MODEL REFERENCE ADAPTIVE CONTROL DESIGN FOR THREE LOOP AUTOPILOT

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ABSTRACT

An Autopilot is certainly one of the most important parts of flying objects which creates stability and achievement to appropriate operation in performing instructions of guidance part. The purpose of this study is to use one of the dynamic models for actuator, in order to evaluate the performance of autopilot system. Moreover, at last by using Model Reference Adaptive Control (MRAC), the system will approach suitable output and have the lowest number of errors. The system is modelled by using MATLAB/SIMULINK and assessed by various amounts of control parameters. Finally, it is compared with the common PID controlling method. In this system, the result of simulation shows less control effort and more appropriate performance for MRAC.

KEYWORDS

Autopilot, Guidance, Actuator, Model Reference Adaptive Control, PID Controller

1. INTRODUCTION

In [1], autopilot has been designed by means of gain scheduling technique. Changeable chronological models to the created system and designed controlling effectiveness are examined for exploring better behaviour and missile operation in state of stability as well. The aim of this research is to simulate real missile system disorder and study the performance of controllers in facing those disorders. In [2], for missile with high maneuver quality, nonlinear autopilot has been done as it is turning. All the features of nonlinear missile such as coupling between Roll, Pitch and Yaw channels are considered in the investigation of its performance. In [3], robust loop has been used to control flying objects. In [4], in order to control a nonlinear flying object, backstopping has been used for robust control system. In this method, for designing controllers, Lyapunov theory and control function are utilized to guarantee stability of system. It uses fuzzy control for managing latitude movement of flying object. Besides, in order to decide about amounts of PID gains, it uses a simple phase control theory. In [6], for controlling an airplane's pitch channel, control phase has been applied. In [7], fuzzy sliding mode has been used for missile autopilot. The phenomenon of chattering is studied as a main problem of these systems to overcome which the border of layer technique is used. In [8], analysis of air to air missile of autopilot has been shown by backstopping and a transferring method has been proposed to improve system operation. In [9], designing autopilot has been done for two spin projectile based on PI and linear feedback. In this study, Pitch and Yaw acceleration effectiveness are examined by a nonlinear simulation. In [10], nonlinear MRAC has been presented that is of use for a model of missile in managing Pitch channel which is directed by aerodynamic forces. Missile nonlinear movement is modelled by uncertainties. Both certain and uncertain parameters are estimated, and based on this estimation controller parameters are updated in each step. In [11], the technique of designing autopilot missile of surface to air has been performed by using LQG/LTR gain. Linear Gaussian function rank 2, by planning loop gain of feedback transition, has been used for designing and planning autopilot missile of surface to air. In [12], the control technique of adaptive predictor has been provided for the inflection of transportation vehicle. These systems' nonlinear dynamics are the main reasons in the creation of problem in the controller designing. The current offer has been operated for channel model of missile pitch. In [13], controlling pitch channel of a missile has been investigated by H∞. Dynamic system has been formulated based on aerodynamic stability derivations and construction of body vibration in the certainty form of state space. In [14], dynamic simulation of a missile surface to air has been done by one axis gimbal seeker, and autopilot model has been considered a first order dynamic. At last, simulated system operation has been studied during flying path. In [15], predictor control has been used for managing one axis gimbal seeker, and to evaluate its operation, both dynamical model of missile of surface to air with 6DOF and autopilot with first order dynamic are simulated. In [16], in order to control SLIM, MRAC based on control of sliding mode has been applied.

In this research, we aim to evaluate autopilot system operation by a dynamical model for actuator and finally make it closer to an appropriate output by using a controlling method; it means that the study will have the lowest number of errors. Therefore, first, we state current math relationships in the system and then simulate autopilot system; next, we design the MRAC for the present system; finally, we compare the effectiveness of the MRAC and common PID controller.

2. PROBLEM FORMULATION

Model reference adaptive control is used in order to control situation tracking of flying objects and compensate for uncertainties that result from modelling error. Using one adaptive element in tracking control enhances tracking operation and provides the designer with the possibility of determining the operational features of the system. The mentioned method estimates the controlling parameters by adaptive gains which are obtained from adaption rules. The mechanism of the adaption of parameters in MRAC are obtained from two approaches; Gradian's method and methods based on stability theory which include Lyapunov and passivity. Figure 1 shows the MRAC for a flying object. In this figure, the reference model represents the system operation and adaption mechanism represents controlling parameters. Moreover, this system includes one simple feedback that has controller and process and another feedback loop that changes controlling parameters. Parameters are changed based on error feedback that is the difference between system output and model reference output.

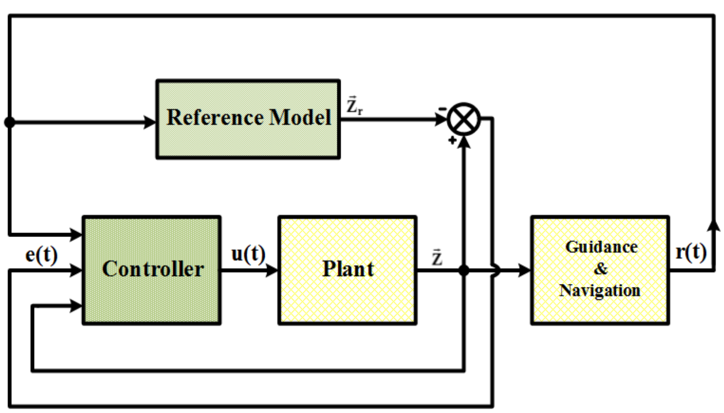

Figure 1. MRAC for a flying object

In this paper, in order to adapt parameters in MRAC, MIT rule or Gradian's method are used. General view of this method is changing regulator parameters to the extent that the error between process output and model output tends toward zero. The response of suitable closed loop is represented by the help of a model with ($\vec{Z}_r$) output. If $e(t)=\vec{Z}-\vec{Z}_r$ is system error, arranging parameters must be done in a way that rate function or scale performance $J(\theta)=1/2e^2$ is minimized. For minimizing J (θ), it is logical to change parameters towards negative Gradian's J(θ). Thus, by considering the abovementioned point MIT equals to [16]:

$$\frac{d\theta}{dt} = -\gamma\frac{\partial j}{\partial\theta} = -\gamma e\frac{\partial e}{\partial\theta} \tag{1}$$

In this relation, $\frac{\partial e}{\partial\theta}$ is called sensitivity derivation.

2.1. Roll channel Model

The main purpose of roll autopilot in flying object is to prevent serious turning from torques in a way that coupling signals minimize direction between both Pitch and Yaw channels. By changing wing angle to turning rate function, we can gain the change function in this channel [17]:

$$\frac{P(s)}{\delta_a(S)} = \frac{K_\delta}{S+\omega_r} \tag{2}$$

Figure 2 represents the block diagram of MRAC for roll channel:

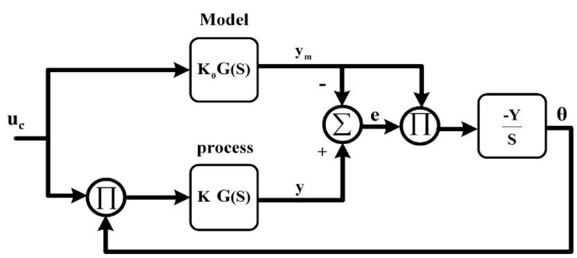

Figure 2. Block diagram of MRAC for roll channel [16].

In the above relationship, effective roll of fins and damping ratio frequency are respectively equal to [17]:

$$K_\delta = \frac{(\frac{1}{2}\rho V^2)S_r L_r C_{l_\delta}}{I_{XX}} \tag{3}$$

$$\omega_r = \frac{\rho V S_r L_r L_{rl} \text{-} C_{l_p}}{4I_{XX}} \tag{4}$$

By considering the above relationships, changing function of simplified roll is:

$$\frac{P(s)}{\delta_a(S)} = \frac{-90}{S+3.7} \tag{5}$$

2.2. Pitch and Yaw Channel Model

Autopilot of Pitch and Yaw channel provides control of body stability with Yaw and Pitch during all flying conditions (acceleration, altitude, angle of attack) and all flying phases of launch till facing. Besides, this autopilot has to quickly and suitably tone the response of both Yaw and Pitch speeds in the final phase which results from the guidance instructions. However, for a long mid-phase, the response of autopilot is slower. Linear conversion function of Yaw and Pitch channel also respectively equals:

$$\frac{q(s)}{\delta_e(S)}=\frac{3.03s+1.951}{0.0175S^2+0.08627s+1}=\frac{281.5s+181.5}{S^2+8s+93} \quad (6)$$

$$\frac{r(s)}{\delta_e(S)}=\frac{3.03s+1.951}{0.0175S^2+0.08627s+1}=\frac{281.5s+181.5}{S^2+8s+93} \quad (7)$$

Figure 3 is to state the block diagram of MRAC for Yaw and Pitch channel.

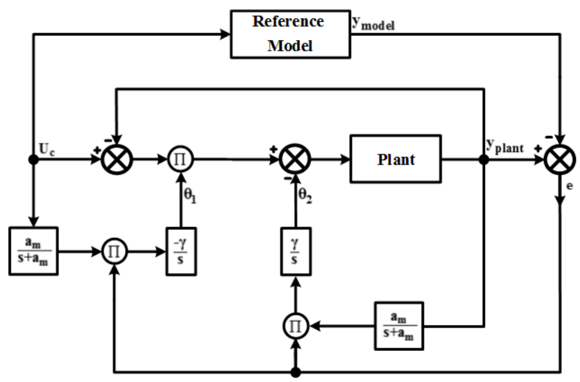

Figure 3.Block diagram of MRAC for Yaw and Pitch channels [16].

3. SIMULATION

Considering the mentioned theorems in the previous part, we simulate each of the channels. In this simulation, PID control parameters' amount for running per channel equals this:

TABLE 1. PID control parameters' amounts.

Channels	K_P	K_I	K_D
Roll Channel	-0.01945	-0.24407	-
Pitch/Yaw Channel	1	0.1	-

Figure 4 shows roll channel output together with adaptive controller for different Gamma parameter amounts.

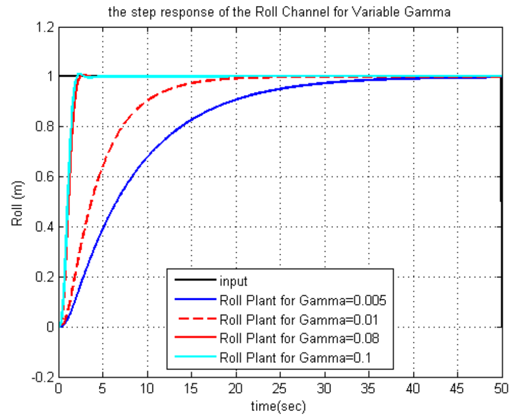

Figure 4. Roll channel output for different controlling amounts.

Figure 5 indicates Pitch channel output with adaptive controller for different Gamma parameter amounts. Yaw channel output is similar to Pitch channel.

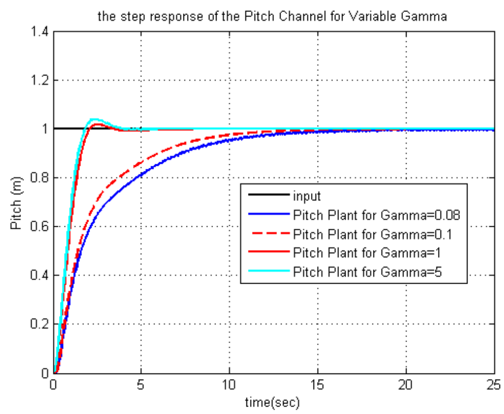

Figure 5. Pitch channel output for different controlling amounts.

Considering the abovementioned issues, for suitable control amounts, roll channel output is represented as the following. In figure 6, the way of responding roll control to one degree Step response is shown. With respect to this figure, the responses of both of the controllers are compared.

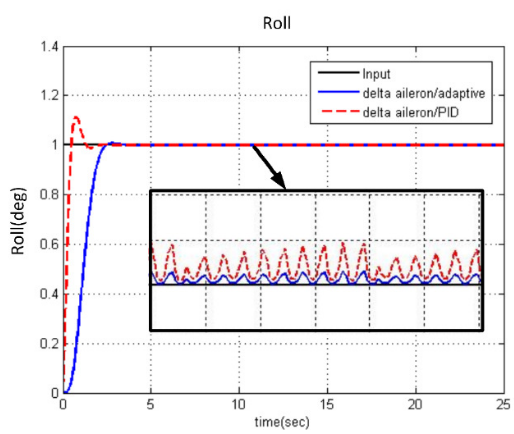

Figure 6. Comparison of autopilot output in roll channel.

In figure (7-8), the response method in the Yaw and Pitch channel controller to one degree Step response is shown. With due attention to this figure, the responses of both controllers are compared together.

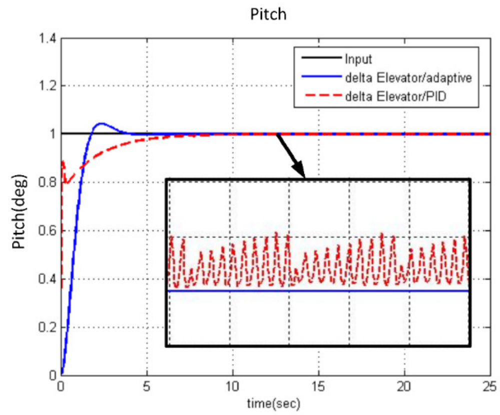

Figure 7. Comparing autopilot output in Pitch channel.

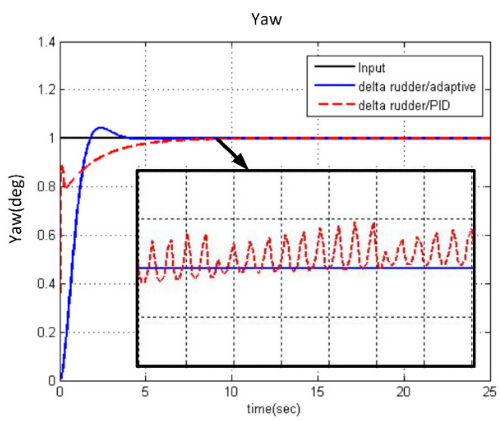

Figure 8. Comparing autopilot output in Yaw channel.

The needed control effort for overcoming Step is also explored and represented in table 2.

TABLE 2. Comparing control effort.

Channels	PID Controller			Adaptive Controller		
	max	min	T_F(sec)	max	min	T_F(sec)
Roll	0.55	0.03	3	0.041	0.04	4
Pitch	0.5	0.1	12	0.042	0.04	4
Yaw	0.5	0.1	12	0.042	0.04	4

Considering the outputs, it is seen that both classic and adaptive controllers in identical states have acceptable abilities and are used for missile control. The important point in this part is to operationalize the referent controller with respect to assurance possibility in the missile systems. Therefore, in the missiles without high manoeuvres, the classic way is utilized. But if the missile has maneuver ability and different flying trajectories, it is necessary to use advance controllers such as adaptive controllers. Also, the results of transient response analysis of the two controlling methods are illustrated in table 3. Regarding the outputs, in PID control, a higher percent of overshoot towards the suggested method is observed and stability table of MRAC is certainly smoother and more appropriate than PID.

TABLE 3. The results of transient response analysis.

Method	Parameter	Roll	Yaw	Pitch
MRAC	OV (%)	0.599	4.09	4.09
	$t_{r(Sec)}$	3.491	2.79	2.79
	$t_{d(Sec)}$	2.159	1.759	1.759
	$t_{s(Sec)}$	5.083	5.083	5.83
PID	OV (%)	11.044	-	-
	$t_{r(Sec)}$	1.492	13.32	13.32
	$t_{d(Sec)}$	1.224	1.037	1.037
	$t_{s(Sec)}$	4.028	13.32	13.32

4. CONCLUSION

In this paper, the performance of autopilot system is investigated by using a dynamic model for Actuator and at the end it is approached to a suitable output by using a system control method. The results of simulation show that adaptive controller which is used in serious manoeuvres in the missile, had better and more suitable performance in adjusting frequencies and sudden accelerations. So, progress of this controller for fast and quick missiles with high maneuver must be paid attention. Furthermore, the results of simulation show less control effort of MRAC and suitable operation of this system in comparison to the classical control.

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