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Fuzzy Expert System for Diabetes using Fuzzy Verdict Mechanism

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ABSTRACT

The fuzzy logic and expert system is an important technique to enhance the machine learning reasoning. In this paper, we propose a fuzzy expert system framework which constructs large scale knowledge based system effectively for diabetes. The knowledge is constructed by using the fuzzification to convert crisp values into fuzzy values. By applying the fuzzy verdict mechanism, diagnosis of diabetes becomes simple for medical practitioners. Fuzzy verdict mechanism uses triangular membership function with mamdani's inference. Defuzzification method is adopted to convert the fuzzy values into crisp values. The result of the proposed method is compared with earlier method using accuracy as metrics. The proposed fuzzy expert system can work more effectively for diabetes application and also improves the accuracy of fuzzy expert system.

Keywords: Diabetes application, Fuzzification, Fuzzy Verdict Mechanism, Fuzzy Expert System

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1. Introduction

Campos-Delgado et al. [1] developed a fuzzy-based controller that incorporates expert knowledge to regulate the blood glucose level. Magni and Bellazzi [2] devised a stochastic model to extract variability from a self-monitoring blood sugar level time series. Polat and Gunes [3] designed an expert system to diagnose the diabetes disease based on principal component analysis. Polat et al. [4] also developed a cascade learning system to diagnose the diabetes. Chang and Lilly [5] developed an evolutionary approach to derive a compact fuzzy classification system. Goncalves et al. [6] introduced an inverted hierarchical neuro-fuzzy BSP system for pattern classification and rule extraction in databases. Kahramanli and Allahverdi [7] designed a hybrid neural network system for classification of the diabetes database. Chang-Shing Lee [8] designed as fuzzy expert system for diabetes decision support application based on the fuzzy ontology with five layer fuzzy ontology.

Ismail saritas et al.[9] developed a fuzzy expert system to determine drug dose in treatment of chronic interstine inflamation using the concept of fuzzification. Mehdi Fasanghari et al.[10] developed a fuzzy expert system for Tehran stock exchange using the concept of fuzification. Diabetes treatment focuses on controlling blood sugar levels to prevent various symptoms and complications through medicine, diet, and exercise. The American Diabetes Association [11] categorizes diabetes into type-1 diabetes, which is normally diagnosed in children and young adults, and type-2 diabetes, i.e., the most common form of diabetes that originates from a progressive insulin secretory defect so that the body does not produce adequate insulin or the insulin does not affect the cells.

The increasing number of diabetics worldwide has drawn the attention of a diverse array of fields, including artificial intelligence and biomedical engineering, explaining why related technologies such as fuzzy inference mechanisms and fuzzy expert systems have been adopted for diabetes research.

The proposed fuzzy expert system gives the description for diabetes and support for the justification of the medical practitioners. The structure of the rest of this paper is as follows: Section 2 deals with the architecture of fuzzy expert system. The experimental results, implemented in MATLAB are presented in Section 3 and experimental results indicate that the proposed fuzzy expert system can work more effectively than other methods can [3], [5], [7],[8] in section 4.

2. Fuzzy Expert System for Diabetes Application

This section describes a fuzzy expert system, including a fuzzification and fuzzy verdict mechanism for diabetes application.

2.1 Pima Indians Diabetes Database

The National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) [13] has examined the Pima Indians for the past three decades. This group has one of the highest known rates of diabetes worldwide. The experimental PIDD is retrieved from the Internet (http://archive.ics.uci.edu/ml/) and it contains the collected personal data of the Pima Indian population. Table I lists the attributes of PIDD.

Table I: Atttributes of PIDD

Abbreviation	Fullname	Units
Pregnant	Number of times pregnant	-
Glucose	Plasma 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	-
DM	Diabetes Mellitus where ‘1’ is interpreted as “tested positive for diabetes”	-

2.2 Architecture of the Fuzzy Expert System for Diabetes Application

Fuzzy concept is to transfer the information of the PIDD into the required knowledge. The fuzzy numbers must be constructed according to the generated concepts. For the PIDD, each case has nine attributes, listed in Table I, and each attribute can be constructed as a fuzzy variable with some fuzzy numbers. The relationship in the PIDD with respect to age is given in Table II

Table II: Description of Fuzzy Relation

Fuzzy Relation	Description
R≥FZ(Age0_25)	Very Very Young
R≥FZ(Age25_30)	Very Young
R≥FZ(Age30_35)	More or Less Young
R≥FZ(Age35_40)	Slightly Young
R≥FZ(Age40_45)	Slightly Old
R≥FZ(Age45_50)	More or Less Old
R≥FZ(Age50_55)	Very Old
R≥FZ(Age55_60)	Very Very Old

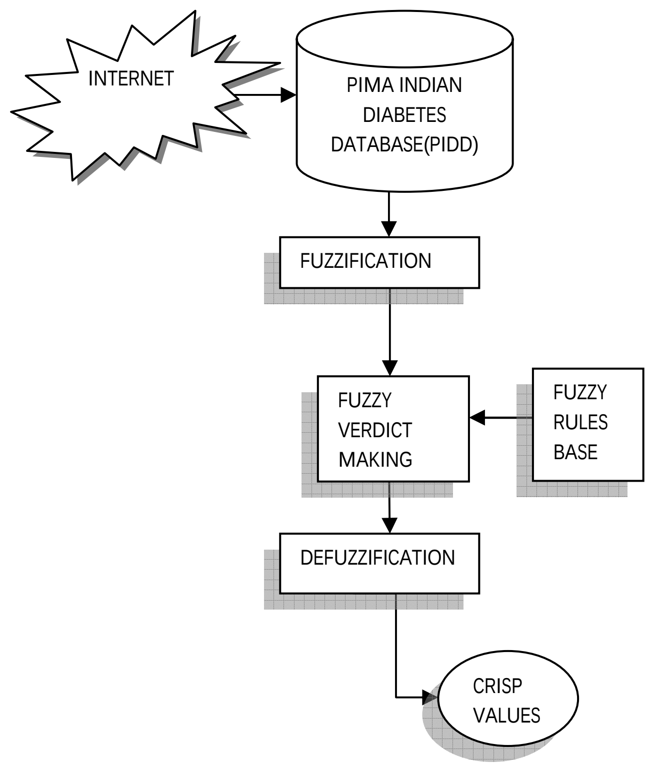

Figure 1:Architecture of the Fuzzy Expert System for diabetes application

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2.3 Fuzzification

Fuzzification simply refers to the process of taking a crisp input value and transforming it into the degree required by the terms[10]. If the form of uncertainty happens to arise because of imprecision, ambiguity, or vagueness, the variable is probably fuzzy and can be represented by a membership function. If the inputs generally originate from a piece of hardware, or drive from sensor measurement, then these crisp numerical inputs could be fuzzified in order for them to be used in a fuzzy inference system [12]

Next, based on the constructed fuzzy concepts, the fuzzy numbers are built by the fuzzy relationship. Additionally, an interface is offered to tune and validate the parameters of the built fuzzy numbers. In this paper a triangular function as shown in (1) is adopted as the membership function of the fuzzy number and can be expressed as the parameter set[a,b,c]. Then the membership function μ (x) of the triangular fuzzy number[12] is given by

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

The PIDD is first retrieved from the Internet to become the experimental database. By fuzzification the crisp input values, its membership values and degrees are obtained. These obtained fuzzy values are processed in fuzzy verdict mechanism. Here, the output values which are also obtained by using rule-base are sending to defuzzification unit and from this unit the final crisp values are obtained as output[9]. The fuzzy values are given in the Figure 2, Figure 3.

The input fuzzy value Glucose (let x), that varies from 56 to 198, the fuzzy expression will be

$$\mu_{low}(x) = \begin{cases} \frac{56-x}{56}; 56 \le x \le 117 \\ 0; otherwise \end{cases}$$

$$\mu_{medium}(x) = \begin{cases} \frac{117}{x}; 56 \le x \le 117 \\ \frac{198-x}{117}; 117 \le x \le 198 \\ 0; otherwise \end{cases} \quad --(2)$$

$$\mu_{high}(x) = \begin{cases} 0; x < 117 \\ \frac{x-117}{117}; 117 \le x \le 198 \\ 1; otherwise \end{cases}$$

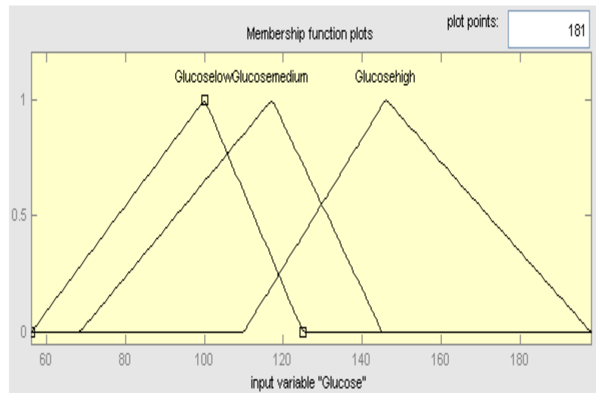

Figure 2: Membership graphics for the fuzzy three values Glucose

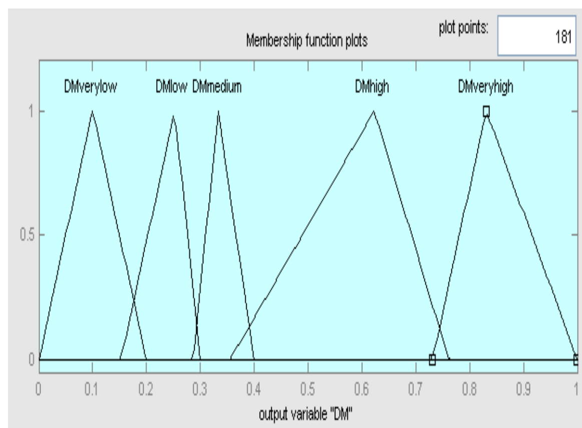

Figure 3: Membership graphics for the fuzzy values DM

2.4 Fuzzy Verdict Mechanism

The fuzzy verdict mechanism separately infers the possibility of an individual developing diabetes for each instance in fuzzification and transfers the possibility into the form of sentences. According to the American Diabetes Association [11], diabetes is associated with obesity, family history, and age. Additionally, the American Diabetes Association also indicates that the 2-hour OGTT with measurement of plasma glucose and serum insulin concentrations are used as the criteria for diagnosing diabetes. Consequently, five attributes, i.e., *Glucose*, *INS*, *BMI*, *DPF*, and *Age*, are selected as the input fuzzy variables of the adopted fuzzy rule-based inference system; in addition, the related information about fuzzy numbers is stored in the fuzzification. The parameters of the fuzzy numbers are listed in Table III

Table III: Parameters of Triangular Membership Functions

Fuzzy Numbers	Fuzzy Numbers	Fuzzy triangular numbers
Glucose	low	[56 100 125]
	medium	[68.2 117 145]
	high	[109.9 146 198]
INS	low	[0 55.11 87.67]
	medium	[63.63 98.42 191.6]
	high	[95.34 188.3 586]
BMI	low	[18 22 30.8]
	medium	[31.01 37.01 45.01]
	high	[36.43 44.43 67]
DPF	low	[0.085 0.5322 1.132]
	medium	[0.547 1.03 1.717]
	high	[1.09 1.476 2.4]
Age	young	[25 25 26]
	medium	[25 26 27]
	old	[26 27 30]
DM	verylow	[0 0.1 0.2]
	low	[0.1524 0.2524 0.3]
	medium	[0.287 0.333 0.3997]
	high	[0.355 0.623 0.762]
	veryhigh	[0.731 0.831 1]

The fuzzy variable *Glucose* has three fuzzy numbers, i.e., *Glucoselow*, *Glucosemedium*, and *Glucosehigh*. For the fuzzy variable *INS*, fuzzy concepts and knowledge of the 2-hour serum insulin are expressed in human communication by using the fuzzy numbers *INSlow*, *INSmedium*, and *INShigh*. The membership functions of *BMI* also have three fuzzy numbers, i.e., *BMIlow*, *BMImedium*, and *BMIhigh*. The fuzzy numbers *DPFlow*, *DPFmedium*, and *DPFhigh* are defined for the fuzzy variable *DPF*. The membership functions of the fuzzy variable *Age* are *Ageyoung*, *Agemedium*, and *Ageold*.

The five fuzzy numbers, i.e., *DMverylow*, *DMlow*, *DMmedium*, *DMhigh*, and *DMveryhigh*, are adopted to represent the possibility of this instance with diabetes for output fuzzy variable *DM*.

The proposed fuzzy verdict mechanism consists of four steps, i.e., fuzzy matching, fuzzy inference, combination, and defuzzification [13]. The membership degrees for all instances of the fuzzification are calculated using the membership functions and then using the OR fuzzy disjunction, the operator combines the matching degree of each rule with multiple conditions. Secondly, fuzzy interface is invoked by using Mamdani's approach. Thirdly, inference results of the rules fired the same consequences are integrated by performing MIN fuzzy operations. The final combined fuzzy conclusion is converted into a crisp value by using the centroid method.

Fuzzy Verdict Mechanism analyzes the personal physical data, converts the inferred results into knowledge, and then presents the decision results through descriptions [14], [15]. The patterns of the sentence of the output descriptions, including a sentence analysis and a decision sentence and Algorithm for the fuzzy verdict mechanism is given below.

Algorithm of Fuzzy Verdict Mechanism

INPUT
Input the fuzzy set for Glucose, INS, BMI, DPF and Age
OUTPUT
Output the fuzzy set for DM
METHOD

Begin
Step1:Input the crisp values for Glucose ,INS, BMI, DPF and Age.
Step 2: Set the triangular membership function for the fuzzy number with equation (1).
Step 3: Built the fuzzy numbers for Glucose, INS, BMI, DPF and Age for input set
Step 3.1: Built the fuzzy number for DM for the output set.
Step4: Fuzzy inference are executed by Mamdani 's method.
Step 4.1: Input the rule as {Rule 1,2…..k}
Step 4.2: Matching degree of rule with OR fuzzy disjunction are calculated for fuzzy input set (Glucoselow, Glucosemedium, Glucosehigh, INSlow, INSmedium, INShigh, BMIlow, BMImedium, BMIhigh, DPFlow, DPFmedium, DPFhigh, Ageyoung, Agemedium, Ageold)
Step 4.3 Calculate the aggregation of the fired rules having same consequences for fuzzy output set DM (DMverylow, DMlow, DMmedium, DMhigh, DMveryhigh).

Step5: Defuzzify into the crisp values by

$$DM_i \leftarrow \frac{\sum_{i=1}^{n} Z_i \mu(Z_i)}{\sum_{i=1}^{i=n} \mu(Z_i)}$$

Where Z_i means the weight for $\mu(Z_i)$ and $\mu(Z_i)$ means the number of fuzzy numbers of the output fuzzy variable DM.
Step6: Present the knowledge in the form of human nature language.
End.

Sentence pattern of output Descriptions.

Sentence Analysis(SA):
The personal physical data exhibit that person is at $[FN_{Age}$:young,medium,old]age, meanwhile the plasma glucose concentration in 2-hour OGIT is $[FN_{Glucose}$:low,medium,high], 2-hour serum insulin is $[FNI_{INS}$:low,medium,high], body mass index is $[FN_{BMI}$:low,medium,high], and diabetes pedigree function is $[FN_{DPF}$:low,medium,high]

Decision Sentence(DS):
The Decision sentence justifies the possibility of suffering from diabetes for this person as $[FN_{DM}$:verylow,low,medium,high,veryhigh] (Possibility:[0,1]).

3. Experimental Results

The proposed fuzzy expert system for diabetes application was implemented with the MATLAB. The experimental environment was constructed to evaluate the performance of the proposed approach; in addition, PIDD was chosen as the evaluated data set. The proposed approach can analyze the personal physical data of the PIDD and generate corresponding human knowledge based on the Fuzzification for the parameter very young [8].

The experiment shows a set of results in Table IV, indicating that the proposed approach automatically supports the analysis of the physical data. The acquired information is then transferred into knowledge, and finally the proposed method presents them in the form of the descriptions of humans.

Table IV: Result obtained from MATLAB

Physical data	Glucose (mg/dl)	INS (mu U/ml)	BMI (Kg/m^2)	DPF	Age
	78	88	31	0.248	26
SA	If(Glucose is glow)or(INS is INSlow)or(BMI is BMIlow)or DPF is DPFlow) or (Ageyoung) then (DM is DMverylow)				
DS	The Decision sentence justifies that the possibility of suffering from diabetes for this person is medium(possibility:**0.382**)				
Medical Practitioner Justification	Medical practitioner justification is the person is non diabetes				

Rule for Fuzzy Expert System

1. If(Glucose is Glucoselow) or(INS is INSlow) or (BMI is BMIlow) or (DPF is DPFlow) or(Age is Ageyoung)is DMverylow
2. If(Glucose is Glucoselow) or(INS is INSlow) or (BMI is BMIhigh) or (DPF is DPFlow) or(Age is Ageyoung) then (DM is DMlow)
3. If(Glucose is Glucosemedium) or(INS is INShigh) or (BMI is BMIhigh) or (DPF is DPFmedium) or(Age is Ageyoung) then (DM is DMmedium)
4. If(Glucose is Glucosehigh) or(INS is INSmedium) or (BMI is BMIhigh) or (DPF is DPFhigh) or(Age is Ageyoung) then (DM is DMhigh)
5. If(Glucose is Glucoselow) or(INS is INSlow) or (BMI is BMImedium) or (DPF is DPFlow) or(Age is Ageyoung) then (DM is DMverylow)

4. Evaluation of System Performance

The second experiment evaluates the performance of the Decision sentence and the medical practitioner. Accuracy is the measuring scale for performance of this experiment. 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 VI lists the various outcomes of a two-class prediction [16]. Accuracy is the proportion of the total number of predictions that were correct. The precision is the proportion of the predicted positive cases that were correct. The eqn. (3) show the formula for accuracy.

$$Accuracy = \frac{TN + TP}{TN + FP + FN + TP} X100\% --(3)$$

Table V: Comparison of Proposed method Accuracy with earlier methods

Method	Accuracy (%)	Author
Our study for Very Young	**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

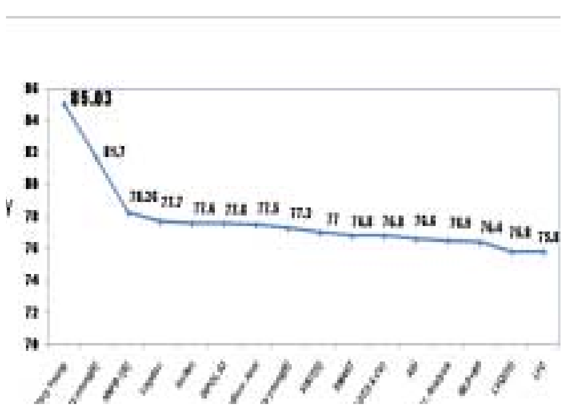

Figure 4: Graphical represent of accuracy

Table VI

DIFFERENT OUTCOMES OF A TWO-CLASS PREDICTION

Actual class	Predicted class: Yes	Predicted class: 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 PIDD [5], [6], [8]. Comparing these methods, as listed in Table V, reveals that the proposed method achieves the first highest accuracy values for "very young" based on the proposed fuzzy expert system.

The accuracy values of the proposed method are compared with the earlier methods and represented graphically figure 4, which shows better accuracy

5. Conclusions and Future Research

This paper presents fuzzy expert system for diabetes using fuzzy verdict mechanism. The experimental data set, PIDD, is initially processed and the crsip values are converted into fuzzy values in the stage of fuzzification. The fuzzy verdict mechanism then executes rules to make a decision on the possibility of individuals suffering from diabetes and to present the knowledge with descriptions. Experimental results indicate that the proposed method can analyze data and further transfer the acquired information into the knowledge to simulate the thinking process of humans. The results further demonstrate that the proposed method works more effectively for diabetes application than previously developed ones. Future works should test the fuzzification approach used herein for other similar tasks or diabetes-related data sets to evaluate its capability to produce a similar accuracy. Future works should undertake the implication and operators for s-norms and t-norms to improve the accuracy of Fuzzy Verdict Mechanism.

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