Asian Research Journal of Mathematics

Volume 20, Issue 10, Page 70-76, 2024; Article no.ARJOM.124090
ISSN: 2456-477X

Comparative Study of Fuzzy Logic Operators

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/arjom/2024/v20i10846

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/124090

Short Research Article

Received: 24/07/2024
Accepted: 26/09/2024
Published: 30/09/2024

Abstract

Fuzzy logic is currently very relevant because it offers a new way to approach tuning and decision-making problems. In this paper, we discuss a comparative study between Zadeh fuzzy operators and probabilistic operators, which are used during the activation outputs of the rules, to see which of them maximize or

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Cite as: *LUKENZU, Anyta MUKAWA, Jonathan OPFOINTSHI ENGOMBANGI, Fernand MAMANYA TAPASA, Camile LIKOTELO BINENE, and Grace NKWESE MAZONI. 2024. "Comparative Study of Fuzzy Logic Operators". Asian Research Journal of Mathematics 20 (10):70-76. https://doi.org/10.9734/arjom/2024/v20i10846.*

minimize the result of the defuzzification, in a fuzzy inference system used to create the fuzzy command control model, in artificial intelligence.
The aim of this paper is to conduct a comparative study of rule output values by applying Zadeh's fuzzy operators and those of probability when activating rule outputs; and not to create other applications or to compare our solutions with previous results.
We point out that we have carried out this comparative study of Zadeh fuzzy operators and probabilistic ones by exploiting several numerical examples such as in [1, 2, 3, 4, 5].
But to lighten the writing of this article, knowing that the steps of fuzzy inference are manually tedious, we consider the control data of a house fan, with two inputs (temperature and humidity) and one output (fan speed) processed by Baali Sabeur & Mahmoudi Messaoud in 2022.
We have presented the cuts of the outputs from Zadeh's methods compared to those called probabilistic.
After Fuzzification, activation of the Rules outputs, Aggregation of the outputs and defuzzification, we identified the fuzzy operators which maximize and those which minimize the net outputs, among the two families.

Keywords: Fuzzification; defuzzification; centroid; membership degree; fuzzy logic operators; Probor.

1 Introduction

In a control system, fuzzy inference is an operation by which we admit a proposition related to other previously admitted propositions [6,1].

This fuzzy operation plays an important role in Artificial Intelligence (AI) for the creation of fuzzy command or control systems, allowing a clear conclusion of the different outputs of the fuzzy rules, passing respectively through the following steps:

- Fuzzification
- Activation (Evaluation) of rule outputs
- Aggregation of rule outputs
- Defuzzification.

Defuzzification is the last step of fuzzy inference which aims to transform fuzzy values into a clean value called a real output [7,6,1].

We know that two methods are then applicable to obtain the retained value of the variable to be predicted, namely:

- The weighted average (WA) method
- The Center of Gravity (COG) Method

According to the literature review, this paper is not the first to talk about Zadeh fuzzy operators and probabilistic operators. But we note that our predecessors have not addressed a comparative study between these two families of operators, to see which one can maximize or minimize the result of defuzzification, in a fuzzy inference system used to create the control model, as evidenced by the works of: [8] Zadeh, LA, [9] Pedrycz, W., & Gomaa, A, [10] Cox, EJ, [4] Dominique Longin, [11] Kamyar Mehran, [12] LKWong,et Al, [13] Gradi Kamingu and [1] Baali Sabeur et Al.

In this essay, we ask why there must be two families: Zadeh operators and probabilistic operators?

This article can help us find answers to this.

Thus, the problem of our article revolves around the following question:

Is it possible to optimize output values during defuzzification?

It would be possible to maximize or minimize the values of the outputs of the rules in the following way:

After the step of aggregating the outputs of the rules, we will first defuzzify with the values of the fuzzy outputs given by the Zadeh fuzzy operators, then we will defuzzify with the values of the fuzzy outputs given by the probabilistic operators and finally, we will proceed to a comparison of the results of the net outputs obtained after applying two above-mentioned methods.

2 Definition of Fuzzy Operators [13,14,15,16,6]

By fuzzy operators, we mean all those that are used to combine premises linked by the conjunction AND or the disjunction OR. We focus on these two, although there may be others.

2.1 Zadeh Fuzzy Operators

In this paper, we address the two fuzzy connectors namely AND and OR by considering the approach advocated by Zadeh. As follows: Let A_1 and be A_2 two fuzzy subsets of the universe X, and $\mu_{A_i}(x)$ the membership degrees of x to the subsets A_1 and A_2.

- Fuzzy intersection case (ET/AND): $\mu_{A_1} \cap \mu_{A_2}(x) = Min\left[\mu_{A_1}(x), \mu_{A_2}(x)\right]$ where $\mu_{A_i}(x)$ are the membership degrees of x to the fuzzy subsets A_i.
- Case of the fuzzy meeting (OU/OR): $\mu_{A_1} \cup \mu_{A_2}(x) = Max\left[\mu_{A_1}(x), \mu_{A_2}(x)\right]$
  In this Approach, Max and Min are respectively the maximum and minimum of two membership degrees of x to the fuzzy subsets A_i.

2.2 Probabilistic Fuzzy Operators [13,17,6,1,2]

Fuzzy operators by the probabilistic approach are applied in the following way

- Case of fuzzy intersection (ET/AND): $\mu_{A_i \cap A_2}(x) = \mu_{A_1}(x) \times \mu_{A_2}(x)$
  The fuzzy operator AND is defined as the product of two membership degrees of X to the fuzzy subsets A_i.
- Case of the fuzzy meeting (OU/OR) $\mu_{A_i \cup A_2}(x) = \mu_{A_1}(x) + \mu_{A_2}(x) - \mu_{A_1}(x) \cdot \mu_{A_2}(x)$
  The OR operator is defined as a total probability of two degrees of membership of x to the fuzzy subsets A_1 and A_2.

3 Results and Application

We recall here that we carried out this comparative study of Zadeh fuzzy and probabilistic operators by exploiting several numerical examples such as [1, 2, 3, 4, 5].

But to make this article easier to write, knowing that the steps of fuzzy inference are tedious manually, we consider the control data of a house fan, with two inputs (temperature and humidity) and one output (fan speed) processed by Baali Sabeur & Mahmoudi Messaoud in 2022 where $\mu_{A_1}(x) = 0{,}5$and$\mu_{B_1}(y) = 0{,}25$ **,** $\mu_{A_2}(x) = 0{,}33$And $\mu_{B_2}(y) = 0{,}55$, $\mu_{A_3}(x) = 0{,}5$And$\mu_{B_3}(y) = 0{,}25$

3.1 Fuzzification

Consider the following rule base:

If X is $A_1(0.5)$ or Y is $B_1(0.25)$ then Z is $C_1(?)$
If X is $A_2(0.33)$ and Y is B_2 (0.75) then Z is C_2 (?)
If X is $A_3(0,0)$ and Y is $B_3(0,0)$ then Z is $C_3(?)$

We realize at this level that the values of the outputs of these three are unknown. We need to enable these rules including the AND and OR operators.

3.2 Evaluation of Rules

We first recall here the evaluation of the rules by the probabilistic method with two Inputs: Temperature $\mu_T(x) = 0{,}5$ and Humidity $\mu_H(y) = 0{,}25$

For rule 1: $\mu_{T \cup H}(x, y) = \mu_T(x) + \mu_H(y) - \mu_T(x) \cdot \mu_H(y)$

$= 0.5 + 0.25 – 0.5 \text{ x } 0.25$

$= 0.625$

For rule 2: $\mu_{T \cap H}(x, y) = \mu_{A_1}(x) \bullet \mu_{A_2}(y)$

$= 0.33 \text{ x } 0.75$

$= 0.25$

Table 1. Table of outputs of activated rules with Zadeh operators and probabilistic operators

Operator	Exit	Rules
	$C_1(0.5)$,	R1
Zadeh	$C_2(0.33)$	R2
	$C_3(0.00)$	R3
Probabilistic	$C_1(0.625)$	R1
	$C_2(0.25)$	R2
	$C_3(0.00)$	R3

After the fuzzification step in fuzzy inference, it is recommended to first activate the (outputs) of the rules before moving on to the aggregation of the rule outputs.

This is where we brought in the Zadeh operators and the probabilistic operators to activate the outputs of the rules, since these rules include premises linked by AND and premises linked by OR.

This Table 1 presents the outputs of the rules obtained with the two families of Zadeh and Probabilistic operators.

In the remainder of this article, we will exploit the outputs of the rules of these two families separately, in order to allow a comparative study on the values of the outputs.

3.3 Aggregation of Rule Outputs [1]

3.3.1 Aggregation of rule outputs obtained with Zadeh

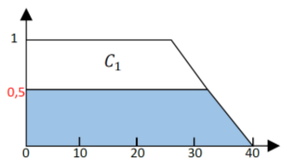

Fig. 1. Coupure de la sortie 1

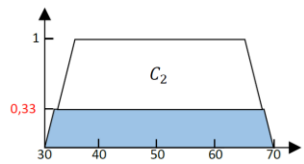

Fig. 2. Coupure de la sortie 2

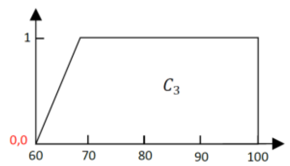

Fig. 3. Coupure de la sortie 3

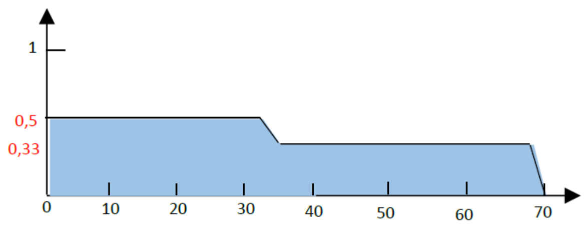

Fig. 4. Agrégation des sorties des règles selon Zadeh

a. Aggregation of rule outputs obtained with Probabilistic

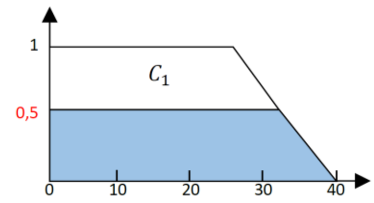

Fig. 5. Cutoff of Output 1

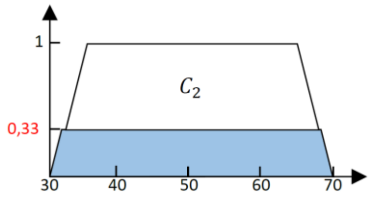

Fig. 6. Cutoff of Output 2

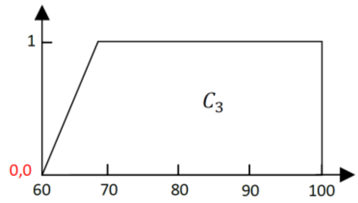

Fig. 7. Cutoff of Output 3

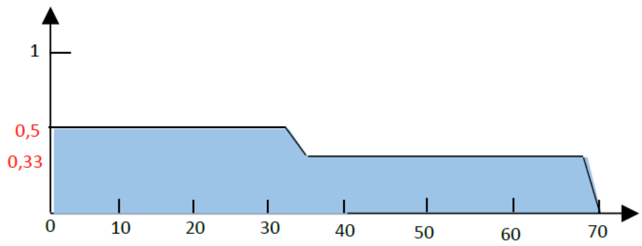

Fig. 8. Aggregation of Rule Outputs According to Zadeh

b. Aggregation of rule outputs According to Probor

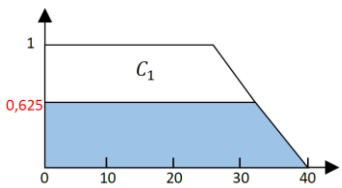

Fig. 9. Cutoff of Output 1

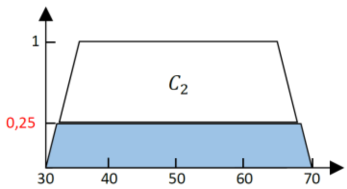

Fig. 10. Cutoff of Output 2

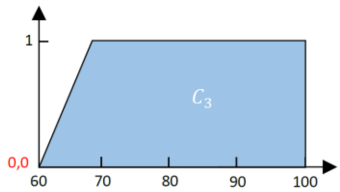

Fig. 11. Cutoff of Output 3

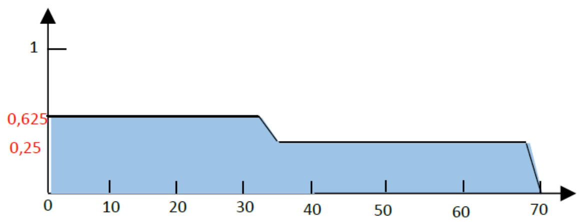

Fig. 12. Aggregation of Rule Outputs According to Probor

3.4 Defuzzification

In this paper, to obtain the unique net output, we will apply the centroid method [6, 1,3, 18,19].

$$CG=\frac{\sum_{x=a}^{b}\mu_A(x).x}{\sum_{x=a}^{b}\mu_A(x)}$$

A) **When defluxing with the values obtained from the operators of Zadeh, we will have** :

$$CG=\frac{(0+10+20+30)(0{,}5)+(40+50+60).(0{,}33)+(70+80+90+100).0}{(0{,}5\ .\ 4)+(0{,}33\ .\ 3\ )\ +(0.4)}$$

CG= 27

B) **When defluxing with the values obtained from the probabilistic operators, we will have** :

$$CG=\frac{(0+10+20+30)(0{,}625)+(40+50+60).(0{,}25)+(70+80+90+100).0}{(0{,}625\ .4)+(0{,}25\ .3)\ +(0.4)}$$

CG= 23

After defuzzifying the rule outputs, it should be noted that:

- The results of the outputs by the CG method are different.
- Zadeh operators maximized the output to 27%.
- The operators of Probabilistic minimized the output to 23%.

4 Conclusion

Throughout this article, the objective was to conduct a comparative study of the output values of the rules by applying Zadeh's fuzzy operators alongside probabilistic operators when activating the outputs of the rules. The focus was not on creating new applications or comparing our solutions with previous results.

After manually performing all steps of fuzzy inference—from fuzzification to defuzzification using the CG method—we found that the decision regarding the net output is made with a low percentage of confidence when using probabilistic operators.

Therefore, there is now a method to minimize or maximize the value of the net output after defuzzification, while considering the same inputs as needed.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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