# PI-Type Fuzzy Controllers for Mobile Satellite Antenna Control System Design with Tracking Loop Gain Parameter Variations

JIUM-MING LIN[1] and PO-KUANG CHANG[2]
[1]Dept. of Communication Engineering and [2]Ph.D. program in the Institute of Engineering Science
Chung-Hua University
707, Sec. 2 Wu-Fu Rd. Hsin-Chu 30012
TAIWAN
jmlin@chu.edu.tw http://www.cm.chu.edu.tw/chinese/teacher/MING/index.htm

*Abstract:* - This research applied Proportion and Integration (PI) type fuzzy methods for mobile satellite antenna control system design. 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. Firstly, the antenna tracking and the stabilization loops were 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 a PI-type fuzzy controller was also applied for tracking loop design. It can be seen that the system performances obtained by the fuzzy controller were better for both lower and higher antenna tracking loop gains, and the tracking loop gain parameter variations effect can be reduced.

*Key-Words:* - Antenna tracking loop, stabilization loop, PI-type fuzzy controller, PI compensator.

## 1 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 of Ku-band should be raised [1-3], 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 [4]. The fuzzy controller was applied for the tracking loop design [5], 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.

Firstly, the antenna tracking and the stabilization loops were designed with the traditional bandwidth and phase margin requirements. This is obtained by applying a simplified model for the antenna control system design, both time and frequency domain analyses are studied to obtain the key parameters of antenna tracking and stabilization loops. Secondly, 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.

Thus this research proposed an intelligent control law by using Proportion and Integration (PI) type fuzzy methods [6-7] for mobile antenna tracking loop control system design. The results show that the performances are better, and the tracking gain parameter variation effect can be reduced. By the way to reduce computer loading for practical implementation, 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 PI-type fuzzy controller for the tracking loop design and performance analyses are given in Section 4. The last part is the conclusion.

## 2 Traditional Antenna Tracking and Stabilization Loops Design

The detailed block diagram of a satellite antenna tracking system is very lousy as shown in Fig. 1[8].

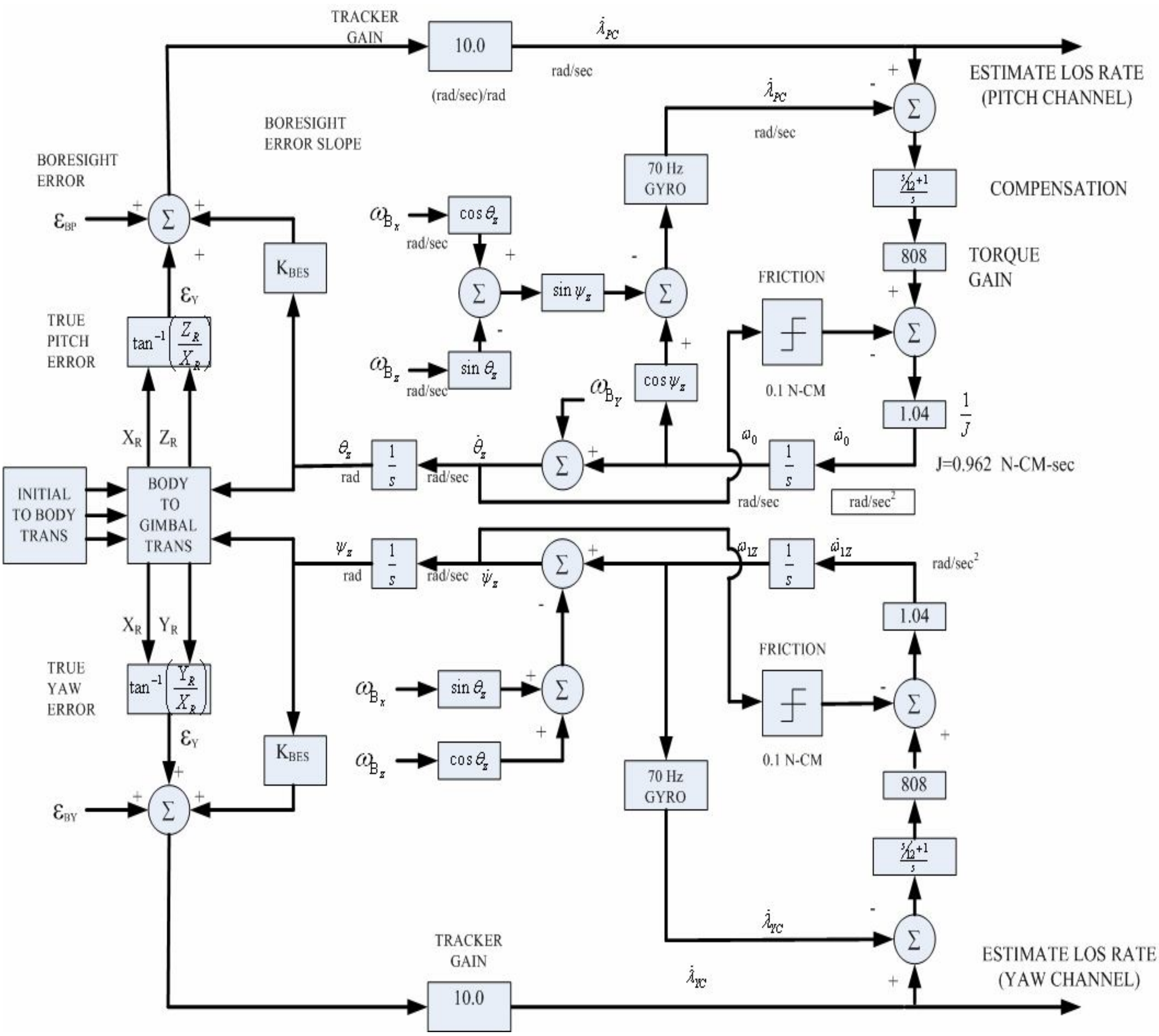


Fig. 1. The detailed block diagrams of antenna tracking and stabilization loops.

It is very difficult to obtain the key parameters for analyses and simulation. 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, 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). Then this research made the time and frequency domain analyses firstly, to obtain the key parameters of antenna tracking and stabilization loops. The tracking loop time constant (T) is set as 0.1 seconds of the practical value.

## 2.1 Stabilization Loop with 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. 3. The gain margins are ∞. Although the phase margin would be increased with larger K1, the increasing rate approaches saturation for K1=100.

## 2.2 Stabilization Loop with 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 and K1, respectively. Fig. 4 shows the Bode plots for several K0's with T=0.1 and K1=100. The phase margin is larger for K0=5. Fig. 5 shows that the phase margin is insensitive with K1 (T=0.1 and K0=5), but the

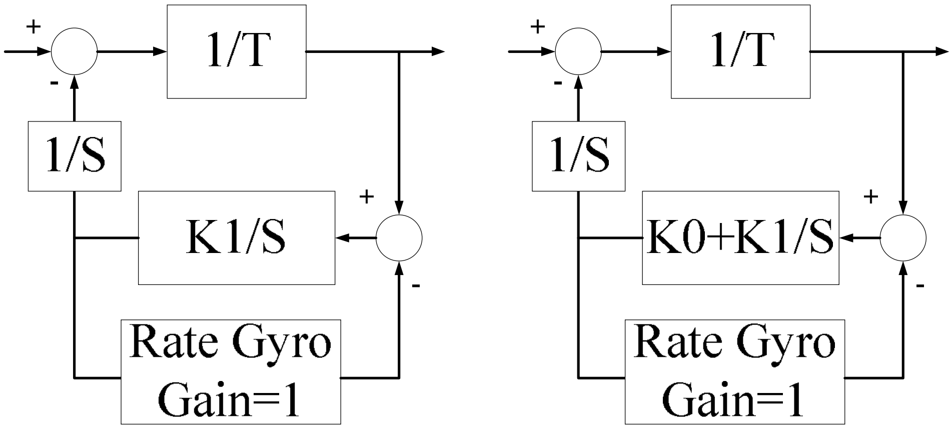


Fig. 2. The simplified block diagram of antenna control systems for the stabilization loop applying (a) pure integration, and (b) PI compensators.

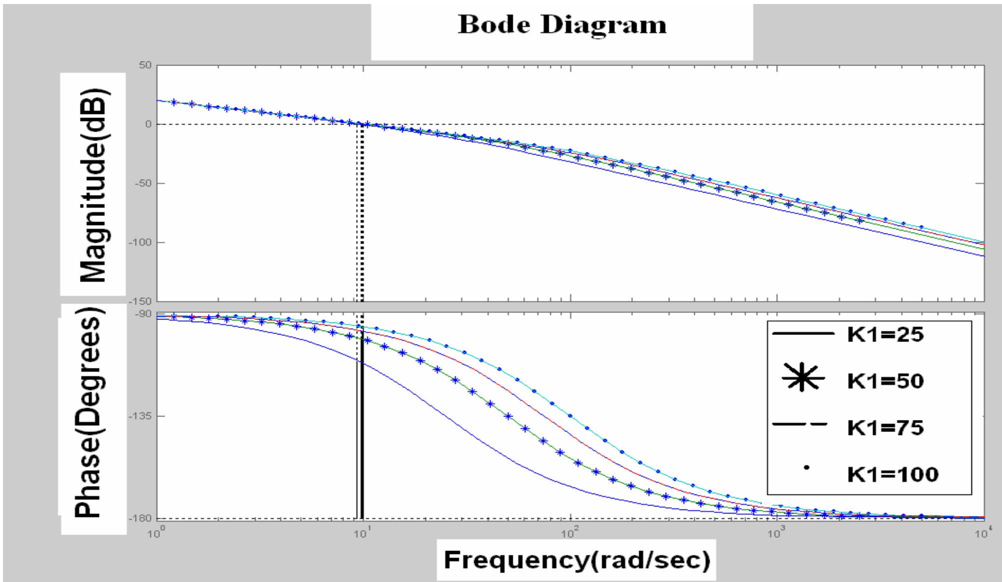


Fig. 3 Bode plots for K1 are as 25, 50, 75 and 100, respectively.

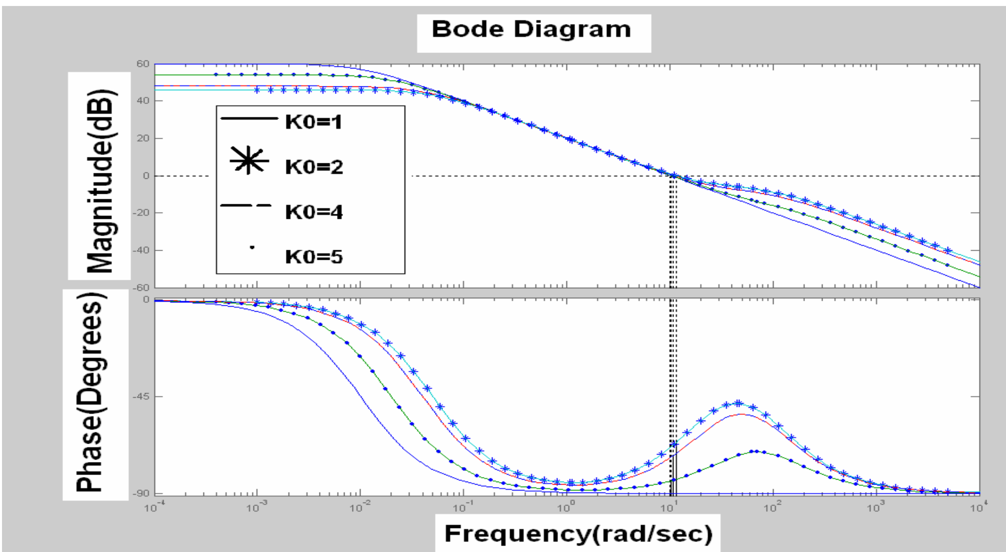


Fig. 4 The Bode plots for several K0's with T=0.1 and K1=100.

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 (132° and 133°) for the cases with K0=5, K1=50, T=0.1 and K0=5, K1=25, T=0.2, respectively. The former is chosen for faster response.

## 3 Antenna Performance Analyses with PI Compensator in the Stabilization Loop

In this section the antenna performance is analyzed by simulation as in Fig. 5. The input line-of-sight angle is a triangular 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. 6, thus the performance is very good. However, in general there is tracking loop gain parameter variation effect. The simulation results with this effect are shown in Figs. 7 and 8 for the parameter T 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.

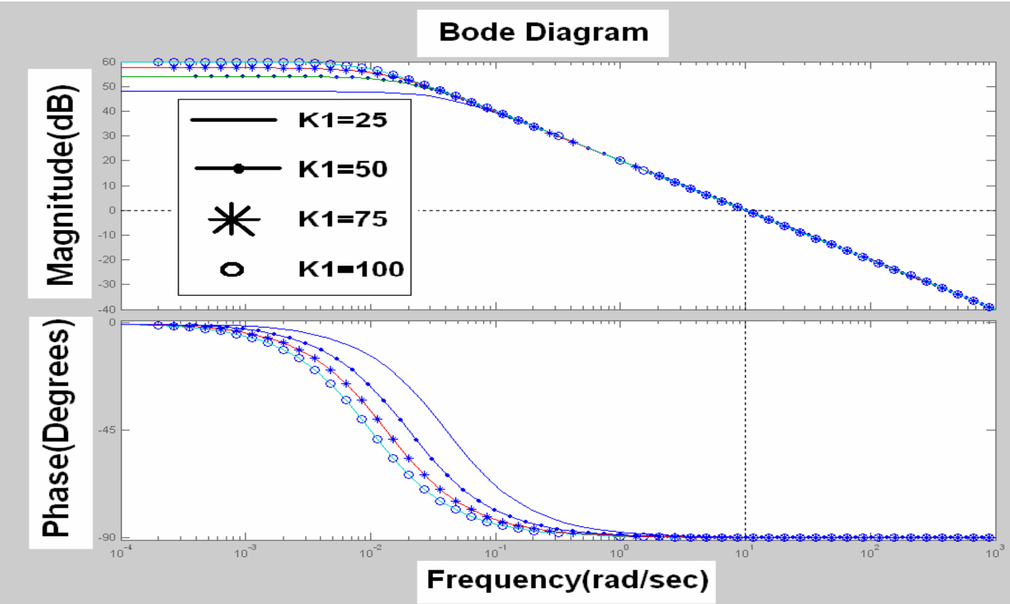


Fig. 5 Bode plots for several K1's with K0=5.

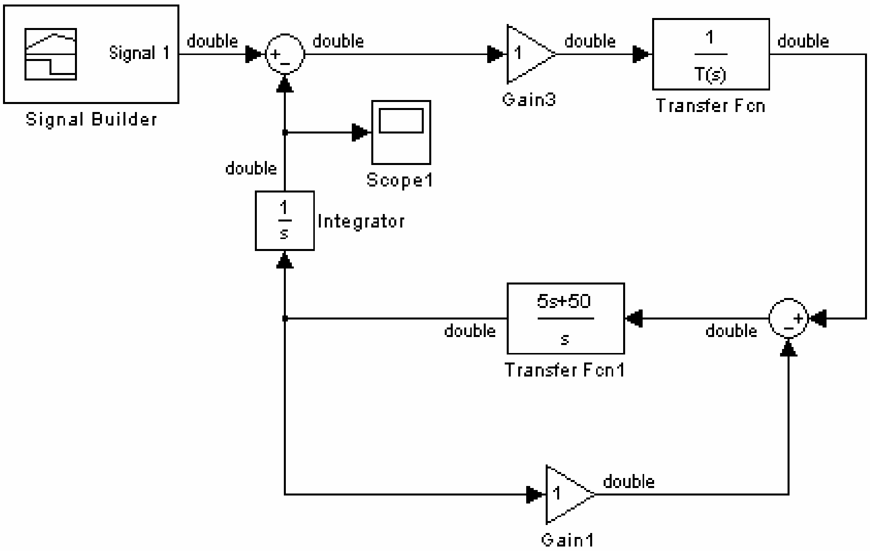


Fig. 6 Block diagram of traditional antenna tracking and stabilization loops design.

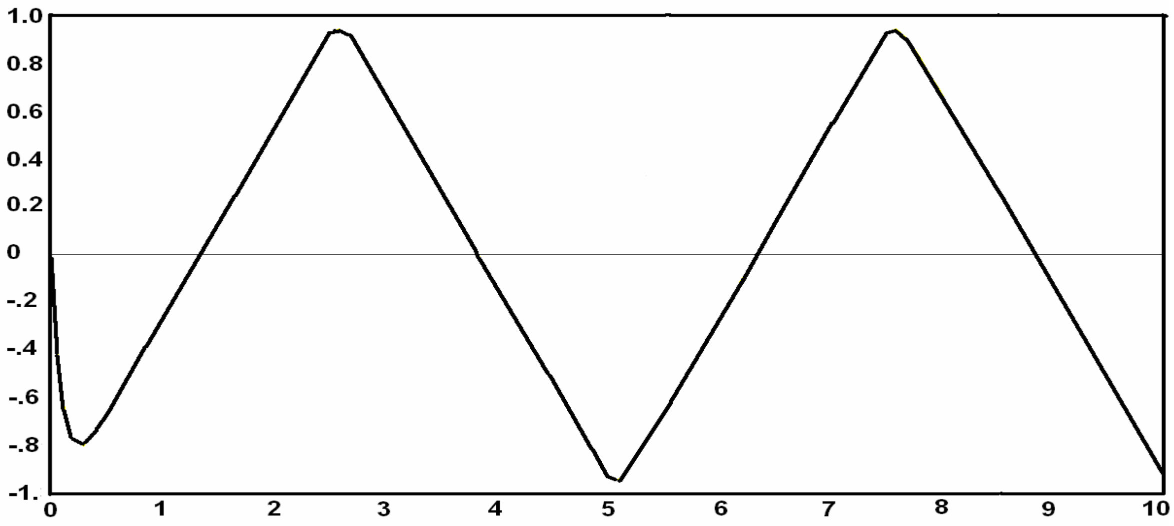


Fig. 7 Gimbal angle output with T=0.1.

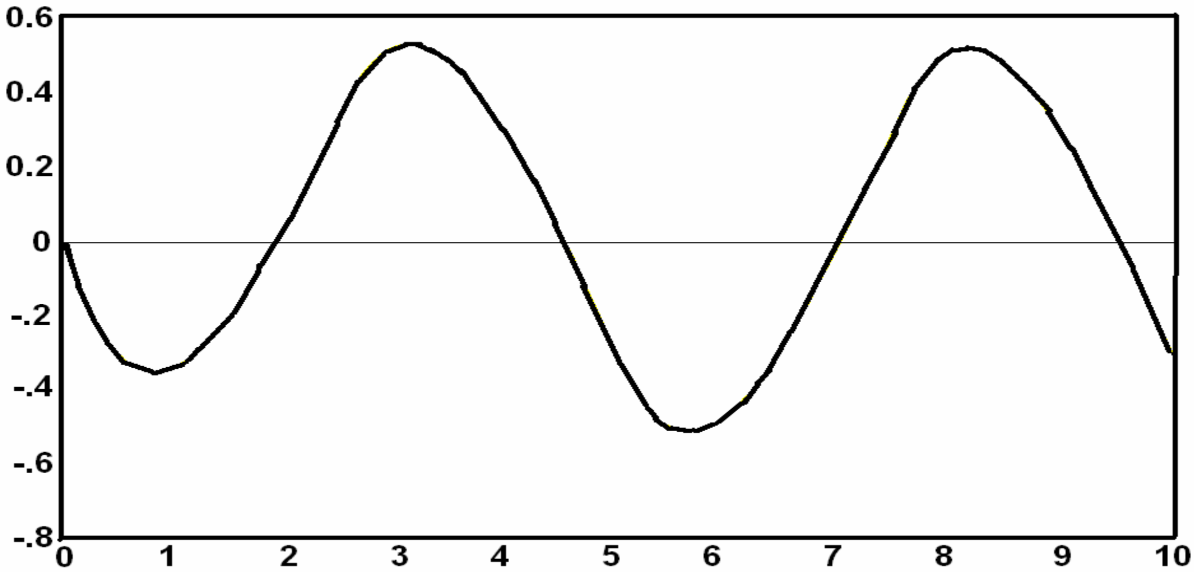


Fig. 8 Gimbal angle output obtained by traditional method with T=1.

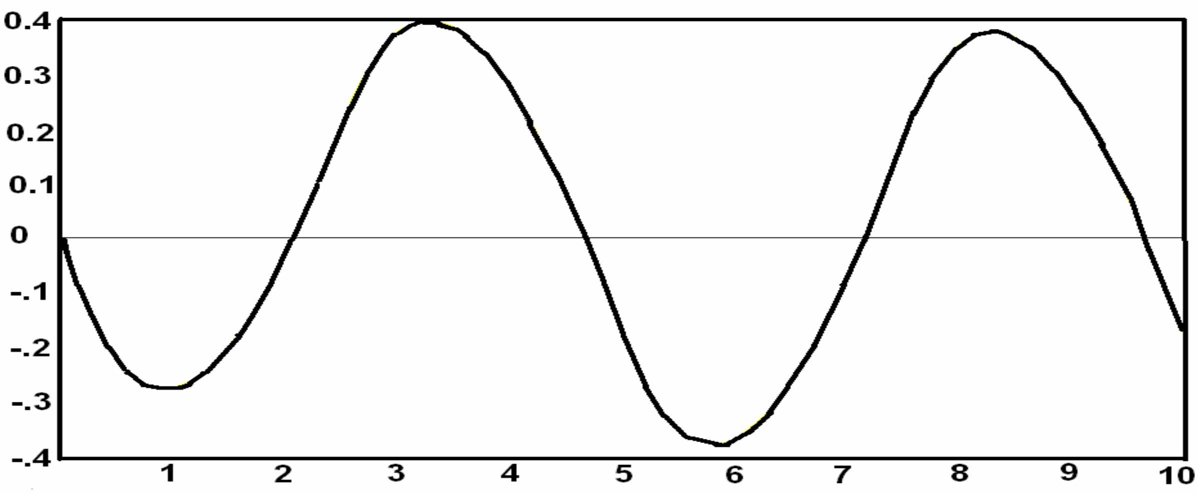


Fig. 9 Gimbal angle output obtained by traditional method with T=1.5.

# 4 PI-Type Fuzzy Controller Tracking Loop Design and Analyses

## 4.1 Fuzzy Controller Relationship Functions Design

In this section a Proportion and Integration (PI) type fuzzy controller [6-7] with gains K1f and K2f is respectively applied in the tracking loop and with the PI compensator in the stabilization loop as in Fig. 7. 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.

The detailed cross reference rules for the inputs and output of fuzzy controller are defined in Table 1. According to fuzzy control design method the relationship function parameters 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 2 and as shown in Figs. 8-10. To reduce the computation time the triangular distribution functions are applied in fuzzy controller relationship functions calculation instead of using the traditional Gaussian ones.

## 4.2 Fuzzy Controller Performance Analyses

Then the antenna performances are analyzed by simulation. Figs. 11, 12 and 13 show the antenna gimbal angle responses with K1f=5, K2f=5 and for T to be as 0.1, 1 and 1.5, respectively. It can be seen that the results are better than those obtained by using only the traditional PI compensators for all the three values of T. Even more if T is as 5, the result is shown in Fig. 14 the performance of the proposed PI-type fuzzy controller is still better.

# 5 Conclusion

This research applied PI-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.

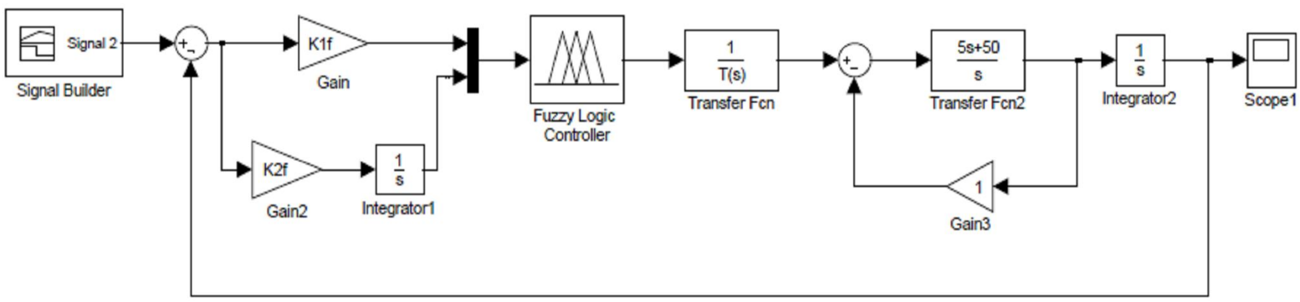


Fig .7 A PI-type fuzzy controller is applied in the tracking loop and with the PI compensator in the stabilization loop.

Table 1 PI-type 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 |

Table 2 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] |

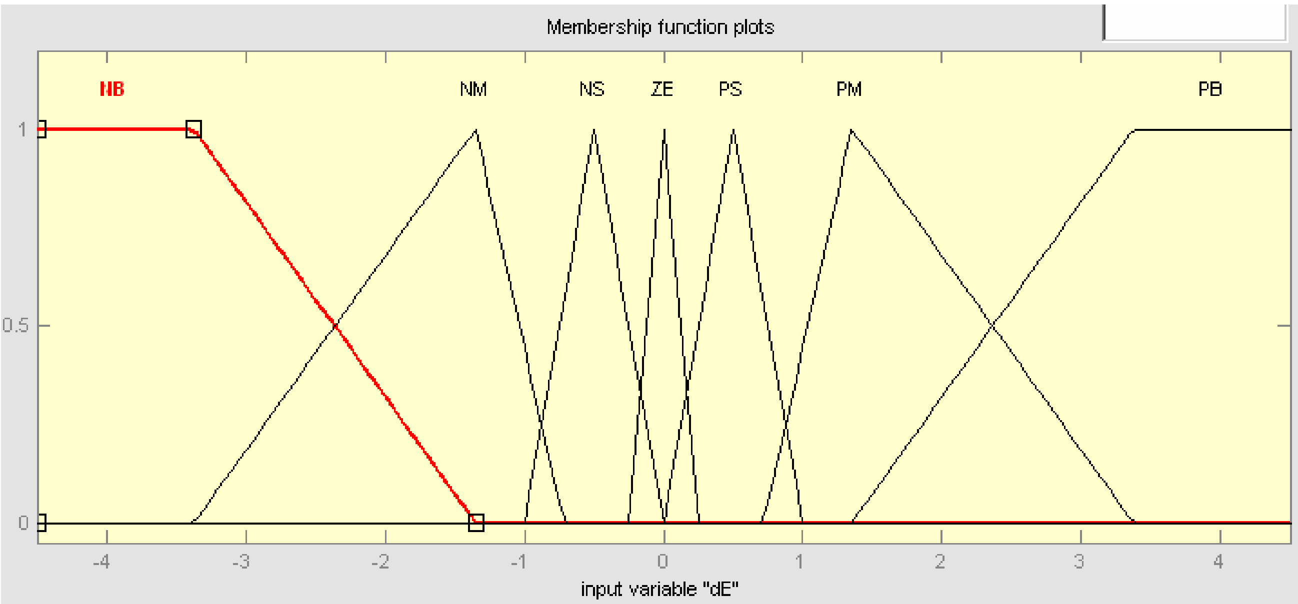


Fig. 8 Relationship functions of error E.

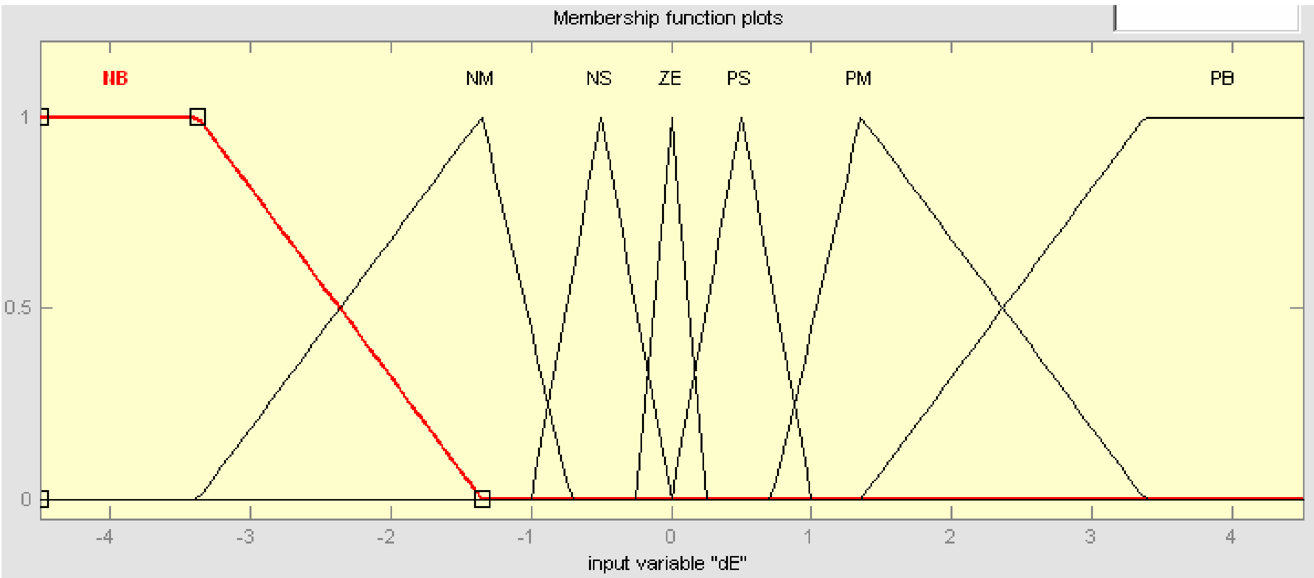


Fig. 9 Relationship functions of error rate ΔE.

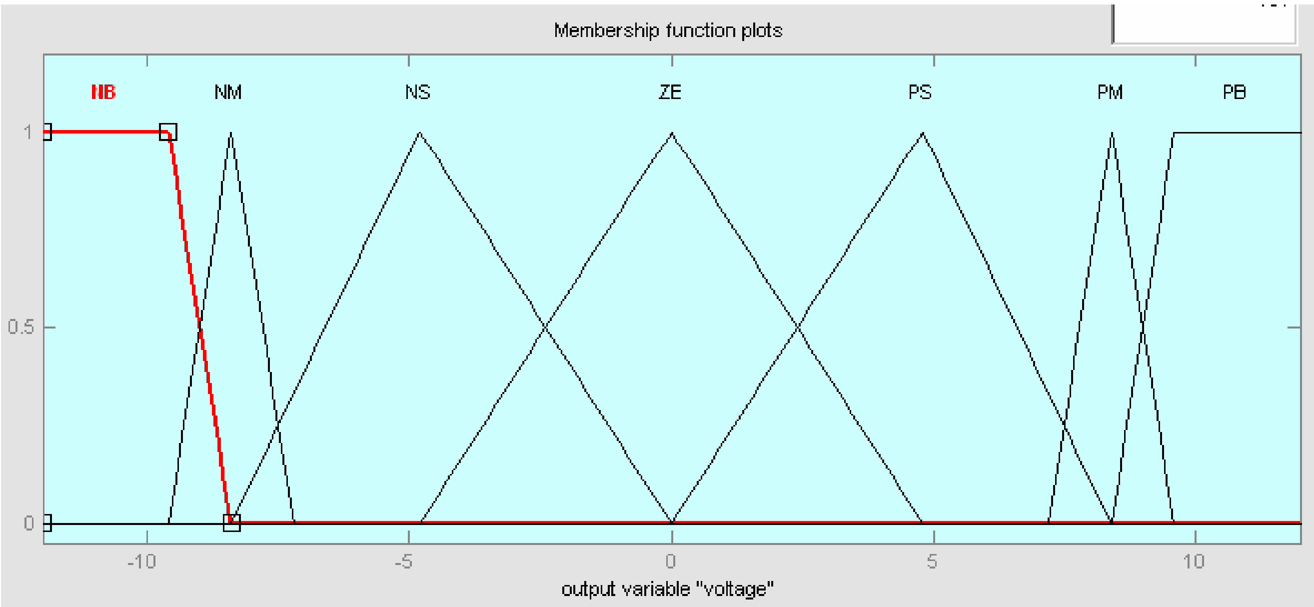


Fig. 10 Relationship functions of fuzzy controller output.

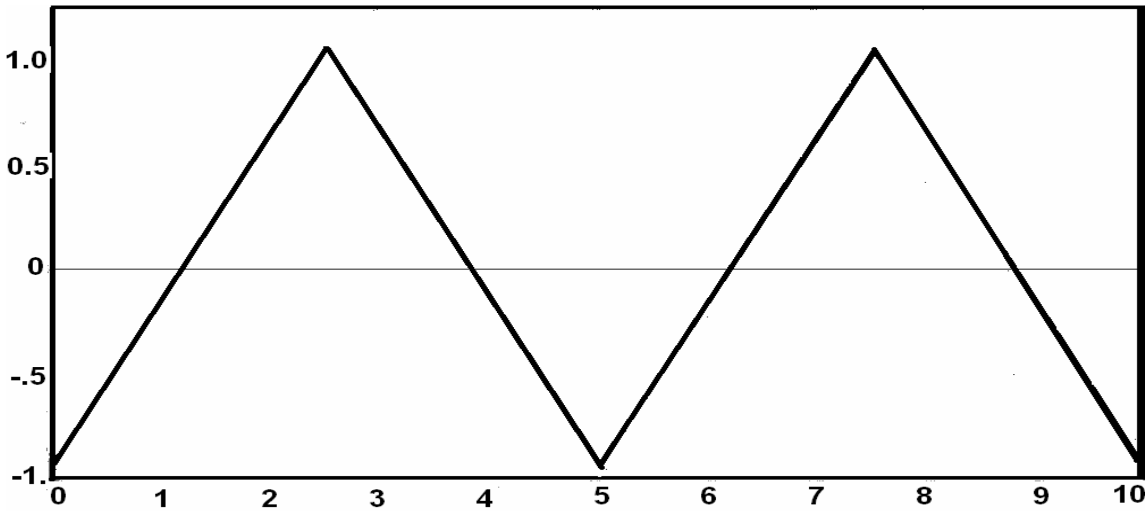


Fig. 11 Gimbal angle output for fuzzy controllers with K1f=5, K2f=5 and T=0.1.

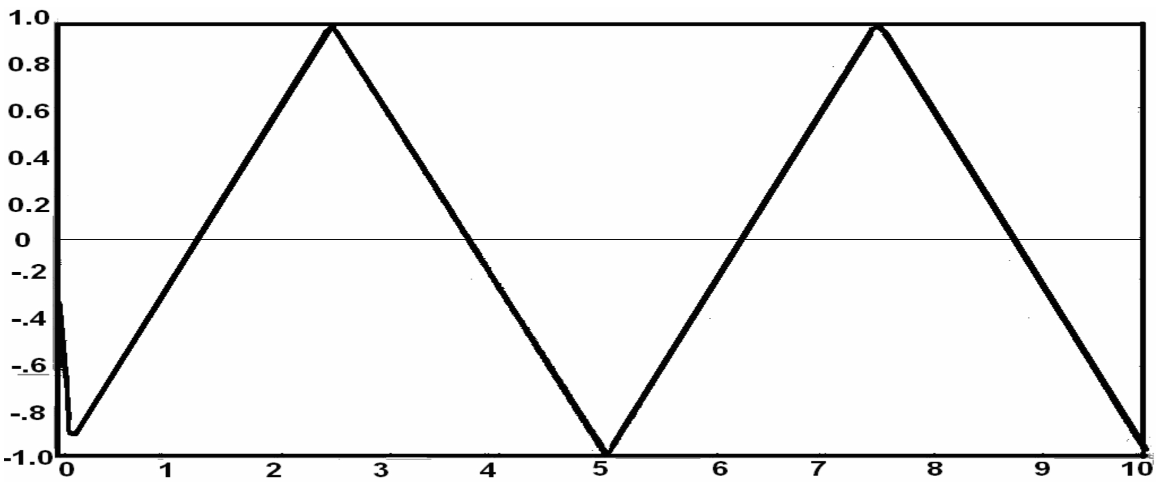


Fig. 12 Gimbal angle output for fuzzy controllers with K1f=5, K2f=5 and T=1.

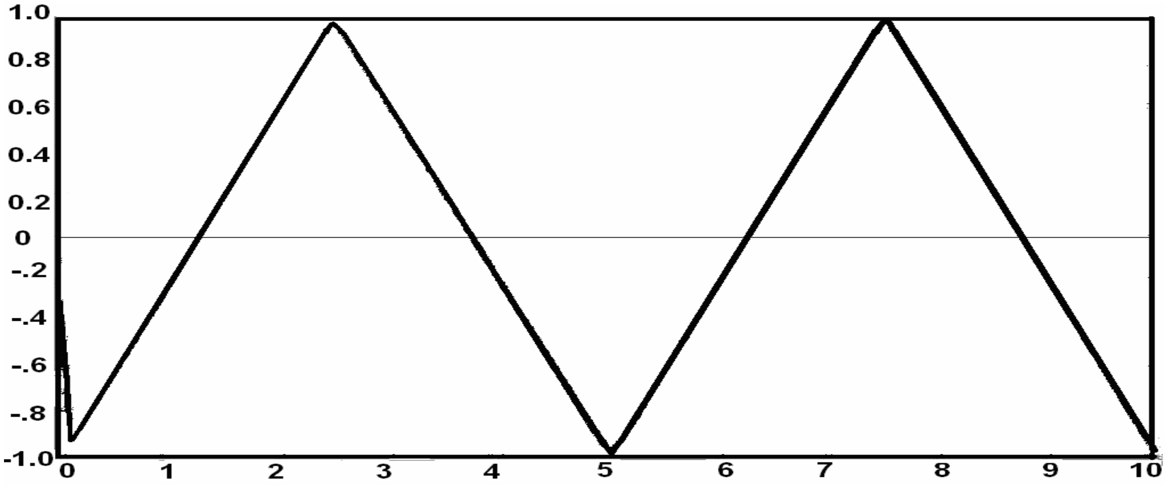


Fig. 13 Gimbal angle output for fuzzy controllers with K1f=5, K2f=5 and T=1.5.

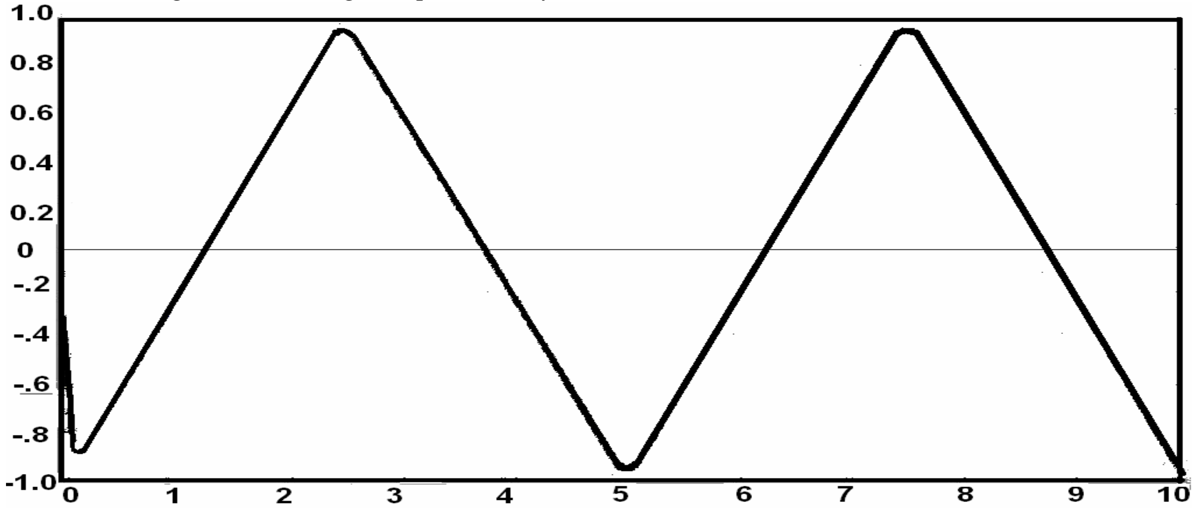


Fig. 14 Gimbal angle output for fuzzy controllers with K1f=5, K2f=5 and T=5.

However, the performance would be degraded if the tacking loop gain is reduced due to parameter variations. On the other hand a PI-type fuzzy controller was also applied for the tracking loop design. It can be seen that the system performances obtained by applying PI-type fuzzy controllers were better for not only lower but higher antenna tracking loop gains. Thus the tracking gain parameter variations effect can be reduced.

**Acknowledgment(s)**
This research was supported by National Science Council under the grant of NSC 97-2221-E-216-013-MY2.

*References:*

[1] A. C. Densmore and V. Jamnejad, "Two WKa-band Mechanically Steered and Mobile Antennas for the NASA ACTS Mobile Terminal," *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. on Vehicular Technology*, Vol. 42, No 4 pp. 502-513, 1993.

[3] V. Jamnejad and A. C. Densmore,"A Dual Frequen cy WKa-band Small Reflector Antenna for Use in Mobile Experiments with the NASA Advanced Satellite Communications Technology," *IEEE APSIURSI Joint Intern. Sym. URSI Digest*, p.1540, 1992.

[4] P. Estabrook and W. Rafferty,"Mobile Satellite Vehicle Antennas: Noise Temperature and Receiver G/T," *Proc. IEEE Vehicular Technol. Conf*, Vol.2, San Francisco, CA, USA, pp. 757-762, 1989.

[5] H. C. Tseng and D. W. Teo,"Ship Mounted Satellite Tracking Antenna with Fuzzy Logic Control," *IEEE Trans. on Aerospace and*

*Electronic Systems*, Vol. 34, No. 2, pp. 639-645, 1998.

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

[9] I. Lagrat, A. El Ougli, and I. Boumhidi, Optimal Adaptive Fuzzy Control for a Class of Unknown Nonlinear Systems, *WSEAS Trans. on Systems and Control,* Issue 2, Volume 3, February 2008, pp. 89-98.

[10] B. Nicu-George, P. Anca, and B. Elvira, Conventional Control and Fuzzy Control Algorithms for Shape Memory Alloy based Tendons Robotic Structure, *WSEAS Trans. on Systems and Control,* Issue 1, Volume 3, January 2008, pp. 115-124.

[11] G Bartolini, A Ferrara, E Usai, Chattering Avoidance by Second-order Sliding Mode Control, *IEEE Transactions on Automatic Control,* Vol. 43, No. 2, February 1998, pp. 241-246.

[12] W Perruquetti, JP Barbot, *Sliding Mode Control in Engineering*, CRC Press, 2002.