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Development of Fuzzy Logic Controller to Enhance the Performance of a HILS for a Homing Guided Missile

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Abstract

This paper investigates the application of fuzzy logic for the development of guidance commands for homing missiles. Fuzzy logic approximation of the well-known proportional navigation guidance law is discussed to enhance the interception of targets performing uncertain maneuvers. Fuzzy logic guidance law development employs triangular membership functions. Simulation results using a HILS system are given.

KEY WORDS

Fuzzy logic controller, Hardware in the loop

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1. INTRODUCTION

In the past, the guidance laws were found to be efficient for the targets that are non maneuverable, and an acceptable miss distance can be obtained. However, more and more new generation attacking targets possess higher speed and maneuverability. Under these situations, it is hard to track these targets by using classical guidance designs [1-3], since system performance sensitivity was rarely considered in the design procedure that usually caused an unacceptable miss distance. In addition, the missile-target dynamics are theoretically highly nonlinear partly because the equations of motion are best described in an inertial system, while aerodynamic forces and moments are represented in missile and target body axis system. Besides, unmodeled dynamics or parametric perturbations are usually remained in the plant modeling procedure, because of complexity of the nonlinear guidance design problem, prior approximations or simplifications were usually required before deriving the analytical guidance gains. Therefore, one does not know exactly what is the true missile model, and the missile behavior may change in unpredictable ways. Consequently, optimality of the resulting design cannot be ensured any more.

In this paper, hardware in the loop simulation (HILS) for semi active homing guidance and control system is carried out. The (HILS) experimental setup has been utilized a test bench for R &D for proposed guidance algorithm based on artificial intelligent (AI) techniques. Fuzzy logic has been tolerated to propose homing guidance law based on proportional navigation method. The experimental setup has been integrated with a six-degree-of-freedom missile model to validate PN guidance law.

2. FUZZY LOGIC-BASED GUIDANCE AND CONTROL DESIGN

The existing applications of fuzzy control range from micro-controller based systems in home applications to advanced flight control systems. The main advantages of using fuzzy are as follows:

(1) It is implemented based on human operator's expertise, which does not lend itself to being easily expressed in conventional proportional-integral-derivative parameters of differential equations, but rather in situation/action rules.

(2) For an ill-conditioned or complex plant model, fuzzy control offers ways to implement simple but robust solutions that cover a wide range of system parameters and, to some extent, can cope with major disturbances.

The fuzzy logic system block diagram is shown in Fig.1. It consists mainly of four basic blocks: the fuzzification interface, the inference engine (mechanism), the rule-base, and the defuzzification interface, [1].

Rule-Base

It is provided by experts or can be extracted from numerical data. It is a set of “IF-THEN” statements, which contains a fuzzy logic quantification of the expert’s linguistic description of how to get a good control. Since a finite number of linguistic variables and linguistic values are specified, there are only a finite number of possible rules. A convenient way to list all possible rules for the case where there are not too many inputs to the fuzzy controller is to use a tabular representation. These rules need to understand the following:

(i) Linguistic variables versus numerical values of a variable.
(ii) Quantifying linguistic variables using fuzzy membership functions.
(iii) Logical connections for linguistic variables (“and”, “or”, ….).
(iv) Implications (“IF A THEN B”).

Fuzzification

Fuzzifier maps crisp input numbers (controller input) into fuzzy input sets (information) that can be used to activate rules, which are in terms of linguistic variables, which have fuzzy sets, associated with them. The fuzzification interface transforms each data received from sensor measurement into fuzzy variables. The number of fuzzy sets defined in the input discourse and their specific membership functions define the fuzzification interface design.

Inference Engine

Inference engine maps fuzzy input sets into fuzzy output sets. It handles the way in which rules are combined and emulates the expert's decision making in interpreting and applying knowledge about the best control method. It uses the fuzzy rules in the rule-base to produce fuzzy conclusions. It simulates human decision making procedure and employs fuzzy knowledge base and fuzzy input to generate fuzzy decisions (outputs). There are two common methods to perform fuzzy logic inferences; the max-min method and the max-product method. In the max-min method, the final output membership function for each output is the union of the fuzzy sets assigned to that output, and the degree for the membership values are clipped at the degree of the membership for the corresponding premise. In the max-product method, the final output membership function for each output is the union of the fuzzy sets assigned to that output in a conclusion, and their degree of membership values are scaled to peak at the degree of membership for the corresponding premise.

Defuzzification

Defuzzifier maps output sets into crisp output numbers, which correspond to control activities or target locations. It converts the fuzzy conclusions into the crisp outputs. All fuzzy logic inference methods result in fuzzy values for all output information. The defuzzification interface transforms the fuzzy values for all output information. The defuzzification interface transforms the fuzzy output into crisp data to be used by the plant. There are several defuzzification methods including the centroid (center of gravity) method and the height method. The centroid method is the commonly used method. It selects the output value corresponding to the centroid of the output membership function as the crisp value for an output.

The application of the fuzzy logic methodology for developing a fuzzy guidance system for an advanced missile is the focus of present paper. The following sections will outline the HILS system and the fuzzy guidance laws.

3. MISSILE CONTROL SYSTEM

The guidance system is used to guide the missile toward the designated target by generating the appropriate guidance commands in accordance with the employed guidance law. To evaluate the performance of this guidance process, the simulation of the missile-target engagement scenarios is indispensable. This simulation is carried out by solving the guidance equations numerically on a digital computer using different engagement scenarios and the proportional navigation guidance law. In this guidance method, the rate of change of missile velocity direction is proportional to the rate of change of the missile-target line of sight (LOS) according to the following guidance law [5]:

$$\dot{\gamma} = N\dot{\sigma} \tag{1}$$

where: γ is the flight path angle (angle of missile velocity vector) and σ is the line of sight angle. The ratio, N, is a design constant greater than unity and is defined as the navigation ratio or gain. To provide a proportional navigation, the guidance system determines the rate of rotation of the line of sight according to which a missile rate of turn is obtained. To carry out this process, the underlying system uses a tracking radar with movable antenna to measure the rate of rotation of the 1ine of sight. The antenna detects the angle between the LOS and the antenna axis (ε), and the radar receiver produces an output voltage (V_R), proportional to this angle which has the form $V_R=K_R\,\varepsilon$. Due to the geometry of Figure 2, the antenna position, the line of sight, and the antenna axis are related by the following equation:

where: ε is the radar antenna error angle, θ is the angular position of longitudinal

$$\varepsilon = \sigma - (\theta + \lambda) \tag{2}$$

axis, and λ is the angular orientation of radar antenna axis w.r.t. the missile longitudinal axis.

Ideally the antenna can be rotated such that its angular velocity ($\dot{\theta} + \dot{\lambda}$) is proportional to the radar receiver output voltage V_R i.e.

$$\dot{\theta} + \dot{\lambda} = K\,V_R \tag{3}$$

The algebraic manipulation of the relations (2, 3) yields the following transfer dynamics:

$$\frac{V_R}{\dot{\sigma}} = \frac{1/K}{1 + \tau_R\, s} \tag{4}$$

where: $\tau_R = 1/(K\,K_R)$ is the receiver time constant. Thus, the radar output voltage is proportional to the rate of rotation of the line of sight but with a time lag inversely proportional to the seeker gain (KKR). Large values of this gain yield small lag and the antenna is closely tracking the target.

Assuming that the antenna axis is accurately pointing to the target i.e. ε = 0, consequently $\dot{\sigma} = KV_R$ where K =f(Ngain)and Ngain =f (Vc) In case of the normal and home-on-jam modes, the guidance command is generated by adding the rate gyro output to the tachometer output. This guidance command is a voltage describing the required normal acceleration for the missile to follow the target and it is limited to certain limit showing the maximum missile maneuver.

The generation sequence of guidance commands is shown in Fig.3. , where the pitch(yaw) command is generated according to the following equation:

$$\eta_{pc} = A\,(\dot{\sigma}_p / k + \dot{\lambda}_p\, F_2) \tag{5}$$

The missile control system is used to control the missile by executing the guidance commands and to correct its trajectory through control surfaces deflections. The underlying system consists of three channels; pitch channel, yaw channel, and roll channel. Each channel consists of linear accelerometer, damping gyro, shaping circuits, and the control fin drive system. The electrical signals are amplified and conditioned within the control loop of each channel, where the control surfaces deviate in the direction that interlocks the input signal.

4-FUZZY LOGIC GUIDANCE LAW

The guidance law generates steering commands to the missile in order to direct it towards the target to achieve interception. It uses the relative missile position/velocity information, and target acceleration information to generate the steering commands, which are in the form of pitch and yaw acceleration components. The missile autopilot has the responsibility for tracking the command acceleration components. Thus, the guidance law can be considered to be mapping between the target relative measurements and the steering commands.

In this section, fuzzy logic will be used to develop the missile guidance law. This guidance law uses the line-of-site rate ($\dot{\sigma}$) and change of line-of-site rate ($\ddot{\sigma}$) to generate the steering commands. This fuzzy guidance law can be a member of the proportional navigation family, and this control method is known as Fuzzy Proportional-Integral-Derivative (FPID) Control [2].

This fuzzy guidance law is based on the observation that the classical proportional navigation guidance law achieves target interception using the line-of-site LOS rate measurements, which is used successfully in several missiles programs. This fact implies that it should be possible to guide the missile towards the target by applying a few fuzzy logic rules on LOS rate measurements. The guidance commands can also be made functions of the instantaneous missile change of LOS rate to improve the smoothness of the missile-target trajectory shape [3].

A fuzzy inference system is set up with two inputs and one output for the pitch plane, and a similar one for the yaw plane. The inputs are line-of-site rate ($\dot{\sigma}$) and change of line -of-site rate ($\ddot{\sigma}$). The outputs are the pitch and yaw acceleration commands as shown in Fig.4.

Seven triangular membership functions are used at the input to convert the LOS rate into linguistic variables, where as three triangular membership functions, and two trapezoidal membership functions are used at the input to convert the change of LOS rate into linguistic variables, similarly, seven output triangular membership functions are used at the output of the inference system.

Thirty-five fuzzy logic rules –in the form of "IF…AND IF … THEN…"-where setup, and are listed in Table 1.

Table 1. Fuzzy logic rules

$\dot{\sigma}$ → ↓ $\ddot{\sigma}$	-Large (-L)	-Med. (-M)	-Small (-S)	Zero	+Small (+S)	+Med. (+M)	+Large (+L)
-Large	-L	-L	-M	-M	-M	+S	+M
-Small	-L	-L	-M	-S	Zero	+S	+M
Zero	-L	-M	-S	Zero	+S	+M	+L
+Small	-M	-S	Zero	+S	+M	+L	+L
+Large	-M	-S	+M	+M	+M	+L	+L

The inputs and output membership functions are shown in figure (5), (6), and (7) respectively.

Also the rule based Madmani type fuzzy logic controller was established and simulated through MATLAB then generating the final control action for the fuzzy logic controller as shown in fig (8). The main was done in tuning the fuzzy logic controller factors to attain the best output performance.

Fig (9) shows the relation between the controller inputs and the output control action through the defuzzification process using 35 rule-based to tune the acceleration command according to LOS rate and change in LOS rate.

5. RESULTS AND CONCLUSIONS

In this section we want to compare between the PID control model and the fuzzy logic control model and there effect on the HILS program. Toward this objective some cases studies with different target paths are considered with the fuzzy logic control model.

Case study 1

Missile-target trajectory for case study 1 is shown in Fig.10. The target made a maneuver near the impact point which resulted in a huge miss distance for the old guidance compared to the one resulted in case of using fuzzy guidance. That's because of the oscillatory response of the old control methods and this issue is clearly shown in the angle of attack profile and side slip angle profile for this scenario which is presented in Fig.11 and Fig.12 respectively.

And for consistency another profile for case study 2 are shown in in Fig.(13-15) .

6. CONCLUSIONS

From the previous work it can be shown that guidance commands generation for missile control can be easily generated using fuzzy logic techniques which is has many advantages over the classical methods to generate this commands.
To achieve this point a HILS system is implemented and several runs for different missile-target engagement scenarios are done and recorded.
The fuzzy guidance has the advantage that besides its smaller miss distance at the end of most of the scenarios it also results in a very smooth missile heading profile all over the missile flight, and consequently no sharp maneuvers are done in normal conditions.

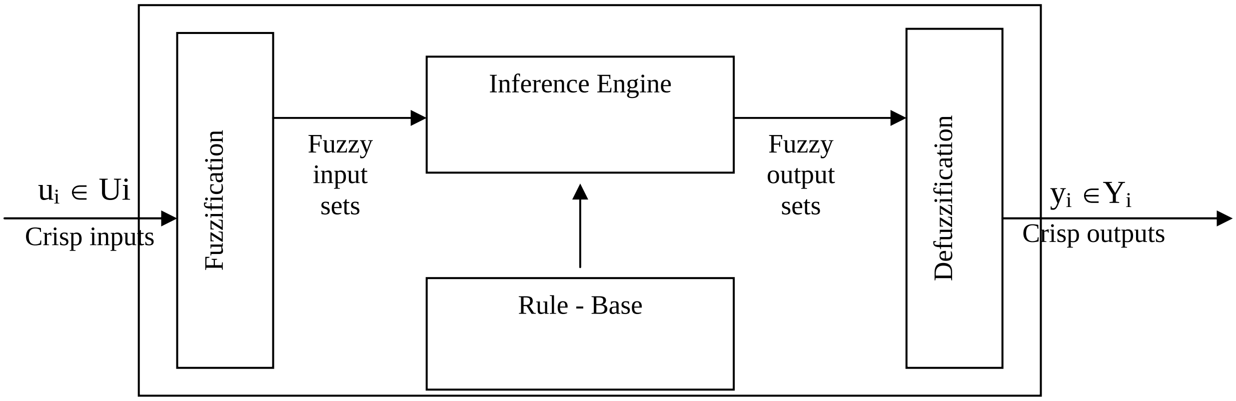


Fig.1. the fuzzy logic system block diagram

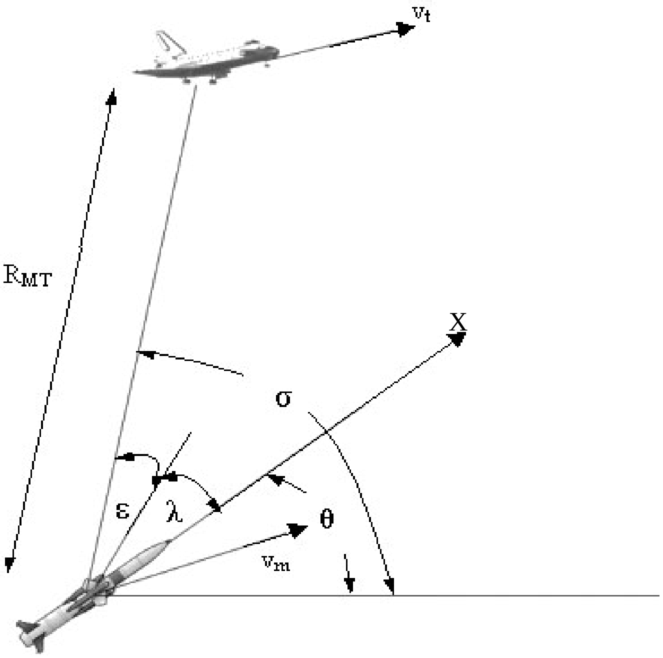
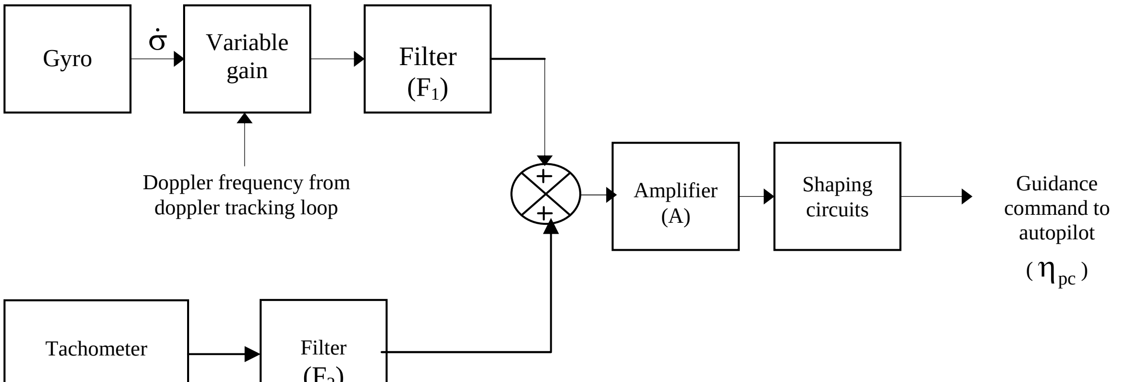


Fig.2. Missile flight and homing



$\dot{\lambda}$

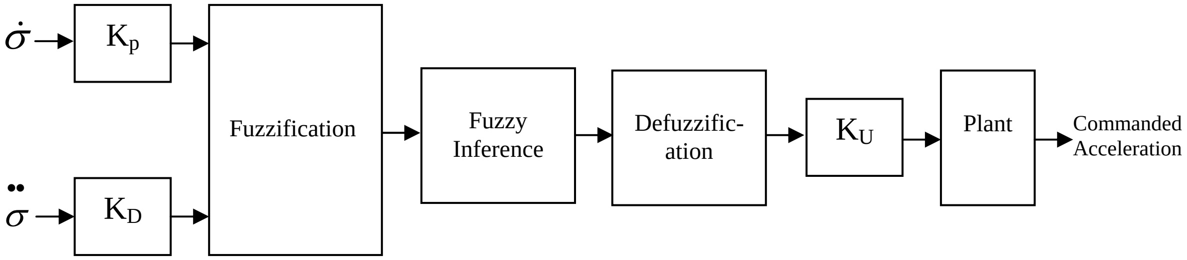


Fig.4. Fuzzy Guidance inference system

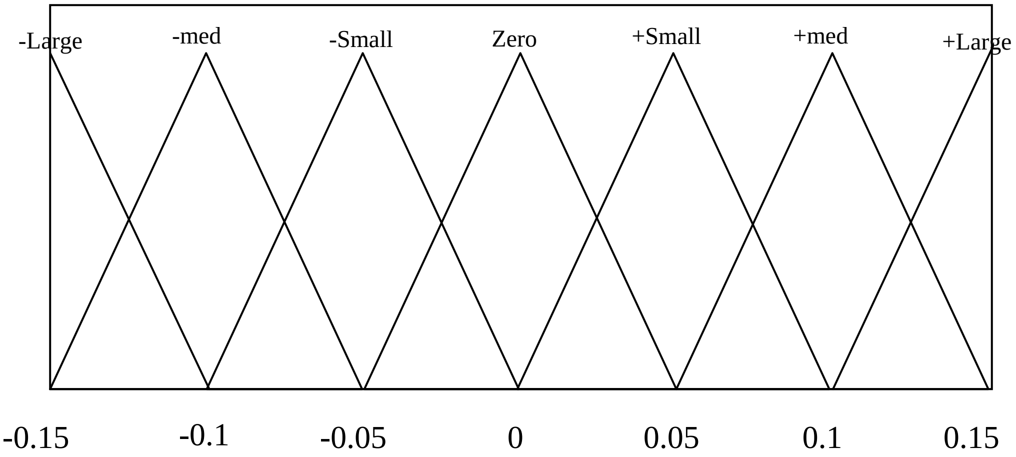


Fig.5. Input variable “LOSrate [rad/sec]”

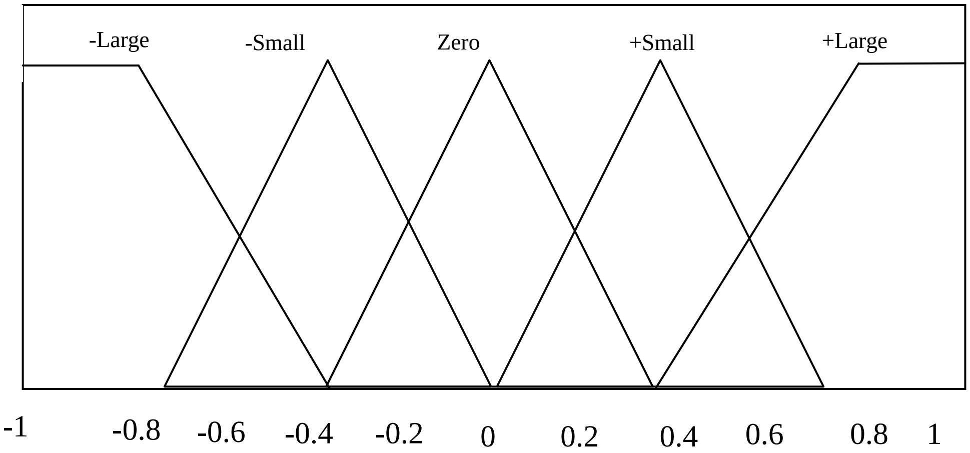
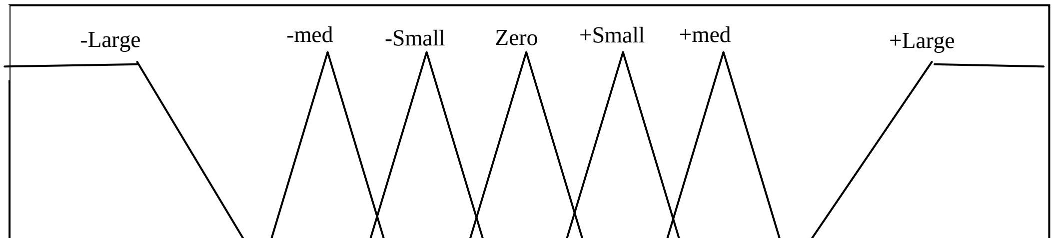


Fig .6. Input variable “change-of-LOS-rate [rad/sec^2]”



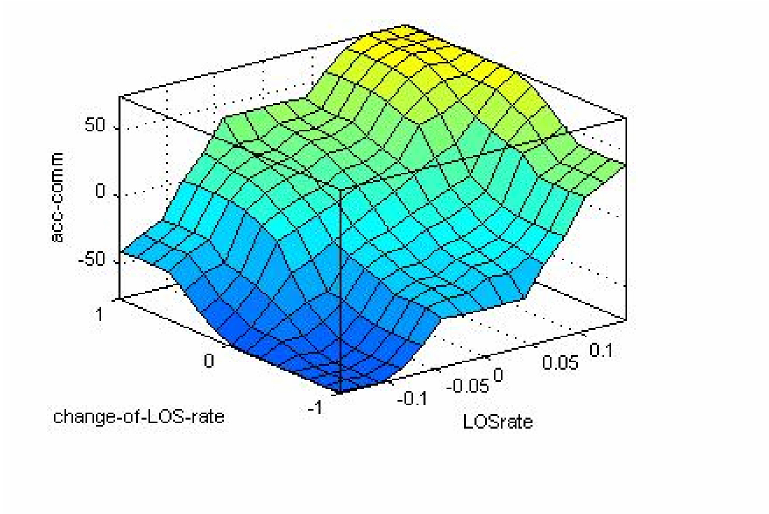
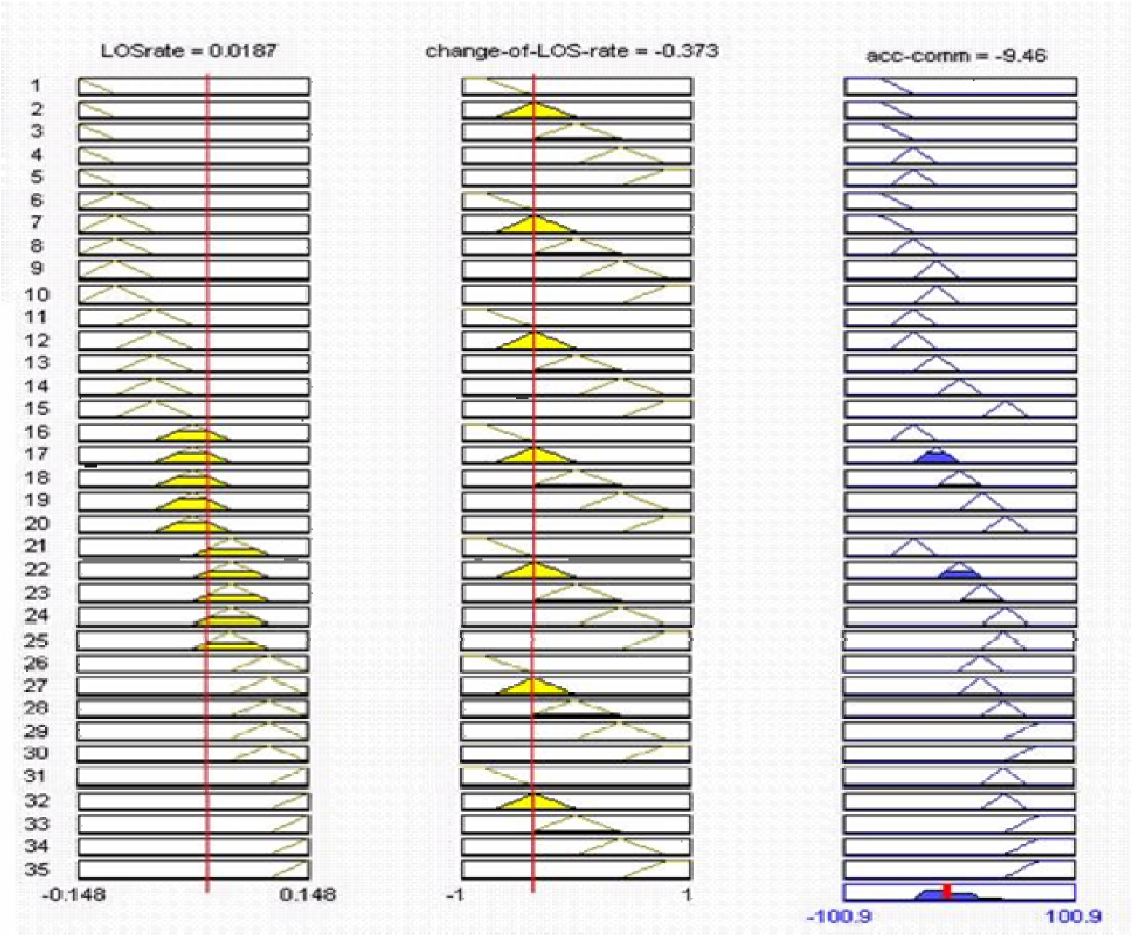


Fig.8. the output control action for the fuzzy logic controller



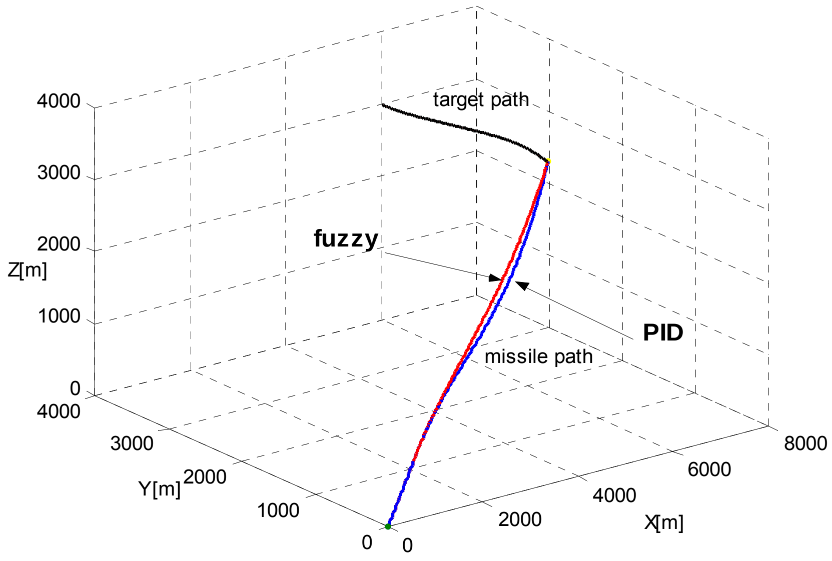
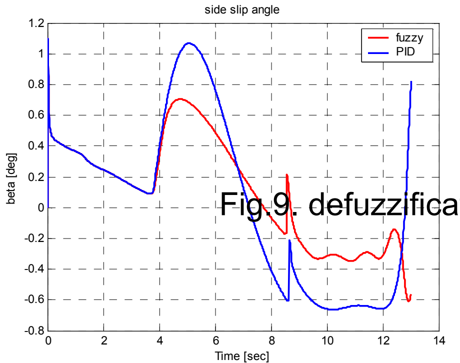


Fig.10. Missile-target trajectory for case study1



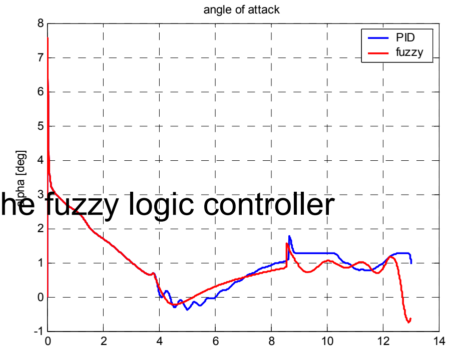


Fig.9. defuzzification process for the fuzzy logic controller

Fig.11. side slip angle profile for case study 1

Fig.12. angle of attack profile for case study 1

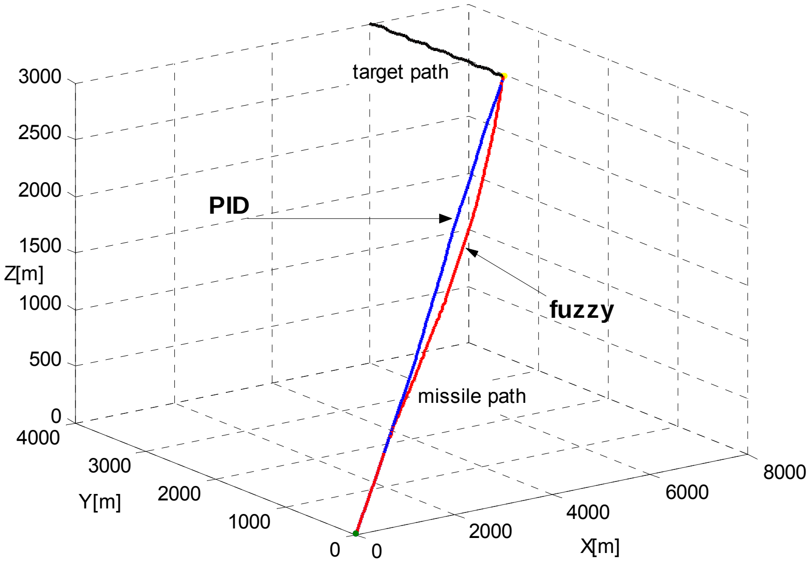


Fig.13. Missile-target trajectory for case study 2

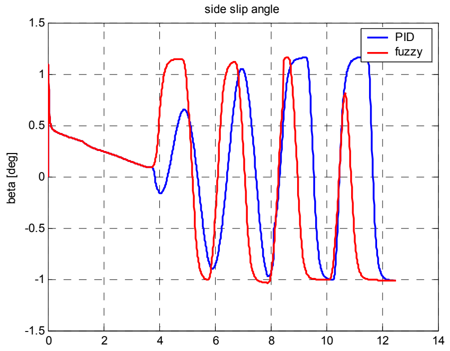


Fig.14. side slip angle profile for case study 2

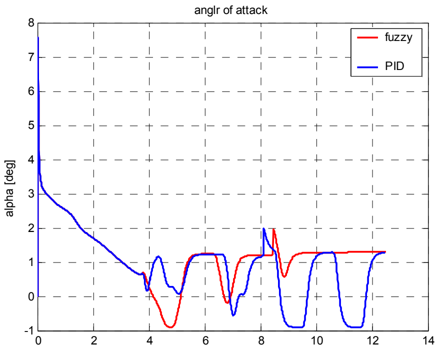


Fig.15. angle of attack profile for case study 2

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