# Type-2 Fuzzy Logic in Pair Formation

**Lakshmi Shrinivasan[1], J. R. Raol[2]**
[1]Department of ECE, M S Ramaiah Institute of Technology, Bangalore, India
[2]Department of ECE, Jain University, Bangalore, India

**Article Info**

***Article history:***

Received Jan 9, 2018
Revised Mar 2, 2018
Accepted Mar 18, 2018

***Keywords:***

Inference engine
IT2FLS
Mamdani model
Pair formation
T1FLS

**ABSTRACT**

This paper gives an overview of Type-2 Fuzzy sets (T2FSs) and Type-2 fuzzy Logic system (T2FLS) considering one aviation scenario. The existing type-1 Fuzzy system has limited capability to handle the uncertainty directly. In order to overcome the limitations of Type-1 fuzzy Logic system (T1FLS), a next level of fuzzy set is introduced, that is known as T2FSs. Here we will discuss about: Type-2 fuzzy sets, type-2 membership functions, inference engine, type reduction and defuzzification. Pair formation is the undertaken aviation scenario which is very critical in a fighting situation. Crisp data are taken by the sensors of aircraft and with the techniques of data fusion, a constant decision is passed whether two aircrafts can achieve pair formation or not. Experiments are evaluated and performance is compared with ground truth and existing T1FLS, which proves better in terms of decision making while a certain amount of uncertainty is present.

*Copyright © 2018 Institute of Advanced Engineering and Science.*
*All rights reserved.*

***Corresponding Author:***

Lakshmi Shrinivasan,
Department of ECE, M S Ramaiah Institute of Technology,
Bangalore, India.
Email: lakshmi.msrit@gmail.com

## 1. INTRODUCTION

Pair formation of aircraft has been a key research in the field of avionics. Pair formation requires an advance technology to get precise kinematic information for maintenance of multiple aircraft flying simultaneously. The existing T1FLS was not enough to fulfill this requirement. So, we go to a next level fuzzy implementation i.e. T2FLS.The main objective of this paper is to identify the problem in existing T1FS considering a pair formation scenario and to overcome those problems why we go for T2FLS.First we try to understand the existing T1FLS which is based on Type-1 Fuzzy set (T1FSs).

The concept of T1FSs is first introduced by Zadeh [1] in year 1965. It is applied successfully in many applications such as modeling and control [2-4], time series prediction and datamining [5-7] etc. The fuzzy set implementations became very popular in the year of 1980 after the work of T. Takagi and M. Sugeno on fuzzy modeling and E. Mamdani on fuzzy controller. A Type-1 Fuzzy set is an extension of a normal set (crisp set). In a normal set an element can be either a member of the given set or not [0 or 1], whereas T1FSs allows elements to have partial membership also which lies in the range of [0, 1].In a practical life scenario, a system can have more than two states, which can’t handle by crisp logic. So there was a need of multi valued logic between two extreme values of 0 and 1. T1FLS was suitable to overcome this drawback of crisp logic. However, T1FLS was capable to handle the multi valued logic problem, but it was not able to handle the problem of uncertainty in T1FLS. So again there was a need to extend the Fuzzy type -1 concept, which is nothing but T2FLS.

T2FSs provides additional degree of freedom to design a Mamdani and TSK fuzzy logic system. It is very useful in such a situation where a certain amount of uncertainty are present [8]. There are different sources of uncertainty which may be present in T!FLS .Some of them are listed:

a. First the word, which is used for antecedent and consequent could be uncertain, that means for different people its meaning may be different.
b. Measurements which trigger type-1 system may be noisy.
c. The data that which is used for tuning purpose may be noisy

In T1FLS we can't model directly these type of uncertainty, because of their membership function which is totally crisp. So to overcome these problem concept of T2FLS has been adopted. T2FSs can easily handle this uncertainty problem because their membership values are themselves fuzzy. Type-1 membership function are two dimensional whereas Type-2 membership function are three dimensional. One extra dimension of this membership function gives it additional degree of freedom due to which it is capable to handle uncertainty directly. Interval Type-2 fuzzy (IT2FLS) system is computationally easy, so it's quite practical compare to General Type-2 system. Though, IT2FLS is computationally easy but there is a lot of knowledge required to implement this. A wide research has been carried out in the field of type-2 fuzzy logic, which is described below.

Classification is globally used in real world applications. Classification problem may involves a high amount of uncertainty. Cancer classification is a key problem in bio-medical field. Here it is required to differentiate between the irrelevant and relevant information to segregate the data. In [9] author has proposed Type-2 fuzzy-neural evolutionary network for classification of cancer disease. The classification results shows, its potential in the bio medical field.

In location based application, Geolocalization is a popular keyword. In [10] a new architecture has developed for a Geolocalization android application, which is based on artificial intelligence concept. Artificial intelligence comes due to implementation of interval type-2 fuzzy logic. Collected radio signal data is process by the Fuzzy Logic and then Fuzzy Location indicator is implemented to characterize the map zones and rooms. With this intelligent localization mobile application it is found that it's providing better positioning accuracy.

A modified Type-1 fuzzy system is developed in [11], which is a combination of Type-1 fuzzy logic system and an interval Type-2 fuzzy logic system. This modified system is reducing the complexity by reducing the computation in rule base. Basically it has two parts parameter learning and fuzzy rule base learning. So it's giving a decent performance with higher efficiency.

In next section we will study about the architecture of IT2FLS and then in next section we simulate the experiment and analyze the performance of the system.

## 2. IT2FLS FOR PAIR FORMATION

Figure 1 represents an architecture diagram of IT2FLS. Different blocks of IT2FLS is briefly described:

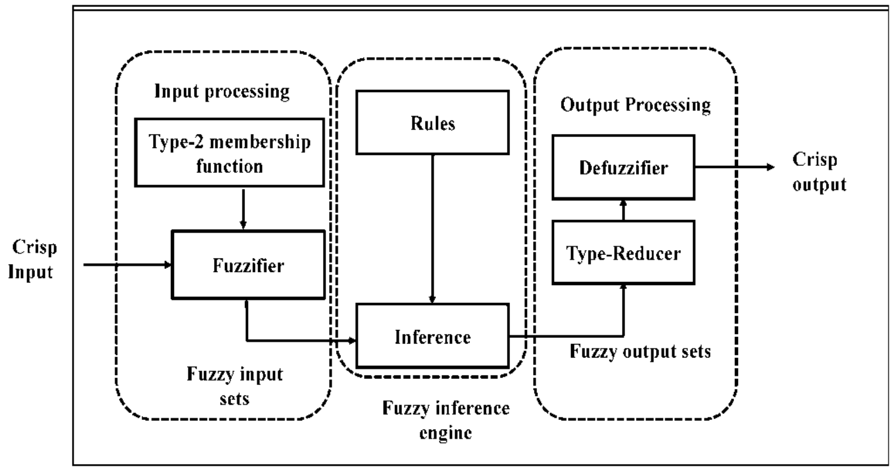


Figure 1. Architecture of Interval Type-2 Fuzzy Logic System

### 2.1 Crisp Input

Inputs which are directly measured by sensors and passed into fuzzy systems, called crisp input. In our pair formation scenario bearing, elevation,speed,class,distance and identity are the crisp inputs. Each inputs which are passed through the sensor have its own group of membership function.

### 2.2 Interval Type-2 membership function

Type-2 membership function defines type-2 set.it is represented as $\mu_{\tilde{A}}(x,u)$.Here, $\widetilde{A}$ is a type-2 fuzzy set. Fuzzy set $\widetilde{A}$ is defined by a membership function given in equation 1.In our scenario we have used Trapezoidal membership function.

$$\tilde{A} = \{\big((x,u),\big), \mu_{\tilde{A}}(x,u) | \forall_x \in X, \forall_u \in J_x \subseteq [0,1]\} \quad (1)$$

Where $0 \le \mu_A(x,u) \le 1$ .Here $J_x \subseteq [0,1]$ represents the primary membership of $x$ and $\mu_A(x,u)$ is a type-1 fuzzy set.

An Interval type-2 Trapezoidal membership function is designed and implemented by expert opinion to get accountability of uncertainties .Obtained Type-2 Fuzzy set acts as input for inference engine which is associated with rule base.

### 2.3 Fuzzifier

Fuzzifier takes input from sensors and converts it into T2FSs based on Type-2 fuzzy membership function. This process is known as fuzzification. Fuzzifier associated with Type-2 membership function and makes one special unit i.e. is called input processing unit, which is shown in Figure 1. This input processing unit is responsible for converting crisp input into T2FSs.

### 2.4 Rules

Rules has always a set of linguistic variable which presents in the form of "IF THEN "statement. The linguistic variable which is connected with IF part is called antecedent and the variable which is connected with THEN part is called consequent. If the system carries more than one rule, then it will connect with AND operator. As for example: In pair formation scenario, IF two aircraft having same elevation, bearing and speed THEN will have same kinematics. Here elevation, bearing and speed are antecedent and kinematics is consequent.

### 2.5 Inference

Inference block transforms the T2FSs inputs into T2FSs outputs using the rules in the rule base and the operators such as union and intersection. In type-2 fuzzy sets, join (⊔) and meet operators (⊓), which are new concepts in fuzzy logic theory, are used instead of union and intersection operators. These two new operators are used in secondary membership functions.

### 2.6 Type-reduction

Type-2 fuzzy outputs of the inference engine are converted into T1FSs that are called the type-reduced sets. There are two common methods for the type-reduction operation in the interval T2FLSs: One is the Karnik Mendel iteration algorithm, and the other is Wu-Mendel uncertainty bounds method. These two methods are based on the calculation of the centroid, which is used in our pair formation.

### 2.7 Defuzzification

The outputs of the type reduction block are passed to defuzzificaton block. The type-reduced sets are determined by their left end point and right end point, the defuzzified value is calculated the average of these points. These defuzzifier values are again a crisp set, which provides decision whether pair formation can be achieved or not. Equation 2 is the required equation to convert it back into a crisp set.

$$z^* = \frac{\int \mu_C(z) z dz}{\int \mu_C(z) z dz} \quad (2)$$

Where $\mu(z)$ is grade of the membership of the fuzzy set.

## 3. RESULTS AND ANALYSIS

Experiment is evaluated in matlab/Simulink environment. A fuzzy logic toolbox is used to get the mamdani model of interval type-2. Fuzzy rules are set by expert's view and pair formation decision is estimated. For experimental study, two aircrafts $X_1$ & $X_2$ are considered. Both aircrafts having constant velocity similar class and similar identity. In order to generate the kinematics data in aircraft, point mass model is implemented which is defined as:

$$X_i\ (k+l) = FX_i(k) + Gw_i\ ,$$

Where $i$ denotes the specific aircraft, k denotes scan number ranges from $1\ to\ 30$ . F & G are Process gain noise matrix. $w$ Represents white Gaussian process noise having variance $Q = 0.1 \times eye(4,4)$.If T denotes sampling rate then we can define the F and G matrix in a following way:

$$F = \begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad G = \begin{bmatrix} \frac{T^2}{2} & 0 & 0 & 0 \\ 0 & T & 0 & 0 \\ 0 & 0 & \frac{T^2}{2} & 0 \\ 0 & 0 & 0 & T \end{bmatrix}$$

Table 1 represents the different parameters and their corresponding values considered in Interval type-2 fuzzy logic system for pair formation.

Table 1. Pair Formation Parameters and Their Values

| Parameter | Simulation values |
|---|---|
| **Initial state of Aircraft 1** $X_1 = [x_1\ \overline{x_1}\ y_1\ \overline{y_1}]$ | $X_1 = [0m\ \ 166m/s\ \ 1000m\ \ 0m/s]$ |
| **Initial state of Aircraft 2** $X_2 = [x_2\ \overline{x_2}\ y_2\ \overline{y_2}]$ | $X_2 = [0m\ \ 166m/s\ \ 990m\ \ 0m/s]$ |
| **No of sensor data considered** | 6 |
| **Type of sensors considered** | $Speed, Bearing\ , elevation, distance, identity\ and\ aircraft\ class$ |
| **Sensor update rate** | $1Hz$ |
| **Simulation time** | $30\ s$ |

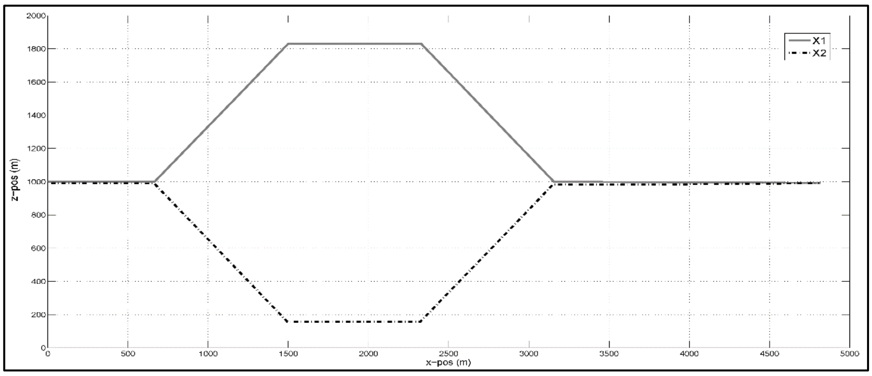


Figure 2. Aircraft $X_1, X_2$ Trajectories in X-Z Plane

In experiment analysis, it is observed that both aircraft $X_1$ & $X_2$ are having in pair formation in first 5 sec and then in next 5 second it splits formation and moving away from each other. After splitting it maintains a constant separation till next 5 sec. From 15-20 seconds again it tries to start forming pair which is shown in Figure 2 & 3. Figure 4 represents the final crisp output for pair formation. A similar environment with same input data is considered for T1FLS also and experiment is evaluated for pair formation scenario. Results are compared in form of graphs. Figure 5 represents T1FLS output with ground truth having a noise variation of 40 dB .Similarly Figure 6 represents T2FLS output with respect to ground truth having same noise variation. It clearly represents that T1FLS is more inaccurate compare to ground truth, but in case of T2FLS this inaccuracy is so minor which is close to ground truth.

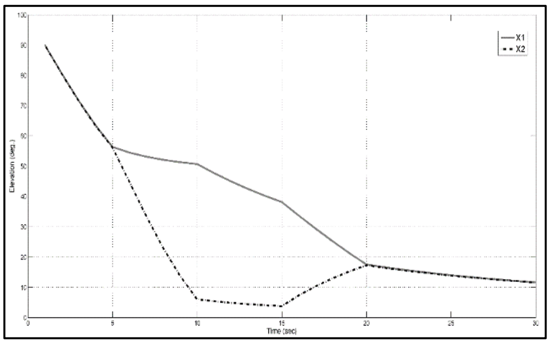


Figure 3. Aircraft $X_1, X_2$ Elevation Angles

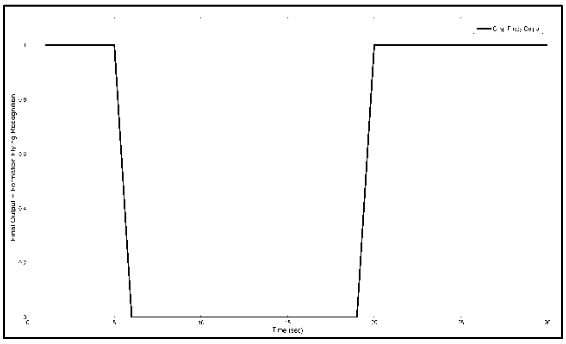

Figure 4: Pair Formation Decision Crisp Fuzzy Output of IT2FLS

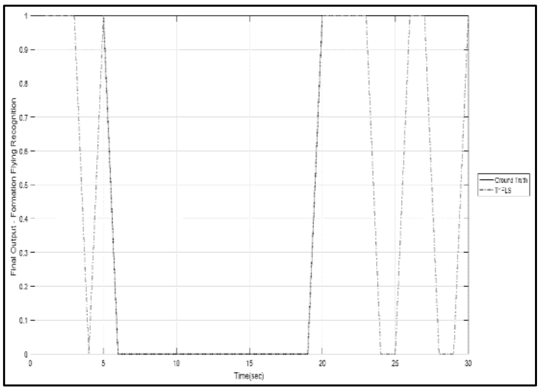


Figure 5. Pair Formation Recognition Comparison of T1FLS with Ground Truth

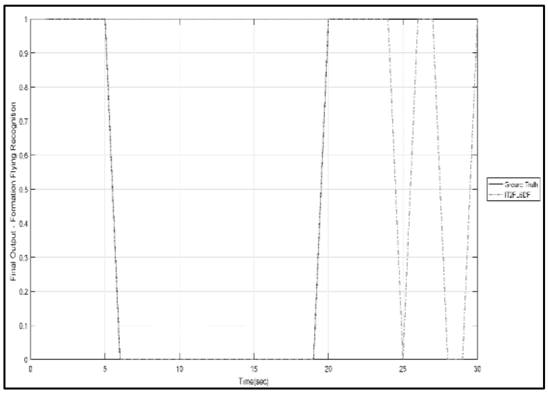


Figure 6. Pair Formation Recognition Comparison of T2FLS with Ground Truth

## 4. CONCLUSION

We discussed about the history of fuzzy set, their significance and how it works in our considered scenario. A T2FL model is developed for constant decision making in pair formation. Evaluation of proposed model is done in Matlab /Simulink interface. A realistic and ideal condition is considered while performance of proposed model is evaluated. Outcomes of our model is compared with Ground truth and existing fuzzy type-1 system, which proves that our model is performing better in realistic conditions where uncertainties presents in input data.

## REFERENCES

[1] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, pp. 338–353, 1965.
[2] J. Bezdek, "Fuzzy models–what are they, and why?" *IEEE Trans. on Fuzzy Systems*, vol. 1, no. 1, pp. 1–5, 1993.
[3] Andino Maseleno, Md. Mahmud Hasan, Norjaidi Tuah. Combining Fuzzy Logic and Dempster-Shafer Theory. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. Vol. 16, No. 3, December 2015, pp. 583 ~ 590. DOI: 10.11591/telkomnika.v16i3.9370.
[4] Ye Xiaoting*1, Zhang Tao2, Wu Shasha3. An Interval Type-2 Fuzzy Neural Network Control on Two-Axis Motion System. *TELKOMNIKA Indonesian Journal of Electrical Engineering*, Vol.11, No.11, November 2013, pp. 6780~6786. e-ISSN: 2087-278X
[5] K. Hirota and W. Pedrycz, "Fuzzy computing for data mining," *Proc. IEEE*, vol. 87, no. 9, pp. 1575–1600, 1999.
[6] W. Pedrycz, "Fuzzy set technology in knowledge discovery," *Fuzzy Sets and Systems*, vol. 98, pp. 279–290, 1998
[7] R. Yager, "Database discovery using fuzzy sets," *International Journal of Intelligent Systems*, vol. 11, pp. 691–712, 1996.
[8] Aminifar, S., & Marzuki, A. (2013). Uncertainty in interval type-2 fuzzy systems.Mathematical Problems in Engineering, 2013, 1–16 (Article ID 452780).

[9] V. Sumati, C. Patvardhan and V. M. Swarup, "Application of interval type-2 subsethood neural fuzzy inference system in classification," *2016 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)*, Agra, 2016, pp. 1-6.doi: 10.1109/R10-HTC.2016.7906852Casadei.

[10] D, Serra G, Tani K. Implementation of a Direct Control Algorithm for Induction Motors Based on Discrete Space Vector Modulation. *IEEE Transactions on Power Electronics*. 2007; 15(4): 769-777. (*in this case Vol.15, Issues 4, and page 769-777*).

[11] N. Baccar and R. Bouallegue, "Intelligent type 2 fuzzy-based mobile application for indoor geolocalization," 2015 *23rd International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, Split, 2015, pp. 165-169. doi: 10.1109/SOFTCOM.2015.7314101.