IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 19, Issue 6, Ver. III (Nov.- Dec. 2017), PP 19-25
www.iosrjournals.org

Comparative Analysis of Defuzzification Approaches from an Aspect of Real life problem

Dr. Sadia Husain, Mr. Yasir Ahmad, Ms. Manju Sharma, Ms. Shazia Ali
(Faculty of Computer Science and Information Systems, Jazan University- K.S.A)

Abstract: *Fuzzy logic has given an edge to deal with uncertainty and vagueness. Fuzzy logic reflects how people think. It attempts to model our sense of words, our decision making and our common sense. As a result, it is leading to new, more human intelligent systems. We can apply fuzzy logic to deal with uncertainties in various fields. There are three basic steps for fuzzy logic system i.e. Fuzzification, rule evaluation and Defuzzification. In this paper we have discussed a real life problem in which different results of same survey were presented when conducted over a period of time. The survey data represent uncertainty in the form of fuzzy sets. To solve the problem we applied defuzzification approaches to get one concrete result from three surveys. We applied some of the mostly-used defuzzification methods and made comparison among them to choose the best one.*
Keywords: *Fuzzy Sets, Fuzzification, Membership functions Defuzzification, Trapezoidal method, Centroid method, Bisector method, weighted average methods, LOM, SOM, MOM.*

Date of Submission: 16-11-2017 Date of acceptance: 20-11-2017

I. Introduction

In 1965 Lotfi Zadeh, published his famous paper “Fuzzy sets” [1-4] Zadeh extended the work on possibility theory into a formal system of mathematical logic, and introduced a new concept for applying natural language terms. This new logic for representing and manipulating fuzzy terms was called fuzzy logic [5-7], and Zadeh became the Master/Father of fuzzy logic. Fuzziness rests on fuzzy set theory, and fuzzy logic is just a small part of that theory. Zadeh used the term fuzzy logic in a broader sense.

Fuzzy logic is based on the idea that all things admit of degrees. Temperature, height, and speed, and distance, beauty: Allof these come on a sliding scale. There are three main methods or steps of fuzzy inference system as given in Figure1 i.e. Fuzzification, Rule Evaluation and Defuzzification.
Fuzzification is the first step of the fuzzy inference system which is used to convert crisp values to the linguistic value.

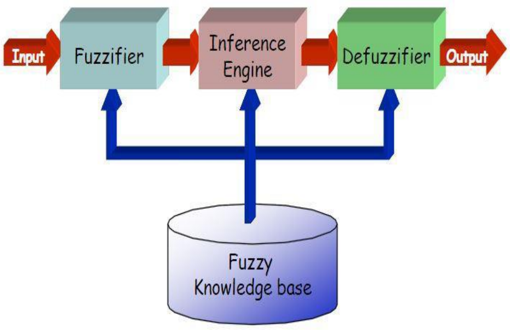

Figure1:Fuzzy Inference System

A fuzzy rule is defined as a conditional statement in the form: IF x is A THEN y is B Where:
x and y are linguistic variables; A and B are linguistic values determined by fuzzy sets on the universe of discourse X and Y, respectively.
Defuzzification [8, 9] is the process of producing a quantifiable result in fuzzy logic. In this step fuzzy output is mapped to a crisp output using the membership functions.
The objective of this paper is to analyze defuzzification techniques from an aspect of a real life problem.
This paper is divided into three sections. The first section is Preliminaries which provided a review on basics of fuzzy set theory and membership functions. In the second section we explained different defuzzification functions. In the third section we presented a real world problem on which we applied defuzzification techniques. Finally after section III we jotted down our conclusion.

II. Preliminaries

A review on Fuzzy set theory

Fuzzy logic is not logic that is fuzzy, but logic that is used to describe fuzziness. Fuzzy logic is the theory of fuzzy sets, sets that calibrate vagueness.

In fuzzy set theory: an element is with a certain degree of membership. Thus, a proposition is not either true or false, but may be partly true (or partly false) to any degree. This degree is usually taken as a real number in the interval [0,1].

The classical example in fuzzy sets is tall men. Consider the table 1 for this example. The elements of the fuzzy set "tall men" are all men, but their degrees of membership depend on their height.

Crisp set asks the question:

Is the man tall? Tall men are above 180, and not tall men are below 180.

Fuzzy set asks the question:

How tall is the man? The tall is partial membership in the fuzzy set, Raj is 0.82 tall.

A fuzzy set is a set with fuzzy boundaries. In the fuzzy theory, fuzzy set A of universe X is defined by function μA (x) called the membership function of set A .

$\mu A\ (x): X \rightarrow [0, 1]$

Where $\mu A\ (x) = 1$ if x is totally in A; $\mu A\ (x) = 0$ if x is not in A; $0 < \mu A\ (x) < 1$ if x is partly in A.

Table 1:NAME	HEIGHT cm	CRISP Degree of Membership	FUZZY Degree of Membership
Ali	208	1	1.00
David	205	1	1.00
Zia	198	1	0.98
Raj	181	1	0.82
Rohan	179	0	0.78
Rehab	172	0	0.24
Peter	167	0	0.15

Fuzzy set allows a continuum of possible choices. For any element x of universe X, membership function μA (x) equals the degree to which x is an element of set A. This degree, a value between 0 and 1, represents the degree of membership, also called membership value, of element x in set A.

Membership function its features

Membership function[10] (MF) - A function that specifies the degree to which a given input belongs to a set.

- Degree of membership- The output of a membership function, this value is always limited to between 0 and 1. It is also known as a membership value or membership grade.
- Membership functions are used in the fuzzification and defuzzification steps of a FLS (fuzzy logic system), to map the non-fuzzy input values to fuzzy linguistic terms and vice versa

Membership functions can be symmetrical or asymmetrical. They are typically defined on one-dimensional universes, or on multidimensional universes.

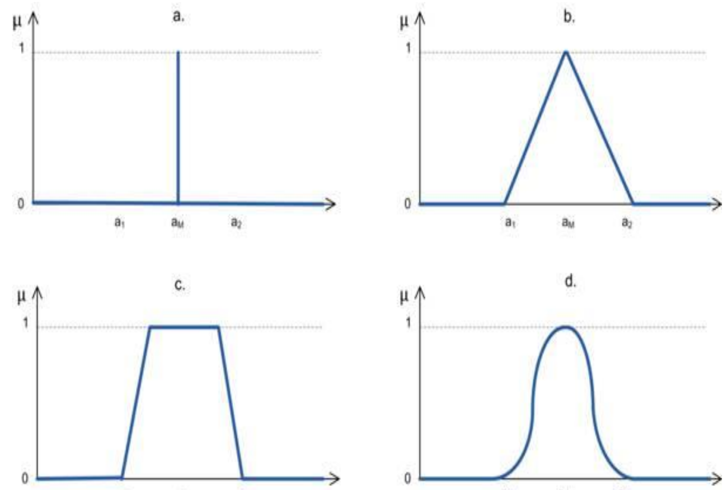

Figure 2 – a) Singleton b) Triangular fuzzy number c) Trapezoidal fuzzy number d) Bell-shaped, piecewise quadratic fuzzy number

There are six basic types of fuzzy membership functions:

- Triangular
- Trapezoidal
- z-shape
- S-shape
- sigmoid
- Gaussian

In Figure 2 graph of some functions are shown.
Features of fuzzy Membership Function:
Support: elements having non-zero degree of membership.
Core: set with elements having degree of 1.
Boundary: region of the universe containing elements that have a nonzero membership but not a complete membership.

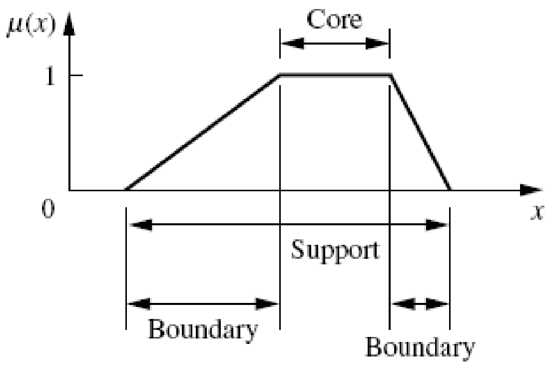

Figure 3:Graph of membership function

The simplest membership functions are formed using straight lines. These straight line membership functions have the advantage of simplicity.
Example: Triangular memberships function: trimf. Trapezoidal membership function: trapmf

We have used Trapezoidal membership function in to represent our problem.
Trapezoidal: Defined by its lower limit a and its upper limit d, and lower and upper limits of its nucleus, b and c respectively.

$$T(x) = \begin{cases} 0 & \text{if } (x \leq a) \text{ o } (x \geq d) \\ (x-a)/(b-a) & \text{if } x \in (a,b] \\ 1 & \text{if } x \in (b,c) \\ (d-x)/(d-c) & \text{if } x \in (b,d) \end{cases}$$

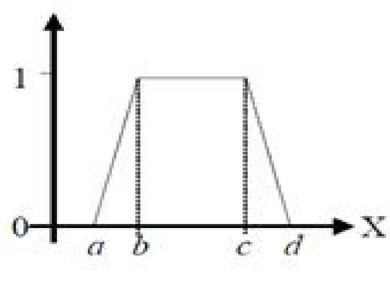

Figure 4: Graph of Trapezoidal function

The parameters *a* and *d* locate the "feet" of the trapezoid and the parameters *b* and *c* locate the "shoulders."

III. Defuzzification Techniques

The conclusion or control output derived from the combination of input, output membership functions and fuzzy rules is still a vague or fuzzy element and this process in called fuzzy inference. To make that conclusion or fuzzy output available to real applications, a defuzzification process is needed. The defuzzification process is meant to convert the fuzzy output back to the crisp or classical output to the control objective. Remember, the fuzzy conclusion or output is still a linguistic variable, and this linguistic variable needs to be converted to the crisp variable via the defuzzification process.
There are many defuzzification methods [11] like: Center-of-Area/Centroid, Center-of-Largest-Area, First-of-Maxima, Middle-of-Maxima etc.

Centroid of Area
This method is also known as center of gravity or center of area[12]. This technique was developed by Sugeno in 1985. This is the most commonly used technique. The only disadvantage of this method is that it is computationally difficult for complex membership functions. The centroid defuzzification technique can be expressed as.

$$z^* = \frac{\int \mu_{\underset{\sim}{C}}(z) \cdot z \, dz}{\int \mu_{\underset{\sim}{C}}(z) \, dz}$$

*Z** is the defuzzified crisp value.

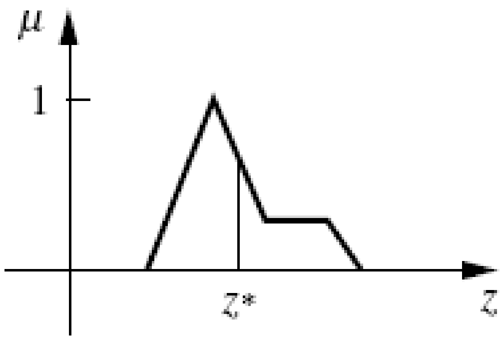

Figure 5: Graph of Centroid function

Bisector Method
The bisector is the vertical line that divides the region into two sub-regions of equal area. It is sometimes, but not always coincident with the centroid line.

$$\int_{\alpha}^{z_{BOA}} \mu_A(z)dz = \int_{z_{BOA}}^{\beta} \mu_A(z)dz$$

Weighted Average method
This method is usually restricted to symmetrical output membership functions [13-14].

$$z^* = \frac{\sum \mu_{\underset{\sim}{C}}(\bar{z}) \cdot \bar{z}}{\sum \mu_{\underset{\sim}{C}}(\bar{z})}$$

Where$\bar{Z}$the centroid of each symmetric membership function. For example:

$$z^* = \frac{a(0.5) + b(0.9)}{0.5 + 0.9}$$

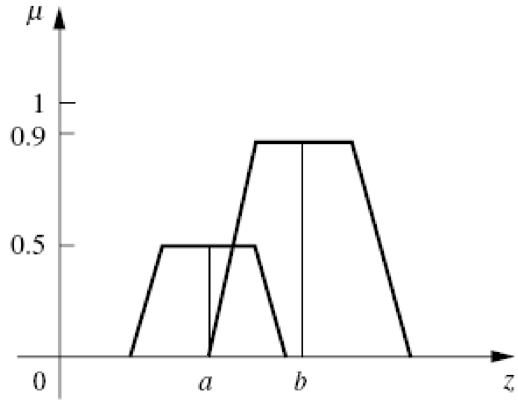

Figure 6: Graph of Weighted average

Mean of Maximum

In this method for defuzzification only active rules with the highest degree of fulfillment are taken into account. The output is computed a

$$z^* = \frac{a + b}{2}$$

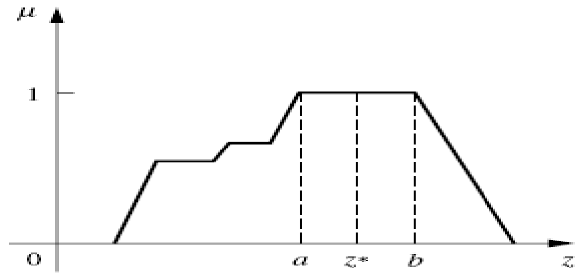

Figure 7: Graph of MOM

Largest of Maximum

Largest of maximum takes the largest amongst all z that belong to [z1, z2] as the crisp value called ZLOM.

Smallest of Maximum

It selects the smallest output with the maximum membership function as the crisp value ZSOM. In other words in Smallest of Maximum chooses smallest among all z that belong to [z1, z2].

IV. Defuzzification Approach in A Real Life Problem:

A Real Life Problem

A government intends to open new hospital with emergency services in the main part of the city to facilitate its citizen. The area in which new hospital is to open must purchase right-of-way considerations. For government to purchase the land, it must have assessment of the area of land to be purchased .Officers surveyed the area three times to collect the data over a period of time. But the three surveys on right-of-way width are found ambiguous as some land along the proposed land is already government owned and will need not to be purchased. Additionally, some ambiguity exists on boundaries and public right-of-way for old building and old roads.

In this problem we received the survey data in fuzzy form and we applied defuzzification to find a concrete result from the surveys done.

Suppose we define the survey data as fuzzy sets S1, S2, S3 which represent the uncertainty in each survey as to the membership of right of way width in meter in privately owned land.

Interpretation of Results

We have used different function available on software MATLAB for calculating our results. We have calculated crisp value using the five defuzzification methods described before.

First we have to find the membership function values of all the fuzzy sets i.e. S1, S2 and S3.Where μ (degree of membership)is .3 for S1, .5 for S2 and .8 for S3.

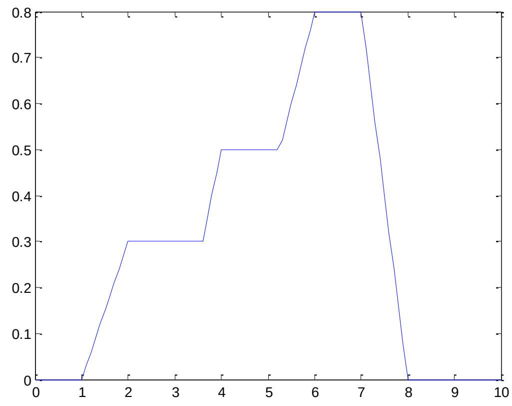

Figure 8: Graph showing trapezoidal fuzzy sets

We use trapezoidal membership function to inputs its values in defuzzification function.

```
x=0:0.1:10
 S1=trapmf(x,[1 2 4 5]);
 S2=trapmf(x,[3 4 6 7]);
 S3=trapmf(x,[4 6 7 8]);
 S1 = max(0.5*S2,max(0.3*S1,0.8*S3));
x1 = defuzz(x,S1,'centroid')
x1 =    5.1523
x1 = defuzz(x,S1,'bisector')
x1 =    5.5000
x1 = defuzz(x,S1,'mom')
X1=    6.5000
x1 = defuzz(x,S1,'lom')
x1 =     7
x1 = defuzz(x,S1,'som')
x1 =    6
```

We also calculated using weighted average method

Z*=(0.3x3)+ (0.5x5)+ (0.8x6)/0.3+0.5+0.9

=5.12

Table 2: Comparison Table

Method	**Defuzzified Value**
Centroid	5.15
Bisector	5.50
Weighted Average	5.12
LOM	7
MOM	6.5
SOM	6

We can clearly see from above table that centroid and Weighted Average are giving almost same result. Whereas in other methods there is lots of variation in result. So the right way path that needs to be purchased by the government is approx.:5.15 meter in a privately owned land.

V. Conclusion

In this paper we worked on a real life problem where we have some fuzzy outputs which need to be defuzzified to give a crisp result. We have presented different defuzzification techniques that can be applied to get an appropriate result. The results obtained using the six defuzzification methods have been shown in table 1. From this table we find that centroid method and weighted average method are giving us approximately the same results. Where for the smallest of maximum, largest of maximum and mean of maxima approaches there is wide variations in the results that are obtained. The reason for this is that these two methods use the two extremes i.e smallest or largest values for calculation of the crisp value.

Hence we conclude that centroid, and weighted Average methods are better as compared to the bisector, MOM, LOM, SOM, as there is more consistency in their results.

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