Ziegler-Nichols-Based Intelligent Fuzzy PID Controller Design for Antenna Tracking System

Po-Kuang Chang, Jium-Ming Lin *Member, IAENG*, and Kun-Tai Cho

Abstract—**This research is to augment the intelligent fuzzy controller with two kinds of traditional Ziegler-Nichols-based PID controller for a antenna tracking system design. The nonlinear parameter variation effect, such as gimbal angle hysteresis, is also taken into consideration. One can see that the system performances obtained by augmenting the intelligent fuzzy controller with Ziegler-Nichols-based method, especially the first type were quite better than the traditional ones.**

Index Terms—**Antenna tracking system, hysteresis effect, intelligent fuzzy PID controller, Ziegler-Nichols-based PID controller**

I. Introduction

In order 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 as well as stabilization loops should be raised [1]–[4], and e.g. the tracking rate, pointing precision as well as stabilization should be upgraded. The traditional PI (Proportion and Integration) compensator was applied for the tracking and stabilization loops design of mobile antennas to lock on the satellites [5]. The fuzzy PI controller was applied for the tracking loop design [6]-[7], and the relationship functions of Gaussian distribution were applied for six degrees of freedom simulation, thus the computation loading was very large.

This research firstly applied two kinds of traditional Ziegler-Nichols-based PID controller [8] for a mobile antenna tracking system design and performance analysis. The antenna tracking and the stabilization loops were designed according to Ziegler-Nichols gain margin and phase margin requirements. However, if taking the nonlinear parameter variation effect into consideration, such as gimbal angle hysteresis, then the performances would be bad.

Thus this research is to augment the intelligent fuzzy controller with the previous Ziegler-Nichols-based PID control method for the antenna tracking system design. The results show that the performances obtained by augmenting the intelligent fuzzy controller, especially the first type were quite better than the traditional ones, and the gimbal hysteresis effect can be reduced.

The organization of this paper is as follows: the first section is introduction. The second one is for Ziegler-Nichols-based PID controller design method. The antenna system design and performance analyses by augmenting the intelligent fuzzy controllers are given in Section 3. The last part is the conclusions.

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II. Ziegler-Nichols-Based PID Controller Design Method

The detailed block diagram of a satellite antenna tracking system [9] is shown in Fig. 1, in which both tracking and stabilization loops as well as pitch, roll and yaw coupling effects are taking into consideration. It is very difficult to obtain the key parameters for design. Thus in general a simplified model of antenna pitching or yawing control system is applied to speed up the design and obtaining the key parameters [10], in which the tracking loop is modeled as a simple gain, and the stabilization loop is replaced by a pure integration, or PI compensators as in Figs. 2 (a) and (b). Finally, the full model is applied in the six degrees-of-freedom simulation for practical verification. This section is for Ziegler-Nichols-based design. Since the pitch channel and yaw channel are symmetry that this paper makes only one channel design. In this paper the stabilization loop design with PI compensators in a previous design as shown in Figs. 2(b) is taken for the demonstration [10]. The result is in Fig. 3. Ziegler and Nichols had proposed two famous PID controller design methods [8], the first method can be applied for a control system design without knowing the system transfer function. The second one can be applied for a control system design if one has the system transfer function in advance. The details are briefed as follows.

A. Ziegler-Nichols-Based PID Controller Design Method 1

The first method is applied for a system without knowing the transfer function in advance, one can make the unit-step input response as shown in Fig.4, in which we can determine the gain K of the steady-state response, the time constant T, the y-intercept a of the intersect point of the maximum slope and the output axis as well as the time delay L. Then the transfer function of the plant is as follows:

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

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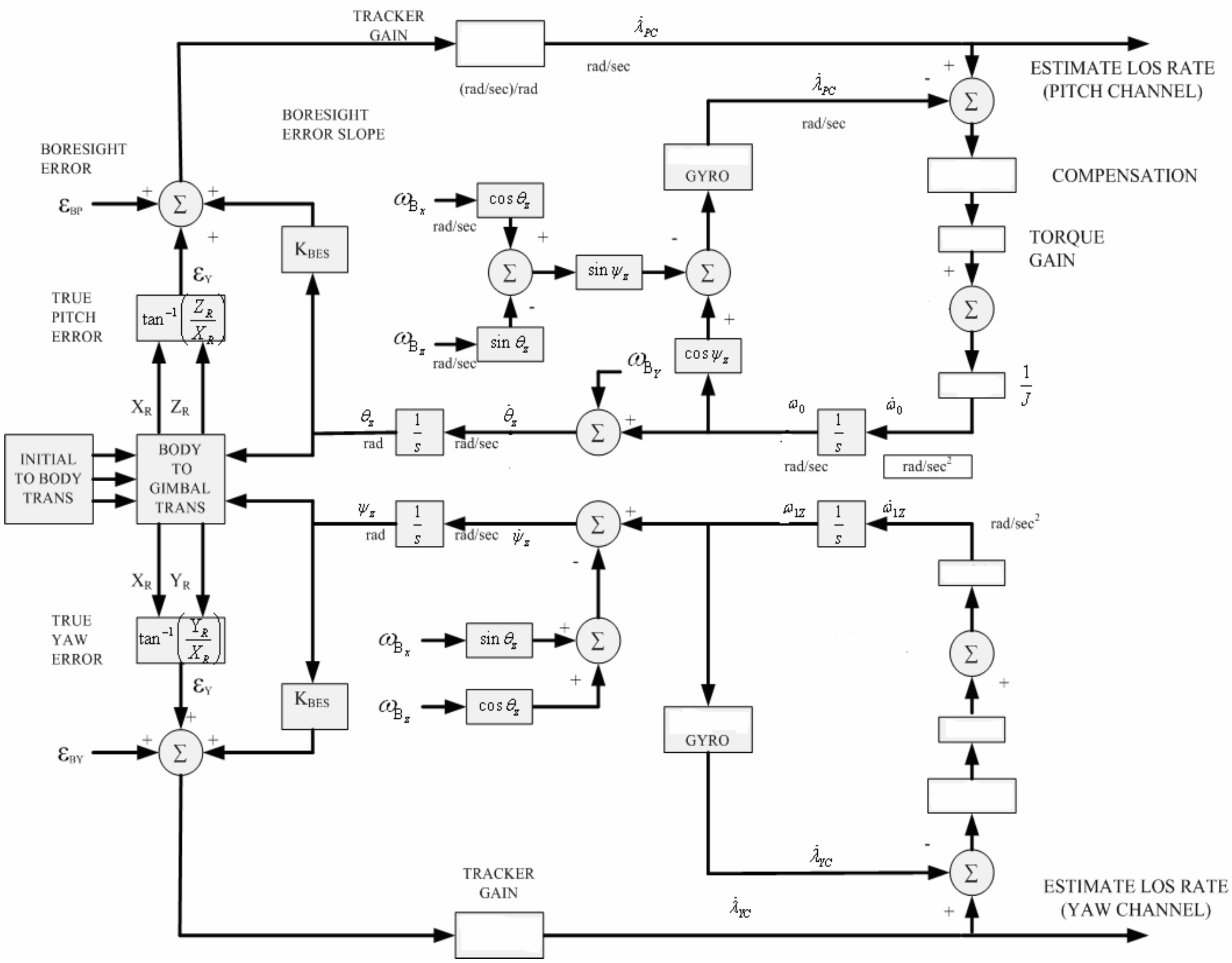

Fig. 1 Detailed block diagram of an antenna control system with tracking and stabilization loops.

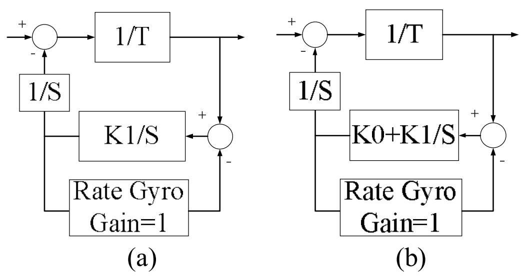

Fig. 2 Simplified block diagrams of the antenna pitching or yawing control systems for the stabilization loop applying (a) pure integration, and (b) PI compensators.

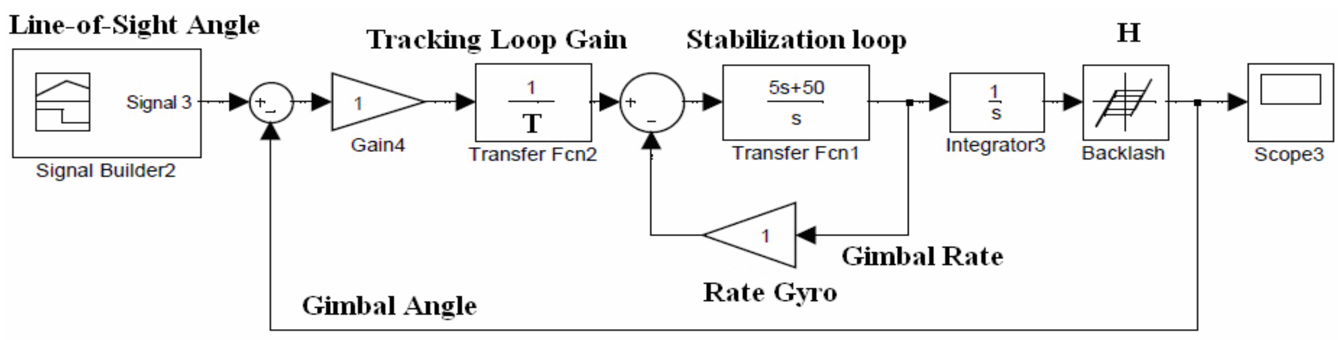

Fig. 3 The block diagram of antenna control systems for the stabilization loop applying PI compensator (T=0.5).

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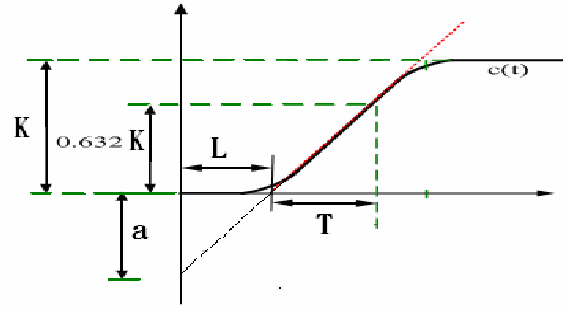

Fig.4 The unit-step input response of a system with a time delay.

The PID coefficients selection rule is as listed in TABLE I, in which K_P, T_I and T_D are respectively the gain coefficients of PID controller and are related to the magnitudes of a and L. The abbreviation NA stands for Not Available.

TABLE I

THE PID GAIN COEFFICIENTS SELECTION RULE OF METHOD 1

Controller Type	K_P	T_I	T_D
P	$1/a$	NA	NA
PI	$0.9/a$	$3L$	NA
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 without the gimbal angle hysteresis effect is in Fig.5. One can find that K=1, L=0.3, and a=0.5. By TABLE I 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 with hysteresis parameter H=0.1 and 0.3 are as shown in Figs.6 and 7, respectively. We can see the hysteresis effects in the outputs are very serious.

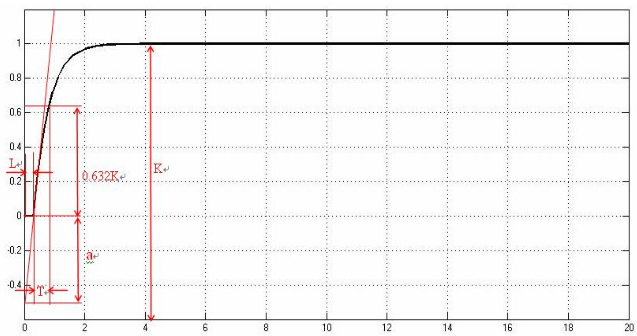

Fig. 5 The unit-step input response of the antenna control system in Fig. 3.

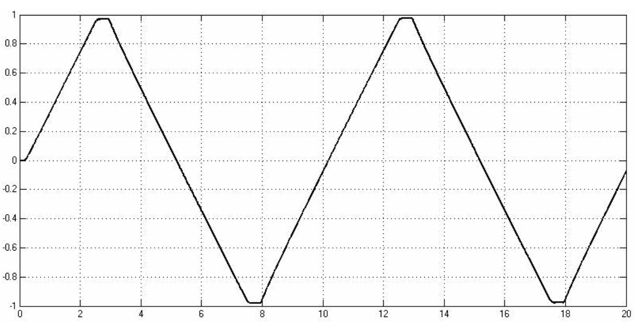

Fig. 6 The response of the system with PID compensator (1) and H=0.1.

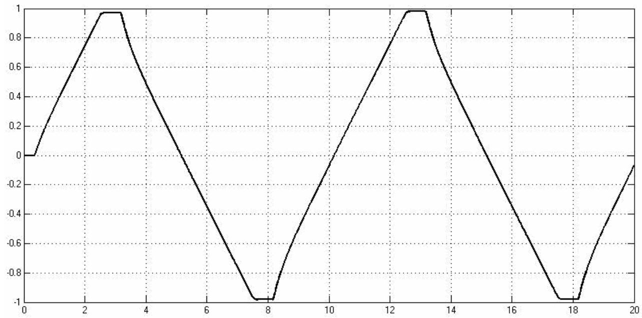

Fig. 7 The response of the system with PID compensator (1) and H=0.3.

B. *Ziegler-Nichols-Based PID Controller Design Method 2*

This method is applied for a system with a predetermined transfer function. The first step is to get the gain margin and the phase-crossover frequency. Then one can obtain K_U and T_U as follows:

$$Ku = log^{-1}\left(\frac{GM}{20}\right) = 10^{\frac{GM}{20}} \quad (2)$$

and

$$Tu = \frac{2\pi}{\omega} \quad (3)$$

The PID coefficients selection rule of method 2 is as listed in Table II; one can see the gain coefficients of PID controller are related to the magnitudes of Ku and Tu.

TABLE II

THE PID GAIN COEFFICIENTS SELECTION RULE OF METHOD 2

Controller Type	K_P	T_I	T_D
P	$0.5Ku$	NA	NA
PI	$0.45\ Ku$	$0.83Tu$	NA
PID	$0.6\ Ku$	$0.5Tu$	$0.125Tu$

Now we can apply the second method to the antenna system design. The Bode plot is shown in Fig. 8, the gain margin and the phase-crossover frequency are obtained as 7.21dB and 4.04 r/s, respectively.

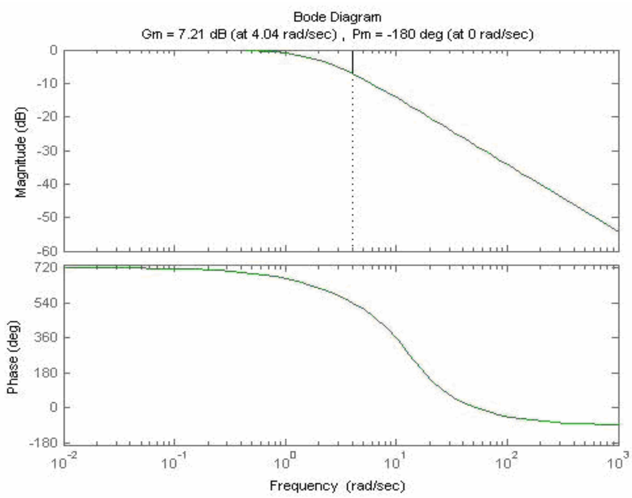

Fig. 8 The Bode plot of the system in Fig.3.

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The next step is to apply (2) and (3) to obtain Ku=2.294, and Tu=1.555. By Table II one has the gain coefficients of PID as: K_P =0.6 Ku=1.377, T_I =0.5 Tu=0.778 and T_D =0.125 Tu=0.194. The responses of the system with method 2 for H= 0.1 and 0.3 are respectively in Figs. 9 and 10. One can see the hysteresis effects are still very serious. Thus we propose to augment and analyze the performances of the intelligent fuzzy controllers with Ziegler-Nichols methods in the next section.

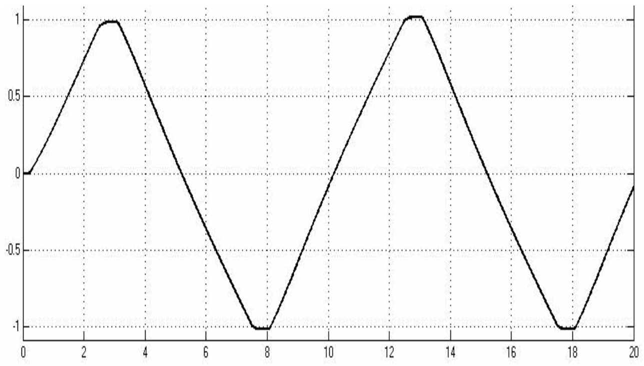

Fig. 9 The response of the system with method 2 and H=0.1.

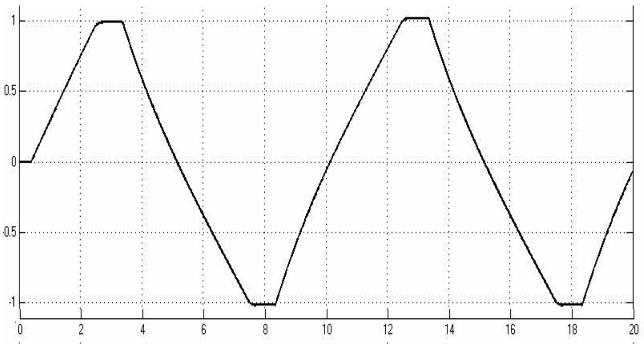

Fig. 10 The response of the system with method 2 and H=0.3.

III. Ziegler-Nichols-Based Intelligent Fuzzy Controller Design

A. Fuzzy Controller Relationship Function Design

In this section a PID-type fuzzy controller is applied [8]-[10] in the tracking loop as in Fig. 11. It is well-known that the fuzzy controller is based on the following IF-THEN RULE, e. g.

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. The detailed cross reference rules for the inputs and output of fuzzy controller are defined in TABLE III. According to the 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 IV.

TABLE III
FUZZY CONTROLLER CROSS REFERENCE RULES FOR INPUTS AND OUTPUT

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

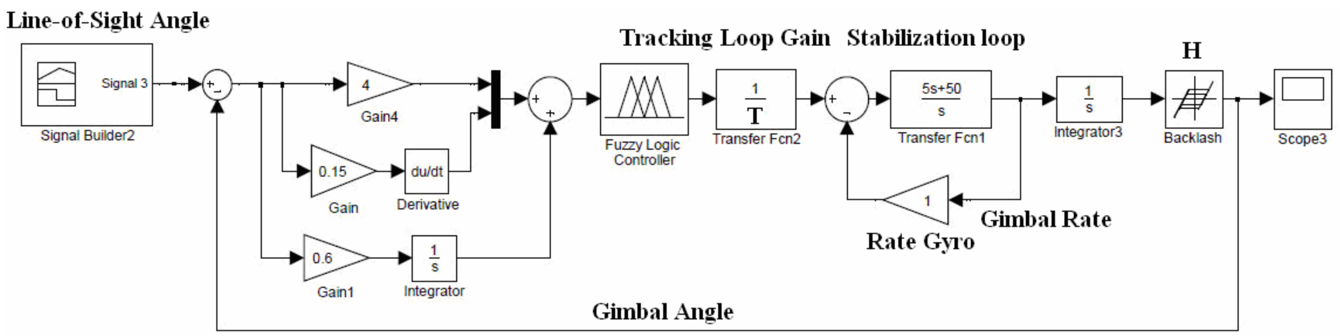

Fig. 11 The block diagram of Ziegler-Nichols-based intelligent fuzzy PID antenna control system.

TABLE IV
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]

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B. Fuzzy Controller Design Based on Ziegler-Nichols-Based PID Controller Design Method 1

Figs. 12-14 show the responses of the system with fuzzy PID controller (1) (H=0.1, 0.3 and 0.5, respectively). It can be seen that the hysteresis effects are almost disappeared, so that the results obtained by the first fuzzy PID control method are quite better than those obtained by only with the PID controllers.

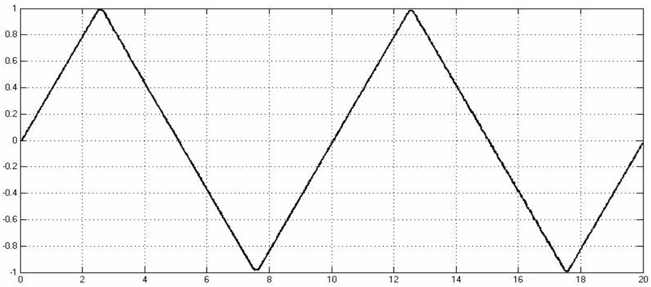

Fig. 12 The output response with fuzzy PID controller (1) (H=0.1).

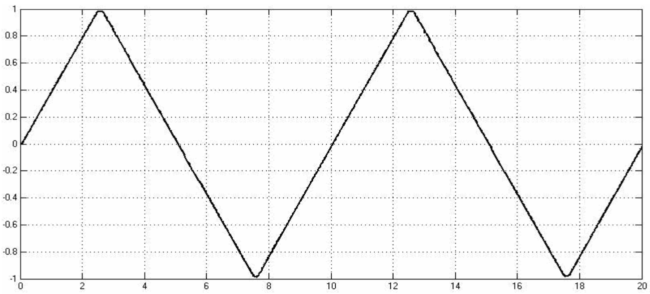

Fig. 13 The output response with fuzzy PID controller (1) (H=0.3).

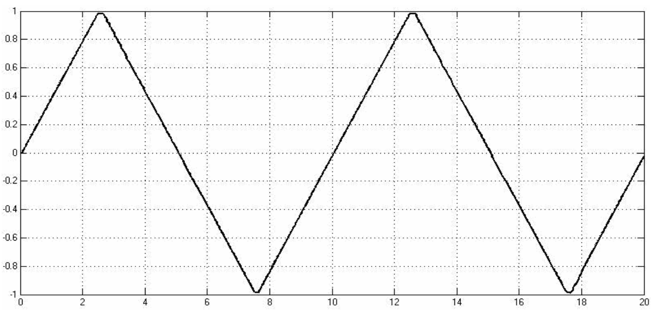

Fig. 14 The output response with fuzzy PID controller (2) (H=0.5).

C. Fuzzy Controller Design Based on Ziegler-Nichols-Based PID Controller Design Method 2

Figs. 15-17 show the responses of the system for method 2 with H=0.1, 0.3 and 0.5, respectively. Although the results are not better than the first method, but the fuzzy PID control method is still better than those obtained by only applying the PID controllers.

IV. Conclusion

This research applied Ziegler-Nichols-based intelligent fuzzy PID controller for a mobile satellite antenna tracking system design. In addition, the nonlinear parameter variation effect, such as gimbal angle hysteresis, is also taken into consideration. Comparing with the traditional Ziegler-Nichols-based PID controllers are also made, it can be seen that the results of system performances obtained by augmenting the intelligent fuzzy PID controllers are better.

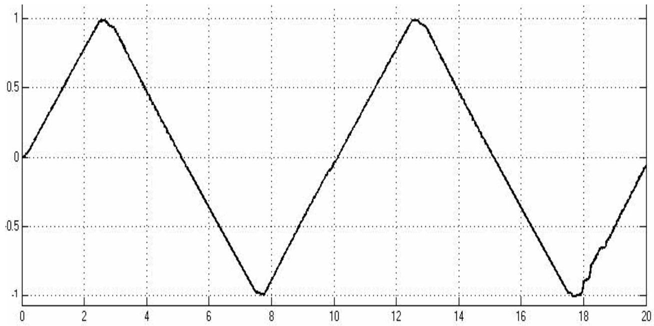

Fig. 15 The output response with fuzzy PID controller (2) (H=0.1).

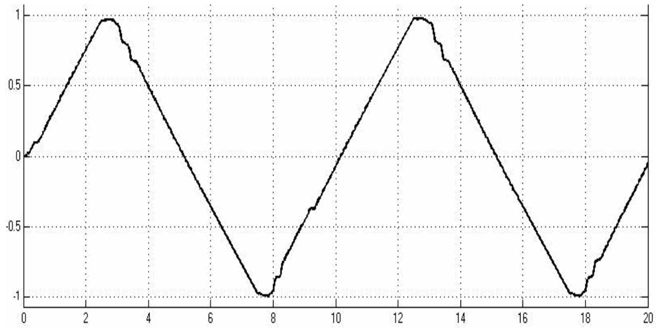

Fig. 16 The output response with fuzzy PID controller (2) (H=0.3).

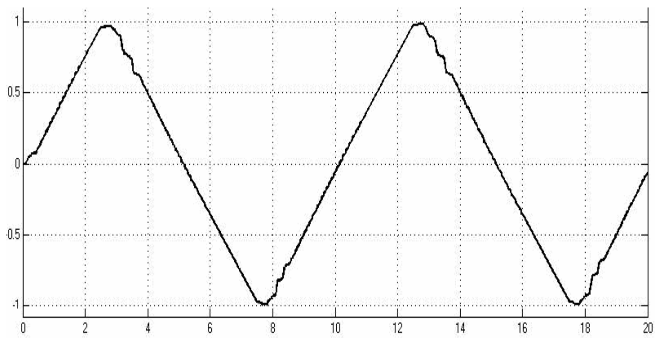

Fig. 17 The output response with fuzzy PID controller (2) (H=0.5).

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References

[1] A. C. Densmore and V. Jamnejad, “Two WKa-band mechanically steered and mobile antennas for the NASA ACTS mobile terminal,” in *Proc. Advanced Communications Technology Satellite Program Conference,* NASA, Wash., D.C., 1992.

[2] A. C. Densmore and V. Jamnejad, “A satellite-tracking Ku- and Ka-band mobile vehicle antenna system,” *IEEE Trans. Vehicular Technology*, vol. 42, no 4, pp. 502–513, 1993.

[3] H. C. Tseng and D. W. Teo, “Ship mounted satellite tracking antenna with fuzzy logic control,” *IEEE Trans. Aerospace and Electronic Systems,* vol. 34, no. 2, pp. 639–645, 1998.

[4] V. Jamnejad and A. C. Densmore, “A dual frequency WKa-band small reflector antenna for use in mobile experiments with the NASA advanced satellite communications technology,” in *IEEE APSIURSI Joint Intern. Sym. URSI Digest*, 1992, p.1540.

[5] P. Estabrook and W. Rafferty, “Mobile satellite vehicle antennas: noise temperature and receiver G/T,” in *Proc. IEEE Vehicular Technol. Conf,* vol.2, San Francisco, CA, USA, 1989, pp. 757–762.

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[6] Y. Zhang, G. E. Hearn, and P. A. Sen, "A neural network approach to ship track-keeping control," *IEEE J. of Oceanic Engineering,* vol. 21, No. 4, pp. 513–527, 1996.

[7] H. Zhang and D. Liu, *Fuzzy Modeling & Fuzzy Control.* New York: Springer-Verlag, 2006.

[8] J. G. Ziegler and N. B. Nichols, "Optimum settings for automatic controllers," *Trans. ASME,* vol. 64, 1942, pp. 759–768.

[9] R. L. Pheysey, AIM-9L, Simulation Parameters, Naval Weapons Center, China Lake, Calif. NWC, July 1975.

[10] P. K. Chang and J. M. Lin, "Integrating traditional and fuzzy controllers for mobile satellite antenna tracking system design," in *Proceedings of WSEAS Conference on Advances in Applied Mathematics, Systems, Communications and Computers,* selected papers from *Circuits, Systems and Signals 2008, Marathon Beach, Attica, Greece,* June 1-3, 2008, pp. 102–108.

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