# Research on Fuzzy Guidance Law Based on Self-adaptive Genetic Annealing Algorithm

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***Abstract*—A new approach about design of guidance law (GL) for integrated self-adaptive genetic annealing algorithm (SGAA) and fuzzy logic (SGAA-FGL) was proposed in this study. Firstly, Based on traditional fuzzy logic control, the nonlinear variable region function was introduced, thus dynamic change of the fuzzy variable region can be realized. Next the self-adaptive simulated annealing genetic algorithm was employed to optimize the fuzzy rule, which was designed by selecting adaptively the cross probability and mutation probability of the proposed algorithm and improved the stability and convergence of system. Finally, the simulation results were presented to show the validity of the proposed method.**

***Keywords*—self-adaptive genetic annealing algorithm; guidance law; variable region; fuzzy control**

## I INTRODUCTION

As we all know, the performance of proportional navigation (PN) degrades with the target maneuver, also other conventional guidance algorithms such as augmented proportional navigation (APN) and optimal guidance law (OGL) prevent the expected performance because the complexity and the cost of their guidance system[1-3].

Recently, sliding mode control method has been employed in guidance law[4,5], but it require high overload in the engagement course.

Over the past decade, fuzzy logic has been successfully applied to many control problems because it don′ t depend on the precise mathematic model of controlled object. Its primary focus is to translate expert knowledge into natural language. And it has been observed that a human operator is sometimes more efficient than an automatic controller in dealing with such systems[6].

However, due to the fixed region, the conventional fuzzy control rules couldn't be tuned well and its performance was not very good. As a result, in actual ceaseless missile guidance process, the guidance performance was not ideal, which made use of the conventional fuzzy control method.

Simulated annealing algorithm and genetic algorithm are two general approximate algorithm to solve large-scale combined optimization problem. Theoretically, it can be proved that simulated annealing algorithm converges to the global optimal solution with the probability of 1[7-8]. However, it can be seen from simulation results that its convergence speed is relatively low.

Genetic algorithm stems from the analogy of biological evolution process. Using group optimization strategy, it constructs a group out of a set of solutions in solution space and produces a new group out of another set of the solutions by selection, hybridization and mutation. In the group evolution process the solutions of the group are continuously optimized. Using Ellips selection operator, the algorithm will find its global optimal solution with the probability of 1[9]. Although at the beginning genetic algorithm is able to find a suboptimal solution quickly, along with the progression of the algorithm, the reducing difference among individuals in the group, causes group degeneration and low searching efficiency, and it takes a long time to get the optimal solution. Mutation probability can be increased to avoid group degeneration, but on the other hand the increase of mutation probability will aggravate the blindness of searching and also decrease the efficiency of the

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algorithm such that the results are not satisfying even if some adaptive strategies are applied.

Recently, a novel idea known as genetic annealing algorithm, which combines genetic algorithm with simulated annealing algorithm[10]. And it not only overcomes the low convergence speed in simulated annealing algorithm but also solves the group degeneration problem in genetic algorithm. This algorithm can be used to solve the problem with uncertain and variant objective function as well as general combined optimization problem.

In order to improve the guidance system's robustness and its response characteristic, on the basis of the above ideas, we present a novel idea of guidance law, which combines fuzzy control with genetic annealing algorithm. In this paper the proposed guidance law is first stated and then the validity of this algorithm is verified through simulation examples.

## II .ENGAGEMENT MODEL

In this section, the engagement model of the yaw plane is formulated firstly between missile and target. To simplify the dynamic equations of the pursuit situation, we assume that the missile and target are point masses and that the overall control loop dynamics of the missile follow a second order reference model. We further assume that the velocities of the missile and target are constant.

The engagement geometry situation in yaw space is depicted in Figure.1, which describes the missile and target relative states.

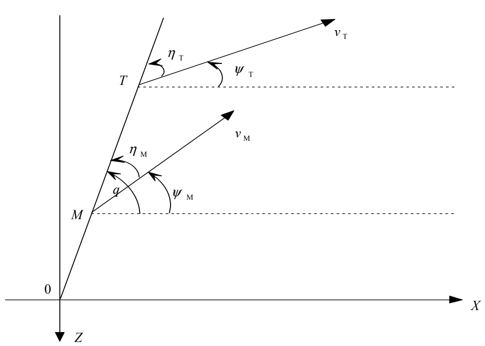


Figure1. Engagement geometry in yaw plane

In Figure.1, $v_m, v_t$ —velocity of missile and target respectively; $\psi_m, \psi_t$—the flight-path angle of missile and target respectively; $q$—the line of sight angle; $\eta_m, \eta_t$—the lead angle of missile and target with respect to the line of sight respectively; $r$—the distance between missile and target。

The engagement geometry situation in Figure1 can be represented by the following dynamic vector equations

$$\begin{cases} \dot r = v_t \cos\eta_t - v_m \cos\eta_m \\ r\dot q = v_t \sin\eta_t - v_m \sin\eta_m \\ q = \psi_t + \eta_t = \psi_m + \eta_m \end{cases} \quad (1)$$

the first two equations of (1) can be rewritten as

$$\begin{cases} \dot r = v_t \cos(\psi_t - q) - v_m \cos(\psi_m - q) \\ r\dot q = v_t \sin(\psi_t - q) - v_m \sin(\psi_m - q) \end{cases} \quad (2)$$

To improve performance, the integrated model for guidance and control loop is formulated as follows, which results from reference [7].

$$\begin{cases} x_1 = q \\ x_2 = \dot q \\ x_3 = -a_{g1}x_{g1} - a_{g2}x_2 - b_g x_{c1} \\ x_4 = -(a_{g1} + \dot a_{g2})x_2 - a_{g2}x_3 - \dot a_{g1}x_{g1} - \dot b_g x_{c1} - b_g x_{c2} \end{cases} \quad (3)$$

where, $x_{c1} = a_m$, $x_{c2} = \dot a_m$, $x_{g1} = q$, $a_{c1} = \omega_n^2$, $a_{c2} = 2\xi\omega_m$, $u_c = a_{mc}$, $b_g = 1/r(t)$, $a_{g1}(t) = \ddot r(t)/r(t)$, $a_{g2}(t) = 2\dot r(t)/r(t)$, $\xi, \omega_n$ denote damp and inherent frequency of missile system respectively, $a_m$ denote missile acceleration, $a_{mc}$ is missile acceleration command.

Let $x = [x_1, x_2, x_3, x_4]^T$, then the state equation is expressed by

$$\dot x = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ a_1 & a_2 & a_3 & a_4 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ x_4(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ -b_g b_c \\ 0 \end{bmatrix} u_c + \begin{bmatrix} 0 \\ \Delta_1 \\ \Delta_2 \\ \Delta_3 \end{bmatrix} \quad (4)$$

where, $u_c = a_{mc}$, $b_c = \omega_n^2$,

$$a_1 = -\ddot{a}_{g1} + \frac{(\ddot{b}_g - b_g a_{c1}) a_{g1}}{b_g} + (2\dot{b}_g - b_g a_{c2}) \left( \frac{\dot{a}_{g1}}{b_g} - \frac{a_{g1}\dot{b}_g}{b_g^2} \right) \quad (5)$$

$$a_2 = -(a_{g1} + 2\dot{a}_{g2}) + \frac{\ddot{b}_g - b_g a_{c1}}{b_g} + (2\dot{b}_g - b_g a_{c2}) \left( \frac{a_{g2}}{b_g} - \frac{\dot{b}_g}{b_g^2} \right) \quad (6)$$

$$a_3 = -a_{g2} + \frac{2\dot{b}_g - b_g a_{c2}}{b_g} \quad (7)$$

$$a_4 = -(2\dot{a}_{g1} + \ddot{a}_{g2}) + \frac{(\ddot{b}_g - b_g a_{c1}) a_{g2}}{b_g} + (2\dot{b}_g - b_g a_{c2}) \left( \frac{a_{g1} + \dot{a}_{g2}}{b_g} - \frac{a_{g2}\dot{b}_g}{b_g^2} \right) \quad (8)$$

$$\begin{cases} \Delta_1 = b_g a_t \\ \Delta_2 = -a_{g2}\Delta_1 \\ \Delta_3 = -(a_{g1} + \dot{a}_{g2})\Delta_1 - a_{g2}\Delta_2 - b_g \Delta_c \end{cases} \quad (9)$$

where, $\Delta_c$ is uncertainty resulting from missile system.

## III. DESIGN FOR FUZZY GUIDANCE LAW BASED ON SELF-ADAPTIVE GENETIC ANNEALING ALGORITHM

In this section, the integrated model for guidance and control loop is formulated. Our approach to an integrated guidance and control is depicted in Fig.2. The controller is designed for the control loop to follow a given reference model.

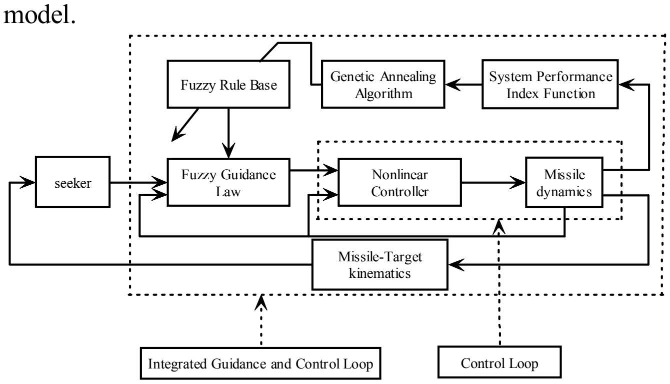


Figure2. Model of fuzzy guidance system principle

During the guidance system, the objects controlled are characterized as multi-variables, nonlinearity and strong coupling factor, etc. It is difficult to build an accurate mathematical model. So, we attempt to adopt fuzzy theory to design nonlinear guidance law, and its input variables are $\Delta\eta = \eta_m - \eta_t$ and $\dot{q}$, there are seven language values, {PB,PM,PS,O,NS,NM,NB}[11], which represent changes about them. The output variable $a_{mc}$, which have eight language values { PB,PM,PS,NO,PO,NS,NM,NB }, then the number of combinations is $7\times7\times8=392$.

However, the fuzzy guidance law is difficult to get satisfactory performance, such as ideal miss distance and required acceleration and so on. Therefore , we select a novel self-adaptive genetic annealing algorithm to optimize the fuzzy rule of guidance law.

The performance index function adopts

$$J = \frac{1}{2} r_{ms}^2 + a_{mc} \quad (10)$$

It can evaluate the missile guidance dynamic. Here, the adaptability function can be described as the following equation:

$$f = \frac{1}{J} \quad (11)$$

In order to ensure the original seed population to have a good coverage in total input space, there are 49 pieces of rules to confirm the individuals of the original seed population, the 49 pieces are complete combination between the two input language values according to above orders. There is only one control output corresponding to a combination of the precondition which came into being through the random combination between the two input values, it keeps nice consistence. Then the problem changes to optimize the control value appropriately. We could get a regulation table about the control value through optimization. On the other hand, the quality and quantity of the original seed population have very large influence to the genetic algorithm's complexity and convergence status. Due to the lack of expert's experience, I absorbed some thought of section-cutting selection method and initiate the original seed population:

1) randomly extract $n$ matrix of $7\times7$, each value in the matrix is a random integer between 0 and 7.
2) compute every individual's adaptation level, order them according to the individual's adaptation level.
3) get rid of $m$ individuals whose adaptation level is bad, the $n-m$ individuals left can be act as the initial seed population. So here the size of the seed population is different according

to the special problem. It is found, through experimentations, it is better that $n$ is commonly selected 100~200 accordingly, $m$ is an integer between 20 and 50.

After the initial population is determined, the population's individual will be selected, and then be dealt with crossing and variation and so on. The selection operation uses scale selection operator, namely obtaining the match value through the match scale function, then obtains each individual's reproducing probability. The number of individuals reproduced in next generation is the product of the reproducing probability and the individual total in each generation of population. More reproducing probability means more descendants in next generation, on the contrary, lower probability means washed out.

The binary code is adopted, because it has advantages of better searching, simpler coding and decoding, easier implementation of crossing and variation, and so on. The values { NB, NM, NS, NO, PO, PS, PM, PB } of the output language variable are coded in order to be $000,001,010,011,100,101,110,111$ . Table 1 shows a chromosome consisting of 49 regular codes in turn: $111\,111\,111\,111\,110\,100\,100\,111\,111\,\ldots\ldots 001\,000\,000\,000\,000$ . Thus, a chromosome includes $49\times3=147$ genes, so that the search space is not very large to the present computer hardware. When decoding, the code of fuzzy guidance rule table starts from 1 in the MATLAB simulation, therefore the integers from 0 to 7 which are obtained after the most optimized individual's chromosome code is decoded by adding 1 separately, then result in a variables code table of 49 regulations which are valued from 1 to 8.

Table 1. Fuzzy guidance law rule table

| $a_{mc}$ \ $\Delta\eta$ / $\dot{q}$ | NB | NM | NS | O | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | PB | PB | PB | PB | PM | PO | PO |
| NM | PB | PB | PB | PB | PM | NO | NO |
| NS | PM | PM | PM | PM | NO | NS | NS |
| O | PM | PM | PS | PO | NS | NM | NM |
| PS | PS | PS | NO | NM | NM | NM | NM |
| PM | PO | PO | NM | NB | NB | NB | NB |
| PB | NO | NO | NM | NB | NB | NB | NB |

In the heredity operation process, the crossing operation is the main method producing the new individual, it determines the global convergence ability of the genetic algorithms, and the variation operator determines the local convergence ability of the genetic algorithms. In order to reduce destruction to the healthy individual, after each generation of heredity operation, following measures are taken: the most optimal individual will be the last individual in this generation population, using the single point crossing method, reducing the variation probability. Because the fuzzy rule set is prone to radical change caused by a minute variation change, for example: 000 represents NB, if the first bit changes to 1, becomes 100, it represents PO, then the control quantity becomes PO from NB. Suppose the position of the intersection is $k$, in range of $[1,147]$, position $k$ is selected randomly, then the chromosome codes of two father individuals are as following:

individual 1: 001100001101100110......111

individual 2: 011101011110110110......010

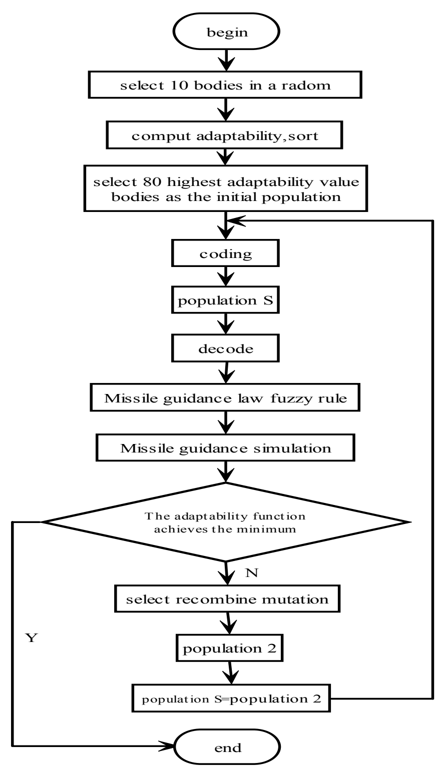


Figure3. Flow chart of optimization algorithm

If determine the position of the intersection is $k=6$, then, after crossing, two children individuals are resulted as:

children individual 1: 001100**011110110110......010**
children individual 2: 011101**001101100110......111**

Namely the genes behind the position of the intersection are swapped mutually, obtaining two new individuals. The determining method of variation position is identical to that of the intersection position. After producing variation position randomly, the gene including the variation position becomes 1 if it is 0, and becomes 0 if it is 1.The individual before variation is: variation gene after variation it becomes:

001101001100100010 10......111

Through the above method, fuzzy rules are optimized and decoding becomes easier. Genetic Algorithm is mainly applied in the operations on the chromosome which can be considered as a 1 $x$ n matrix (n is the number of genes contained in the chromosome). Figure 3 shows the flow of the algorithm

## IV. SIMULATION

In the section, we take the anti-ship missile as an example to simulate. In simulation, we consider the dynamic property of missile as ideal two-order property, and utilize (1)~(9) to simulate point-mass trajectory, The parameters of the genetic operator in simulation are:

n=100, m = 20, S= 80, PC = 0.6, p, = 0.001(n is the size of the seed population which appears randomly; m is the number of units which was washed out from the original seed population; S is the size of the population which attends the genetic operation; PC is crossover rate; pm is variation rate), after 30 generations. Simulation results are as shown from figure .4 to figure 8.

Simulation conditions are as follows:

**1) The missile and target property**

- Missile acceleration in yaw channels: $a_{\mathrm{m}}$ transfer property with transfer function form express

$$\frac{a_{\mathrm{m}}(s)}{a_{\mathrm{mc}}(s)} = G(s) = \frac{10^2}{s^2 + 2\times 0.8\times 10\times s + 10^2}$$

- Missile velocity is $V_{\mathrm{m}} = 450$ (m/s); Target velocity is $V_{\mathrm{t}} = 25.5 + 5\sin(t)$ (m/s), $\psi_t = 60 + 50\sin(3t)$;

**2) Initial conditions**

- The initial position of missile is $[x, y, z] = [0m, 7m, 0m]$, and the initial position of target is chosen: $[x_{t0}, y_{t0}, z_{t0}] = [5000m, 7m, 500m]$;
- The initial azimuths of LOS to reference coordinate system were chosen: $\psi_t(0) = 60^{\circ}$;

**3) All simulation steps are chosen as 0.001s.**

The distributing curve of missile acceleration is shown in Figure.2, which reflect furthest the leading property of guidance laws.

Simulation results can been shown that the meeting time of the missile to target is 11.5990s in the present of the fuzzy guidance law, and the miss distance is 0.1510m。

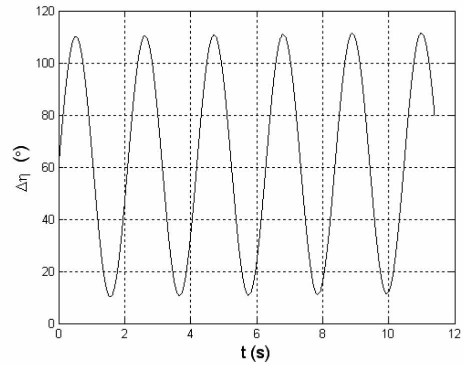


Figure4. the lead angle $\Delta\eta$ curve

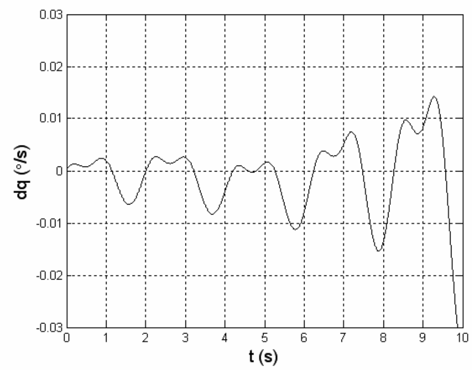


Figure5. the LOS angle $\dot{q}$ curve

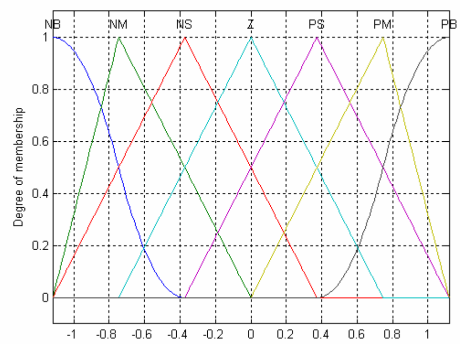


Figure6. Membership function curve of missile acceleration demand $a_{mc}$

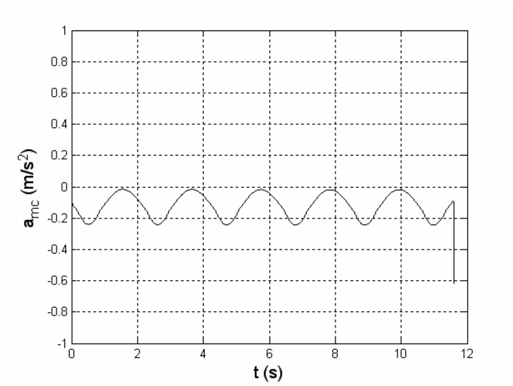

Figure7. missile acceleration demand $a_{mc}$ curve

Based on simulation results, the fuzzy guidance law with angle constraint is of obvious effect, which can reduce the larger overload, and decrease the miss distance of the anti-ship missile to maneuvering target at the terminal stages.

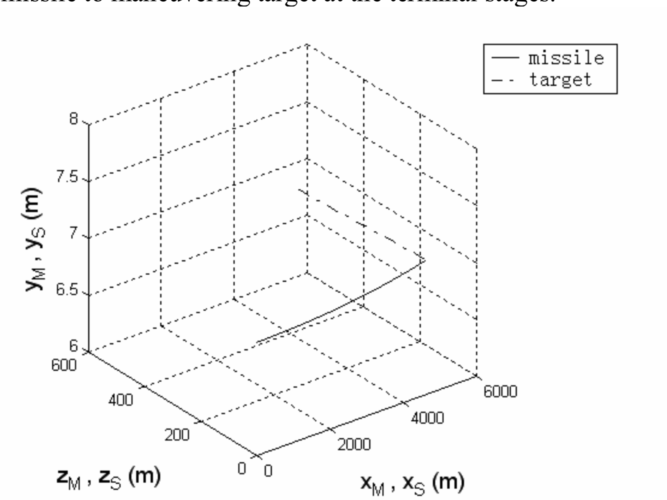

Figure8. Trajectory curve of missile and target

Finally, we carry through simulation comparation for acceleration demmand of different guidance law SMGL[12], PPNG[13] and SGAA-FGL.

Table 2. Acceleration demmand comparation of different guidance law

| Guidance law | Miss distance (m) | Acceleration maxmun (m/s$^2$) |
|---|---|---|
| SMGL | 0.3516 | 35.72 |
| PPNG | 12.7149 | 32.13 |
| SGAA-FGL | 0.1510 | 0.62 |

## V. CONCLUSION

A new guidance law that is incorporated self-adaptive genetic annealing algorithm and fuzzy logic for short-range homing missiles based on the integrated model for guidance and control loop is presented, which reduce missile acceleration comparing PPNG and sliding mode guidance law. and the performance index function of missile is constructed in the presence of target maneuvering. The simulation results have shown the rightness and effectiveness of proposed method.

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