

# Evaluation of Sugeno Fuzzy Inference System performance to track multiple targets using Autopilot System

Shubhechchha Rane<sup>1</sup>, Dr. L. K. Ragha<sup>2</sup> & Deepak Kurule<sup>3</sup>  
<sup>1,2,3</sup>Department of Electronics and Telecommunication Engineering  
Terna Engineering College, Mumbai, India

---

*Abstract* - The status of the progress of a country can be seen from the successful development of the country. Now a day, nation's poor security due to lack of technological progress is a major hurdle in success of development. This paper gives new vision towards security issue. We are using Sugeno Fuzzy Inference System (FIS) for the evaluation of multiple targets tracking which are fired from our enemies by Missile guidance. We are using MatlabR2014a software with simulink8.3 toolbox for the purpose of modelling, scrutinizing, and simulating linear and nonlinear systems. The simulation result gives an idea of missile attack against enemy's targets.

## 1. Introduction

There are several factors, that could be used to judge a country and to measure country's status are standards of education, employment, population growth, income per capita, productivity, mortality rate, technology progress, automation and security techniques. Basically, success of different countries is usually defined in both health and wealth terms. As along with, wealth, health of human being should be seen as the most important indicator of its success and level of development. Now a day, terrorism becomes a major hurdle in maintaining health of society. These terrorist attacks are being reason in disturbing nation's security which includes bombings and Missile attacks that creates enormous economic loss, assets damage, and human dying; so the nation is trying to get rid of this headache. So research is going on against those attacks and our work creates attention against missile attacks by missile guidance techniques.

Conventional design methods need the development of a mathematical model of the control system, and then use this model to construct the controller that is described by the differential equations. These design procedures require restrictive assumptions like linearity so even if a relatively accurate model of a dynamic system can be developed, it becomes too complex to use for development of controller.

As opposed to conventional control design, fuzzy logic control focus on gaining an intuitive understanding of how to best control the process [1]. When linearity and time invariance of the controlled process cannot be assumed, when the process inadequate a well-mannered mathematical model, or when human understanding of the process is very different from its model, there Fuzzy logic control appears very useful [2]. Fuzzy logic control provides a formal approach for representing, handling and implementing a human's experience based knowledge about control a system working [1]. Fuzzy logic uses human knowledge and expertise to pledge with uncertainties in the control process [3]. These features make it an emphatically evoking and promising approach to give more accuracy.

To design Fuzzy logic controller we are using Matlab R2014a and simulink8.3. Simulink can display information graphically with modeling and simulation [4]. There are two types of fuzzy inference systems that can be implemented using Fuzzy Logic Toolbox are Mamdani and Sugeno. Here, we are using Sugeno Fuzzy inference systems which produce missile paths to track multiple targets by representing knowledge via linguistic if-then rules, allow for exact output inference starting from inexact inputs. So we are using autopilot system with fuzzy logic controller to launch missile which will hit multiple targets fired from enemies in the air simultaneously which is based on Command missile guidance, explained in below section. Therefore human death, property damage and financial losses can be prevented. The advantage of this work is no need to fire multiple missiles for destroying multiple targets so this work reduces budgets for nation's security.

This paper is systematized as follows. In section II and III we describe the concept of command Guidance System and Fuzzy Inference System. Section IV describes the Sugeno Fuzzy Inference System. Section V describes the development of Sugeno Fuzzy Inference System. Experimental results and discussions are presented in Section VI. Finally, Section VII

provides conclusion.

## 2. Command Missile Guidance System

Missiles are the one of the widely used self-propelled aerial projectiles weapon containing explosives in the wars. Over the last 30 years, there have been many studies in the area of missile guidance. Missile guidance concerns the means by which the missile receives commands to maneuver missile in company with targets to reach it. The basic problem is to intercept a target with great accuracy in an environment that is uncertain. For this purpose we are using guidance technologies. Missile guidance systems can be divided into four groups such as Self-contained, Command, Beam-rider, Homing [5].

In command guidance, all commands come from internal/external sensors. The data generated by sensors is fed into the computer then processed data is used for guidance commands generation. Then the computer autopilot sends commands to the control surfaces that depend on relative status between the missile and the target at any given point, to adjust the missile's course. Today's widely used sensor types include infrared, radar, and the global positioning system. Here, we are using RADAR.

Command Guidance method is divided into two sub methods such as Remote control by Radio and Remote control by Radar. Using these techniques, the control link could be stretched many miles, and any physical contact between launching platform and the missile eliminated. But we are using Remote control by Radar method as it replaces the human operator that we needed in the radio remote control system.

Here, single radar is used to track the missile and target. As soon as the radar is locked on the target, tracking information is fed into the computer. The missile is then launched and is tracked by the radar. Target and missile ranges, angle of attack, and bearings are continuously fed to the computer. This information is analysed and a missile intercept flight path is computed. The appropriate guidance signals are then transmitted to the missile receiver. A computer at the launch point determines whether the interceptor missile is on the proper trajectory to intercept the target. If it is not, steering commands are generated by the ground computer and transmitted to the in-flight missile. Furthermore, the computer compares this computed flight path with the predicted flight path of the missile based on current tracking information, and determines the correction signals required to move the missile control surfaces to change the current flight path to the

new one. The radar command guidance method can be used in ship, air, or ground missile delivery systems.

The guidance computer is located on a stationary platform, or on a mobile platform. The guidance computer has Matlab R2014a software. In that software, Simulink8.3 Toolbox is used for tracking target and Missile position by using Fuzzy Inference System. Fuzzy inference system takes tracking data and issues commands so that the missile will either collide with the target or pass within lethal range of it. Missile is moving based on angle of attack calculation so feedback loop is there for error calculation and at high angle of attack missile will blast to destroy targets.

The Simulink model for multiple target tracking is shown below in Fig. 1. Theta1 gives output of system and Theta2 gives angle of attack information.

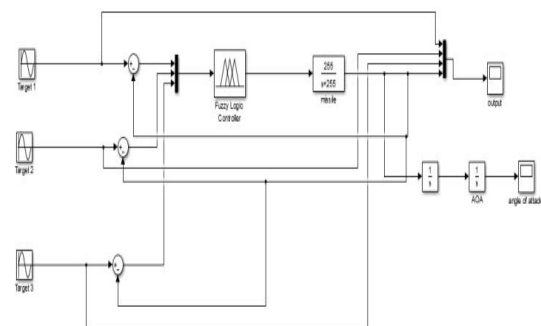


Fig. 1 Simulink model for multiple target tracking

## 3. Fuzzy Inference System

Fuzzy inference is the approach for mapping from given input(s) to output(s) using fuzzy logic. This mapping provides decision making basis. It has successfully applied in automatic control, decision analysis, time series prediction, robotics, computer vision, and pattern recognition [6]. Due to its versatile nature, the fuzzy inference system is known by so many names like fuzzy-rule-based system, fuzzy expert system, fuzzy model, and fuzzy associative memory. Easy way to build, edit and observe the system is use of graphical user interface rather than working on command line. There are five primaries GUI in the Fuzzy Logic Toolbox is sequential as follows:

- i. Fuzzy Inference System or FIS Editor,
- ii. Membership Function Editor,
- iii. Rule Editor,
- iv. Rule Viewer, and
- v. Surface Viewer.

The Structure of the Fuzzy Inference system is described in Fig.2 as follows [7].

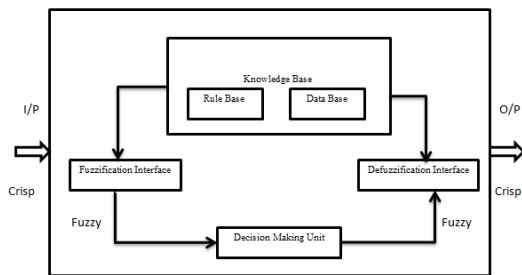


Fig. 2 Structure of the Fuzzy Inference system

There are two types of FIS editors such as Mamdani FIS and Sugeno FIS which includes membership functions, fuzzy logic operators, and if-then rules. Here Sugeno FIS is used. Rule base have fuzzy if-then rules and database describes the membership functions of the fuzzy sets used in fuzzy rules together referred to as the knowledge base. A membership function defines how each point in the input range and output range is mapped to a membership value between the range 0 and 1. The different forms of membership functions for different application are triangular, Gaussian, trapezoidal, and bell shape which is problem depended. Gaussian membership function has advantage of being smooth and nonzero throughout, so we are using it. Decision-making unit performs the inference operations such as Logical AND, Logical OR, Logical NOT on the rules. We want to perform intersection operation so Logical AND operator is used. Fuzzification interface act as input interface which converts the crisp inputs into degrees of match with linguistic values by a lookup in membership functions. The resulting fuzzy set must be converted to a number that can be sent to the process as a control signal by output interface known as defuzzification interface. There are a number of defuzzification methods such as weighted average (wtaver), weighted sum (wtsum). We are using weighted average method for Sugeno FIS. Fuzzy if-then rules are expressions in the implication form: If  $x$  is  $A$  (antecedent) Then  $y$  is  $B$  (consequent) where,  $x$  and  $y$  are input and output linguistic variables. Fuzzy values  $A$  and  $B$  are membership functions. Here we are using twelve membership functions, logical AND as fuzzy logic operators, and twelve if-then rules.

#### 4. Sugeno Fuzzy Inference System

Sugeno, or Takagi-Sugeno-Kang method of fuzzy inference first introduced in 1985 [Sug85]. The

Sugeno fuzzy model was proposed by Takagi, Sugeno, and Kang in an effort to formalize a system approach to generating fuzzy rules from an input-output data set [7]. Sugeno fuzzy model is also known as Sugeno-Takagi model

It is similar to the Mamdani method in many respects. In fact the first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, are exactly the same. The main difference between Mamdani fuzzy inference and Sugeno is that the output membership functions are only linear or constant for Sugeno fuzzy inference. In fact, in the Sugeno FIS there is no output membership function at all. Instead the output is a crisp number computed by multiplying each input by a constant and then adding up the results. One of the large problems with the Sugeno FIS is that there is no good intuitive method for determining the coefficients. Also, the Sugeno has only crisp outputs. The reason is that there are algorithms which can be used to automatically optimize the Sugeno FIS like Adaptive neuro-fuzzy inference system (ANFIS). The only distinctions are the fact that all output membership functions are singleton spikes, and the implication and aggregation methods are fixed and cannot be edited. The implication method is simply multiplication, and the aggregation operator just includes all of the singletons. Because of the linear dependence of each rule on the system's input variables, the Sugeno method is ideal for acting as an interpolating supervisor of multiple linear controllers that are to be applied, respectively, to different operating conditions of a dynamic nonlinear system. A Sugeno fuzzy inference system is extremely well suited to the task of smoothly interpolating the linear gains that would be applied across the input space; it's a natural and efficient gain scheduler. Similarly, a Sugeno system is suited for modeling nonlinear systems by interpolating multiple linear models. Because it is a more compact and computationally efficient representation than a Mamdani system, the Sugeno system lends itself to the use of adaptive techniques for constructing fuzzy models. These adaptive techniques can be used to customize the membership functions so that the fuzzy system best models the data. Higher-order Sugeno fuzzy models are possible, but they introduce significant complexity with little obvious merit. Sugeno fuzzy models whose output membership functions are greater than first-order are not supported by the Fuzzy Logic Toolbox.

#### 5. Development of Sugeno FIS

The proposed FIS for tracking multiple targets consist of three inputs and one output.

Number of Inputs depends upon number of reference signals send by Radar. These signals represent path of targets fired from other countries. Here we are considering three targets. The system has one output that indicates path of our missile to hit all those targets. So path of missile is the output of FIS. The primary GUI in the Fuzzy Logic Toolbox for Sugeno are explained below. The fuzzy inference system or FIS Editor consist of one input and one output, then add two input variables from Edit and named them as Target1, Target2, Target3 and output as missile; shown in Fig. 3. Reference Signals of Target1, Target2, Target3 which was send by Radar are taken to be in the ranges of -0.9525 to 0.9512, 1.1489 to 1.1482, and -1.1249 to 1.1239, respectively. Each of the selected input and output variables is expressed by a set of twelve linguistic fuzzy values, defined by a Gaussian membership function as shown in Fig 4 for target1 by membership Editor; where “p” represents positive, “n” represents negative and “z” represents near to zero similar for target2 and target3 and then the fuzzification interface takes place followed Weighted average method. Fig. 5 shows missile membership function.

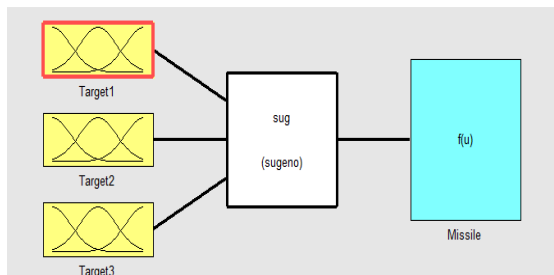


Fig.4 Sugeno FIS

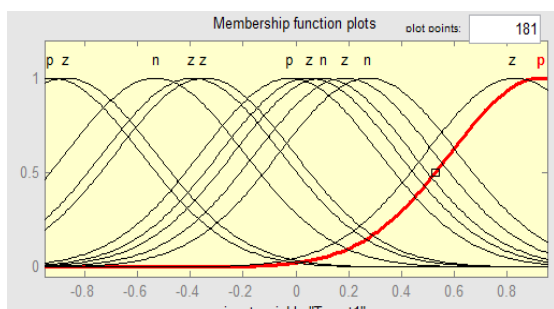


Fig. 5 Target 1 Membership Function Editor

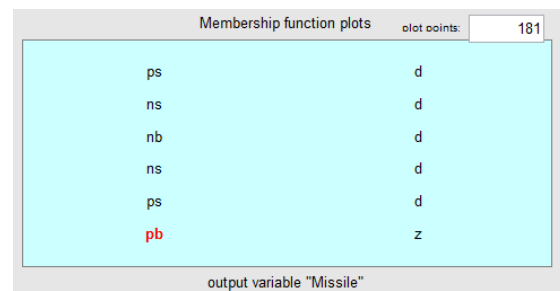


Fig. 6 Missile Membership Function Editor

The fuzzy inference rules for multiple Target tracking are derived from the concept that missile will move in positive domain or in negative domain depends on maximum targets in either domains, which are represented by “pb” for positive big, “ps” for positive small, “nb” for negative big, and “ns” for negative small. If two targets are in either of two domains and one target close to zero then missile will move to domain where target close to zero moving, which is represented by “d” for depends and if all targets are near to zero then missile blasts itself, which is represented by “z” for zero. The fuzzy inference rules for multiple target tracking are described Table I.

Table I. Rule base of Sugeno FIS

Rule	Target 1	Target 2	Target 3	Missile
1	Positive	Positive	Positive	Positive Big
2	Positive	Positive	Negative	Positive Small
3	Positive	Negative	Negative	Negative Small
4	Negative	Negative	Negative	Negative Big
5	Negative	Negative	Positive	Negative Small
6	Negative	Positive	Positive	Positive Small
7	Zero	Zero	Zero	Zero
8	Zero	Zero	Positive	Depends
9	Zero	Zero	Negative	Depends
10	Zero	Positive	Positive	Depends
11	Zero	Negative	Negative	Depends
12	Zero	Positive	Negative	Depends

Fuzzy rules can be shown in three formats such as Verbose, Symbolic, and Index. Rule base in symbolic format is shown in Fig.6.

1. If (Target1 is p) and (Target2 is p) and (Target3 is p) then (Missile is pb) (1)
2. If (Target1 is p) and (Target2 is p) and (Target3 is n) then (Missile is ps) (1)
3. If (Target1 is p) and (Target2 is n) and (Target3 is n) then (Missile is ns) (1)
4. If (Target1 is n) and (Target2 is n) and (Target3 is n) then (Missile is nb) (1)
5. If (Target1 is n) and (Target2 is n) and (Target3 is p) then (Missile is ns) (1)
6. If (Target1 is n) and (Target2 is p) and (Target3 is p) then (Missile is ps) (1)
7. If (Target1 is z) and (Target2 is z) and (Target3 is z) then (Missile is z) (1)
8. If (Target1 is z) and (Target2 is z) and (Target3 is p) then (Missile is d) (1)
9. If (Target1 is z) and (Target2 is p) and (Target3 is p) then (Missile is d) (1)
10. If (Target1 is z) and (Target2 is n) and (Target3 is n) then (Missile is d) (1)
11. If (Target1 is z) and (Target2 is z) and (Target3 is n) then (Missile is d) (1)
12. If (Target1 is z) and (Target2 is p) and (Target3 is n) then (Missile is d) (1)

Fig. 6 Rule Base (Symbolic)

Rule Base Editor is shown in Fig. 7

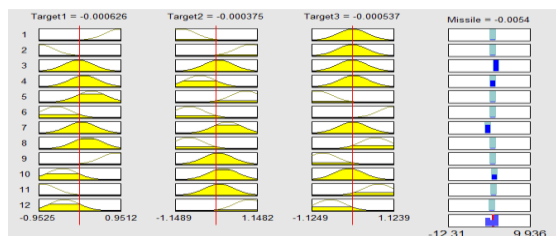


Fig. 7 Rule Base Editor

The Sugeno FIS can be trained using Adaptive Neuro Fuzzy Inference System (ANFIS) [11]. ANFIS is helpful in tuning the membership function parameters by using either a back propagation algorithm or hybrid algorithm to model a given set of I/O data. ANFIS tool is used to optimize the outputs. ANFIS model is shown in Fig. 8

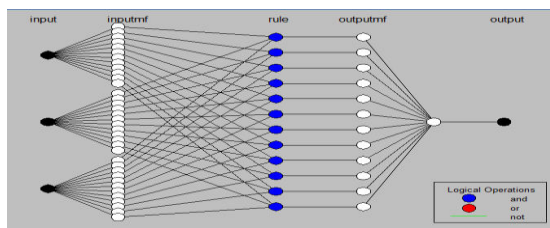


Fig. 8 ANFIS Model

Sugeno FIS specifications used here are as shown in Table II

Table II. FIS Specifications

Parameters	Value (%)
And	Min
Or	Max
Defuzzification	Weighted Average

## 6. Results

The following results were acquired during the simulation of Mamdani fuzzy inference systems. Fig. 9 illustrates the three-dimensional surface view of the relationship between the Target1, Target2 and missile; like this three dimensional surface view of other combination of targets with missile is possible. Fig. 10 illustrates two dimensional view of the relationship between the Target1 and missile; in the similar manner two dimensional surface views of other targets with missile is possible.

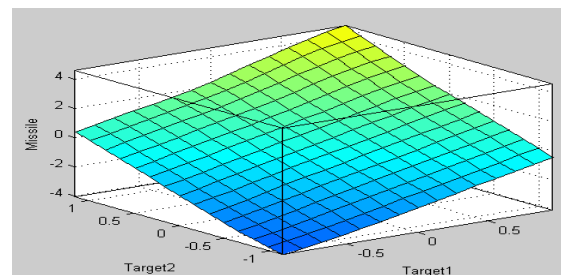


Fig. 9 Surface view of Target1 and missile in Sugeno FIS

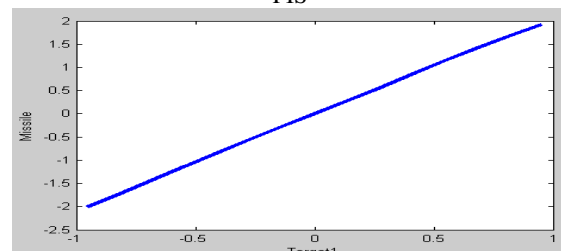


Fig. 10 Two dimensional relationship between Target1 and missile in Sugeno FIS

The following results were obtained after simulation of simulation model using Mamdani FIS. Fig. 11 illustrates angle of attack. Fig. 12 illustrates output of multiple targets tracking system; which shows at high angle of attack missile will destroy all nearby targets at a time.

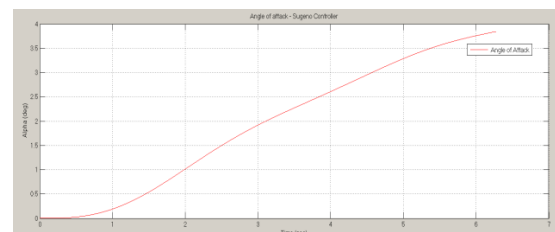


Fig. 11 angle of attack

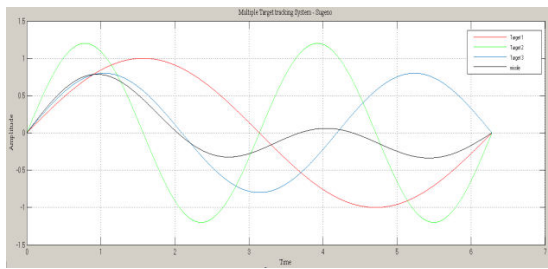


Fig. 12 output of multiple targets tracking system

## 7. Conclusion

A variety of fuzzy inference systems exist and employed these days. This paper described Sugeno Fuzzy inference systems to improve the priority to evaluate the missile's course. It can be concluded that Mamdani FIS and Sugeno FIS perform quite similar, but Sugeno FIS allows the evaluation of risk to work at its full capability with smooth operational performance. Although the designing of both systems is same but the output membership functions of Sugeno can only be either constant or linear and also the crisp output is generated in different ways for both FIS. Most likely we are going to utilize the Sugeno FIS due to its accuracy and because we can use ANFIS tool which optimizes the inputs. Sugeno FIS has also an advantage that it can integrate with neural networks and genetic algorithm or other optimization techniques so that the system can acclimate to system characteristic powerfully. Sugeno FIS is more flexible because it permits more parameters in the output and since the output is a function of the inputs it states a more explicit relation. Sugeno FIS is sensitive in areas where the fuzzy sets overlap. Therefore, Sugeno FIS should be used MISO systems. In computational terms the Sugeno

FIS is more effective because as it uses weighted average defuzzification method. From the above, it seems that any Sugeno FIS is always more proficient than a Mamdani FIS. As a future work, we plan to extend this study beyond simulations by dealing with the problem theoretically.

## REFERANCES

- [1] K. M. Passino, S. Yurkovich, Fuzzy control, Addison Wesley, 1998.
- [2] P. Isomursu, T. Rauma, "A self-tuning fuzzy logic controller for temperature control of superheated steam", Fuzzy Systems, IEEE World Congress on Computational Intelligence., Proceedings of the Third IEEE Conference, Vol.3, 1994.
- [3] M. S. I. Md., S. Z. Sarker, K. A. A. Rafi, M. Othman, "Development of a fuzzy logic controller algorithm for air conditioning system", ICSE Proceedings, 2006.
- [4] S. N. Sivanandam, S. Sumathi and S. N. Deepa, "Introduction to Fuzzy Logic using MATLAB", and Springer publication
- [5] T. V. Karthikeyan, A. K. Kapoor, "Guided Missiles", Scientists at Defence Research & Development Laboratory, Hyderabad, published in 1990.
- [6] "Fuzzy Logic with Engineering Applications", by Timothy Ross, McGraw Hill Publications, 1997.
- [7] Jan Jantzen, "Design of Fuzzy Controller" - technical university of Denmark 19 Aug 1998