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Fuzzy Logic Guidance Law with Optimized Membership Functions

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Abstract - Fuzzy guidance law is the fuzzy logic implementation of well known proportional navigation (PN) guidance law. The fuzzy logic controller is used to get the performance of PN guidance with respect to missile acceleration. Fuzzy logic controller (FLC) is generally built by designers with trial and error and based on their experience or some experiments. This paper introduces a Genetic Algorithm (GA) based method to tune the membership functions of the FLC spontaneously. With the specific structure of the chromosome, the special mutation operation and the adequate fitness function, the proposed method with GA produces a membership functions to optimize the missile acceleration and gains the performance with proper tuning. A fuzzy logic controller is knowledge based controller which alters the value of the effective navigation constant to reap the maximum benefits in terms of missile performance.

Keywords— *Genetic algorithms, fuzzy controller, missile guidance law*

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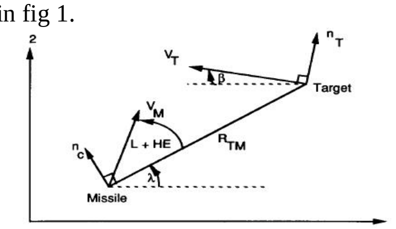
I. INTRODUCTION

This Effective guidance is the key to the successful performance of any missile. But this is the operation which is hampered by the presence of large number of uncertainties ranging from atmospheric turbulence to variations in radar parameters .The presence of several other factors like sensor noise, inaccurate representation of missile flight control, system dynamics, components driven to saturation etc forms the problem [1]. It is difficult to formulate what the true missile model is and what the behavior of the missile change. It is therefore obvious to design the robust controller which solves the problem. In recent years, the fuzzy logic has been applied successfully in several of fields, such as image processing, VLSI design, power system, industry's control, etc. The fuzzy control has become an effective method in industry applications because it has the ability to solve difficult nonlinear control problems or it works without the exact model of the controlled plant. Trial-and-error method always exists in building a satisfactory fuzzy rule base for controlling a nonlinear system or an un-modeled system. Designers usually cannot guarantee that the fuzzy control system designed with trial-and-error has a good performance. Furthermore, there has been a lot of literature discussing about the fuzzy modeling for approaching an unknown system. However, their modeling methods are always complicated and/or hard to be implemented. To optimize the FLC, a variety of methods have been proposed ranging from the genetic algorithm to more classical techniques like LMI based method ,gradient optimization standard for designing the fuzzy logic controllers.

In this work procedure for tuning a Mamdani fuzzy logic controller for missile guidance law is introduced. Genetic algorithm is used to design the optimal fuzzy logic controller (OFLC) through missile-target closed loop simulation. The strategy is getting the missile acceleration by optimizing the membership functions. This paper is organized as follows Problem formulation and some preliminary are stated in second section, introduction to fuzzy logic controller and its tuning is presented in third section .Fourth Section discusses the simulation results. Fifth section gives the conclusion of this study.

II. PROBLEM FORMULATION AND SOME PRELIMINARY

For problem formulation, the missile is modeled as a point mass. The missile and target are moving with constant velocity and drag and gravitational effects are neglected .The missile is fired from random positions around the target. The engagement scenario considered is shown in fig 1.



2-D missile target engagement geometry

In vertical plane, the closing velocity Vc which is negative rate of change of the distance from the missile to the target can be written as a

(1)

Where

and

The missile target Line of Sight (LOS) rate and LOS can be given as

$$\lambda = \frac{R_{TM1}V_{TM2} - R_{TM2}V_{TM1}}{R^{2}_{TM}} \quad (2)$$

(3)

Generally proportional navigation guidance is used in many missiles. The guidance law is known to perform satisfactory for long distance targets. Theoretically proportional navigation guidance law gives the commanded acceleration perpendicular to the instantaneous Line of sight (LOS), the magnitude being proportional to the LOS rate and the closing velocity. Mathematically the guidance law can be stated as

$$n_c = N' \lambda V_C$$

In this equation N' is the effective navigation constant. It is generally considered between 3 to 5 according some thumb rules. The important observation here N' is set to some fixed value and remains same throughout the flight regime. This is where fuzzy logic controller works to modify the navigation constant to get the performance.

III. FUZZY GUIDANCE LAW AND ITS OPTIMISATION

The design of the Fuzzy logic controller is given in [3].Fuzzy logic controller with 49 rules and 7 membership functions are applied. The fuzzy controllers used in the implementation of Fuzzy guidance have fixed rule base and same membership functions. The fuzzy controller has basically three main components: scaling factors, membership functions and the rules. The fuzzy controller is formed by the rule base shown as in the figure.

$\dot{\lambda}$ \ V_c	***NB***	***NM***	***NS***	***ZE***	***PS***	***PM***	***PB***
PB	NB	NM	NS	ZE	PS	PM	PB
PM	NM	NM	NS	ZE	PS	PM	PM
PS	NS	NS	ZE	ZE	ZE	PS	PS
ZE	ZE	ZE	ZE	ZE	ZE	ZE	ZE
NS	PS	PS	ZE	ZE	ZE	NS	NS
NM	PM	PM	PS	ZE	NS	NM	NM
NB	PB	PM	PS	ZE	NS	NM	NB

Common Rule Base

The rule base is obtained by the general consideration of PN guidance law. The equal isosceles triangle are taken as the membership functions for the input values like closing velocity (Vc) and line of sight rate (λ) and output value as commanded acceleration(η_c). Seven membership functions are taken to get the granularity and cover all the negative and positive values.

The important step is to determine the scaling factors which converts the physical ranges between -1.0 and 1.0.The scaling factors can be determined from the expected maximum values of the controllers variables which is taken from the simulations carried out for the simple PN guidance law for different case scenarios. The defuzzification method used is center of gravity method which is used to get the crisp values from the output values taken from the range -1 to 1.This is denormalized by again factor based on the maximum allowable acceleration of the missile and is chosen to be 400 ft/s^2.

A. *Tuning FLC with GA optimisation*

The above implementation shows simple fuzzy rule base and membership functions are used. In this study fine tuning of the membership functions and scaling factors are carried out with the help of genetic algorithm. This study proceeds with the systematic procedure to fine tune membership functions and scaling factors. The genetic algorithm proposed by Holland gives the most used technique for the optimization of fuzzy controller. GAs uses the concept of survival of the fittest to determine, through successive generations of randomised information exchange, the optimal sample value or point in a search space. Genetic algorithm uses the coding procedure, the selection procedure, crossover and mutation.

B. *GA optimisation of the fuzzy logic controller*

The genetic algorithm technique employed in this study is used to tune the fuzzy controller based on the method described in [6].The tuning approach employs the use of MATLAB M-files and functions to manipulate the fuzzy inference system and scaling gains, run the simulation, check the resulting performance and continuously modify the fuzzy inference system in search for an optimal solution. The objective function used here is as a measure of the system performance as it is known to give the optimal performance. The parameters of fuzzy logic controller like membership function and scaling factors are encoded as binary chromosome. The chromosome contains seven bits each for all three linguistic variables and seven bits for the scaling for closing velocity and line of sight rate. The chromosome structure looks like as follows.

Membership Function			**Scaling**	
(1:7)	(8:15)	(16:21)	(22:28)	(29:35)
Vc	λ	ηc	Vc	λ

CHROMOSOME STRUCTURE

The output scaling gain of the controller is not considered in the solution vector as it is fixed to 400 as mentioned earlier. The propotional input scaling (Vc) and derivative input scaling gains were adjusted over range of 3500-4500 and 0.01-0.03 respectively. These figures were obtained from the prior experimentation carried out. Membership functions formulated are considered as symmetric at zero for all the variables. They are allowed to vary for triangular shapes to trapezoidal shapes. The rule base is fixed as in fig 2 for all the simulations and different membership functions and scaling factors are used as per solution vectors. The solution vector with minimum performance index is taken as converged solution. The flow diagram given in figure is self explanatory.

Genetic algorithm parameters used are as follows: Initial population is generated randomly so as try the different solutions for the existing rule base. It is seen that bigger the population better would be optimization performance however more computation efforts required .The population size used is 30 chromosomes and 300 generations. The crossover rate is considered here is 0.7 as more crossover probability rate more the performance advantage. The mutation probability controls the rate of mutation in the process of reproduction. The mutation probability will cause insufficient diversity for continued improvement. Mutation rate around 0.001 is suggested.

C. *Optimisation Problem Formulation*

The aim of the optimization problem here is basically to minimize performance index which is the function of commanded acceleration and miss distance. The miss distance is distance between missile and target at the time of interception which is given by

$Y_d = Y_T - Y_M$. The optimization problem taken here is

$$J = k1 * y_d + k2 \int_0^{t_f} \eta_c{}^2 \qquad (5)$$

where

tf : Time of Flight

y_d : Terminal miss distance at the interception time

η_c : commanded acceleration

Equation (5) is formulation of cost function k1 and k2 are used as constants which are used to prefer the different objectives like miss distance and missile latex requirement.

IV. SIMULATION

The simulation is carried out with different cases as mentioned in [1] so as to compare it with results obtained from [3].The initial conditions for all these cases are given below. British units are employed for the ease of comparison with the existing results from the literature.

Missile co-ordinates (0, 10000) ft

Target co-ordinates (40000, 10000) ft

Missile velocity (Vm) 3000 ft/s

Target velocity (Vt) 1000 ft/s.

The two different cases are simulated in order to analyze the results. The different cases are as follows:

Case 1:

Target Acceleration=0 g and Heading error = -20 Target is simple non maneuring target. Missile is fired with -20 degree heading error.

Case 2:

Target Acceleration=3g and Heading error=0 Target is accelerating with 3g and missile intercepts it without any heading error.

A. *Results*

The effectiveness of any guidance law is mainly defined by the following factors: Time of interception, control effort, miss distance, Peak acceleration [2]. Simulation was performed for simple PN guidance law, fuzzy guidance law including fuzzy logic controller and tuned fuzzy logic controller. The Fuzzy Logic Controller and Genetic algorithm is developed using MATLAB. The simulation is stopped when closing velocity becomes positive. To get the exact miss distance, the step size is decreased to 0.001. The GA algorithm is executed according the flow diagram shown in figure. The numbers of runs are executed to get the final fine tuned Fuzzy logic controller. The number of chromosomes (solution vectors) in each generation is chosen to be 30 and number of generations used is 300.Linear ranking with the method of roulette wheel is used to select the individuals who produce the offspring that join the next generation. At the end of the simulation the best FLC are obtained from the individual that gives the best minimum objective function at the final generation. The tuned fuzzy guidance law shows the better performance with respect peak acceleration and fuel which is the area under curve of acceleration-time profile and miss distance compared to existing PN guidance and Fuzzy guidance law. The scenario 1 results are indicative of the all other scenarios. The modified membership functions for case 1 are as

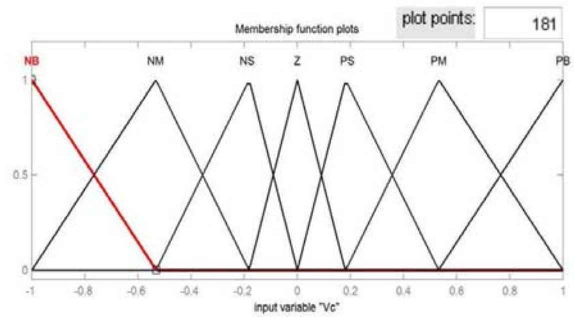


Fig. 3 : Modified membership function (Vc) for case 1

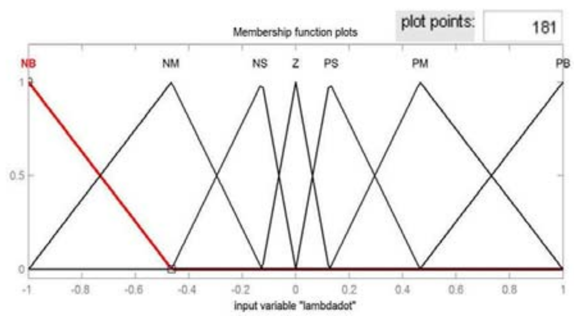


Fig. 4 : Modified membership function(λ) for case 1

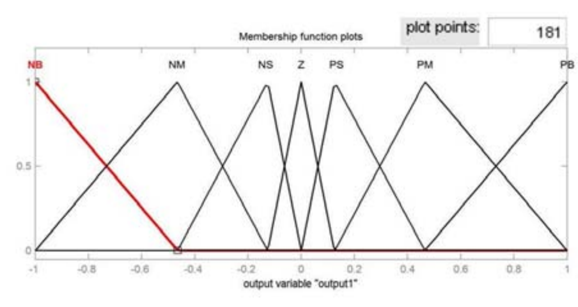


Fig. 5 : Modified membership function(η_c) for case 1

The time history of interception and the resulted control action using optimized fuzzy controller is shown in figure.

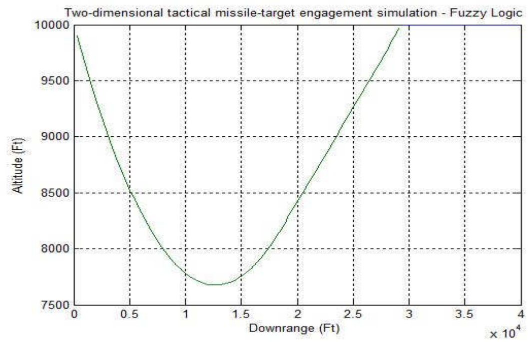


Fig. 6 : Missile Target acceleration history for case 1

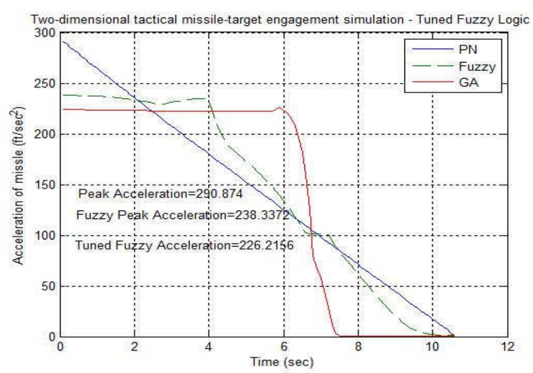


Fig. 7 : Missile Target Trajectory for case 1

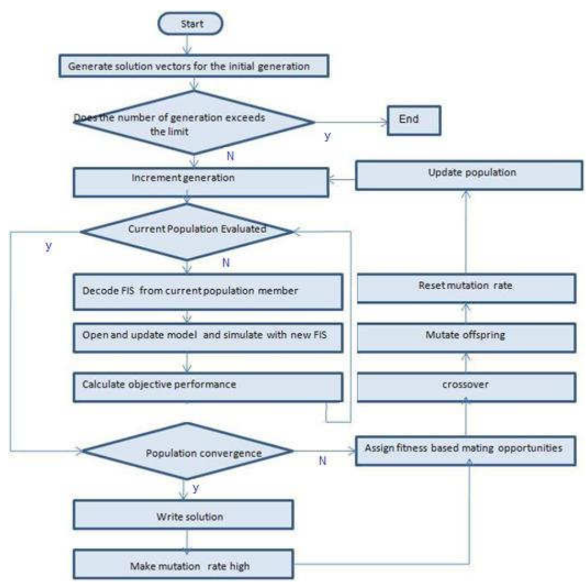


Fig. 8 : Genetic Algorithm Method

From the results we are able to get the results with respect to peak acceleration, fuel and miss distance. The fine tuned membership functions are given in fig.3, fig.4 and fig.5. The results indicate that although the fuzzy-based guidance law can be designed with simple reasoning and engineering experience, the better tuning of parameters like membership functions and scaling gains is possible with genetic algorithm to reap the benefit of the performance. The different scenarios are simulated to show the better tuning of the membership functions and scaling factors with Genetic algorithm. The performance index for the different parameters like miss distance ,control effort, time of flight and peak acceleration can be obtained by defining the appropriate objective function .The different engagement scenario are being tried out. These simulations required intensive computing.

V. CONCLUSION

Fuzzy logic controller as mentioned in literature is attractive alternative for the implementation missile guidance law. The FLC is optimized with the genetic algorithm to tune the various parameters like membership function, scaling factors. The selection of proper objective function is the main criteria to determine the performance index .The method gives the proper way for tuning of the membership function and scaling factors. Extensive simulations and tuning with Genetic algorithm in the presence of sensor noise and system dynamics along with rule base are being continued.

Results									
	Peak Acceleration ft/s^2			*Fuel*			*Miss Distance(ft)*		
	PN	*Fuzzy*	*Tuned fuzzy*	*PN*	*Fuzzy*	*Tuned Fuzzy*	*PN*	*Fuzzy*	*Tuned Fuzzy*
Case 1	290.87	238.05	226.22	1509.73	1508.06	1486.07	0.0763	0.1203	0.0397
Case 2	175.30	145.58	103.43	1218.49	1115.28	842.17	0.0755	0.0497	0.0392

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