 3 show the linguist rules used in the FLC. In these tables, N, P, ZO, S, M, B represent negative, positive, approximately zero, small, medium, and big respectively. For example NB means Negative Big, and so on.

Table 2. Fuzzy tuning rules for K_d.

		Δe(k)						
		NB	NM	NS	ZE	PS	PM	PB
e(k)	NB	B	B	B	B	B	B	B
	NM	S	B	B	B	B	B	S
	NS	S	S	B	B	B	S	S
	ZE	S	S	S	B	S	S	S
	PS	S	S	B	B	B	S	S
	PM	S	B	B	B	B	B	S
	PB	B	B	B	B	B	B	B

Table 3. Fuzzy tuning rules for Ki.

		Δe(k)						
		NB	NM	NS	ZE	PS	PM	PB
e(k)	NB	B	B	B	B	B	B	B
	NM	M	M	B	B	B	M	M
	NS	S	M	M	B	M	M	S
	ZE	ZE	S	M	B	M	S	ZE

	PS	S	M	M	B	M	M	S
	PM	M	M	B	B	B	M	M
	PB	B	B	B	B	B	B	B

The generated surfaces for the FLC are shown in Figure 6 and figure 7.

4. Lyaponov approach-PID strategy.

The objective is the synthesis of an adaptive PID control law so that the output y(t) best follows a bounded and differentiable reference trajectory yd(t), while guaranteeing the boundlessness of all the signals of the control loop.

To achieve this objective, we define the tracking error by:

$$e(t) = y_d(t) - y(t) \tag{13}$$

And an error filtered by:

$$s(t) = (\frac{d}{dt} + \lambda)^{n-1} e(t), \quad \lambda > 0 \tag{14}$$

Choose the Lyapunov function:

$$V = \frac{1}{2} s^2 \tag{15}$$

The derivative of (15) is bounded by:

$$\dot{V} \le -\alpha s^2 \tag{16}$$

The derivative of the filtered error can be written as

$$\dot{s} = v - f(x) - g(x)u \tag{17}$$

The ideal control law was then approximated by a PID controller of the form:

$$u = u_{PID} = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_d \frac{de(t)}{dt} \tag{18 }$$

where:

$$u = \prod^T (e)\theta \tag{19}$$

$$\prod(e) = \begin{bmatrix} e(t) & \int_0^t e(\tau) d\tau & \frac{de(t)}{dt} \end{bmatrix}^T \tag{20}$$

θ is the vector of parameters adjusted in the control, which is defined by:

$$\theta = \begin{bmatrix} k_p, & k_i & k_d \end{bmatrix}^T \tag{21}$$

$$u^* = \prod^T (e)\theta^* \tag{22}$$

From equation (17)

$$\dot{s} = -\alpha s - \beta \tanh(s / \varepsilon) + g(x)(u^* - u) \tag{23}$$

$$g(x) \mathrm{e}_u = \dot{s} + \alpha s + \beta \tanh(s / \varepsilon) \tag{24}$$

From (21), the law of adaptation parameters is given by

$$\dot{\theta} = \eta \prod(e)\left\{\dot{s} + \alpha s + \beta \tanh(s/\varepsilon)\right\} \qquad (25)$$

5. Simulation Results.

The proposed control scheme presented in this paper was tested on a model of helicopter, which is called a twin rotor MIMO system (fig. 6).

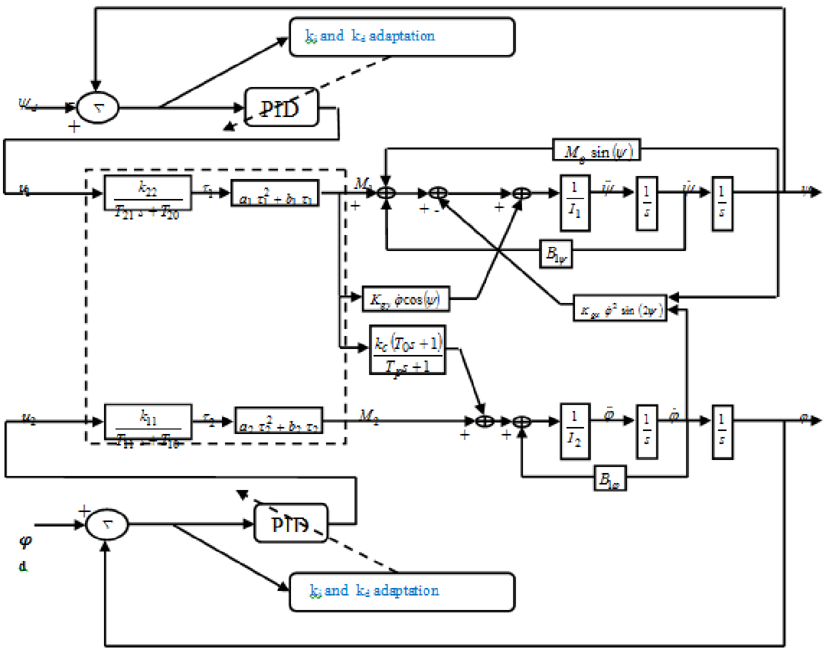

Fig.06. gain scheduling scheme for PID controller.

1. First Scenario (fuzzy-PID)

Figure 7,8 show a comparison between the PID control and the fuzzy adaptive PID controller for the horizontal position (φ) and vertical position (psi), the gains of the PID_ver are: Kp=5, Ki =25 and Kd =8, and the gains of PID_hor are: Kp=14, Ki =6 and Kd =3.

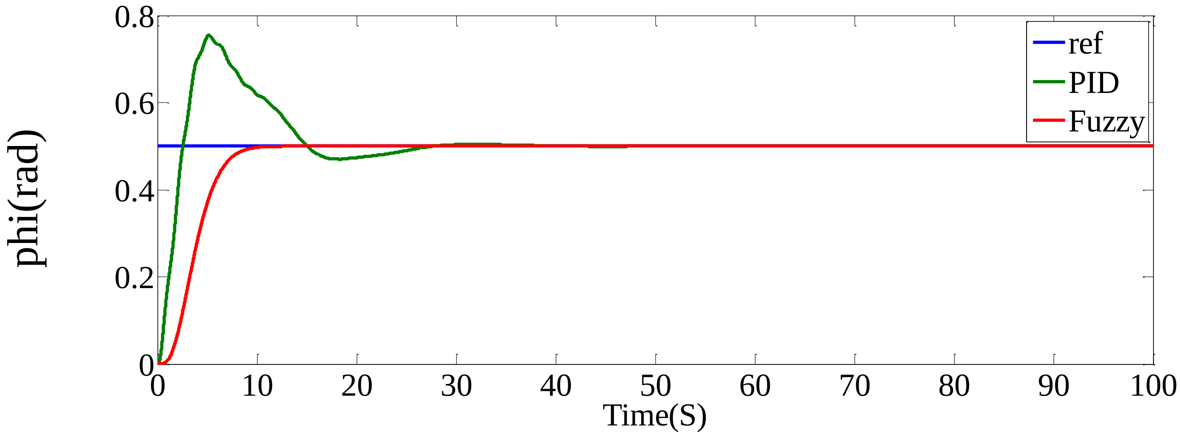

Fig.7. PID control and the fuzzy adaptive PID controller for the horizontal position (φ).

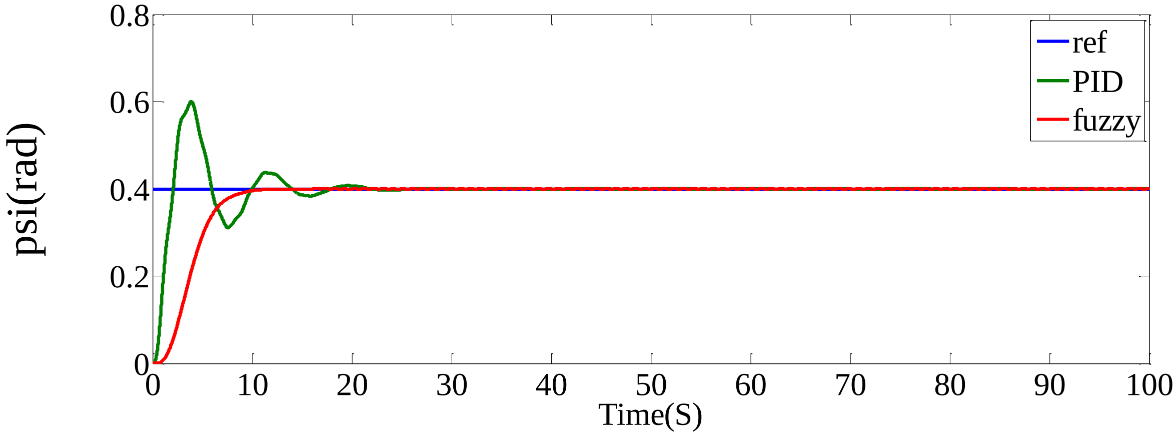

Fig.8. PID control and the fuzzy adaptive PID controller for the vertical position (psi).

In the case of the fuzzy adaptive PID controller, the actual φ of the helicopter converge, without oscillation, to their desired values. While in the case of the PID control, oscillations with big amplitude are observed.

The time evolutions of the fuzzy adaptive PID gains are illustrated in Figs 7 and 8. Unlike those of the PID control, the fuzzy gains are time-varying to adapt to uncertainties, disturbances as can be clearly in the figure of angle φ and angle psi.

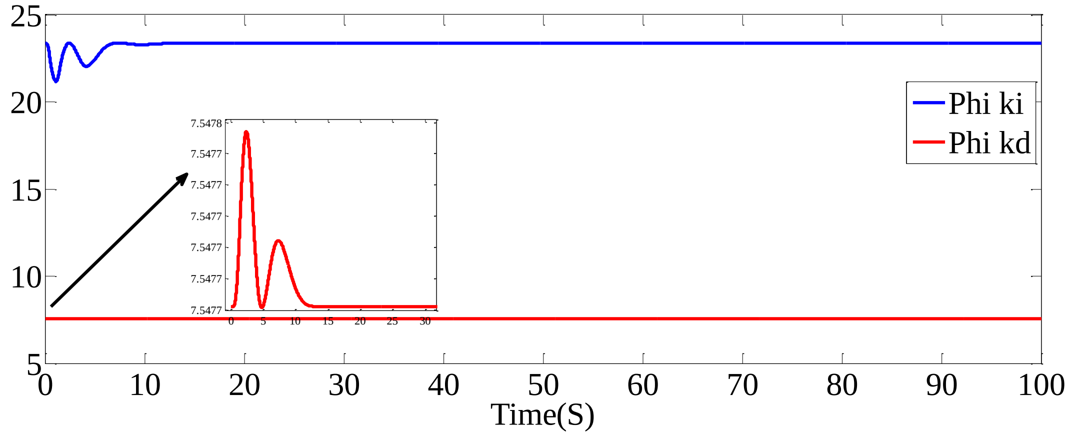

Fig.9. k_i and k_d adaptation of fuzzy adaptive PID controller for the horizontal position (φ).

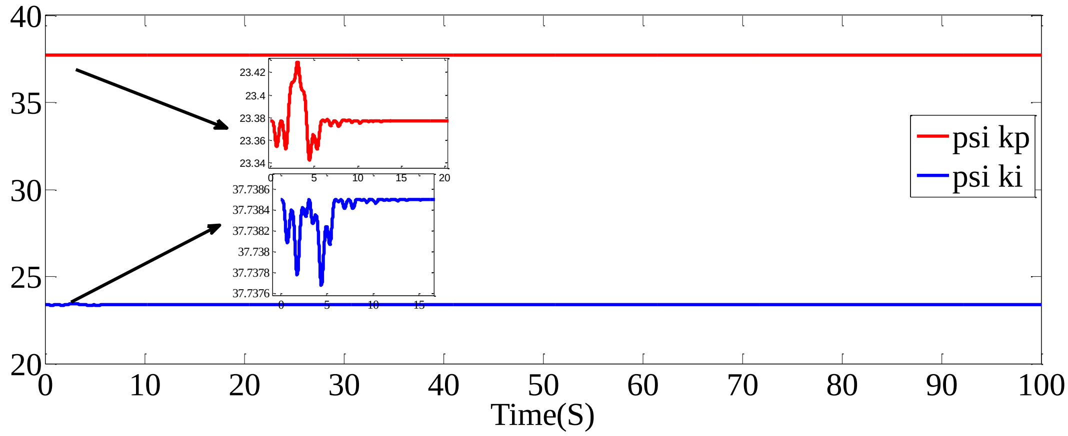

Fig.10. k_i and k_d adaptation of fuzzy adaptive PID controller for the vertical position (psi).

Fig 10 and 11 show the adaptation of fuzzy adaptive PID controller for the vertical and horizontal position, the adaptive of ki and kd minimize the PID classic inconvenients (response time and oscillation even the overshoot)

2. Second Scenario (lyaponov approach).

For the second senario, the lyaponov approch replace fuzzy as another solution to adapt the PID parameters, in his approach ,the three gains are adaption, the results are clear in fig 11 and 12 for the two angle the vertical and the horizontal.

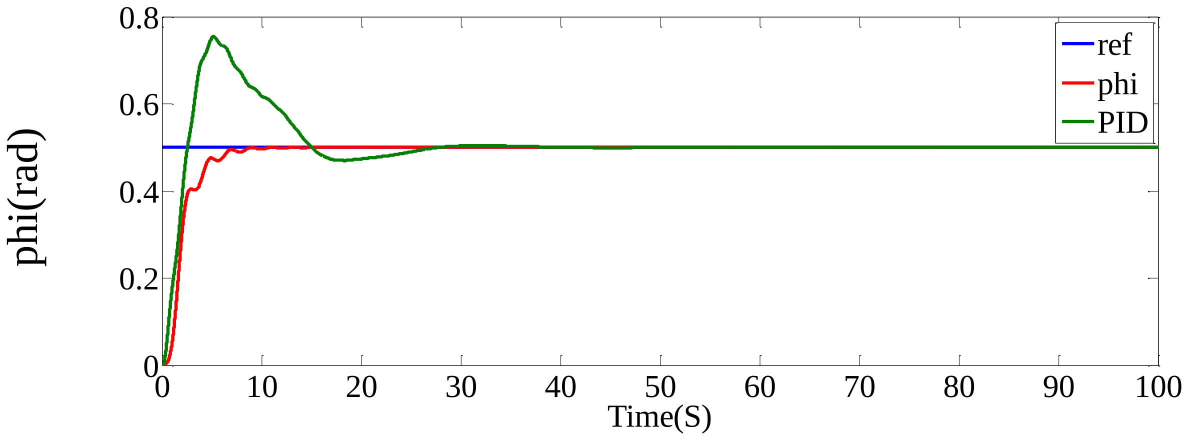

Fig.11. PID control and the lyaponov approach PID controller for the horizontal position (φ).

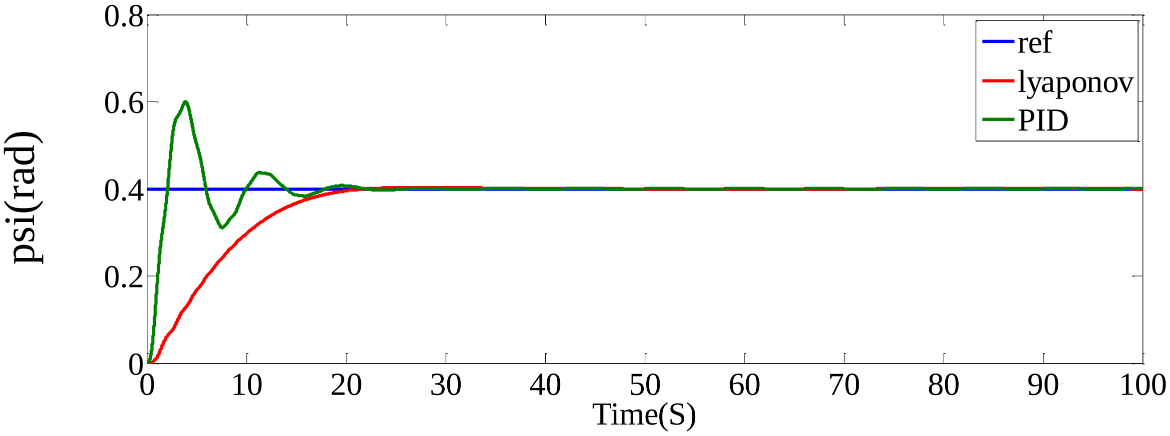

Fig.12. PID control and the lyaponov approach PID controller for the vertical position (psi).

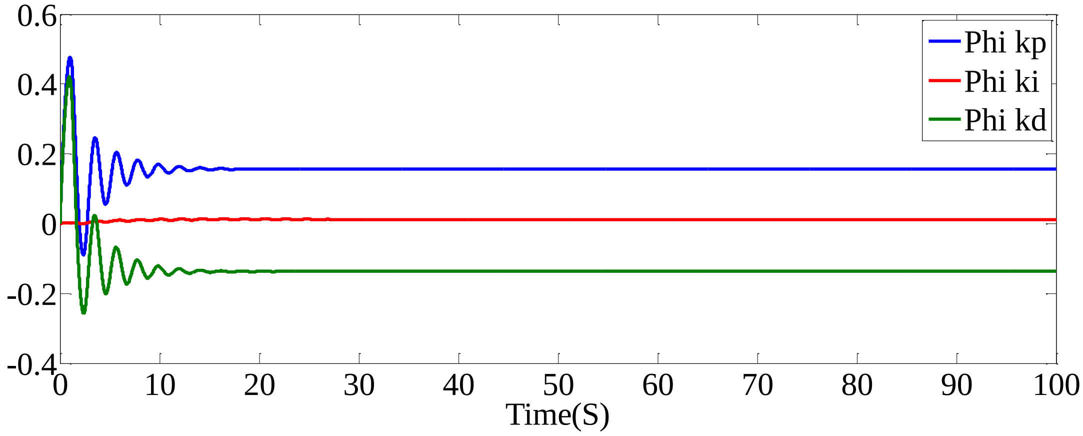

Fig.13. k_p, k_i and k_d adaptation of lyaponov approach PID controller for the horizontal position (φ).

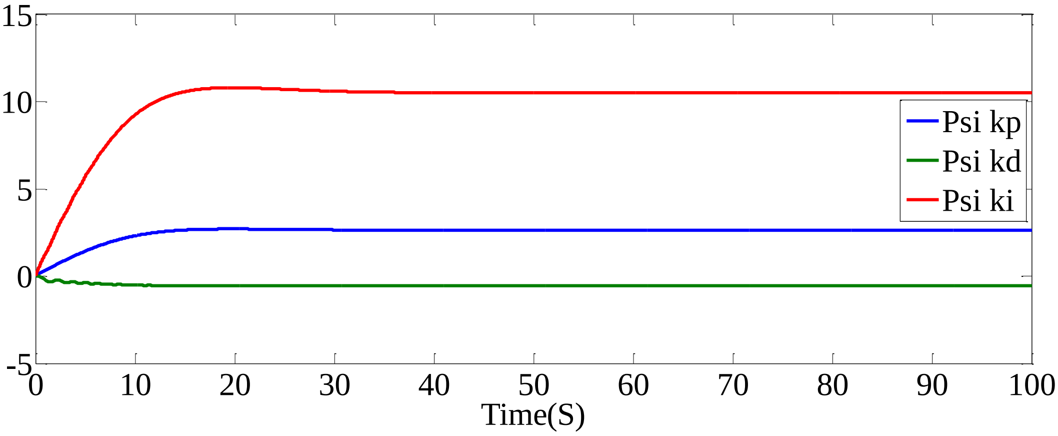

Fig.14. k_p, k_i and k_d adaptation of lyaponov approach PID controller for the vertical position (psi).

As is clear from fig 11 and 12, the lyaponov approach provide a well performance with no oscillation or overshoot and with less response time compared to PID classical, also fig 13 and 14 show the three gains adaptation in the vertical and horizontal position.

We can also use the values of lyaponov approach kp, ki and kd in the permanent time and use it in PID classic, this method can give as a perfect result to PID classic.

6. Conclusion

In this paper, new approaches to adapt the PID classic parameters kp, ki and kd, fuzzy and lyaponov approaches was presented and applied to TRMS system -33-949S, in which each method provided a perfect results with high performance (no oscillation or overshoot and less response time, both methods are the best solution to regulate the PID regulators inconvenients, also both method specially lyaponov approach is best solution to calculate the kp, ki and kd parameters.

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