Volume 1, No.1, March – April 2012
International Journal of Science and Applied Information Technology
Available Online at www.warse.ijatcse.current

Design and implementation of Fuzzy Expert System using Fuzzy Assessment Methodology

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ABSTRACT

This paper describes the design, implementation of fuzzy expert system for diagnosis of diabetes. The components of fuzzy expert system are fuzzification interface, Fuzzy assessment methodology and Defuzzification interface. Fuzzification interface converts the crisp values into fuzzy values. Fuzzy assessment methodology uses fuzzy operators, membership function, correlation fuzzy logic and probability to manage uncertainity in rules. Defuzzification interface converts the resulting fuzzy set into crisp values. To demonstrate the effectiveness of the proposed algorithm MATLAB Fuzzy Logic tool box is used for performance assessment. The result indicates that the fuzzy assessment methodology is very effective in improving the accuracy for diabetes application.

Keywords: Fuzzy Expert System, Fuzzy Assessment Methodology, Correlation Fuzzy Logic, Probability, Diabetes Application

1. NOMENCLATURE

Pregnant	Pregnant count
Glucose	Glucose concentration in 2-hours OGTT (mg/dl)
DBP	Diastolic blood pressure(mmHg)
TSFT	Triceps skin fold thickness(mm)
INS	2-hour serum insulin(mu U/ml)
BMI	Body mass index(Kg/m^2)
DPF	Diabetes Pedigree Function
Age	Age of the patients
DM	Diabetes Mellitus

2. INTRODUCTION

In the field of medicine the use of fuzzy expert system is highly increased to diagnosis disease. Fuzzy expert system incorporates fuzzy sets and fuzzy logic into knowledge representation schemes and Fuzzy Assessment Methodology. Blood sugar levels are controlled through medicine, diet and exercise in the treatment of diabetes**.**

Chang-Shing Lee [1] designed fuzzy decision making mechanism for fuzzy expert system to diagnosis diabetes. Ismail Saritas et al. [2] used the concept of fuzzification, fuzzy inference mechanism and defuzzification to design fuzzy expert system. D. U. Campos-Delgado et al. [3] used to regulate the blood glucose level with mamdani interface and developed an advisory/control algorithm for type 1 diabetes patients. Magni and Bellazzi[4] used stochastic model for self-monitoring blood sugar level in variety of clinical contexts to extract time course variability. Polat and Gunes[5] designed an expert system to improve the diagnostic accuracy of diabetes disease based on principal component analysis. K. Polat et al. [6] developed a methodology to diagnosis diabetes based on two stages. In first stage generalized discriminant analysis is used for healthy and patients and in second stage least square support vector machine is used to classify diabetes dataset. Chang and Lilly [7] proposed new evolutionary approach to derive a compact fuzzy classification system directly from data. L. B. Goncalves et al. [8] designed an inverted hierarchical neuro-fuzzy BSP system that extracts knowledge with rules and evaluated with different benchmark databases. Kahramanli and Allahverdi[9] designed hybrid neural network system to increase the reliability of the result using diabetes database. Mehdi Fasanghari et al.[10] with the concept of fuzzification a fuzzy expert system for Tehran stock exchange was developed. The American Diabetes Association [11] categorizes diabetes for children and young adults as type-1 diabetes and type-2 diabetes, i.e., the most common form of diabetes that the body does not produce adequate insulin. M. Kalpana and A. V Senthilkumar [12] used the concept of fuzzification, fuzzy verdict mechanism and defuzzification for diabetes.

This paper is organized as follows: Section 3 deals with the Design of fuzzy expert system. The experimental results, implemented in MATLAB fuzzy logic toolbox are presented in Section 4 and experimental results indicate that the proposed method are compared with other methods [1] [5] [7] [9][12][14][15] and [17]in section 5.

3. DESIGN OF FUZZY EXPERT SYSTEM

This section describes design of the fuzzy expert system, including Fuzzification interface, Fuzzy Assessment Methodology for diabetes application and Defuzzification interface represented in Figure 1.

3.1 Pima Indians Diabetes Database

The proposed fuzzy expert system is tested with Pima Indians Diabetes Database[16] retrieved from http://archive.ics.uci.edu/ml/

3.2 Modeling Fuzzy Expert Systems

Fuzzy expert system modeling can be pursued using the following steps.
1) Identify the input, output variables, fuzzy set and fuzzy numbers 2) Fuzzification interface 3) Fuzzy Assessment Methodology 4) Defuzzification interface

3.2.1 Identify the input, output variables, fuzzy set and fuzzy numbers

Input variables used to test the proposed Fuzzy Assessment Methodology algorithm are Glucose, INS, BMI, DPF, Age and the output variable are DM.

Input and output variables are organized summarized and knowledge are generalized using fuzzy set. Fuzzy set are
Glucose {low, medium, high},
INS {low, medium, high},
BMI {low, medium, high},
DPF {low, medium, high},
Age {young, medium, old} and
DM {verylow, low, medium, high, veryhigh}.

Special types of fuzzy sets restricting the possible types of membership functions are called Fuzzy numbers. Fuzzy set and fuzzy numbers are listed in Table 1.

3.2.2Fuzzification Interface

The fuzzification interface which transforms crisp inputs into fuzzy variables that are processed by Fuzzy Assessment Methodology[10]. With membership function crisp input is converted to fuzzy equivalent values. In this paper a triangular function is adopted as the membership function with parameter set[a,b,c] as shown in eqn. (1). The parameter is fixed with Minimum value, Mean, Standard Deviation, Maximum value for each variables[13]. Then the membership function μ(x) of the triangular fuzzy numbers[21] is given by

$$\mu(x) = \begin{cases} 0, x \le a \\ (x-a)/(b-a), a < x \le b \\ (c-x)/(c-b), b < x < c \\ 0, x > c \end{cases} --(1)$$

Table 1: Representation of Fuzzy variables and numbers

Fuzzy Variables	Representation of Fuzzy Variables	Fuzzy Numbers	Representation of fuzzy numbers
Glucose	D_1	low	d_{11}
		medium	d_{12}
		high	d_{13}
INS	D_2	low	d_{21}
		medium	d_{22}
		high	d_{23}
BMI	D_3	low	d_{31}
		medium	d_{32}
		high	d_{33}
DPF	D_4	low	d_{41}
		medium	d_{42}
		high	d_{43}
Age	D_5	young	d_{51}
		medium	d_{52}
		old	d_{53}
DM	O	verylow	O_1
		low	O_2,
		medium	O_3
		high	O_4
		veryhigh	O_5

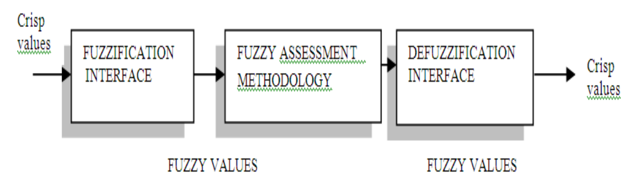

Figure 1: Diagram of the Fuzzy Expert System for diabetes

Figure 2 and Figure 3 represents fuzzy values. The input fuzzy value Age (let x), that varies from 26 to 30, the fuzzy expression will be

$$\mu_{low}(x) = \begin{cases} \frac{26-x}{26}; 26 \le x \le 27 \\ 0; otherwise \end{cases}$$

$$\mu_{medium}(x) = \begin{cases} \frac{27}{x}; 26 \le x \le 27 \\ \frac{30-x}{27}; 27 \le x \le 30 \\ 0; otherwise \end{cases} --(2)$$

$$\mu_{high}(x) = \begin{cases} 0; x < 27 \\ \frac{x-27}{27}; 27 \le x \le 30 \\ 1; otherwise \end{cases}$$

3.2.3 Fuzzy Assessment Methodology

Fuzzy Assessment methodology undergoes following steps

1. Choose the membership function and fuzzy operator
2. Calculate probability for fuzzy rules.
3. Compute the correlation fuzzy logic.
4. Rules are evaluated with OR operator.
5. MIN operator map the antecedent part of the rule into consequence and SUM operator combines the output of each rule into single set.

Membership functions and Fuzzy Operators

Three triangular membership functions (MFs) for each input variable(D_1,D_2,D_3,D_4,D_5)and four triangular MFs for the output variable (O) using eqn (1) with parameters D_1 [Min, Mean-SD, Mean+SD, Max], D_2 [Min, Mean-SD, Mean+SD, Max], D_3 [Min, Mean-SD, Mean+SD, Max], D_4 [Min, Mean-SD, Mean+SD, Max] and D_5 [Min, Mean-SD, Mean+SD, Max] listed in Table 2.

The overall performance of fuzzy expert system is improved by fuzzy operator. In Fuzzy Assessment Methodology T-norm operator used is algebraic product and T-conorm operator used is algebraic sum[20]. Fuzzy operators are intersection and union. Let D_1,D_2,D_3,D_4,D_5 are input variable. Fuzzy intersection operator is represented by T-norm

$$Tp(D_1,D_2,D_3,D_4,D_5)= D_1,D_2,D_3,D_4,D_5$$

where Tp is algebraic product and Fuzzy union are represented by T-conorm. Fuzzy union operator are represented by

T-cornorms

$$Cp(D_1,D_2,D_3,D_4,D_5)= D_1+D_2+D_3+D_4+D_5 - (D_1,D_2,D_3,D_4,D_5)$$

where Cp is algebraic sum.

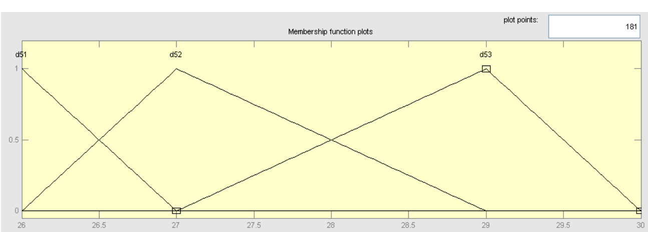

Figure 2: Membership graphics for the fuzzy three values Age

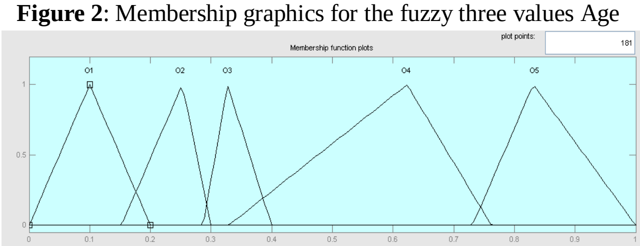

Figure 3: Membership graphics for the fuzzy values DM

Table 2: Parameters of Triangular Membership Functions

Fuzzy Variables	**Fuzzy Numbers**	**Fuzzy triangular numbers**
D_1	d_{11}	[71 94.41 121.27]
	d_{12}	[94.41 121.27 148.12]
	d_{13}	[121.27 148.12 196]
D_2	d_{21}	[0 15.16 89.82]
	d_{22}	[15.16 89.82 194.81]
	d_{23}	[89.82 194.81 579]
D_3	d_{31}	[0 24.46 33.24]
	d_{32}	[24.46 33.24 42.03]
	d_{33}	[33.24 42.03 67.1]
D_4	d_{41}	[0.13 0.21 0.44]
	d_{42}	[0.21 0.44 0.67]
	d_{43}	[0.44 0.67 0.96]
D_5	d_{51}	[26 26 27]
	d_{52}	[26 27 29]
	d_{53}	[27 29 30]
O	O_1	[0 0.1 0.2]
	O_2,	[0.1524 0.2524 0.3]
	O_3	[0.287 0.327 0.3997]
	O_4	[0.329 0.623 0.762]
	O_5	[0.731 0.831 1]

Probability values for Fuzzy Rules

Conditional Statements forms fuzzy rules. Fuzzy rule includes two parts

1) Evaluating the rule antecedent ie., if part of the rule.

2)Implication or applying the result to the consequent ie., then part of the rule.

All the rules fire to some extent in the antecedent part of the fuzzy system. Independent evidences $D_1(d_{11},d_{12},d_{13})$, $D_2(d_{21},d_{22},d_{23})$, $D_3(d_{31},d_{32},d_{33})$, $D_4(d_{41},d_{42},d_{43})$, $D_5(d_{51},d_{52},d_{53})$ are mutually exclusive and exhaustive hypotheses $O(O_1,O_2,O_3,O_4,O_5)$ and provides probabilities for hypothesis $p(O_1)$, $p(O_2)$, $p(O_3)$, $p(O_4)$ and $p(O_5)$ respectively. Conditional probabilities are determined for each hypothesis. The expert system computes the probabilities for all hypotheses according to Eqn. 3

$$P(O_i/D_1\ D_2\ D_3 D_4\ D_5) = \frac{P(D_1/O_i) * P(D_2/O_i) * P(D_3/O_i) * P(D_4/O_i) * P(D_5/O_i) * P(O_i)}{\sum_{k=1}^{3} P(D_1/O_k) * P(D_2/O_k) * P(D_3/O_k) * P(D_4/O_k) * P(D_5/O_k) * P(O_k)} \quad --> (3)$$

$$where (i = 1,2,3,4,5)$$

For the nine set of rules probability values are calculated using the eqn. (3) and results are displayed in Figure 4.

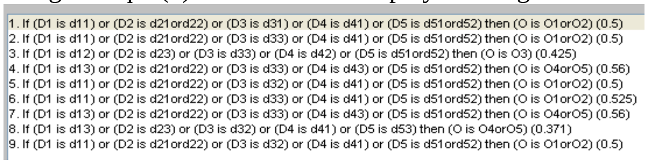
1. If (D1 is d11) or (D2 is d21ord22) or (D3 is d31) or (D4 is d41) or (D5 is d51ord52) then (O is O1orO2) (0.5)
2. If (D1 is d11) or (D2 is d21ord22) or (D3 is d33) or (D4 is d41) or (D5 is d51ord52) then (O is O1orO2) (0.5)
3. If (D1 is d12) or (D2 is d23) or (D3 is d33) or (D4 is d42) or (D5 is d51ord52) then (O is O3) (0.425)
4. If (D1 is d13) or (D2 is d21ord22) or (D3 is d33) or (D4 is d43) or (D5 is d51ord52) then (O is O4orO5) (0.56)
5. If (D1 is d11) or (D2 is d21ord22) or (D3 is d32) or (D4 is d41) or (D5 is d51ord52) then (O is O1orO2) (0.5)
6. If (D1 is d11) or (D2 is d21ord22) or (D3 is d33) or (D4 is d41) or (D5 is d51ord52) then (O is O1orO2) (0.525)
7. If (D1 is d13) or (D2 is d21ord22) or (D3 is d33) or (D4 is d43) or (D5 is d51ord52) then (O is O4orO5) (0.56)
8. If (D1 is d13) or (D2 is d23) or (D3 is d32) or (D4 is d41) or (D5 is d53) then (O is O4orO5) (0.371)
9. If (D1 is d11) or (D2 is d21ord22) or (D3 is d32) or (D4 is d41) or (D5 is d51ord52) then (O is O1orO2) (0.5)

Figure 4: Rule for Fuzzy Expert System in MATLAB

Correlation Fuzzy Logic

Correlation is to find the relationship between two variables. While plotting the Membership function there occurs an overlapping between each and every function[17]. The overlapping may be solved by using correlation fuzzy logic.

Let fuzzy number and memberships function for D_5 may be defined for d_{51} and d_{52} represented as $d_{51} = \mu_{d51}(x)$ and $d_{52} = \mu_{d52}(x)$. Output fuzzy number and memberships function for O may be defined for O_1, O_2, O_4, O_5 represented as $O_1 = \mu_{O1}(x)$, $O_2 = \mu_{O2}(x)$, $O_4 = \mu_{O4}(x)$ and $O_5 = \mu_{O5}(x)$. We compute the correlation coefficient using the formula (4)

$$\begin{aligned} \rho &= \mathrm{cov}(\mu_{d51}(x),\mu_{d52}(x)) \Big/ \sqrt{\mathrm{var}(\mu_{d51}(x)).\mathrm{var}(\mu_{d52}(x))} \\ \rho &= \mathrm{cov}(\mu_{O1}(x),\mu_{O2}(x)) \Big/ \sqrt{\mathrm{var}(\mu_{O1}(x)).\mathrm{var}(\mu_{O2}(x))} \\ \rho &= \mathrm{cov}(\mu_{O4}(x),\mu_{O5}(x)) \Big/ \sqrt{\mathrm{var}(\mu_{O4}(x)).\mathrm{var}(\mu_{O5}(x))} \end{aligned} \quad (4)$$

The correlation coefficient for membership function d_{51} and d_{52} is obtained from eqn(4). If $\rho=-1$there is no overlap. The membership function d_{51} or d_{52} and O_1 or O_2 and O_4 or O_5 using correlation logic is shown in the Figure 5 and Figure 6.

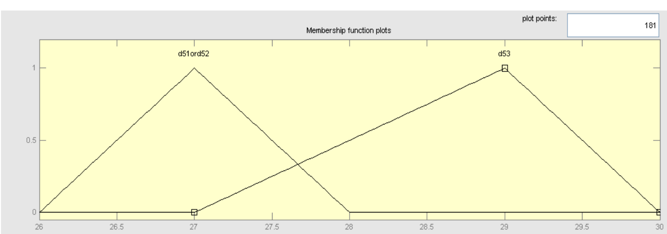

Figure 5: A membership function Ageyoung or Agemedium using correlation logic

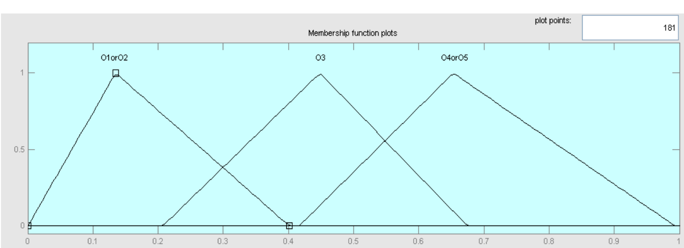

Figure 6 : A membership function DMverylow or DMlow and DMveryhigh or DMhigh using correlation logic

OR operator

The rule base consists of nine if-then rules. Fuzzy operator is applied if there is more than one part in antecedent to obtain the result. The OR operator is used to evaluates the antecedent part of the rule. The fifteen different pieces of the antecedent (d_{11},d_{12},d_{13},d_{21},d_{22},d_{23},d_{31},d_{32},d_{33},d_{41},d_{42},d_{43},d_{51},d_{52},d_{53}) gives the fuzzy membership values respectively. The developed fuzzy rule has multiple antecedents. Implication is the process of mapping result of the fuzzification from antecedent part into the consequence [21].

MIN and SUM operator

Antecedent gives single number as input for implication process and output is fuzzy set**.** For more than one fuzzy rule fired at same time, MIN operation is conducted by the system. Implication results through the aggregation process. The outputs of each rule are combined into a single fuzzy set by aggregation process and uses SUM operation.

3.2.4 Defuzzification

Defuzzification process is conducted to convert aggregation result into crisp value for O output. Transforms the fuzzy set obtained in Fuzzy assessment methodology into crisp values. The final combined fuzzy conclusion is converted into a crisp value by using the centroid method[2]. Fuzzy assessment methodology analyzes the personal physical data, converts the inferred results into knowledge, and then presents the decision results through descriptions. The patterns of the statement for output descriptions, includes Statement study and Assessment Statement.

Proposed Algorithm: Fuzzy assessment methodology

Input: All terms (D_1,D_2,D_3,D_4,D_5) selected
Output: Output term O
Method
Step 1: Create input fuzzy set $D_1(d_{11},d_{12},d_{13})$, $D_2(d_{21},d_{22},d_{23})$, $D_3(d_{31},d_{32},d_{33})$, $D_4(d_{41},d_{42},d_{43})$, $D_5(d_{51},d_{52},d_{53})$ and input fuzzy set $O(O_1,O_2,O_3,O_4,O_5)$
Step 2: Set fuzzy operator to T-norm $Tp(D_1,D_2,D_3,D_4,D_5)= D_1,D_2,D_3,D_4,D_5$
where Tp is algebraic product.
Step 2.1: Set fuzzy operator to T-cornorms $Cp(D_1,D_2,D_3,D_4,D_5)= D_1+D_2+D_3+D_4+D_5 - (D_1,D_2,D_3,D_4,D_5)$
Where Cp is algebraic sum.
Step 3: Calculate D_1,D_2,D_3,D_4,D_5 [min,mean-SD.mean+SD,max] using triangular membership function.
Step 4: Compute correlation coefficient with formula

$$\rho = \frac{\mathrm{cov}(d_{51}, d_{52})}{\sqrt{\mathrm{var}(d_{51})}\sqrt{\mathrm{var}(d_{52})}}$$

Step 5: Estimate Probability using the formula

$$P(O_i/d_{11}\, d_{21}\, d_{31}\, d_{41}\, d_{51}) = \frac{P(d_{11}/O_i)*P(d_{21}/O_i)*P(d_{31}/O_i)*P(d_{41}/O_i)*P(d_{51}/O_i)*P(O_i)}{\sum_{k=1}^{3} P(d_{11}/O_k)*P(d_{21}/O_k)*P(d_{31}/O_k)*P(d_{41}/O_k)*P(d_{51}/O_k)*P(O_k)}$$

where i=1,2,3

Step 6: If D_1 is d11 or D_2 is d_{21} or D_3 is d_{31} or D_4 is d41 or D_5 is d_{51} then O is O_3(probability)

Step 7: Antecedent part (D_1 is d11 or D_2 is d_{21} or D_3 is d_{31} or D_4 is d41 or D_5 is d_{51}) into consequent (O is O_3) by MIN operator

SUM operator

Step 8: Set rules output $\longrightarrow$ { output term O}

End

Statement pattern of output Descriptions

Statement study (SS):

The data exhibit that person is at [Age: Agey, Agem, Ageo], meanwhile the plasma glucose concentration in 2-hour OGIT is [Glucose: Gl, Gm, Gh], 2-hour serum insulin is [INS: INSl, INSm, INSh], body mass index is [BMI: BMIl, BMIm, BMIh], and diabetes pedigree function is [DPF: DPFl, DPFm, DPFh]

Assessment Statement(AS)

The Assessment Statement justifies that the possibility of suffering from diabetes for this person as [DM: DMvl, DMl, DMm, DMh, DMvh](Possibility:[0,1]).

4. EXPERIMENTAL RESULTS

The performance of the proposed fuzzy expert system has been developed in MATLAB fuzzy logic toolbox. Pima Indians Diabetes Database was chosen to evaluated data set. Through Pima Indian Diabetes Database, Knowledge can analyzed based on the Fuzzification interface, Fuzzy assessment methodology and Defuzzification interface for the parameter very young [1].The first experiment shows sets of results in Table 3 and Figure 6, indicating that the proposed approach automatically supports the analysis of the data. The acquired information is then transferred into knowledge, and finally the proposed method presents them in the form of the descriptions of humans. Then collected information's are transferred into knowledge and the results of the method proposed are presented in the human understandable form

5. PERFORMANCE ASSESSMENT

Performance of the Assessment Statement and the medical practitioner are the basic evaluation criteria. Result of this experiment can be assessed based on the accuracy level. The True Positive (TP) and the True Negative (TN) denote the correct classification. False Positive (FP) is the outcome when the predicted class is yes (or positive) and actual class is no (or negative). Still, a False Negative (FN) is the outcome when the predicted class is no (or negative) and actual class is yes (or positive). Table 4 lists the various outcomes of a two-class prediction [16].Accuracy is the proportion of the total number of predictions that were correct. The eqn. (5) show the formula for accuracy.

$$Accuracy = \frac{TN + TP}{TN + FP + FN + TP} X\, 100\, \% \; -- > (5)$$

Table 3 : Final Result for Medical practitioner

Data	Glucose (mg/dl)	INS (mu U/ml)	BMI (Kg/ m^2)	DPF	Age
	172	579	42.4	0.702	28
Statement study	If(Glucose is Gh) or(INS is INSm) or (BMI is BMIh) or (DPF is DPFh) or(Age is Agey) then (DM is DMh)				
Assessment Statement	The Assessment Statement justifies that the possibility of suffering from diabetes for this person is medium(possibility:**0.532**)				
Justification by Medical Practitioner	Medical practitioner justification is the person is diabetes				

Table 4 : Different Outcomes of a Two-Class Prediction

Actual class	Predicted class	
	Yes	No
Yes	True positive (*TP*)	False Negative (*FN*)
No	False positive (*FP*)	True Negative (*TN*)

The final experiment compares the accuracy of the proposed method with results of studies involving the Pima Indians Diabetes Database [1][5][7][9][12][14][15][17]. The proposed method achieves the highest accuracy value for "very young" which is indicated in the Table 5 and Figure 7.

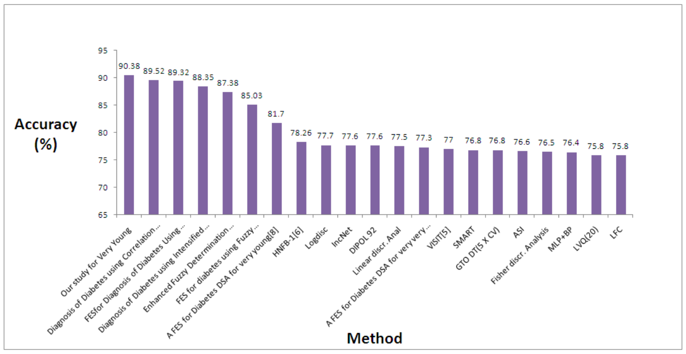

Figure 7: Graphical represent of accuracy

Table 5: Comparison of accuracy of Proposed Method with Earlier Methods

Method	Accuracy (%)	Author
Our study for Very Young	**90.38**	M.Kalpana and Dr. A.V.Senthil Kumar
Diagnosis of Diabetes using Correlation fuzzy logic in Fuzzy Expert System[17]	89.52	M.Kalpana and Dr. A.V.Senthil Kumar
FESfor Diagnosis of Diabetes Using Fuzzy Determination Mechanism [15]	89.32	M.Kalpana and Dr. A.V.Senthil Kumar
Diagnosis of Diabetes using Intensified Fuzzy Verdict Mechanism[14]	88.35	Dr. A.V.Senthil Kumar and M.Kalpana
Enhanced Fuzzy Verdict for Diabetes using Fuzzy Expert System	87.38	M.Kalpana and Dr. A.V.Senthil Kumar
FES for diabetes using Fuzzy Verdict Mechanism	85.03	M.Kalpana and Dr. A.V.Senthil Kumar
A FES for Diabetes Decision very young[8]	81.7	Lee and Wang
$HNFB^{-1}$[6]	78.26	Goncalves et al.
Logdisc	77.7	Statlog
IncNet	77.6	Norbert Jankowski
DIPOL 92	77.6	Statlog
Linear discr. Anal	77.5-77.2	Statlog, ster and Dobnikar
A FES for Diabetes Decision very very young[8]	77.3	Lee and Wang
VISIT[5]	77	Chang and Lilly
SMART	76.8	statlog
GTO DT(5 X CV)	76.8	Bennet and Blue
ASI	76.6	Ster and Dobnikar
Fisher discr. Analysis	76.5	Ster and Dobnika
MLP+BP	76.4	Ster and Dobnika
LVQ(20)	75.8	Ster and Dobnika
LFC	75.8	Ster and Dobnika

6. CONCLUSION AND FUTURE RESEARCH

The proposed fuzzy expert system is very effective to diagnosis the diabetes. Pima Indians Diabetes Database is taken as an experimental data set to test the proposed method. Fuzzy assessment methodology evaluates the number of membership function, correlation fuzzy logic to identify area overlap between fuzzy number and membership and probability to manage uncertainty in rules. Accuracy achieved through this method is 90.38% which can also improved through future works. Future works includes certainty factors in rules to improve accuracy.

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