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Subtractive clustering Fuzzy Expert System for Engineering Applications

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Abstract

Performance of a fuzzy expert system is related with how good the membership functions are normalized, tuned for a problem statement and correlation of antecedents and consequents. This paper helps in tuning and designing the membership functions that are best suited for the problem statement by integrating subtractive clustering method for fuzzy expert system design. Subtractive clustering algorithm is used to generate the tuned membership functions automatically in accordance to the domain knowledge. The proposed integrated design of clustering based fuzzy expert system acts in improving the accuracy and leads to a précised decision making environment. A practical example for ageing assessment of transformer insulation oil has been included to illustrate the method much effectively; the discussed example has been validated practically in the laboratory and is found that the proposed method is efficient in decision making

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1. Introduction

Decision making is a cautioned issue for thetechnocrats in various engineering domains which is being survived by the cutting edge advancements made to the methodologies that involved in thedecision making process. Choice of decision making is preferably done by using Multiple AttributeDecision Making (MADM) methods or Artificial Intelligent (AI)techniques depending on the problem constraints and available domain knowledge along with data related to the problem. MADM methods involve Simple additive weighting (SAW), Weighted Product Method (WPM),Analytical Hierarchy Process (AHP), TOPSIS, PROMETHEE [5]. Artificial Intelligent techniques include Artificial Neural Networks, Fuzzy systems, Evolutionary techniques, Data clustering algorithms; Knowledge based systems and Expert systems. The present paper is dealt with fuzzy expert system and subtractive clustering method which acts in proposing a novel alternative designing ideology for integrated fuzzy clustering expert system in detailed with practically validated example at the end of the day The accuracy of the decision making rely on the accuracy the decision maker involved with the problem statement because it is the choice of the decision maker to decide the weight age for the individual attributes for all the available alternatives in case of applying MADM methods. In case of AI techniques it is based on domain expert's knowledge and framing of relation between IF parts (Antecedents) and THEN parts (Consequents). In order to bring down human errors and increase accuracy, tasks were shifted to machines which mimic the human thinking. At first expert systems were developed in 1970s and by 1080s these were not only confirmed to laboratories but introduced to the fields. Fuzzy Expert System (FES) has found increasingly interest in engineering applications for its behavior towards reduction of errors, it is to be noted that that FES performance is based in construction of rules and tuning of membership functions which is quite complex [3]. The basic process involved in designing a FES is as depicted in Fig. 1.

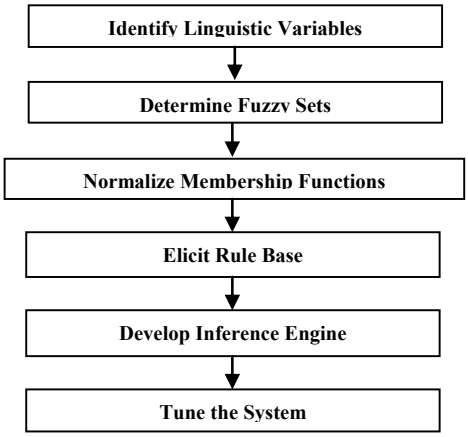

Fig. 1. Design of Fuzzy Expert System

So a step ahead this work presents a methodology for tuning the membership functions that deals in modification of the last step which is highlighted in the above figure. This tuning is done by integrating subtractive clustering algorithm as this algorithm has a remarkable feature of developing a fuzzy inference engine whose members ship functions were tuned according to the problem data, tuning of membership functions is done by identifying the number of linguistic variables as a cluster having a common center. An example of classifying the age group of power transformer insulation oil has been considered with New Age (NA), Medium Age (MA), and Old Age (OA) as linguistic variables.An expert system has been designed with the proposed method i.e. by integrating subtractive clustering method with existing method and found that this method is efficient by validating and comparing the obtained results with the practical results obtained in the laboratory. [4]. Observations on variations in shape of

membership functions were also compared and discussed to highlight the significance of the proposed method along with its performance in identifying the age of insulation oil.

2. Proposed Design of subtractive clustering FES

The design of FES became much complex with tuning of system, which involves with tuning of membership functions. So an attempt is made to bring the problem from complex and high dimensional space to a designer friendly space by handling this particular tuning of membership function task to Subtractive clustering algorithm. After applying the subtractive clustering algorithm an inference engine with the tuned membership functions will beobtained and the same can be further employed for expert system design. The proposed design of FES is as shown

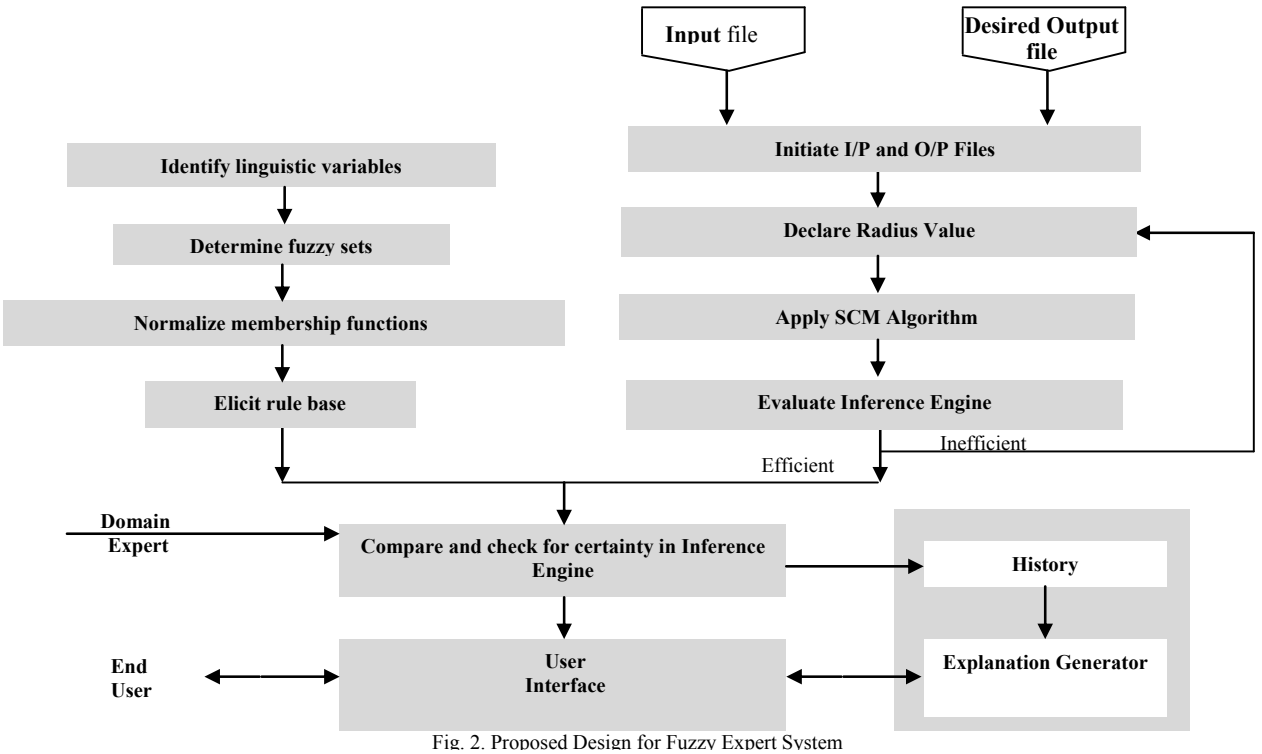

Fig. 2. Proposed Design for Fuzzy Expert System

For using subtractive clustering algorithm the following are required

- Input file: A data sheet with a single column and number of rows as required, containing all the linguistic variables data in ASCII format.
- Desired Output file: A data sheet with a single column and number of rows as required containing all the desired outputs for the corresponding input vectors present input file. It is to be noted that the number of rows for input and output files should be equal and the file is in ASCII format.
- *Radius value*: An integer which decides the influence for the cluster in the space. However an accurate value of radius can be found by the performance parameters of the algorithm.

At first an inference engine has been developed in Matlab environment which involves with identifying linguistic variables from the problem statement and developing membership functions in the universe of discourse, Evolution of all the antecedents and their implication to the associated consequents and develop an inference engine. The designing done so far is a usual method of designing a fuzzy inference engine, say IE-1 for instance, now instead of going for the tuning the inference engine(IE-1). Develop input file and desired output file as demonstrated above initiate both the files and confirm with an integer value as the radius value and declare the same value. Once the

input and output files were initiated and radius value declared apply subtractive clustering algorithm the function for applying the said algorithm in Matlab environment is shown in Equation 1 below

$$[C,S] = \text{subclust}([\text{filein fileout}],r); \quad (1)$$

Where, C = centre matrix, S = sigma values matrix, filein, fileout are input and output files, r = Radius

After applying the algorithm function for input and output files, entire data is plotted in a multi-dimensional space and each point acts a data point to form a cluster. Cluster centres are calculated and all the data points having higher influence on any cluster center will fall within that cluster. The formulation of clusters is based on density calculation which is calculated by the Eqn 2

$$D_i = \sum_{j=1}^{n} \exp\left(\frac{\left\| x_i - x_j \right\|^2}{r_a / 2^2} \right) \quad (2)$$

Here r_a is radius, x_i, x_j are data points. So a data point will have a high density value if there lie many number of data points in its surrounding. [2,6] The highest density point is chosen as first cluster center x_{c1} . In the next iteration the density measure of each data point x_i is obtained from Eqn 3 below

$$D_i = D_i - D_{C_i} \sum_{j=1}^{n} \exp\left(\frac{\left\| x_i - x_j \right\|^2}{r_a / 2^2} \right) \quad (3)$$

This process continues until a sufficient number of clusters are attainted. The main tasks of the algorithm are as follows:

- After calculation of density at each point first cluster center is identified as the point having highest density.
- Eliminates all data points in the area around the first cluster center as laid by the radius value for obtaining the next cluster center.
- The process continues until all the data points fall within the radii of a cluster center.

It is a matter of fact that a center matrix C, Sigma values matrix S and an inference engine say IE-2 for instance will be developed automatically after the algorithm terminates or simply called as the products of the algorithm. Evolution of this inference engine (IE-2) can be done by having knowing about the relationship between the C and S matrices and cluster center values in accordance to the membership functions of IE-2.

3. Example of insulation Oil age assessment

Problem statement: - *To identify the ageing of power transformer insulation oil within three age groups viz New Age (NA), Medium Age (MA), and Old Age (OA).*

Step 1: To define linguistic variables: The first, and probably the most important, step in building any expert system is to specify the problem. Problem input and output variables and their ranges are to be determined. In the current problem of this work, three linguistic variables are New age, Medium age, and Old age.***Step 2: To determine fuzzy sets***: Fuzzy sets can have a variety of shapes. However, a triangle membership function is selected in random. Fig.3 and Fig.4. represents input and output membership functions. Input membership function is justified by extracting features from the UV/VIS (spectroscopy) response as (-8.2) to 0 for NA, (0.1) to 64 for MA, 64.1 and above for OA [1, 7]. Output membership function is classified as 0-3 for NA, 3.1-6 for MA and 6.1-9 for OA and sets for all linguistic variables accordingly.
Step 3:Elicit fuzzy rules: All the rules that are to be accomplished with our system are to be developed with proper logical reasoning, in the current problem three rules based on If-Then; conditions were framed related to three

conditions in according to the age of oil.**Step 4:*Develop IF-1***: Inference Engine-1 is developed using Matlab Fuzzy logic tool

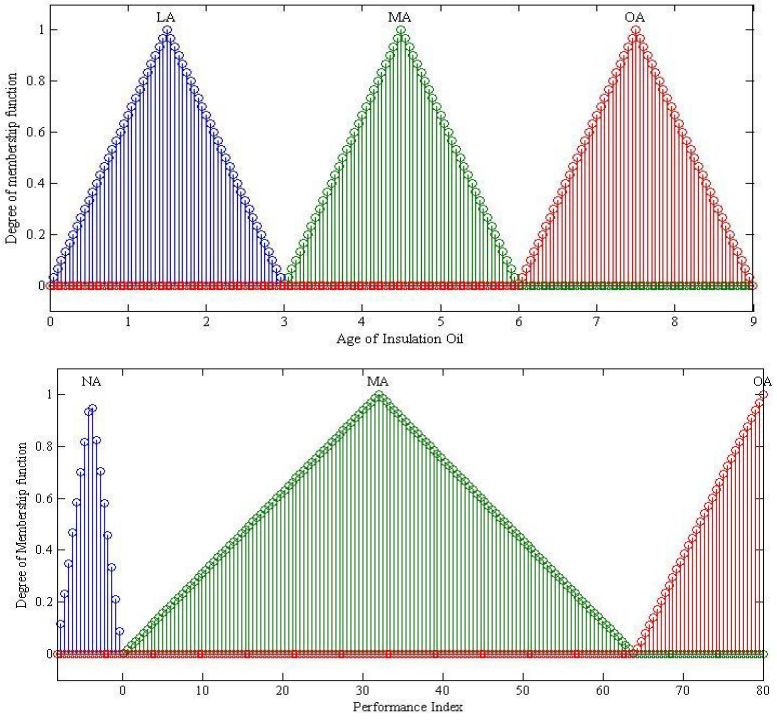

Fig.3. Input membership function of IE-1

Fig. 4. Output membership function of IE-2.

Step 5: Files and radius: For input file is of A total of 150 P.I values has been generated, 50 values for each age group and organized as (150 X 1) matrix in ASCII format. And for output file 150 desired outputs were designated in the same order and ASCII format. And a radius value of 5 is given and SCM function is applied. An inference engine IE-2 is generated here and is evaluated for all the input vectors by using rule viewer in Matlab environment.The inference engine IE-2 obtained from subtractive clustering algorithm has its membership functions which are best suit and optimal for the insulation oil ageing problem statement. The input membership function obtained from algorithm is shown in Fig 5. The discrimination between the shapes of input membership functions of IE-1 and IE-2 is observed from Fig. 3. and Fig. 5.

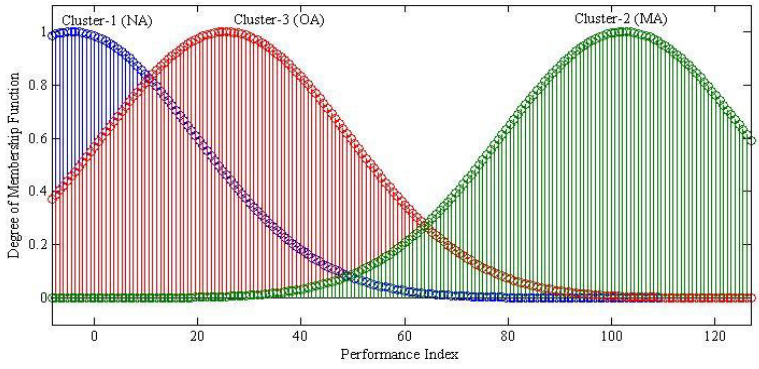

Fig. 5. Input membership function of IE-2

Using the cluster centers and their range of influences a FIS is developed which will then be used to explore and understand oil ageing. In this case fuzzy inference engine is generated with three input membership functions which represent three clusters followed by three rules because only three cluster centers were identified by the algorithm. The parameters of the membership function obtained are [23.9 -4.19], where 23.9 represents the spread coefficient of the gaussian curve and -4.19 represents the center of the gaussian curve. Input membership function of cluster1 captures the position and influence of the first cluster for the input variable (C (1, 1) = - 4.19, S(1)=23.9). The developed system is tested and the results are discussed in Table 1.

S.no	Ten Different Oil samples	Spectroscopy Result	Mean Absorbance	Performance Index	Proposed FES Result
1	S-1	New Oil	-0.05774	-5.774	1(NA)
2	S-2	New Oil	-0.063012	-6.3012	1(NA)
3	S-3	New Oil	-0.035247	-3.5247	1(NA)
4	S-4	Medium Oil	0.430253	43.0253	2(MA)
5	S-5	Medium Oil	0.577060	57.7060	2(MA)
6	S-6	Medium Oil	0.379901	37.9901	2(MA)
7	S-7	Medium Oil	0.304751	30.4751	2(MA)
8	S-8	Old Oil	0.958037	95.8037	3(OA)
9	S-9	Old Oil	0.690279	69.0279	3(OA)
10	S-10	Old Oil	0.730380	73.0380	3(OA)

Table 1.Performance comparison of proposed method with spectroscopy results.

For testing the efficiency or decision making capability of the proposed methodology using the current problem statement 10 different insulation oil samples from ten different transformers have been considered for ageing analysis and are tested using Ultra violet visual infrared spectroscopy and from the absorbance curve obtained mean absorbance is calculated which is used in performance index (P.I.) calculation for a particular sample, and further these performance index values has been subjected to fuzzy rule evaluation of Inference engine (I.E-2) which is generated by the subtractive clustering algorithm and the subtractive clustering fuzzy expert system with Inference engine (I.E-2) has been simulated in the Matlab environment and found that the proposed developed system hasbeen tested for several samples and is found efficient in identifying the ageing of power transformer insulation oil.

4. Conclusion

A methodology which is based on integrated clustering and fuzzy expert system has been proposed for effective and improved design of fuzzy expert system. The developed ideology helps in decision making and classification for any engineering indecisive statements. Design details along with implementation of the novel alternative method have been discussed. The proposed design methodology is explained step by step in detailed by considering an example of classification of power transformer oil ageing and its implementation is also discussed and found that the designed expert system is efficient in classifying the age group of the oil. This model helps in moving the decision making environment to a much précised environment.

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