Intelligent Ziegler-Nichols-Based Fuzzy Controller Design for Mobile Satellite Antenna Tracking System with Parameter Variations Effect

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Abstract: - This research applied both the traditional, Ziegler-Nichols-based and Ziegler-Nichols-based fuzzy control methods for mobile satellite antenna tracking system design. Firstly, the antenna tracking and the stabilization loops were roughly designed according to the traditional bandwidth and phase margin requirements. However, the performances would be degraded if the tacking loop gain is reduced due to parameter variations. On the other hand both Ziegler-Nichols-based PID-type and Ziegler-Nichols-based fuzzy controllers were also applied in the tracking loop for refinement. But we can find only the fuzzy controller were better for both low and high antenna tracking loop gains, and the tracking loop gain parameter variations effect can be reduced.

Key-Words: - Tracking Loop, Stabilization loop, PD-type Fuzzy Controller; PI Compensator

1 Introduction

To cope with the satellite Ka-band and broadband mobile communication requirements, the capacity is five times of Ku-band before. The mobile antenna needs to lock on the satellite in spite of disturbances, thus the performances of antenna tracking and pointing precision as well as stabilization should be raised [1-3]. The traditional PI (Proportion and Integration) compensator was applied for the tracking and stabilization loops design of mobile antennas to lock on the satellites [4]. The fuzzy controller was applied for the tracking loop design [5-6], and the relationship functions of Gaussian distribution were applied for six degrees of freedom simulation, thus the computation loading was very large. In addition, the noise and wind disturbance was taken into antenna design consideration. However, the parameter variations effects were not considered in the methods aforementioned.

In this paper firstly we use a simplified model for the antenna control system design [7-8], the antenna tracking and the stabilization loops were roughly designed with the traditional bandwidth and phase margin design rules to obtain the key parameters of antenna tracking and stabilization loops. The stabilization loop was designed by using proportion and PI compensators for comparison. Noted the performances with PI compensation method were better. However, if taking tracking loop gain degradation effect into consideration, then the performances becomes worse for the cases of lower tracking loop gains.

On the other hand both Ziegler-Nichols-based PID-type [8] and Ziegler-Nichols-based fuzzy controllers [9-10] were also applied in the tracking loop for refinement. But we can find only the fuzzy controller were better for both low and high antenna tracking loop gains, and the tracking loop gain parameter variations effect can be reduced. By the way to reduce computer loading the simplified triangular distribution relationship functions of the fuzzy controller was applied.

The organization of this paper is as follows: the first section is introduction. The second one is for traditional design of antenna tracking and stabilization loops. The antenna performance analyses with a traditional design are given in Section 3. The PD-type fuzzy controller design and performance analyses are given in Section 4. The last part is the conclusions.

2 Traditional Antenna System Design

The detailed block diagram of a satellite antenna tracking system is in Fig. 1, in which both tracking and stabilization loops as well as pitch, roll and yaw coupling effects are taking into consideration [7]. It is very complicate and difficult to obtain the key parameters for analyses and simulation. Thus in general a simplified pitch or yaw model of antenna control system is applied to speed up the design and obtaining the key parameters, in which the tracking loop is modelled as a simple gain, and the stabilization loop is replaced by a pure integration, or PI compensators as in Figs. 2 and 3. Then this research made a roughly designed first according to the bandwidth and phase margin requirements to obtain the key parameters of antenna tracking and stabilization loops. The stabilization loop was designed by using proportion and PI compensators for comparison as shown in Figs. 2 and 3. The tracking loop time constant (T_c) is set as 0.1 seconds of the practical value for the bandwidth requirement.

2.1 Stabilization Loop Compensator Design

2.1.1 Pure integration compensator

Firstly, the stabilization loop is designed with pure integration compensator. Let the integrator gain (K1) of stabilization loop be 25, 50, 75 and 100, respectively, then the Bode plots are in Fig. 4. The gain margins are ∞. Although the phase margin would be increased with larger K1, the increasing rate approaches saturation for K1=100. So we can set K1=100 for the initial design.

2.1.2 PI compensator

Secondly, the PI compensator is applied for the stabilization loop design. The gains of the proportion and integration terms are denoted as K0

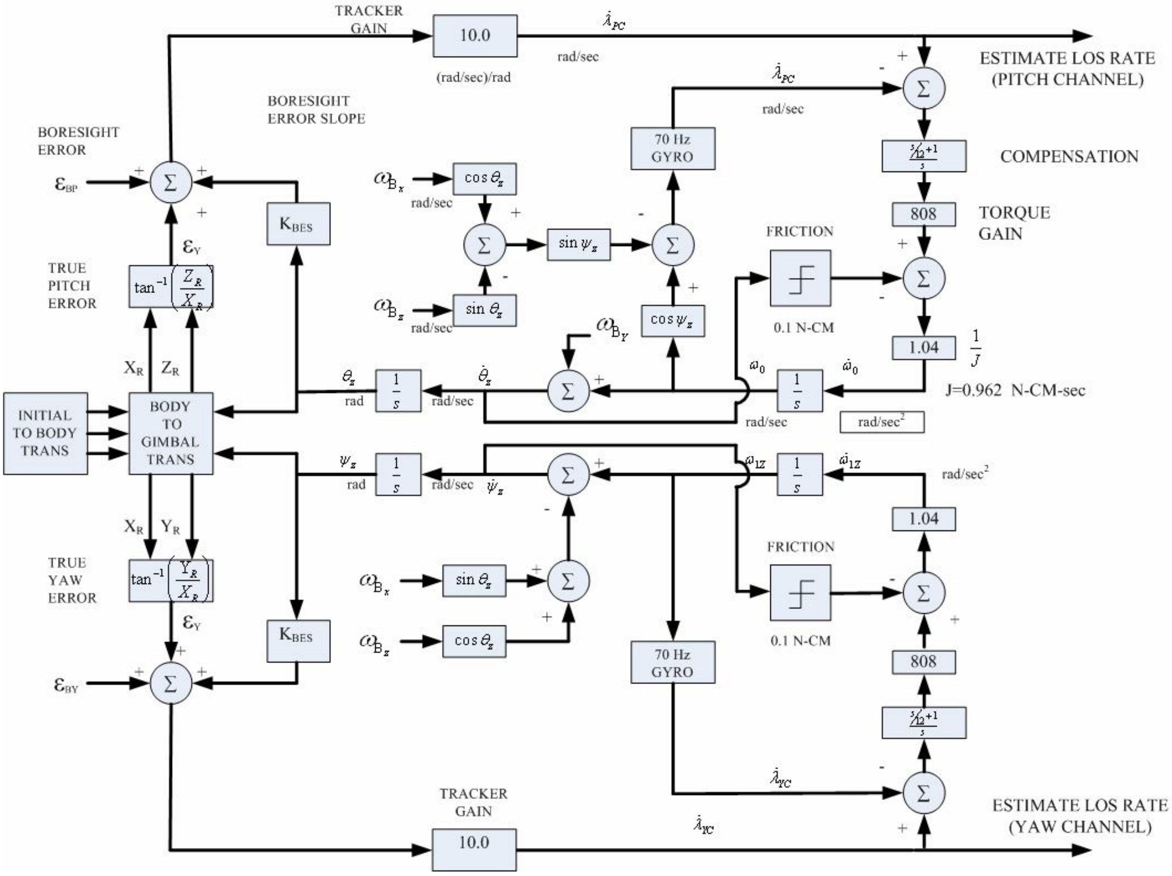

Fig. 1 The detailed block diagram of the antenna control system.

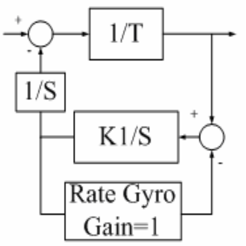

Fig. 2 The block diagrams of antenna stabilization loop with a pure integration compensator.

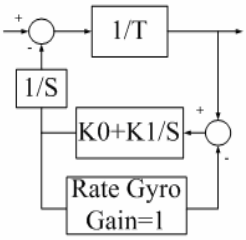

Fig. 3 The block diagrams of antenna stabilization loop with a PI compensator.

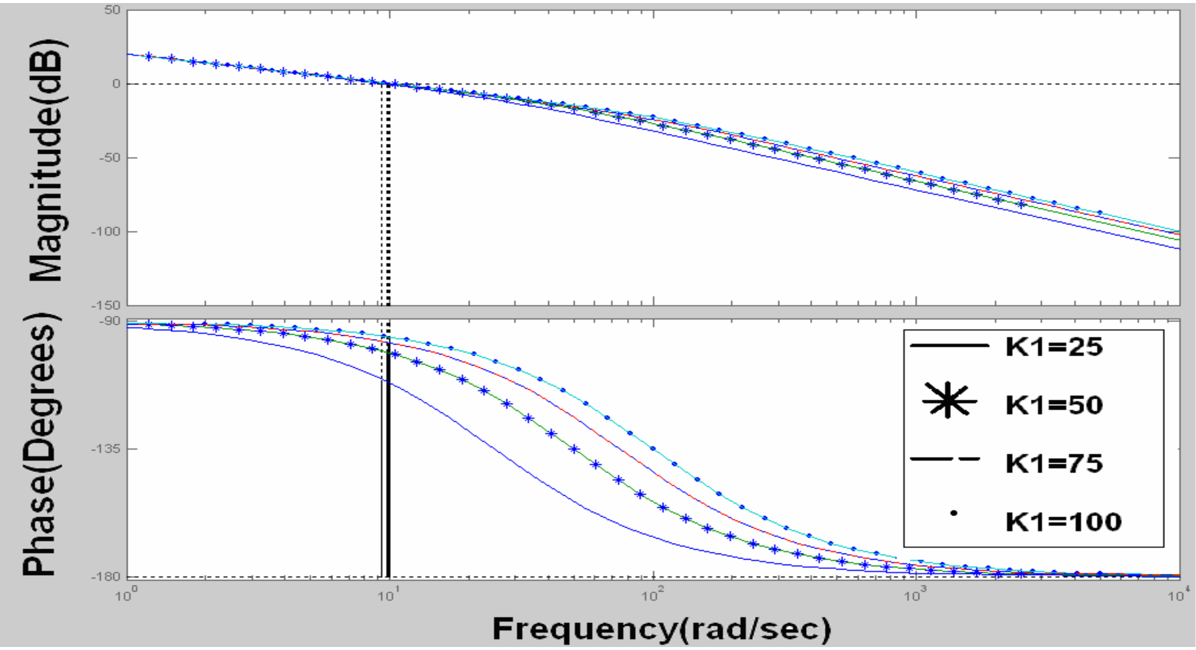

Fig. 4 Bode plots for K1 are as 25, 50, 75 and 100 for the stabilization loop be a pure integration compensator.

and K1, respectively. Fig. 5 shows the Bode plots for several K0's with T_c=0.1 and K1=100. The phase margin is larger for K0=5. Fig. 6 shows that the phase margin is insensitive with K1 (T=0.1 and K0=5), but the steady-state error can be eliminated with the larger K1's. By some trial-and-error one can see that the phase margins are larger, say 132° and 133°, for the cases with K0=5, K1=50, T_c=0.1 and K0=5, K1=25, T_c=0.2, respectively. The former is chosen for faster response and easy of realization.

3 Performance of Traditional Design

In this section the antenna performance is analyzed by simulation with the block diagram in Fig. 7. The input line-of-sight angle is a triangle one with amplitude and period respectively as 1 radian and 5 seconds. It can be seen that the gimbal angle can track with the input line-of sight angle as in Fig.8, thus the performance is very good.

However, in general there is tracking loop gain parameter variation due to the pointing disturbance.

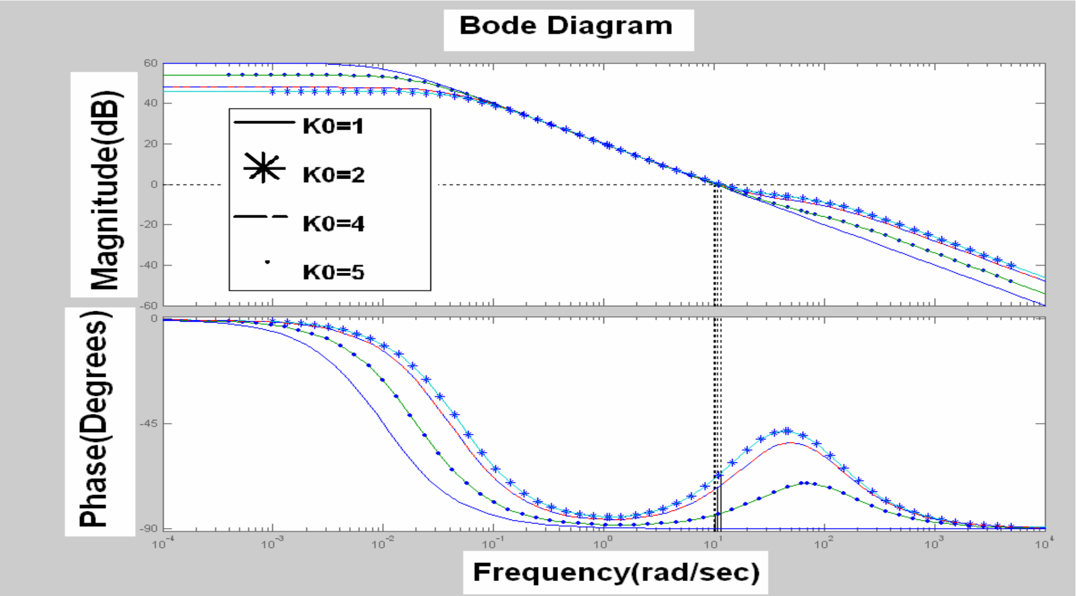

Fig. 5 Bode plots for several K0's with T_c=0.1 and K1=100 for the stabilization loop be a PI compensator.

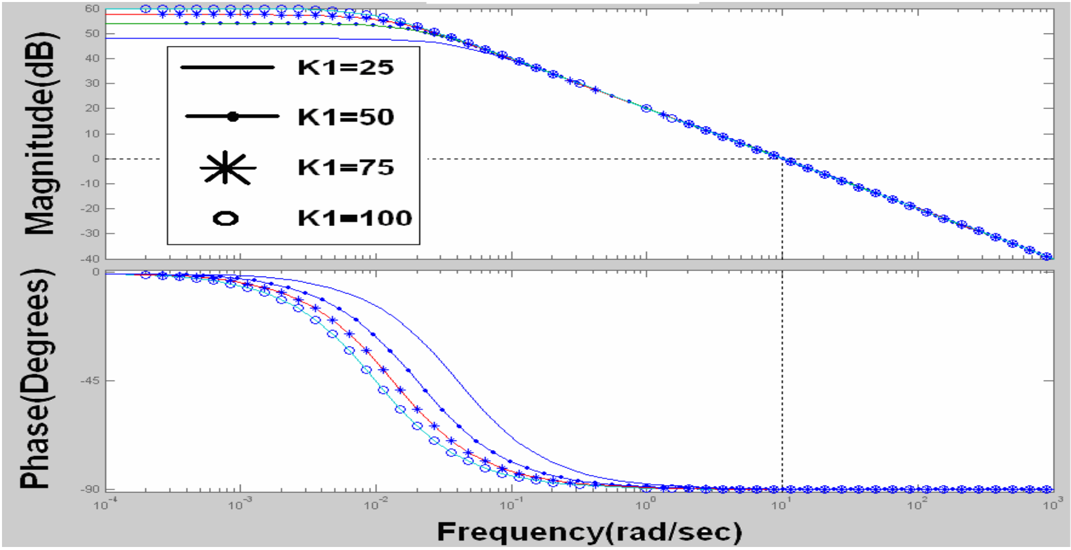

Fig. 6 Bode plots for several K1's with K0=5 for the stabilization loop be a PI compensator.

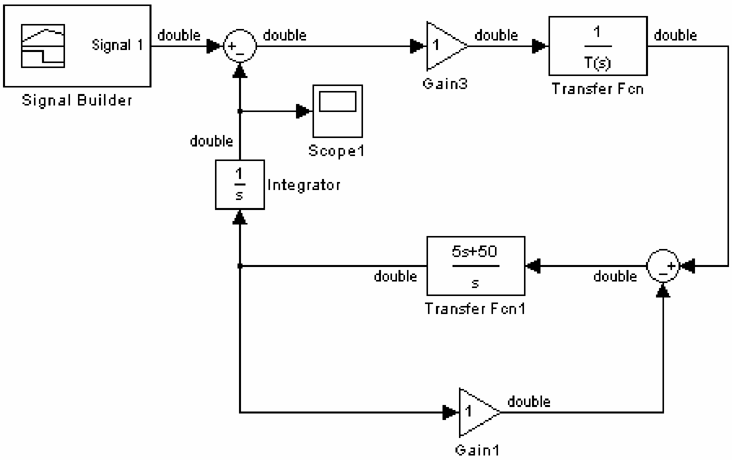

Fig. 7 Block diagram of antenna system by the traditional control design method.

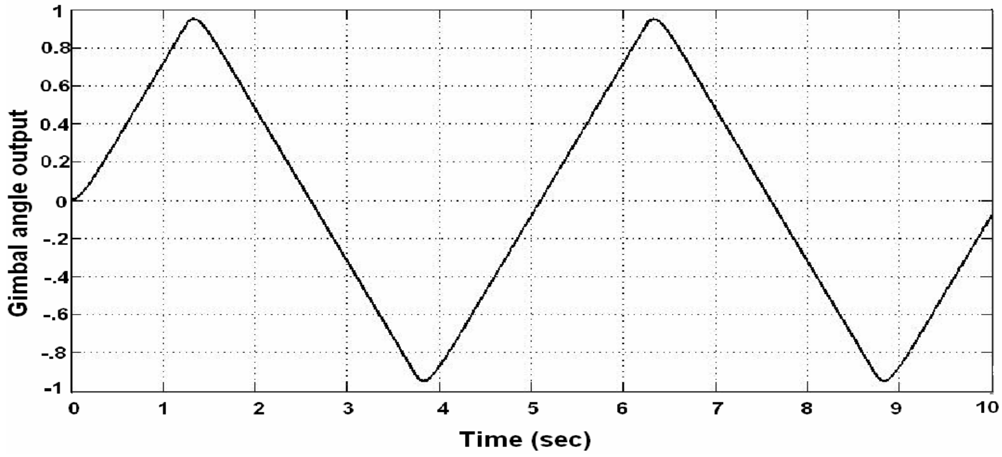

Fig. 8 Gimbal angle output with T_c=0.1 for the antenna system designed by the traditional method.

The simulation results with this tracking loop gain reduced effect are shown in Figs. 9 and 10 for the parameter T_c changing from 0.1 to 1 and 1.5, respectively. It can be seen that the tracking performances of gimbal angles are reduced. Thus the traditional method would not be applied for the systems with lower tracking loop gains.

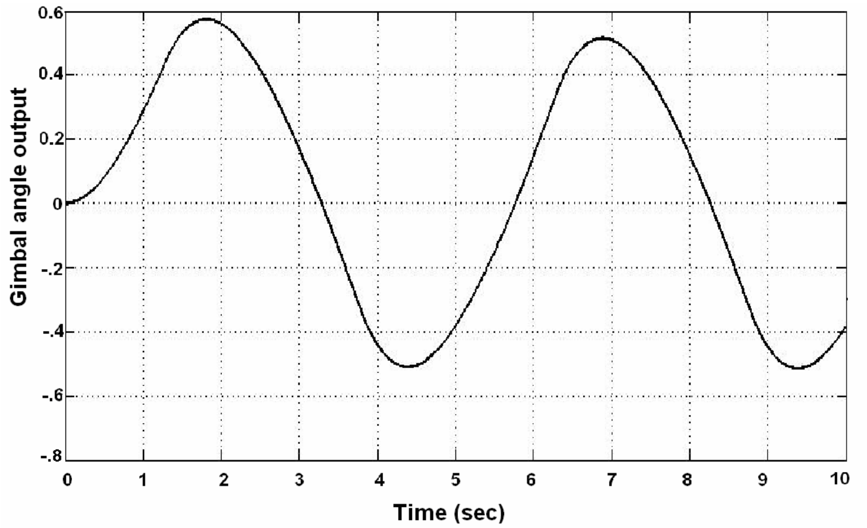

Fig. 9 Gimbal angle output with T_c=1 for the antenna system designed by the traditional method.

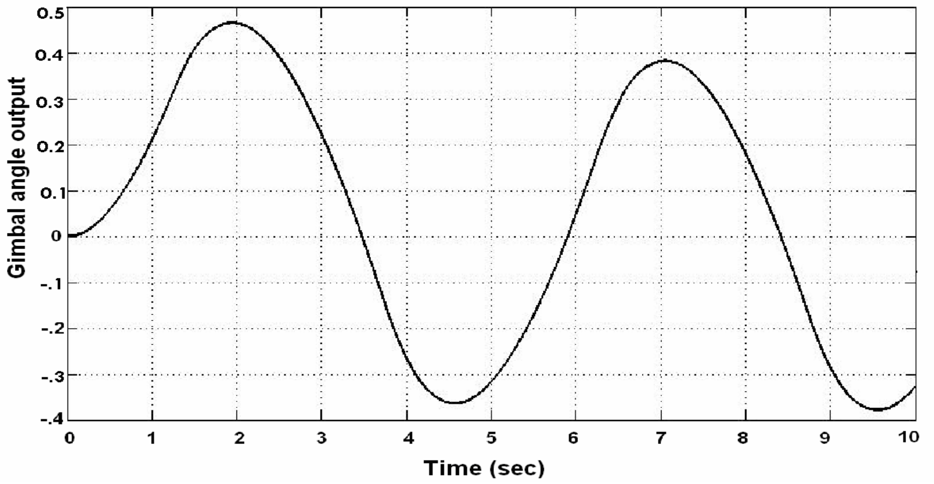

Fig. 10 Gimbal angle output with T=1.5 for the antenna system designed by the traditional method.

4 Fuzzy Controller Design

4.1 Ziegler-Nichols-Based Controller Design

The first Ziegler-Nichols-Based method [8] is applied for the design in this section. The method is to make the unit-step input response as shown in Fig.11, in which we can determine the gain K of the steady-state response, the time constant T. In Fig. 11, both a and L are the coordinates of y- and x-intercept points for a line tangent to the curve at the maximum slope of the unit-step input response. Then the transfer function of the plant is as follows:

$$G(s) = \frac{Ke^{-Ls}}{Ts+1} \tag{1}$$

Then the PID coefficients selection rules are used as listed in Table 1, in which K_P, T_I and T_D are the gain coefficients of PID controller and are related to the magnitudes of a and L. The abbreviation NA stands for Not Available.

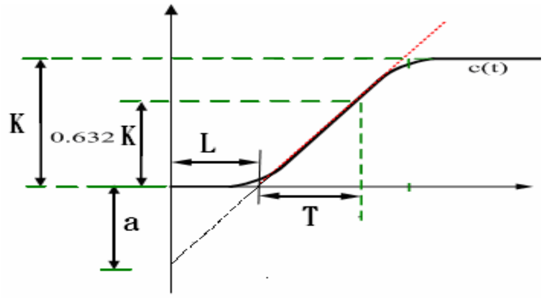

Fig .11 The unit-step input response of the antenna control system with a time delay.

Table 1 The PID gain coefficients selection rules.

Controller Type	K_P	T_I	T_D
P	$1/a$	NA	NA
PI	$0.9/a$	$3L$	NA
PD	$1.2/a$	NA	L/2
PID	$1.2/a$	$2L$	L/2

So the first step is to apply a unit step input to the antenna control system in Fig.3, the unit step response is in Fig.12. One can find that K=1, L=0.3, and a=0.5. By Table 1 one has the gain coefficients of PID compensator as: K_P=1.2/a≒2.4, T_I=2L=0.6 and T_D=L/2=0.15. If the input line-of sight is a saw tooth wave, then the responses for the gimbal angle for the PI, PD and PID compensators with T_c=0.1 are as shown in Figs.13-15, respectively. We can see all the results are acceptable. But for T_c=1 we can see all the delay effects in the outputs are very serious as in Figs. 16-18. Finally, for T_c=1.5 we can see both the delay effects in the outputs are evenly slow down with the PI, PD and PID compensators as shown in Figs.19-21, respectively. Thus the Ziegler- Nichols-based controller cannot be applied.

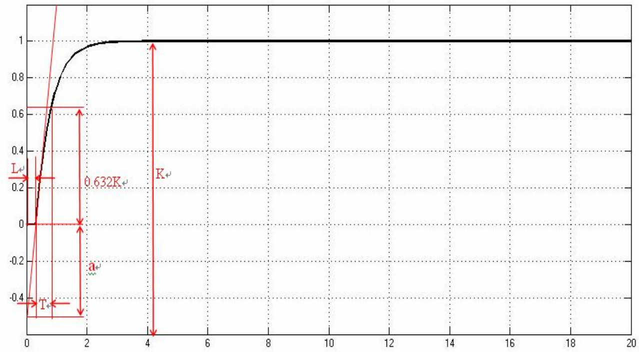

Fig. 12 The unit-step input response of the system.

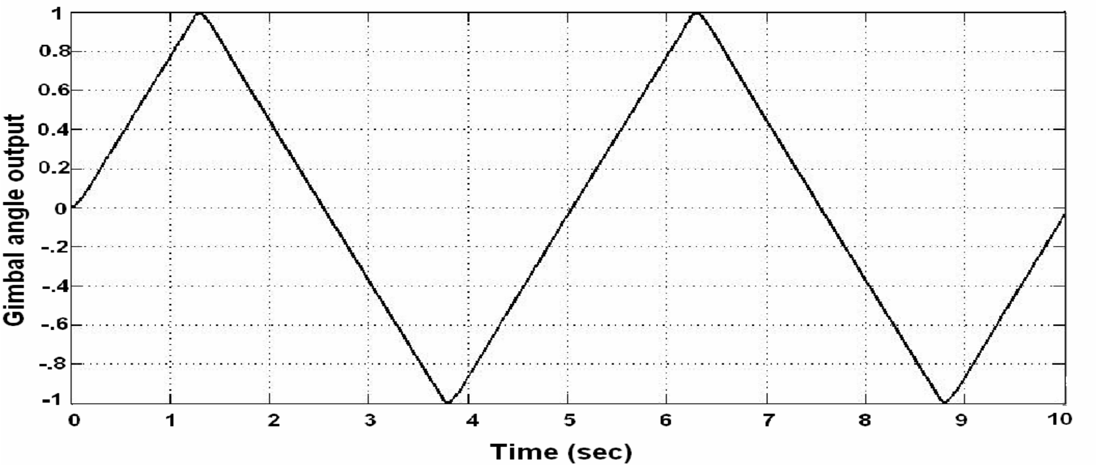

Fig. 13 Gimbal angle output with T_c=0.1 with Ziegler-Nichols-based PI compensator.

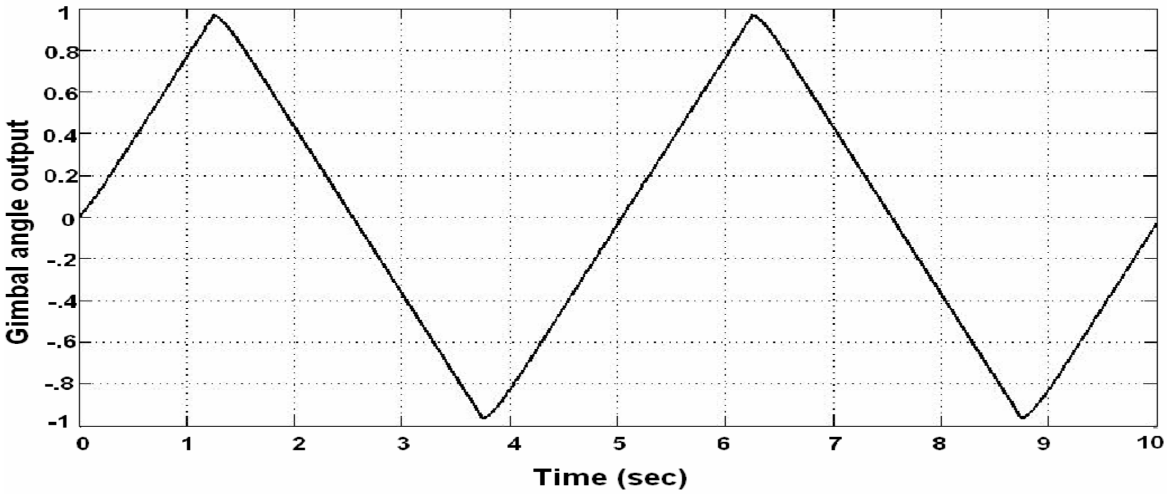

Fig. 14 Gimbal angle output with T_c=0.1 with Ziegler-Nichols-based PD compensator.

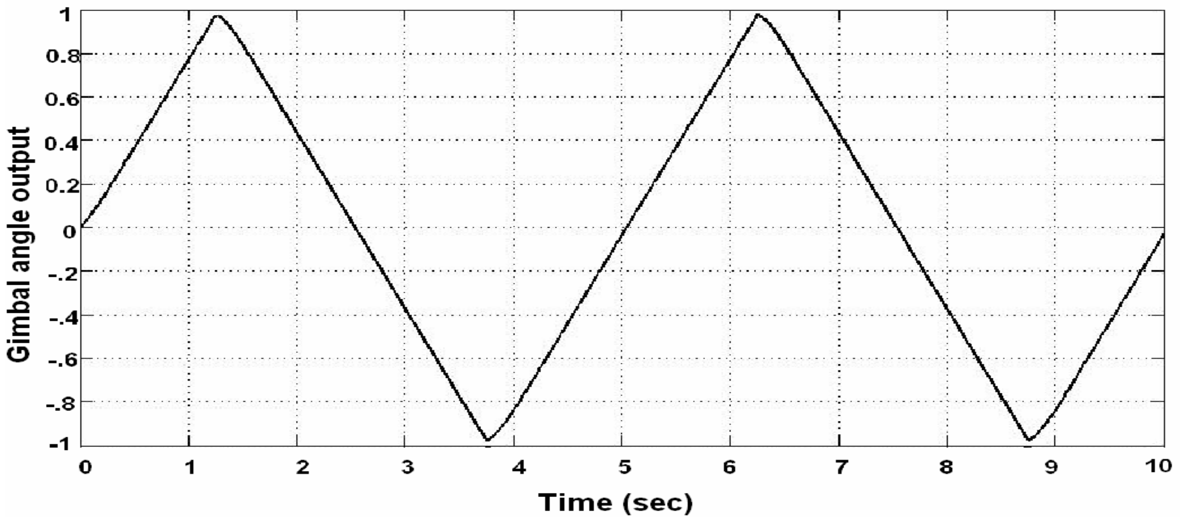

Fig. 15 Gimbal angle output with T_c=0.1 with Ziegler-Nichols-based PID compensator.

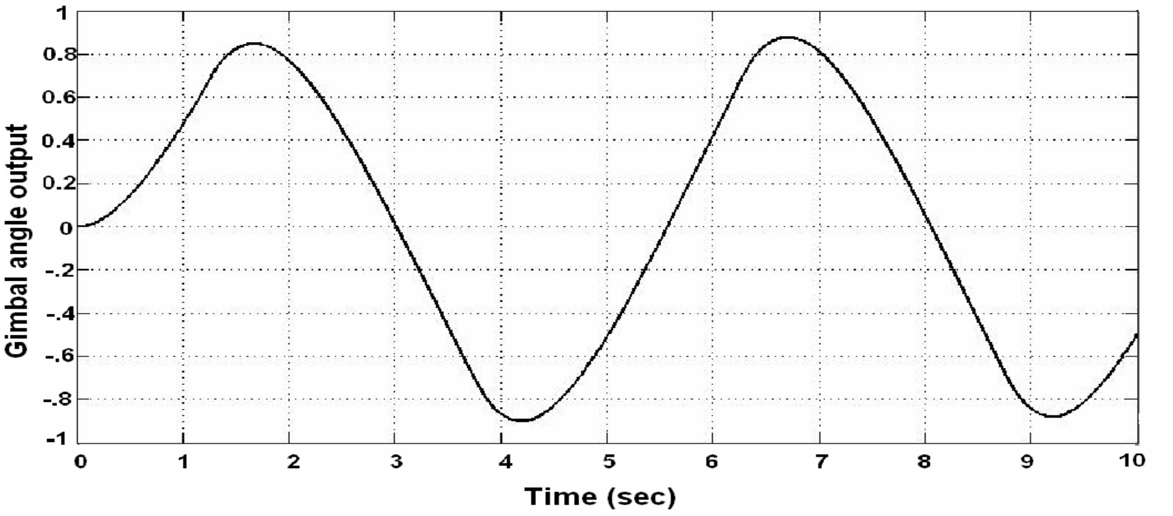

Fig. 16 Gimbal angle output with T_c=1 with Ziegler-Nichols-based PI compensator.

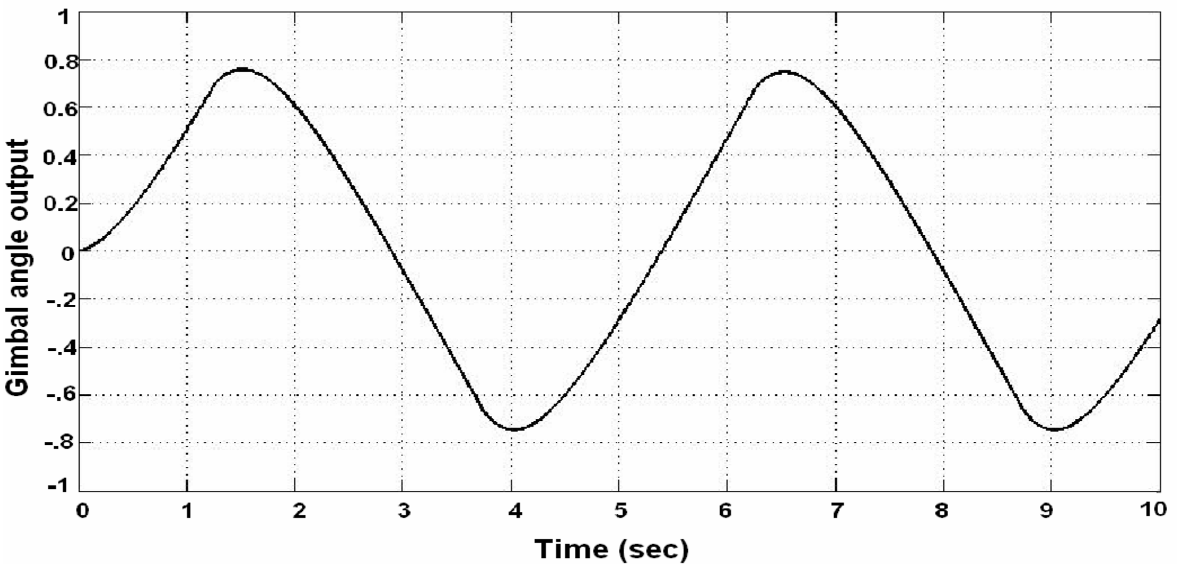

Fig. 17 Gimbal angle output with T_c=1 with Ziegler-Nichols-based PD compensator.

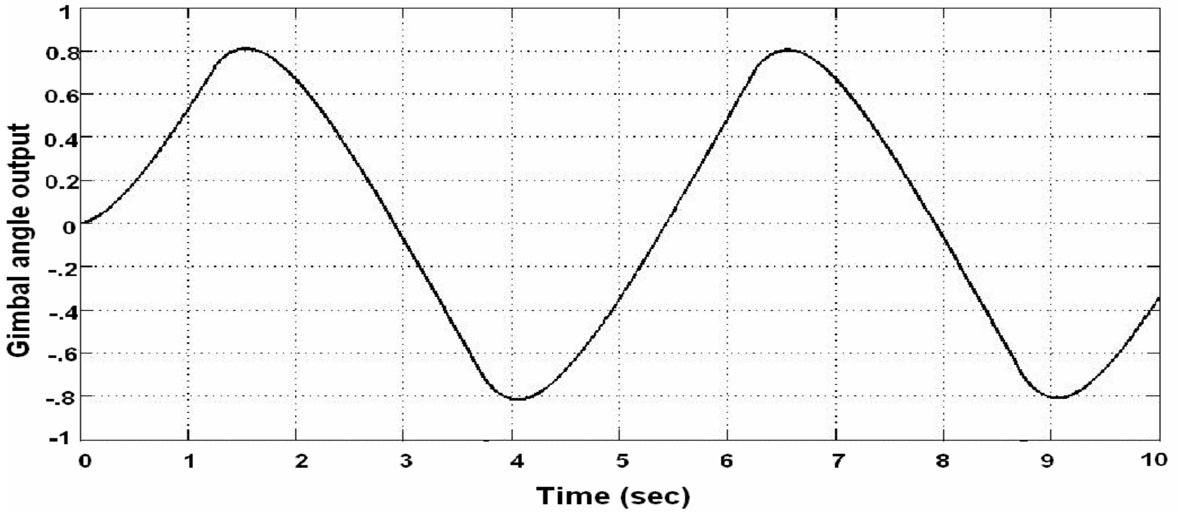

Fig. 18 Gimbal angle output with T_c=1 with Ziegler-Nichols-based PID compensator.

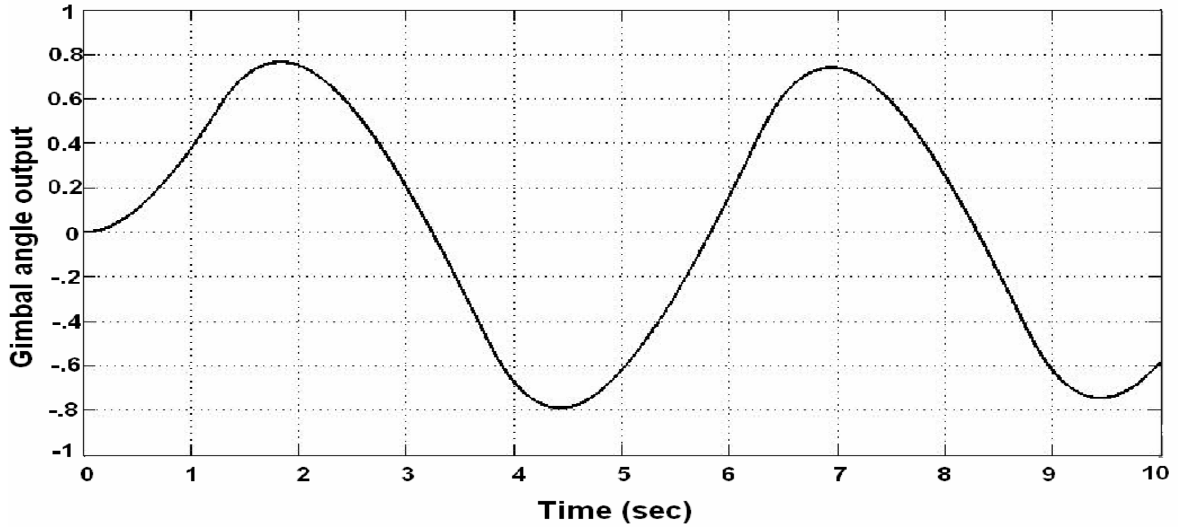

Fig. 19 Gimbal angle output with T_c=1.5 with Ziegler-Nichols-based PI compensator.

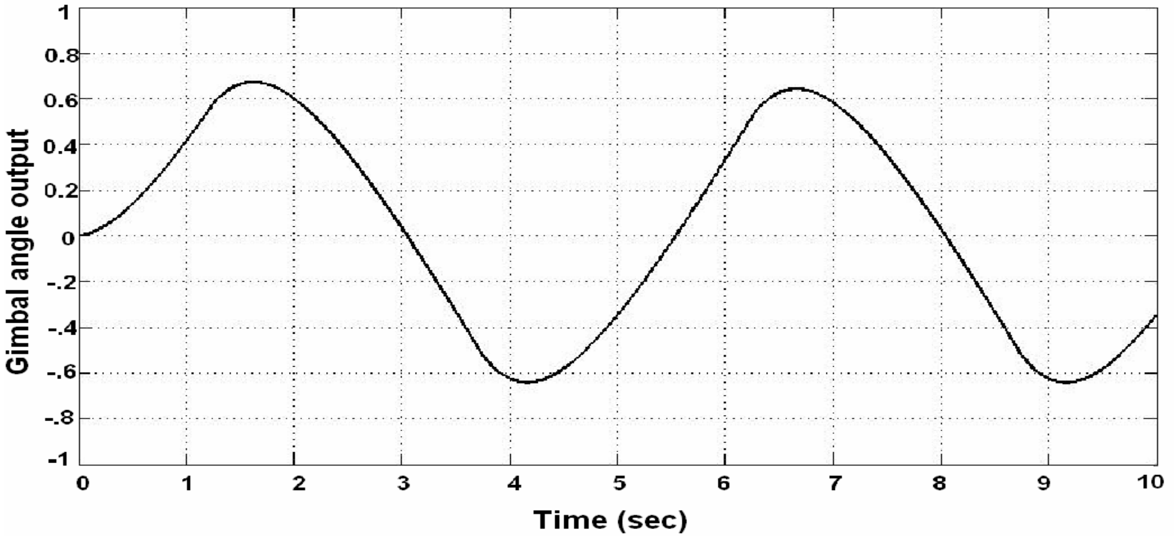

Fig. 20 Gimbal angle output with T_c=1.5 with Ziegler-Nichols-based PD compensator.

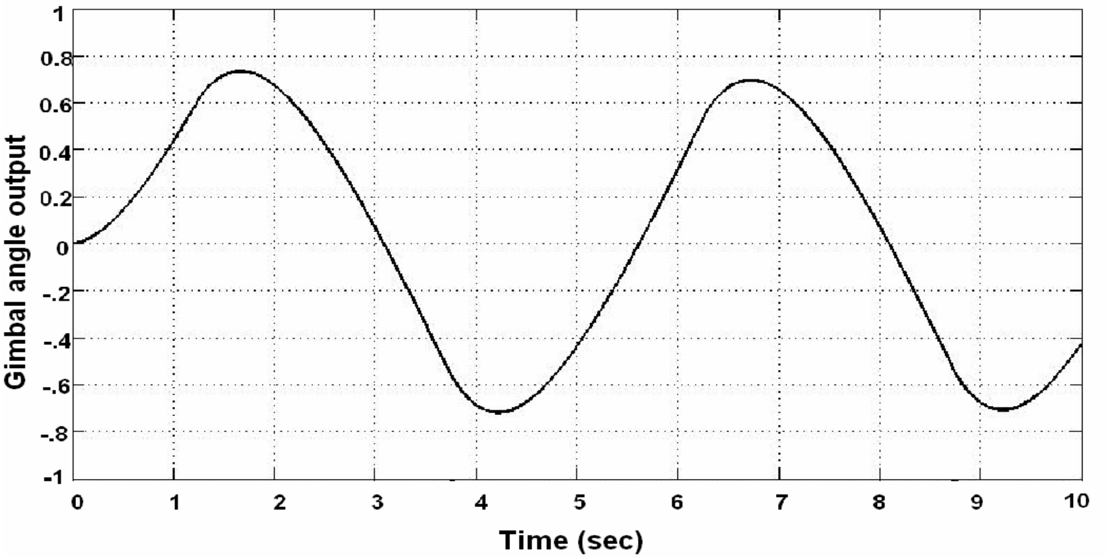

Fig. 21 Gimbal angle output with T_c=1.5 with Ziegler-Nichols-based PID compensator.

4.2 Ziegler-Nichols-Based Fuzzy Controller

In this section the Ziegler-Nichols-based PI, PD and PID type fuzzy controllers [6-7] are applied in the tracking loop as in Fig.22. It is well-known that fuzzy controller is based on the IF-THEN RULE as follows.

R1: IF E is NB AND ΔE is NB THEN U is NB,
R2: IF E is NB AND ΔE is ZE THEN U is NM,
R3: IF E is NB AND ΔE is PB THEN U is ZE,
R4: IF E is ZE AND ΔE is NB THEN U is NM,
R5: IF E is ZE AND ΔE is ZE THEN U is ZE,
R6: IF E is ZE AND ΔE is PB THEN U is PM,
R7: IF E is PB AND ΔE is NB THEN U is ZE,
R8: IF E is PB AND ΔE is ZE THEN U is PM,
R9: IF E is PB AND ΔE is PB THEN U is PB,

where NB, NM, NS, ZE, PS, PM, and PB respectively stand for negative big, negative middle, negative small, zero, positive small, positive middle, and positive big.

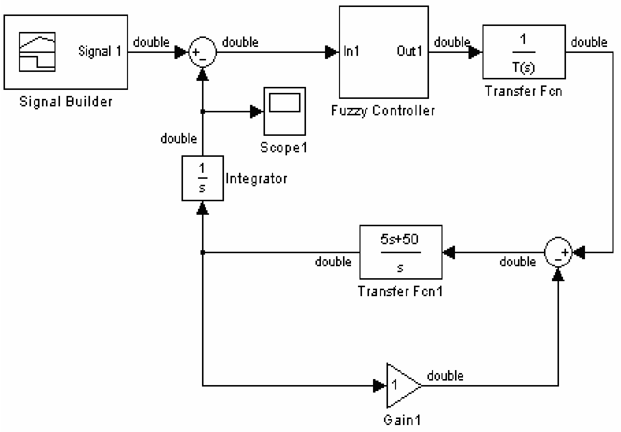

Fig.22 A fuzzy controller is applied in the tracking loop design.

The detailed cross reference rules for the inputs and output of the fuzzy controller are defined in Table 2. According to fuzzy control design method the relationship functions of boresight error E, ΔE (deviations of present E and the previous E), and U (control input) are defined at first, which are listed in Table 3. To reduce the computation time the triangular distribution functions are applied in fuzzy controller relationship functions calculation instead of using the traditional Gaussian ones.

Table 2 Fuzzy controller cross reference rules.

E, ΔE	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NM	NM	NS	NS	ZE
NM	NB	NM	NM	NS	NS	ZE	PS
NS	NM	NM	NS	NS	ZE	PS	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	NS	ZE	PS	PS	PM	PM	PB
PB	ZE	PS	PS	PM	PM	PB	PB

Then the antenna performance is analyzed by simulation. Figs.22-24 show the antenna tracking responses with fuzzy PI, Pd and PID compensator for T_c to be as 0.1, 1 and 1.5, respectively. It can be seen that the results are better than those obtained by using the traditional compensators for all the three values of T_c.

Table 3 Relationship functions of E, ΔE and U.

Item	Parameter E	Parameter ΔE	Parameter U
Negative Big (NB)	[-1 -1 -0.75 -0.3]	[-4.5 -4.5 -3.375 -1.35]	[-12 -12 -9.6 -8.4]
Negative Medium (NM)	[-0.75 -0.3 -0.15]	[-3.375 -1.35 -0.72]	[-9.6 -8.4 -7.2]
Negative Small (NS)	[-0.15 -0.1 0]	[-1 -0.5 0]	[-8.4 -4.8 0]
Zero (ZE)	[-0.05 0 0.05]	[-0.25 0 0.25]	[-4.8 0 4.8]
Positive Small (PS)	[0 0.1 0.15]	[0 0.5 1]	[0 4.8 8.4]
Positive Medium (PM)	[0.15 0.3 0.75]	[0.72 1.35 3.375]	[7.2 8.4 9.6]
Positive Big (PB)	[0.3 0.75 1 1]	[1.35 3.375 4.5 4.5]	[8.4 9.6 12 12]

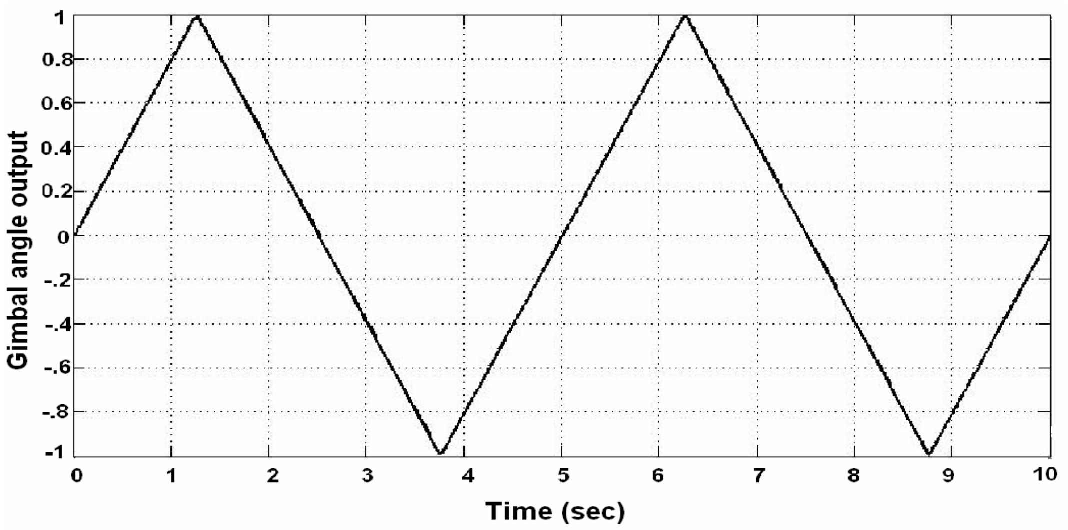

Fig. 19 Gimbal angle output with T=0.1 with Ziegler-Nichols-based fuzzy PI compensator.

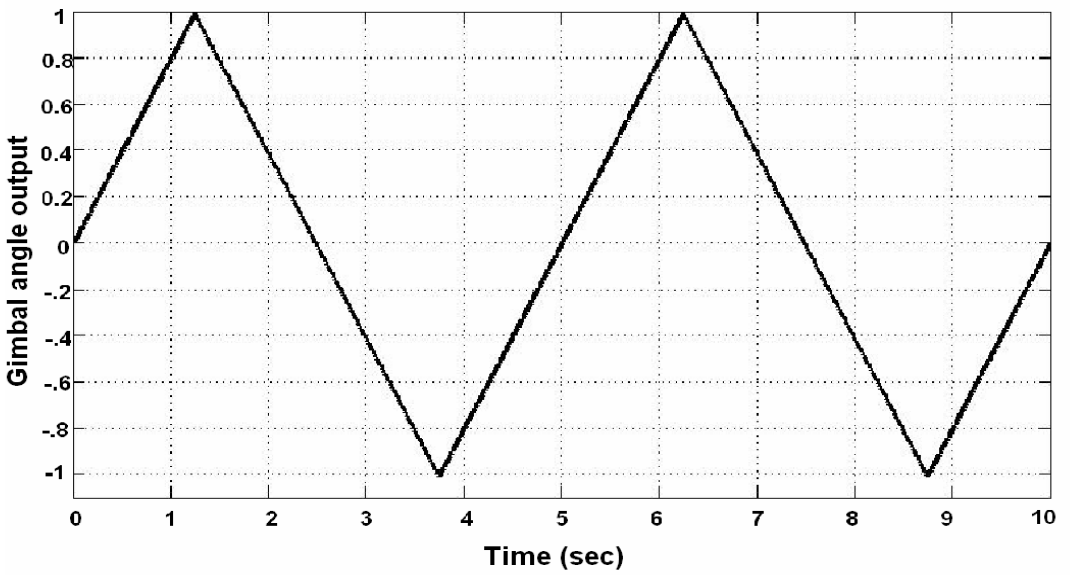

Fig. 19 Gimbal angle output with T=0.1 with Ziegler-Nichols-based fuzzy PD compensator.

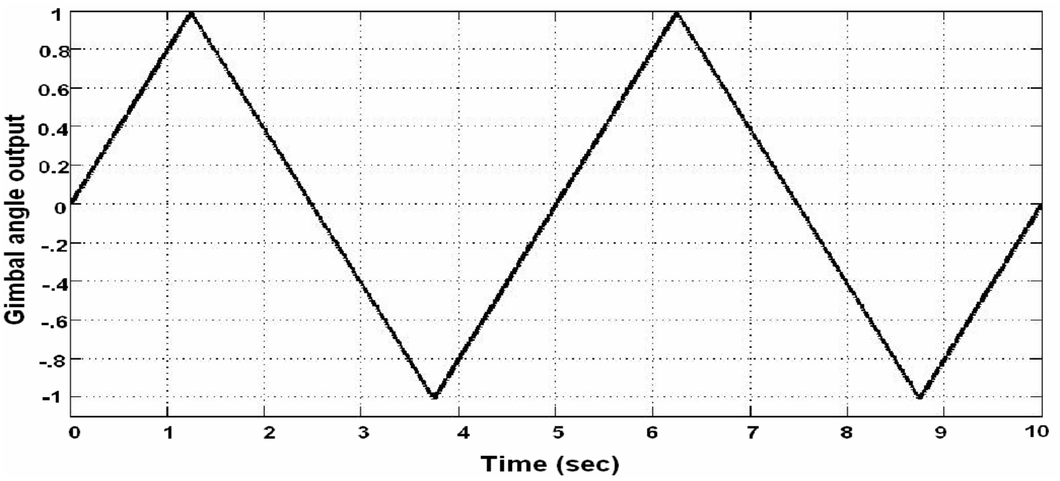

Fig. 19 Gimbal angle output with T=0.1 with Ziegler-Nichols-based fuzzy PID compensator.

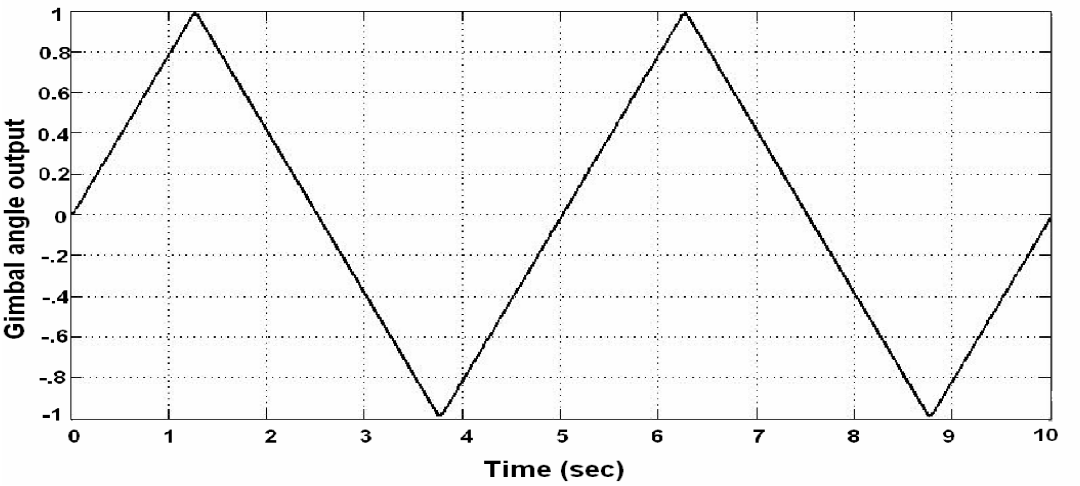

Fig. 19 Gimbal angle output with T=1 with Ziegler-Nichols-based fuzzy PI compensator.

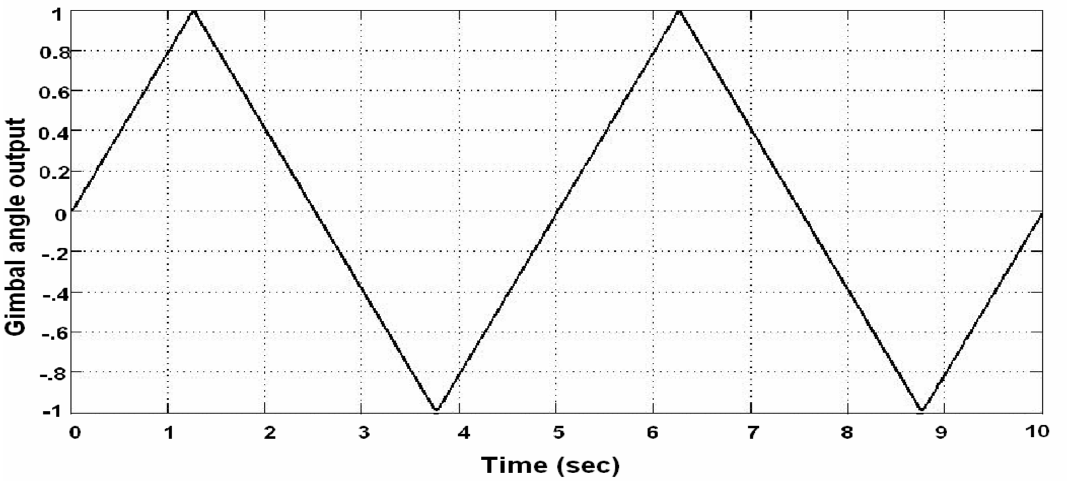

Fig. 19 Gimbal angle output with T=1 with Ziegler-Nichols-based fuzzy PD compensator.

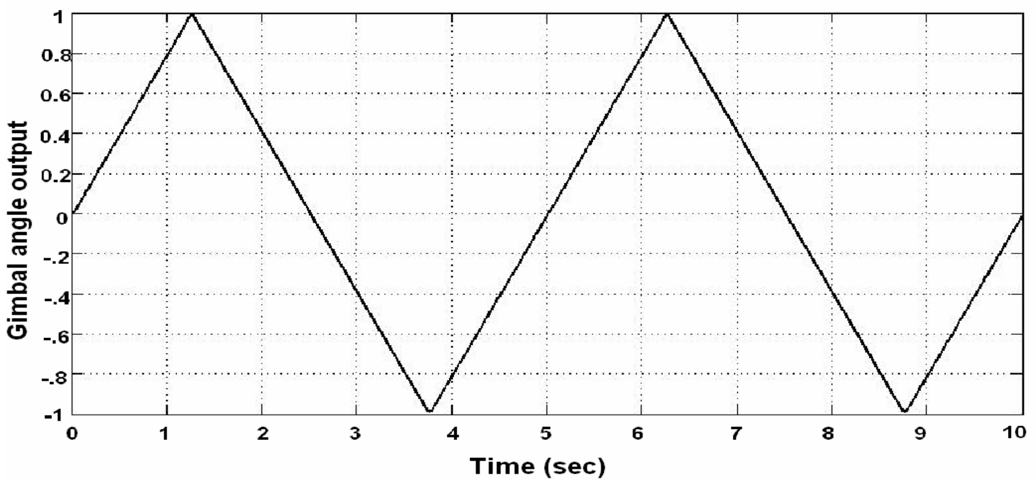

Fig. 19 Gimbal angle output with T=1 with Ziegler-Nichols-based fuzzy PID compensator.

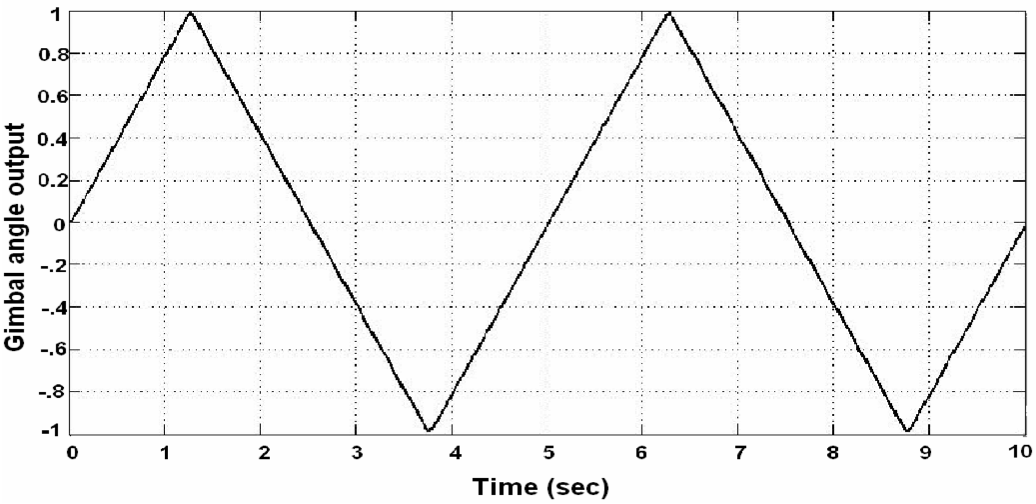

Fig. 19 Gimbal angle output with T=1.5 with Ziegler-Nichols-based fuzzy PI compensator.

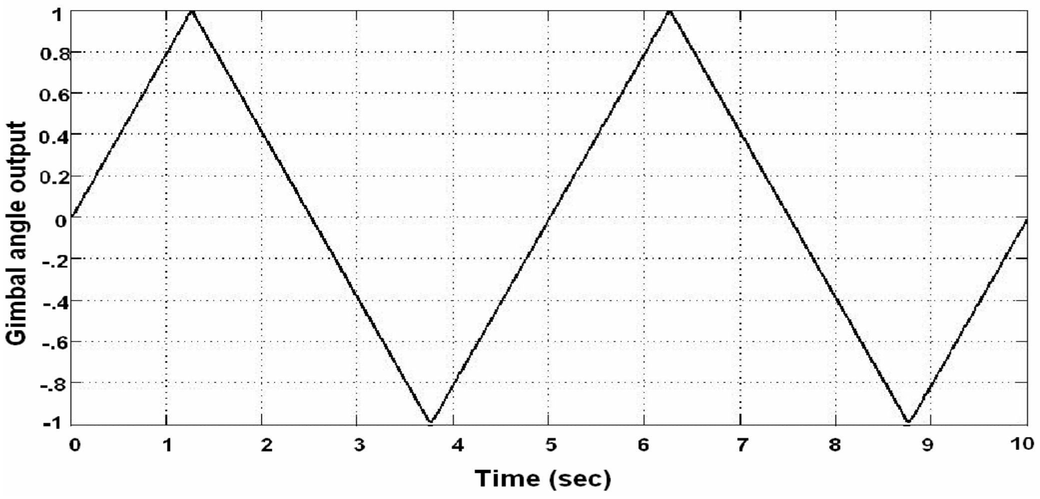

Fig. 19 Gimbal angle output with T=1.5 with Ziegler-Nichols-based fuzzy PD compensator.

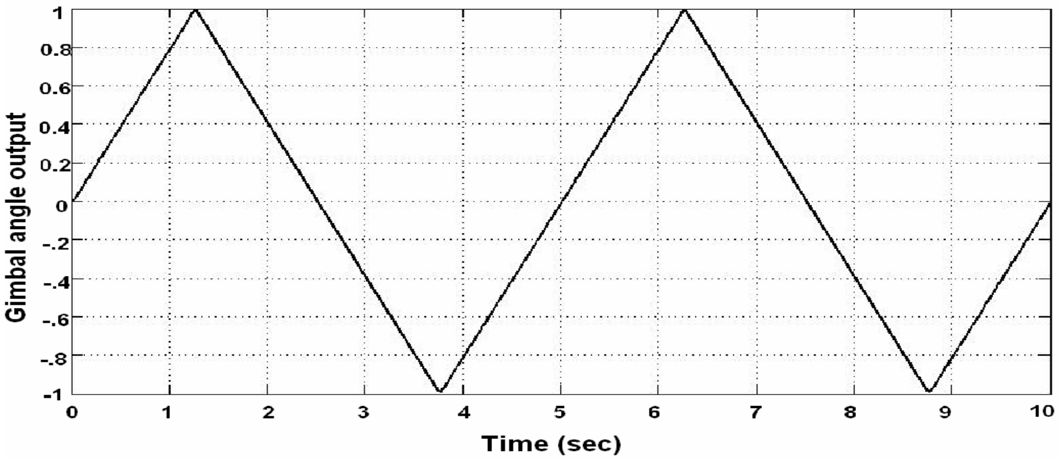

Fig. 19 Gimbal angle output with T=1.5 with Ziegler-Nichols-based fuzzy PID compensator.

5 Conclusion

This research applied both the traditional compensator as well as the PD-type fuzzy control methods for mobile satellite tracking antenna system design. Since the detailed block diagram of a satellite antenna tracking system is very lousy, it is very difficult to obtain the key parameters for analyses and simulation. Thus, a simplified model of antenna pitching or yawing control system is applied to speed up the design and obtain the key parameters. The antenna tracking and the stabilization loops were designed firstly according to the traditional bandwidth and phase margin requirements. However, the performance would be degraded if the tacking loop gain is reduced due to parameter variations. On the other hand a PD-type of fuzzy controller was also applied for the design. It can be seen that the system performances obtained by the fuzzy controller were better for not only lower but higher antenna tracking loop gains. Thus the tracking gain parameter variations effect can be reduced.

Acknowledgment

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