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Design of NSGA-III Tuned FPC for AMSS

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ABSTRACT

Airborne missile servo system (AMSS) is a complex time-varying nonlinear system and the design of which is a multi-objective optimization problem. Fuzzy PID controller (FPC) is demonstrated appropriate for complex time-varying nonlinear systems but the design of which needs a tedious trial and error process. Non-dominated Sorting Genetic Algorithm III (NSGA-III) is a multi-objective evolutionary algorithm with good generality and robustness which can do a big favor for parameter tuning of complex system. This paper develops NSGA-III for parameter tuning in design process of FPC. Resulting FPCs are tested with model of AMSS on simulink. For further comparison, performance of conventional PID controller and sectional PID controller which is widely used in the engineering are also shown. Comparison shows that NSGA-III tuned FPCs have the better performance in AMSS.

Keywords: NSGA-III; FPC; AMSS

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1. Introduction

AMSS is a complex electromechanical hybrid system with time-varying and nonlinear features. Conventional PID controller is so simple that it can't get a high performance in complex systems like AMSS. At present, the most popular controller of AMSS is the sectional PID controller whose coefficients are different on different sections depending on input signal error because it can improve performance to some extent and simple to design. However, the improvement is scant because the coefficients can't adapt to the system all the time.

Fuzzy control is an intelligent control mode using control rules described by fuzzy mathematical language. FPC is the combination of conventional PID controller and fuzzy control. FPC doesn't need exact mathematical model of controlled object and has satisfactory performance in complex systems. However, the large number of coefficients to be tuned makes the design of FPC a tedious trial and error process.

This paper develops NSGA-III for parameter tuning of FPC. The tuning process becomes simple because of the automatic heuristic random search. In addition, non-dominated sets of parameters will be got due to the multi-objective feature and different set of parameters will be used to satisfied different requirements, like high speed, high precision, low power and so on. The detailed design process is elaborated in the methodology section. Then the resulting NSGA-III tuned FPCs with different parameters are tested with model of AMSS. As a comparison, conventional PID controller and sectional PID controller are tested in the same way. The performances of proposed controllers are compared, analyzed in the result and discussion section.

2. Methodology

2.1 AMSS

AMSS follows commands of flight controller to assist the airborne missile in adjusting its flying attitude to hit the target. The block diagram of AMSS is shown in figure 1, which includes 3 parts, namely power supply, controller, actuator. The power supply includes low voltage used for controller and high voltage used for actuator. The controller includes MCU and processing circuit. The processing circuit modulates signal from flight controller and actuator to the format which can be processed by MCU and the MCU implements the control algorithm by commands of flight controller and feedback from actuator. The actuator receives the commands from controller, makes the wing rotate following the commands by motor and transmission mechanism and sends the wing position which is got by position sensor installed on the wing axle back to the controller.

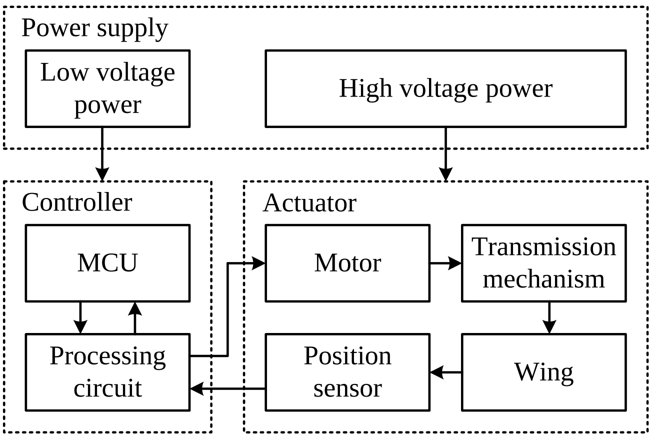


Fig. 1. AMSS block diagram

Under the influence of manufacturing process, installation error, material and other factors, the actuator of AMSS has nonlinear characteristics such as dead zone, saturation and load torque disturbance. Similar to the actuator, the controller and power supply of AMSS also have nonlinear characteristics as performance and structure of the components in them always change nonlinearly with the change of working conditions. All the nonlinearities mentioned above make the AMSS an complex system and hard to design. For this reason, this paper uses FPC instead of conventional PID controller.

2.2 FPC

FPC is the PID controller who uses fuzzy logic to improve adaptability to nonlinear or time-varying system. Considering design complexity and control performance, this paper selects the 2-dimensional FPC whose block diagram is shown in figure 2.

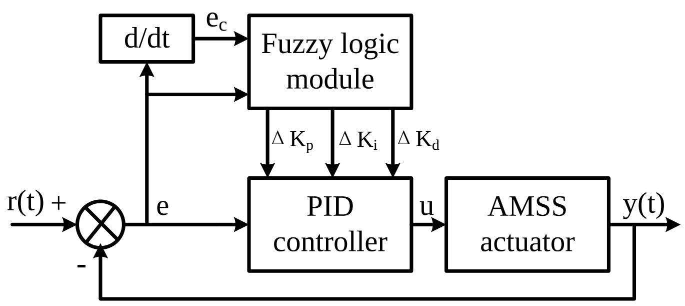


Fig. 2. FPC block diagram

The working principle of proposed FPC is as follows: First, input signal error e and change_in_error ec are translated into fuzzy linguistic terms which are specified by membership functions of the fuzzy sets; Then, the fuzzy linguistic terms are used for calculation of compensatory coefficients ΔKp, ΔKi and ΔKd with the fuzzy rule_set look_up table. Finally, the compensatory coefficients are transferred to the PID controller to finish the coefficient modification.

In order to allow full play to the advantage of fuzzy logic, this paper uses the symmetrical exponential membership functions which is shown in (1).

$\mu_{\pm i}(x)=\exp(-|x\pm\alpha_i|^{\beta_i/\sigma_i})$, $x\in[-big,+big]$ (1a)

where

$i=\{zero,\pm small,\pm medium,\pm big\}$

and

$\mu_{+big}=1$ $x>\alpha_{+big}$ (1b)

$\mu_{-big}=1$ $x>\alpha_{-big}$ (1c)

It's easy to see that shapes of the membership functions are determined by the coefficients αi, βi and σi. αi determines the center point, βi resembles the shapes from a triangular to a trapezoidal, and σi determines the base_length and overlapping. Shapes of the membership functions are shown in figure 3. It should be noted that membership functions of e is different from ec, so different symbols μe and μec are used to distinguish them.

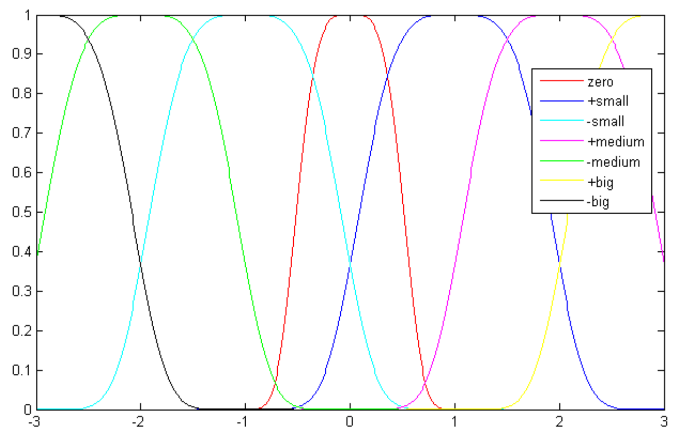


Fig. 3. Symmetrical exponential membership functions

As mentioned earlier, a FPC has 3 coefficients to modify, represently ΔKp, ΔKi and ΔKd. Accordingly, 3 fuzzy rule_set look_up tables are required and shown in figure 4.

	NB	NM	NS	ZO	PS	PM	PB
NB	**p_{11}**	**p_{12}**	**p_{13}**	**p_{14}**	**p_{15}**	**p_{16}**	**p_{17}**
NM	**p_{21}**	**p_{22}**	**p_{23}**	**p_{24}**	**p_{25}**	**p_{26}**	**p_{27}**
NS	**p_{31}**	**p_{32}**	**p_{33}**	**p_{34}**	**p_{35}**	**p_{36}**	**p_{37}**
ZO	**p_{41}**	**p_{42}**	**p_{43}**	**p_{44}**	**p_{45}**	**p_{46}**	**p_{47}**
PS	**p_{51}**	**p_{52}**	**p_{53}**	**p_{54}**	**p_{55}**	**p_{56}**	**p_{57}**
PM	**p_{61}**	**p_{62}**	**p_{63}**	**p_{64}**	**p_{65}**	**p_{66}**	**p_{67}**
PB	**p_{71}**	**p_{72}**	**p_{73}**	**p_{74}**	**p_{75}**	**p_{76}**	**p_{77}**

(a) ΔK_p look_up table

	NB	NM	NS	ZO	PS	PM	PB
NB	**i_{11}**	**i_{12}**	**i_{13}**	**i_{14}**	**i_{15}**	**i_{16}**	**i_{17}**
NM	**i_{21}**	**i_{22}**	**i_{23}**	**i_{24}**	**i_{25}**	**i_{26}**	**i_{27}**
NS	**i_{31}**	**i_{32}**	**i_{33}**	**i_{34}**	**i_{35}**	**i_{36}**	**i_{37}**
ZO	**i_{41}**	**i_{42}**	**i_{43}**	**i_{44}**	**i_{45}**	**i_{46}**	**i_{47}**
PS	**i_{51}**	**i_{52}**	**i_{53}**	**i_{54}**	**i_{55}**	**i_{56}**	**i_{57}**
PM	**i_{61}**	**i_{62}**	**i_{63}**	**i_{64}**	**i_{65}**	**i_{66}**	**i_{67}**
PB	**i_{71}**	**i_{72}**	**i_{73}**	**i_{74}**	**i_{75}**	**i_{76}**	**i_{77}**

(b) ΔK_i look_up table

	NB	NM	NS	ZO	PS	PM	PB
NB	**d_{11}**	**d_{12}**	**d_{13}**	**d_{14}**	**d_{15}**	**d_{16}**	**d_{17}**
NM	**d_{21}**	**d_{22}**	**d_{23}**	**d_{24}**	**d_{25}**	**d_{26}**	**d_{27}**
NS	**d_{31}**	**d_{32}**	**d_{33}**	**d_{34}**	**d_{35}**	**d_{36}**	**d_{37}**
ZO	**d_{41}**	**d_{42}**	**d_{43}**	**d_{44}**	**d_{45}**	**d_{46}**	**d_{47}**
PS	**d_{51}**	**d_{52}**	**d_{53}**	**d_{54}**	**d_{55}**	**d_{56}**	**d_{57}**
PM	**d_{61}**	**d_{62}**	**d_{63}**	**d_{64}**	**d_{65}**	**d_{66}**	**d_{67}**
PB	**d_{71}**	**d_{72}**	**d_{73}**	**d_{74}**	**d_{75}**	**d_{76}**	**d_{77}**

(c) ΔK_d look_up table

NB: Negative Big
NM: Negative Medium
NS: Negative Small
ZO: Zero
PB: Positive Big
PM: Positive Medium
PS: Positive Small
Pij={NB,NM,NS,ZO,PS,PM,PB}
Iij={NB,NM,NS,ZO,PS,PM,PB}
Dij={NB,NM,NS,ZO,PS,PM,PB}

(d) Comparison table

Fig. 4. Fuzzy rule_set look_up tables of FPC

The compensatory coefficients are calculated by weighted average method which is shown in (2). The coefficients gp, gi, gd in (2) are the gain factors of Kp, Ki, Kd from actual domain to fuzzy domain.

ΔKp=Σμe ,pij(e) •μec ,pij(ec)•pij•gp (2a)

ΔKi=Σμe ,iij(e) •μec ,iij(ec)•iij•gi (2b)

ΔKd=Σμe ,dij(e) •μec ,dij(ec)•dij•gd (2c)

The major task of design lies in the optimal choice of membership functions parameters (αi, βi, σi), look_up tables parameters (pij, iij, dij) and gain factors (gp, gi, gd). That's an arduous task for manual design and therefore this paper develops the automatic optimal design using adaptive NSGA-III Tuned FPC.

2.3 NSGA-III Tuned FPC

NSGA-III is an elitist multi-objective evolutionary algorithm which is developed from Genetic algorithm (GA). The main difference between NSGA_III and GA is the selection operator. Optional objects in NSGA-III includes the current generation and the lase generation while those in GA only include the current one. Meanwhile NSGA-III uses non-dominated sorting and reference point distance sorting to choose excellent individuals into genetic pool which can make the distribution of solutions more uniform and avoid of locally optimal solution.

In order to use NSGA-III in FPC design, parameters of FPC must be encoded to constitute chromesomes. Considering accuracy and complexity, Membership functions parameters (αi, βi, σi) are encoded in 2 bits and look_up tables parameters (pij, iij, dij) are encoded in 1 bit and gain factors (gp, gi, gd) are encoded in 3 bits. Relationship between these parameters and encoded ones is shown in (3). C represents the value of parameters and string_val represents the corresponding code and n represents the encoding bits of the parameter.

C= Cmin+(Cmax-Cmin)•string_val/(7n-1)   (3)

Then the encoded parameters are combined together as chromosomes whose total length comes 228 bits. The chromosomes will be disposed by crossover, mutation and selection operators in iterations so that optimal solutions can be got.

In every iteration, parent population generate the progeny one by chromosome crossover and mutation. This process don't change size of the population, so either size of them is equal to N. Then the parent and progeny population are put together to make up a candidate set whose size is 2N for selection. Finally half of candidates get through the selection and become the parent population in the next iteration. The algorithm flow chart is shown in figure 5.

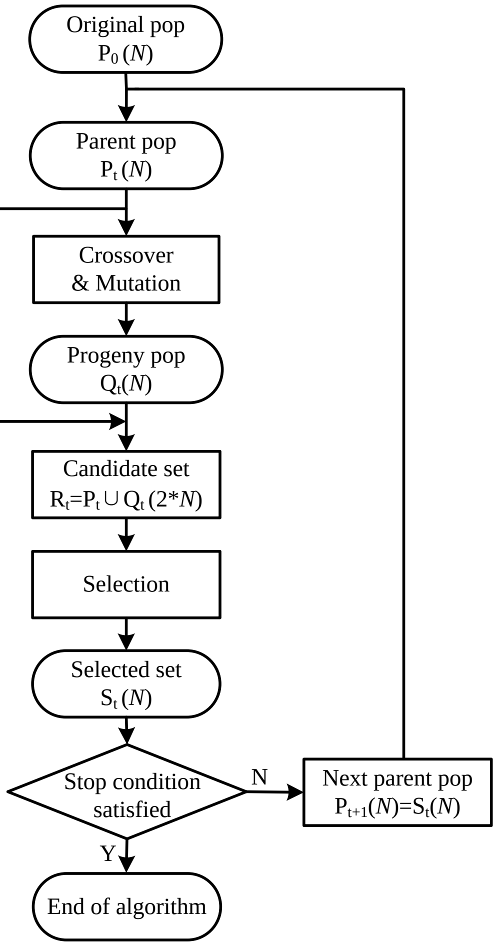


Fig. 5.   Flow chart of NSGA-III

In order to maintain diversity of population and improve efficiency of iteration, this paper uses adaptive crossover and mutation operators in NSGA-III. Specifically, the probability of crossover and mutation changes with the similarity of the parent chromosomes. The higher the similarity, the lower the crossover probability and the higher the mutation probability. The similarity between chromosomes A and B is measured by (4). The subscript i represents the location in the chromosome and the symbol L represents the length of the chromosome. In this paper, L is equal to 228.

$$S(A,B)=1-(\Sigma A_i \oplus B_i)/L \qquad (4)$$

The selection operator is the core of NSGA-III. Firstly, all the individuals in candidate set will be sorted in groups with different grade by the dominant relationship between them and this process is called non-dominated sorting. By the way, this paper selects overshoot, steady-state error and rise time as objective functions. Secondly, the groups are transferred into an intermediary set from high grade to low grade until more than N individuals in the candidate set are transfered. Thidly, if intermediary set size is not exactly equal to N, individuals of group with the lowest grade in the intermadiary set will be sorted by the distance with associated reference point and associated candidates amount of every reference point. Fouthly, the superior ones in the sorting of reference point distance sorting are left to make sure the intermediary set size is exactly equal to N. Finally, individuals in the intermediary set are transferred to the parent population in the next iteration. The algorithm flow chart of selection operator is shown in figure 6.

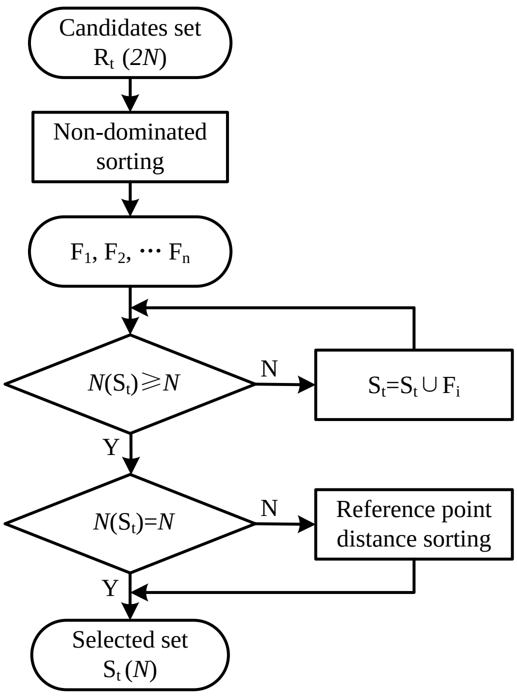


Fig. 6. Flow chart of selection operator

3. Result and Discussion

Proposed algorithm is implented and tested with the AMSS model on the Simulink. The block diagram is shown in figure 7. In this paper, 3 indexs are concerned and treated as objective functions, namely overshoot, steady-state error and rise time. In order to acquire the indexs, step test is implented at each iteration.

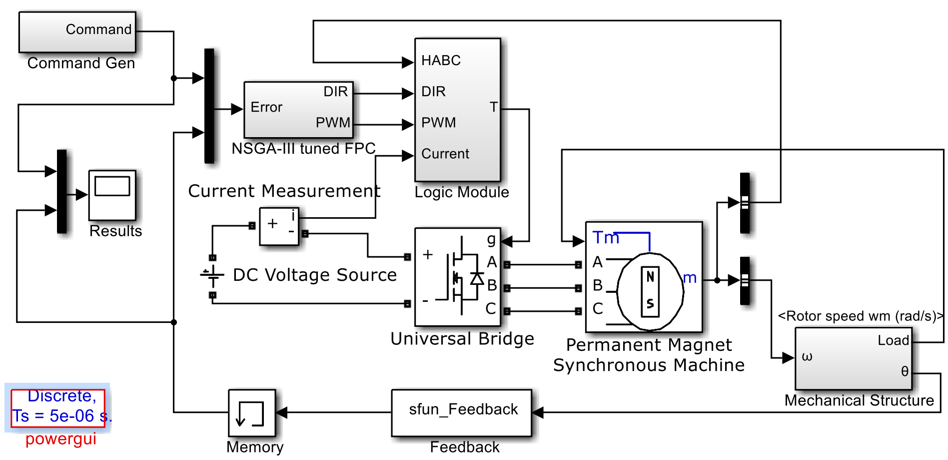
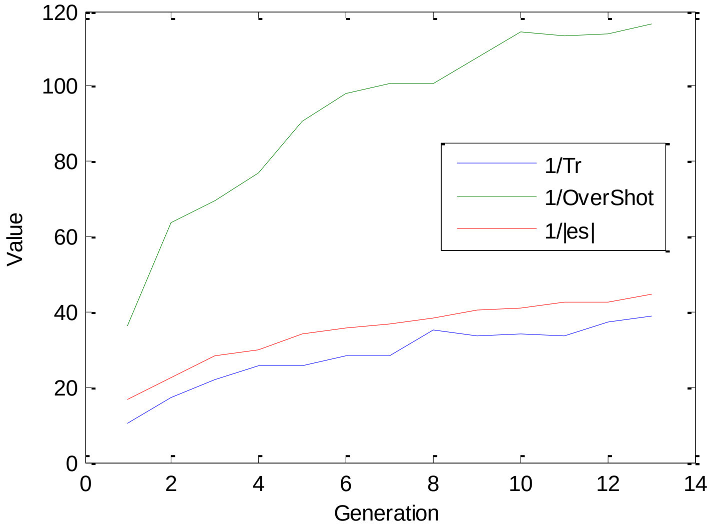
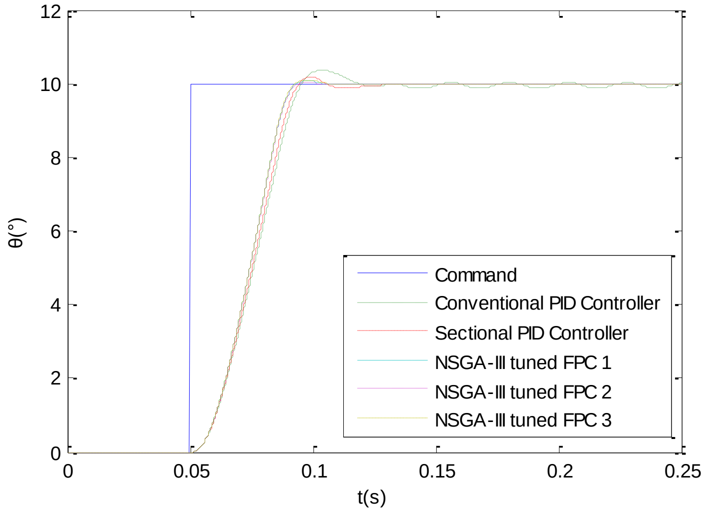


Fig. 7. System block diagram on the Simulink

After 13 iterations, the stop conditions are satisfied. The average objective function values of population in each generation is shown in figure 8.



For further comparison, the step reponse of conventional PID controller and sectional PID controller are put together with NSGA-III tuned FPCs. The step response curves are shown in figure 8 and specific data of indexs are shown in table I.



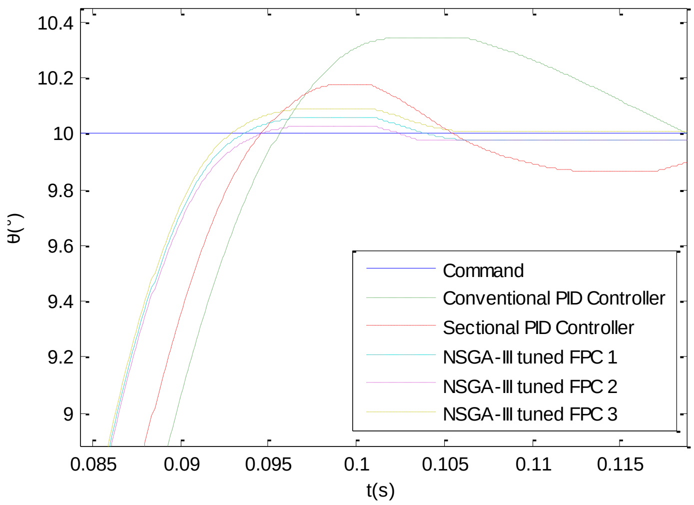


Fig. 8. Step response of AMSS with different controllers

TABLE I. INDEX OF AMSS WITH DIFFERENT CONTROLLERS

	Overshot	Rise time	Steady-state error
conventional PID controller	3.44%	29.2ms	振荡
sectional PID controller	2.15%	28.0ms	0.039°
NSGA-III tuned FPC1	0.83%	26.1ms	0.023°
NSGA-III tuned FPC2	0.53%	26.3ms	0.023°
NSGA-III tuned FPC3	0.89%	26.0ms	0.007°

From the results shown in table I, we can draw the following conclusions: NSGA-III tuned FPC can get the better performance than conventional PID controller and sectional PID controller in the AMSS and NSGA-III tuned FPC can provides a variety of options for different objectives.

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