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Presenting a Fuzzy Expert System for Diagnosis of Diabetes

Abolfazl Kazemi[a,*], Ali Mohammadi[a]

Department of Industrial Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran

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Abstract

Today, the problem of non-infectious diseases has overshadowed many health beliefs and has attracted the attention of scientific communities. In the past, the main problem of society and people was infectious diseases and the high mortality caused by these diseases, while today, due to the control of infectious diseases, the development of urbanization, the advancement of industry and machine life, in other words, the change in the quality and lifestyle of people, the spread of diseases Non-communicable diseases have increased and gradually contagious diseases have given their place to non-communicable diseases, so that today the most important causes of death in societies are non-communicable diseases, especially cardiovascular diseases, cancers and accidents. Diabetes mellitus is a chronic disease that is very expensive, complicated and debilitating. By the end of 2017, more than 425 million people between the ages of 20 and 79 were suffering from diabetes, which will reach 619 million people by 2045. For this reason, it is very important to provide diabetes control solutions. In this paper, a new method for simulating control in diabetic patients is presented. For this purpose, the technique of fuzzy expert system has been used in MATLAB software to analyze the data.

***Keywords**:* Diagnosis of diabetes, Control and treatment, Symptoms of diabetes, Fuzzy expert system

1.Introduction

Diabetes mellitus, which is called diabetes for short from now on; it is a disease in which the amount of insulin secretion is less than the amount necessary to maintain normal blood sugar. Insulin is a substance that is made in the body of all people by a part of the pancreas and is poured into the bloodstream. This substance plays an important role in the metabolism of starches and simple sugars and thus blood sugar regulation. Therefore, its relative reduction in diabetes leads to an increase in blood sugar, which, if not properly controlled and regulated, leads to irreparable damages in different parts of the body. The meaning of the relative reduction of insulin is that either the secretion of insulin from the pancreas is reduced or its effectiveness in the body is reduced; it means that there is not enough insulin in the body anyway (Moucheraud, et al., 2019).

Diabetes has been identified by the UN and WHO as one of the five priority non-communicable diseases (NCDs) in their Action Plan to confront the NCDs challenge. Prevention and management of the chronic complications in patients with diabetes involve complex, long-lasting, and costly endeavors (Cousin, et al., 2022).

Diabetes is one of the most common metabolic diseases. Diabetes, high blood pressure and blood lipid disorders are called diseases of the new civilization. New civilization due to urbanization and limiting human activity and increasing the consumption of energy-rich substances has created new diseases that were previously referred to as diseases of the rich. In the past, when the occupation of most people was agriculture, horticulture and animal husbandry, the masters and their families, considering that their work was done by others and had access to most different types of food, were more exposed to obesity and diabetes; While the current mechanical life and the consumption of high-calorie foods have put all people at risk (Vanelli, et al., 1999).

Although type 1 and type 2 diabetes both have things in common, there are lots of differences. Like what causes them, who they affect, and how you should manage them. For a start, type 1 affects 8% of everyone with diabetes. While type 2 diabetes affects about 90%. Some people get confused between type 1 and type 2 diabetes. This can mean you have to explain that what works for one type doesn't work for the other, and that there are different causes. The main thing to remember is that both are as serious as each other. Having high blood glucose (or sugar) levels can lead to serious health complications, no matter whether you have type 1 or type 2 diabetes. So if you have either condition, you need to take the right steps to manage It (Preumont & Buysschaert, 2020).

Considering that type 2 diabetes includes about 85-95% in developed countries and an even higher percentage of all types of diabetes in developing countries, so prevention and care of this type of diabetes is of particular importance (Uchenna, et al., 2010). For this reason, in this research, we investigated type 2 diabetes.

In order to reduce the number of deaths, it is necessary to develop methods and techniques that help in early

* Corresponding Author. Email: abkaazemi@qiau.ac.ir

diagnosis. In this regard, the main problem of the current research is a comprehensive and accurate diagnostic solution in diabetes control, which should be researched in this field. In this article, the control of blood sugar levels in diabetic patients is investigated. The presented model for the considered insulin-glucose system has nonlinear dynamics with high dependence of variables on each other. This model is more accurate and complete than other models, but it has flaws and problems, in this research, the model has been improved and the controller has been designed for this model. In order to obtain effective techniques for the early diagnosis of diabetes, advanced technology information has been needed. One of the best techniques in this field is data mining. Data mining provides the ability to extract and explore large data. These patterns help to diagnose and make decisions in medicine. In addition, unfortunately, we see a decrease in the age of contracting this disease. It is estimated that about 149 million people worldwide, or 1.5% of the adult population, have diabetes, and this amount will increase to 333 million or 6.3% by 2025 (Simmons, 2021).
The rest of this paper is organized as follows. Section 2 introduces the theory of types of diabetes. Section 3 reviews related literature. Section 4 presents some basic concepts of proposed methodology. Section 5 explains problem definition. Section 6 analyzes the computation results. Finally, Section 7 will be the conclusions and directions for future research.

2. Types of Diabetes

Diabetes is an important and costly health problem that affects almost all age groups. Diabetes causes many complications due to hyperglycemia. So that approximately four million deaths occur annually due to complications related to diabetes, which is about 9% of deaths worldwide. These complications include cardiovascular diseases, heart attacks, stroke, kidney problems, non-traumatic amputation of the end organs, retinopathy, nephropathy, neuropathy, blindness and reduced life expectancy of patients. The increase in the prevalence of this disease is caused by continuous changes in lifestyle such as improper diet, lack of physical activity, obesity and stress, which is often related to urbanization, mechanization and industrialization. The development of urbanization, life in the industrial world and the control of infectious diseases along with the change in the age structure of the society in the direction of aging, our population is increasingly affected by the increase in the incidence and prevalence of important non-communicable diseases such as cancers, cardiovascular diseases, stroke, diabetes and They will face risk factors (Wentzell, et al., 2022). There are four types of diabetes:

2.1. Type 1 Diabetes

Usually, people with type 1 are children, teenagers and young people (people under 30 years old). This type of disease is caused by the destruction of insulin-producing cells. People who suffer from this disease are usually thin and the symptoms of the disease are noisy; so that binge drinking (more than usual consumption of water), polyuria (excessive excretion of urine so that they may need to urinate several times even during the night) and weight loss occur in them over a period of several days to several weeks and It progresses. These patients need insulin injections to control blood sugar; otherwise, in addition to the aggravation of the above symptoms, they will experience heartache, nausea, vomiting, lethargy and shortness of breath; which is called diabetic ketoacidosis. Failure to diagnose and treat diabetic ketoacidosis on time can be fatal. For diagnosis, a blood sugar test should be done, especially when fasting for at least 8 hours.

2.2. Type 2 Diabetes

This type of diabetes is usually seen in middle-aged and elderly people, and its cause is a lack of insulin secretion or a decrease in its effectiveness. Affected patients are usually obese or overweight. The symptoms of this type of diabetes include: excessive drinking, excessive urination, nocturnal urination, and in more severe cases, visual disturbances, weight loss, and severe fatigue. Unlike type 1 diabetes, its onset is usually very slow and silent, so that the affected person may not have any symptoms at first or they may be few. As a result, a person may be unaware of his disease for years, and the emergence of one of the long-term complications of diabetes, such as long-term tingling and numbness in the legs, leads to the investigation and identification of the disease. Due to the high prevalence of this disease, it is recommended to perform a fasting blood sugar test at maximum intervals of 3 years in all people over 45 years old and other people at risk. Fasting for 8-10 hours is enough to perform this test. But if blood lipids are to be tested, 12-14 hours of fasting is needed. Blood sugar-lowering tablets are usually used for medical treatment of these patients, but insulin may be needed after a while to better control blood sugar.

2.3. Gestational Diabetes

It is a type of diabetes that usually starts for the first time during pregnancy, especially in the second half, that is, after the 20th week. About 5-9% of pregnant women get this type of diabetes. Its cause is often the secretion of substances in the body that increases during pregnancy and the source of their secretion is the placenta. These substances cause resistance to the effect of insulin; therefore, gestational diabetes usually improves with delivery and delivery of the placenta. This type of diabetes is usually asymptomatic; but in severe cases, the affected person suffers from excessive drinking and excessive urination. After the first infection, the probability of this type of diabetes recurring in subsequent pregnancies is higher, and even after childbirth, to prevent

diabetes, special measures such as weight control, increasing physical activity and following a diet (to prevent overweight) must be done. To control gestational diabetes, the use of a balanced diet, not skipping meals (timely consumption of at least three meals), increasing physical activity, especially upper body exercises, and sometimes the use of drugs (usually insulin) are required. Failure to identify and control the disease can cause special problems for the mother and fetus. To identify gestational diabetes, blood sugar test after consuming a sugar solution (sugar syrup with a specific concentration) is used, which is usually done at the end of the sixth or seventh month of pregnancy.

2.4. Diabetes Due to Various Reasons

The use of certain drugs such as corticosteroids, diseases of the pancreas, some endocrine diseases such as excessive secretion of growth hormone and overactive adrenal glands, etc. can also cause diabetes mellitus. Obviously, the above cases are among the rare causes of diabetes and in these cases, the treatment should focus on the underlying cause.
People with diabetes continuously experience certain symptoms. These symptoms include:

- Extreme thirst
- Frequent urination
- Weight Loss
- Increased hunger
- Blurred vision
- Immobility
- Numbness or tingling in hands and feet
- Frequent blistering of the skin
- Infection of the gums
- Severe and unexplained fatigue

Also, in some cases, there are no symptoms that usually occur in type 2 diabetes. In such cases, a person may not realize that he has diabetes for months or even years . Symptoms in these people develop so slowly that they cannot be detected.

3. Literature Review

Polat and Güneş (2007) detected on diabetes disease using principal component analysis (PCA) and adaptive neuro-fuzzy inference system (ANFIS). They improved the diagnostic accuracy of diabetes disease combining PCA and ANFIS. The proposed system had two stages. In the first stage, dimension of diabetes disease dataset that has 8 features is reduced to 4 features using principal component analysis. In the second stage, diagnosis of diabetes disease is conducted via adaptive neuro-fuzzy inference system classifier. Dogantekin et al. (2010) presented an intelligent diagnosis system for diabetes based on Linear Discriminant Analysis (LDA) and Adaptive Network Based Fuzzy Inference System (ANFIS): LDA-ANFIS. The structure of this LDA-ANFIS intelligent system for diagnosis of diabetes consisted of two phases: The Linear Discriminant Analysis (LDA) phase and classification by using ANFIS classifier phase. In the first phase, Linear Discriminant Analysis (LDA) is used to separate characteristics variables between healthy and patient (diabetes) data. In second phase, the healthy and patient (diabetes) features obtained in first phase are given to inputs of ANFIS classifier.

Beloufa and Chikh (2013) conducted diagnosis of diabetes disease with artificial intelligence techniques. They proposed a novel Artificial Bee Colony (ABC) algorithm in which a mutation operator is added to an Artificial Bee Colony for improving its performance. This modified version of ABC use as a new tool to create and optimize automatically the membership functions and rules base directly from data. Duangpim and Assawinchaichote (2016) presented a method for controlling the blood glucose and free fatty acid (FFA) of body in type 1 diabetes patients in order to obtain the appropriate value in case of insulin limited. They developed a model of Takagi-Sugeno (TS) fuzzy for the nonlinear system of blood glucose and free fatty acid.

Eghbali-Zarch, et al. (2018) presented computer-aided medical decision support using a fuzzy Multi-Criteria Decision-Making (MCDM) model that hybridizes a Step-wise Weight Assessment Ratio Analysis (SWARA) method with a modification of Fuzzy Multi-Objective Optimization on the basis of a Ratio Analysis plus the full multiplicative form (FMULTIMOORA) method for pharmacological therapy selection of Type 2 Diabetes (T2D). Rani et al. (2020) introduced an innovative Complex Proportional Assessment (COPRAS) to solve the Type 2 Diabetes (T2D) medication selection problem under the Pythagorean fuzzy environment. They addressed a new formula based on entropy measure and score function is introduced to evaluate the unknown criteria weights. To doing so, they developed a new entropy measure and score function under the PFSs context. Thakkar et al. (2021) used data mining and fuzzy logic techniques for diabetes diagnosis. The methodology presented the pipeline of various tasks such as selecting the dataset, preprocessing the data by applying numerous methods such as standardization, normalization etc. After that, feature extraction technique was implemented on the dataset for improving the accuracy and finally dataset worked on data mining and fuzzy logic various classification algorithms.

Dymova et al. (2022) presented an interval-valued intuitionistic fuzzy extension of rule base evidential reasoning which generally is a synthesis of fuzzy logic, the Dempster–Shafer theory of evidence (DST) and Atanassov’s intuitionistic fuzzy sets (A-IFS) theory

redefined in the framework of DST. They analyzed a case study of the type 2 diabetes diagnostics to prove the correctness and applicability of this approach to the solution of decision making problems. Mosavi et al. (2022) proposed a novel approach for glucose regulation in type-I diabetes patients. They presented a new approach on the basis of the Immersion and Invariance (I&I) theorem to derive the adaptation rules for the unknown parameters. Also, they proposed a new deep learned type-II fuzzy logic system (T2FLS) to compensate the estimation errors and guarantee stability. The suggested T2FLS was tuned by the singular value decomposition (SVD) method and adaptive tuning rules that are extracted from stability investigation. They applied the modified Bergman model (BM) to evaluate the performance.

Fuzzy inference is a method that interprets the values in the input vector and, based on some sets of rules, assigns values to the output vector. In fuzzy logic, the truth of any statement becomes a matter of a degree. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made or patterns discerned (Kalogirou, 2013). In this paper, a new model for diagnosing diabetes is presented. For this purpose, the fuzzy expert system technique has been used for data analysis, which by simulating blood sugar factors, provides a suitable suggestion for the appropriate use of insulin dosage.

4. The Proposed Methodology

Nowadays, uncertainty of the environment which cannot be solved by crisp insight makes researchers to consider this vagueness in their computations. In view point of Prediction of diabetes, qualitative nature of parameters in evaluating efficiency of Prediction of diabetes which is based on linguistic variables of decision makers cannot be calculated by deterministic mathematical function. To formulate these qualitative factors, Zadeh (1965) proposed fuzzy logic concept. In this paper, a fuzzy expert system is used to predict diabetes. The fuzzy expert system is implemented according to the following steps (Kazemi, 2020):

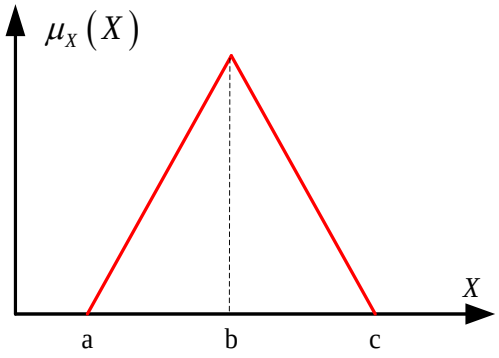

Fig. 1. Membership function of trapezoidal fuzzy number

4.1. Preliminaries

In this subsection some basic definitions of fuzzy logic are described.

Definition1. Let U be a universe set. A fuzzy set X of U is defined by a membership function $\mu_x \in [0,1]$ where $\mu_x \forall x \in U$ indicates the degree of x in X.

Definition2. Let X be a fuzzy set of U, where U is a universe set. X is normal, if and only if $sup_{x\in U}\ \mu_X(x)=1$

Definition3. Let X be a fuzzy set of U, where U is a universe set. X is convex, if and only $\mu_x(\lambda x+(1-\lambda)y)\geq(\mu_x(X)\wedge\mu_y(X)),\forall x,y\in U,\forall\lambda\in[0,1]$

Definition4. A fuzzy number X is a fuzzy set which is both normal and convex in the universe set U.

Definition5. Let U be a universe set. Fuzzy set of $A_1, A_2, \ldots$ in the U are completeness of fuzzy sets if for each $x\in U$ there is at least one A^j as $\mu_{A^j}(x)>0$

Definition6. A triangular fuzzy number X can be defined by (a, b, c) as shown in Fig. 1. The membership function $\mu_X(x)$ is presented as Eq.

$$\mu_X(x)=\begin{cases}\dfrac{x-a}{b-a} & a\le x\le b\\ 1 & x=b\\ \dfrac{c-x}{c-b} & b\le x\le c\end{cases} \quad (1)$$

Defitition7. A trapezoidal fuzzy number Y can be defined by (a, b, c, d) as shown in Fig 2. The membership function $\mu_X(X)$ is presented as Eq. (2).

$$\mu_X(x)=\begin{cases}\dfrac{x-a}{b-a} & a\le x<b\\ 1 & b\le x<c\\ \dfrac{c-x}{c-b} & b\le x\le c\end{cases} \quad (2)$$

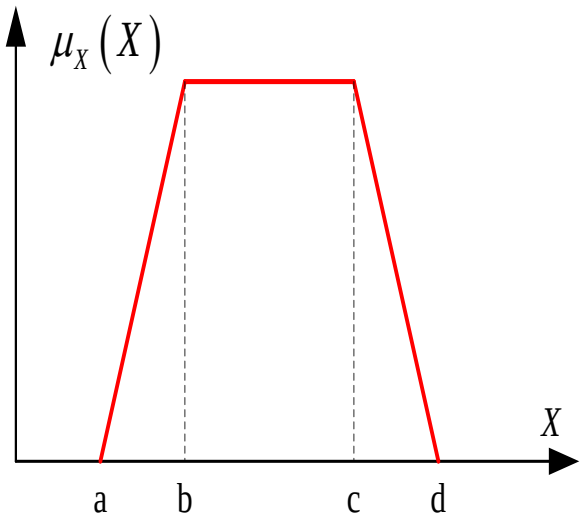

Fig. 2. Membership function of trapezoidal fuzzy number

4.2. Defining the Inputs and Output Variables

In order to evaluating of Prediction of diabetes in different situations in this paper an expert fuzzy system including multiple inputs and single output (MISO) is employed. Linguistic term are defined by triangular and trapezoidal fuzzy numbers.

4.3. The Fuzzy Rule Base of Analyzing Utility

The uncertainty environment can be analyzed by using one of the well-known developed methods called fuzzy expert system which leads to the ability of formulating ambiguous data by means of human knowledge. A fuzzy rule consists of two main parts:
1.'If' part which describes premise section of the fuzzy rule.
2.'Then' part which describes conclusion section of fuzzy rule.
In proposed fuzzy system, 'If' part consists of 'Age', 'Weight', 'Sport' as input variables and 'Then' part comprises 'diabetes' as output variable. A general form of fuzzy rule is as fallow:
If $input_1$ is $<$linguistic variables$>$ and $input_2$ is $<$linguistic variables$>$ then $output_1$ is $<$linguistic variables$>$.

4.4. The Fuzzy Expert System

In order to convert input variables to output variables one can use fuzzy expert system. To implement the proposed fuzzy expert system, following cases have been considered (Iancu, 2012).

1.Fuzzification interface by using a singleton fuzzifier
2.Inference the fuzzy system by using Mamdani implication engine
3.Defuzzification interface by using a centroid defuzzifier

According to MISO (Three inputs and an output) type of the proposed fuzzy rule-based system, x_0, y_0, z_0, r_0 are considered as fuzzy singleton. Fuzzy interface procedure is illustrated as fallowing steps:

Step 1: Involve inputs fuzzy singleton into their universe sets
Step 2: Combine fuzzy sets which consist of fuzzy singleton and obtain the active rules.
Step 3: Calculate $\mu_X(x_0),\mu_Y(y_0),\mu_Z(z_0),\mu_R(r_0)$ as Eq. (1) and Eq. (2) which named h_1, h_2, h_3, h_4 respectively.
Step 4: Determining matching degree (δ_j; j = 1, 2, 3…,J) for each active rules Eq. (3).

$$\delta_j=\min(h_1,h_2,h_3,h_4) \quad (3)$$

Step 5: Implement Max-Min operator to transform the outputs (u'_j) into the crisp values by centroid defuzzification in Eq. (3).
Let $\bar{u}^j$ be in the middle of u'_j.

$$u_0 = \frac{\sum_{j=1}^{J} \bar{u}^j \times \delta_j}{\sum_{j=1}^{J} \delta_j} \quad (4)$$

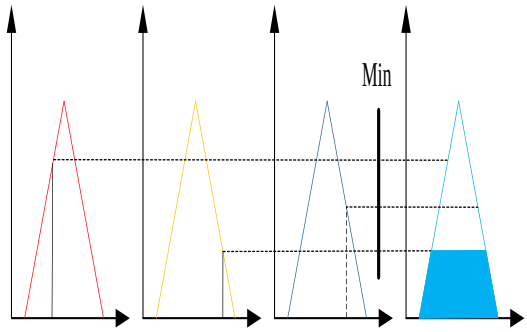

Fig. 3. Mamdani inference system

5. Problem Definition

Applied research method has been used in this article and it is classified as causal research because it deals with discovering the cause or factors of an event in diabetic patients. In this regard, the fuzzy expert system technique, which basically examines the variables, has been used. The model used in this article is Multiple Input Single Output (MISO). For this purpose, three input variables of Age, Weight and Sport and one output variable of diabetes with three terms of type 1 diabetes (gestational diabetes), type 2 diabetes, and healthy people have been considered. To illustrate the results of this model, fuzzy toolbox of MATLAB software is used. In the following, the input and output variables and their ranges are defined.

5.1. Input Variables

a- Age: The range of [0, 100] is used for age input variable. Fuzzy terms for age input variable are considered as follows:

- *Child:* Trapezoidal fuzzy number [0, 0, 7, 15] is considered.
- *Teenager:* Triangular fuzzy number [12, 16, 20] is considered.
- *Young:* Triangular fuzzy number [18, 30, 40] is considered.
- *Middle-age:* Triangular fuzzy number [35, 45, 60] is considered.
- *Old:* Trapezoidal fuzzy number [55, 80, 100, 100] is considered.

At the end, obtained value of the latest step (u_0) is considered as utility index in Fig. 3.

b- Weight: The range of [10, 100] is used for weight input variable. Fuzzy terms for weight input variable are considered as follows:

- *Low:* Trapezoidal fuzzy number [10, 20, 30, 40] is considered.
- *Medium:* Trapezoidal fuzzy number [50, 60, 70, 80] is considered.
- *High:* Trapezoidal fuzzy number [90, 100, 110, 110] is considered.

c- Sport: The range of [0, 90] is used for sport input variable. Fuzzy terms for sport input variable are considered as follows:

- *Low:* Trapezoidal fuzzy number [0, 0, 10, 20] is considered.
- *Medium:* Trapezoidal fuzzy number [30, 40, 50, 60] is considered.
- *High:* Trapezoidal fuzzy number [70, 80, 90, 90] is considered.

5.2. Output Variable

Considering that there are four types of diabetes, in which the range of diabetes in children and pregnant people is similar and it is in type 1, and young, middle-aged and old people are also exposed to type 1 and 2 diabetes. Therefore, we have defined three fuzzy terms of healthy people (Health), people with type 1 diabetes and pregnant (Diabets1) and people with type 2 diabetes (Diabets2) using standard medical ranges for the output variable.

Diabetes: The range of [70, 400] is used for diabetes output variable. Fuzzy terms for diabetes output variable are considered as follows:

- *Health:* Gaussian fuzzy number [70, 100] is considered.
- *Medium (Type 1 diabetes and pregnancy):* Gaussian fuzzy number [70, 200] is considered.
- *High (Type 2 diabetes):* Gaussian fuzzy number [70, 400] is considered.

6. Data Analysis

To simulate the proposed model, MATLAB software was used, which is a suitable environment for simulating such systems. For this purpose, input and output variables along with related membership functions and also 15 rules are defined in MATLAB software. The results of 27 cases

of tests that have been conducted in relation to diabetes show that in 26 cases of the tests, the results of the fuzzy expert system were in accordance with the correct diagnosis, and in only 1 case there was a mismatch, the reasons for which It can be known due to the conditions with uncertainty in the prediction of diabetes and also the effect of other parameters that are not included in this system.

6.1. If-then Rules

In order to analyze the inputs (age, weight and sport) and output (prediction of diabetes type one, type two and healthy people) of the proposed model, 15 rules have been defined. The results of the analysis and application of the rules will be explained below.
15 rules are defined by experts as follows:

1: if (age is child) OR (weight is medium) OR (sport is high) Then (diabetes is health)

2: if (age is child) OR (weight is high) OR (sport is low) Then (diabetes is diabets1)

3: if (age is young) OR (weight is high) OR (sport is medium) Then (diabetes is diabets1)

4: if (age is young) OR (weight is high) OR (sport is low) Then (diabetes is diabets2)

5: if (age is meddle-age) OR (weight is low) OR (sport is high) Then (diabetes is health)

6: if (age is meddle-age) OR (weight is high) OR (sport is low) Then (diabetes is diabets2)

7: if (age is older) OR (weight is low) OR (sport is medium) Then (diabetes is health)

8: if (age is older) OR (weight is high) OR (sport is low) Then (diabetes is diabets2)

9: if (age is older) OR (weight is medium) OR (sport is low) Then (diabetes is diabets1)

10: if (age is older) OR (weight is high) Then (diabetes is diabets2)

11: if (age is teenager) OR (weight is high) Then (diabetes is diabets2)

12: if (age is child) OR (weight is high) Then (diabetes is diabets1)

13: if (age is young) OR (sport is low) Then (diabetes is diabets1)

14: if (age is young) OR (weight is high) Then (diabetes is diabets1)

15: if (age is meddle-age) OR (sport is low) Then (diabetes is diabets2)

6.2. Designing the Proposed Model in MATLAB Software

Figure 4 shows how to choose the name of the proposed model.

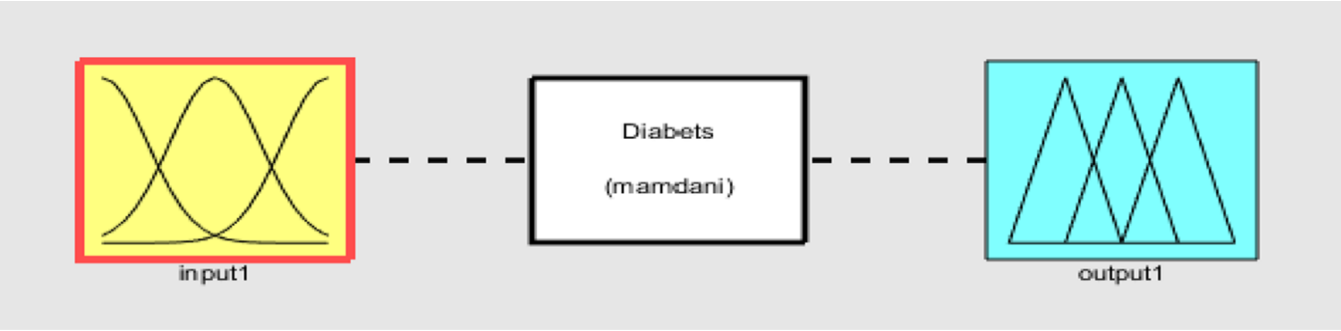

Fig. 4. Name of the proposed model

In Figure 5, the three variables of age, weight and sport are considered by experts for the fuzzy expert system, and the input variables have their own membership functions.

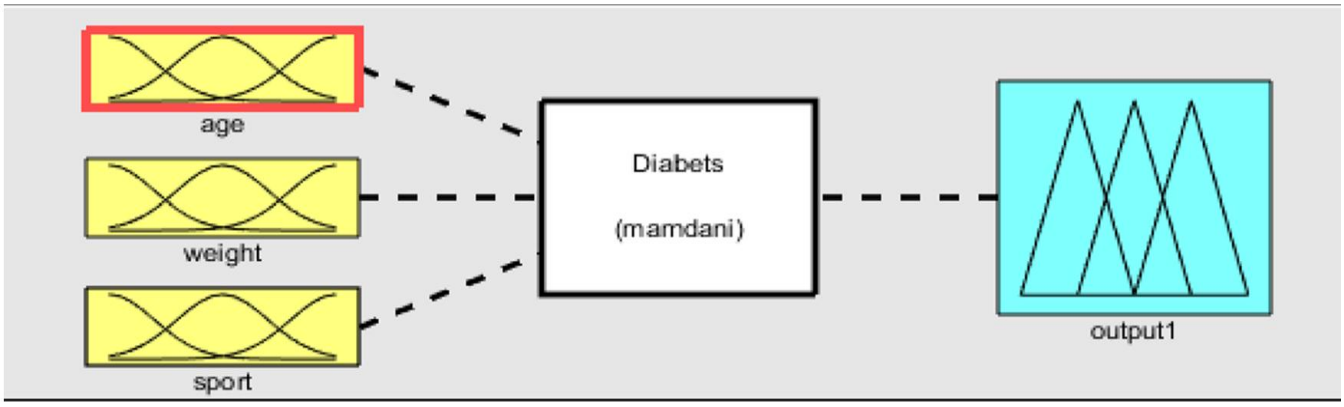

Fig. 5. Determining the number of input variables of the proposed model

Figure 6 shows the membership function related to terms of age as an input variable.

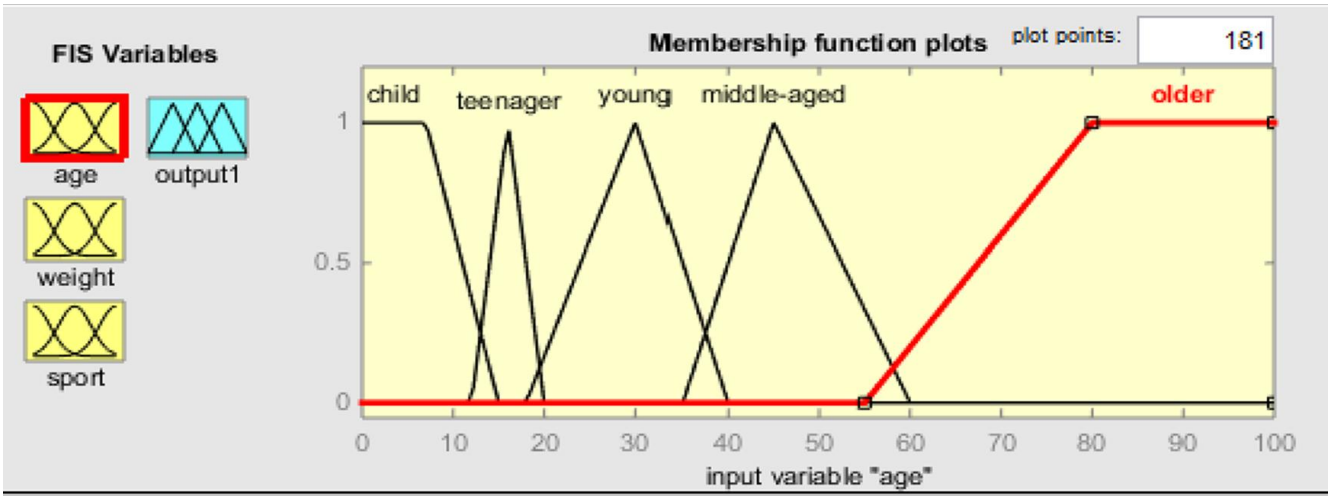

Fig. 6. Define terms of age as an input variable

Gaussian membership functions have been used for the output variable (diabetes), which is shown in Figure 7.

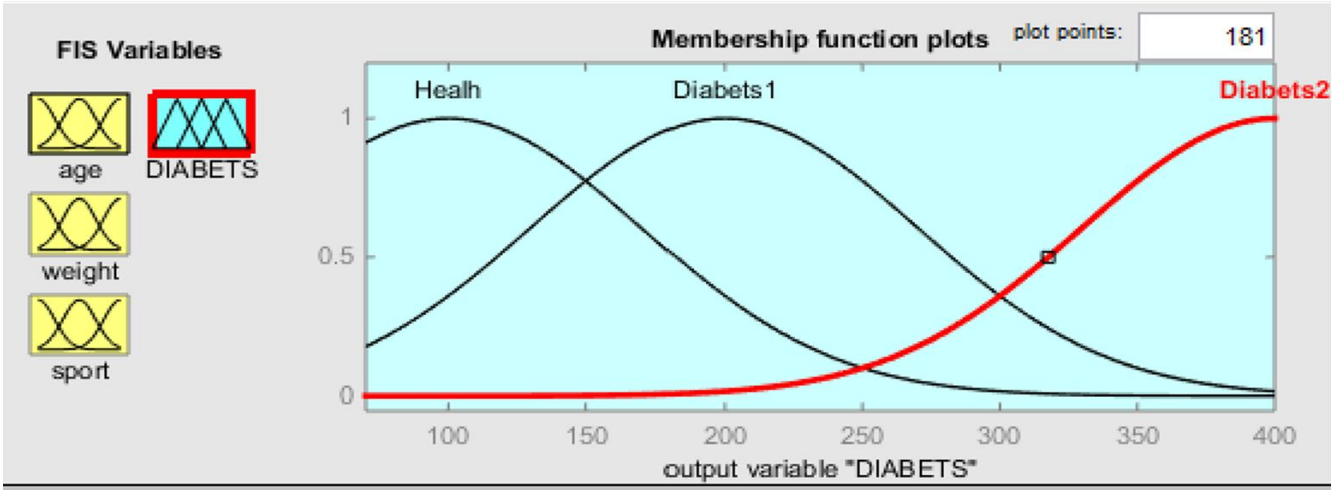

Fig. 7. Gaussian membership functions related to the output variable

15 rules are defined by experts as shown in Figure 8.

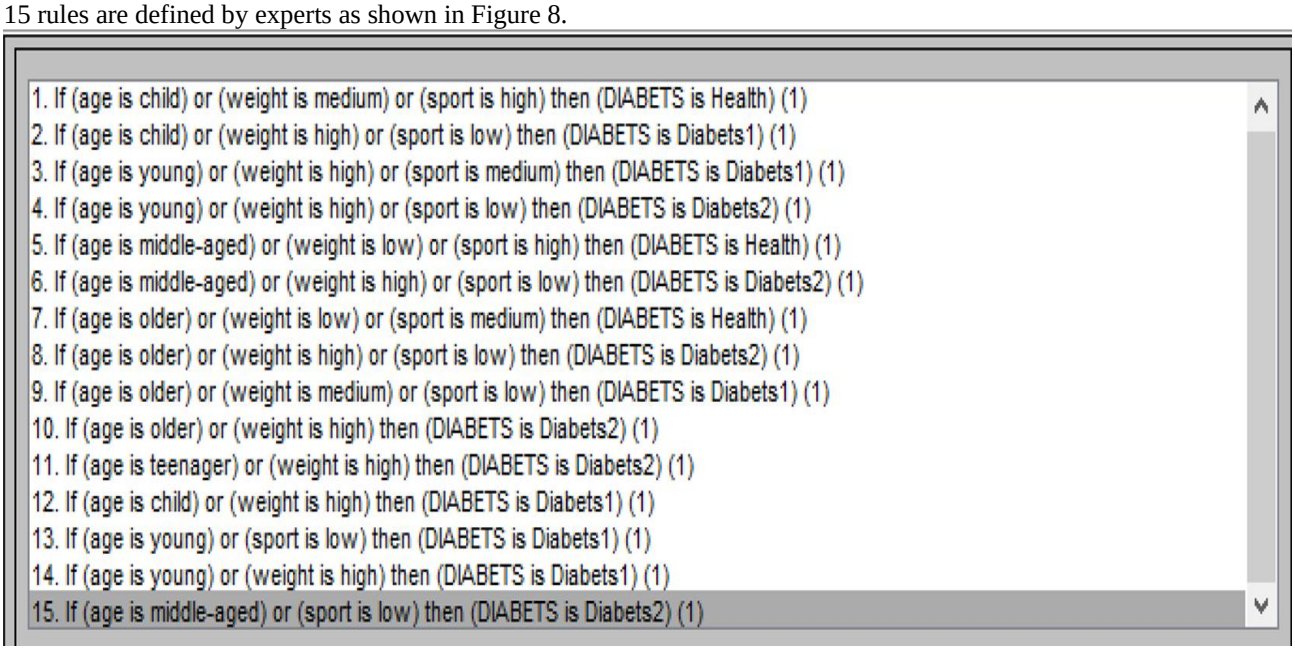

Fig. 8. Rules related to the proposed model

After defining the membership functions of the input and output and the range determined for the variables, by specifying a crisp value for each of the inputs, a crisp value for the output is obtained. As shown in Figure 9, a 74-year-old person with a weight of 90 kg who exercises 4 minutes daily (very sedentary) will have a sugar range of 240 and type 2 diabetes.

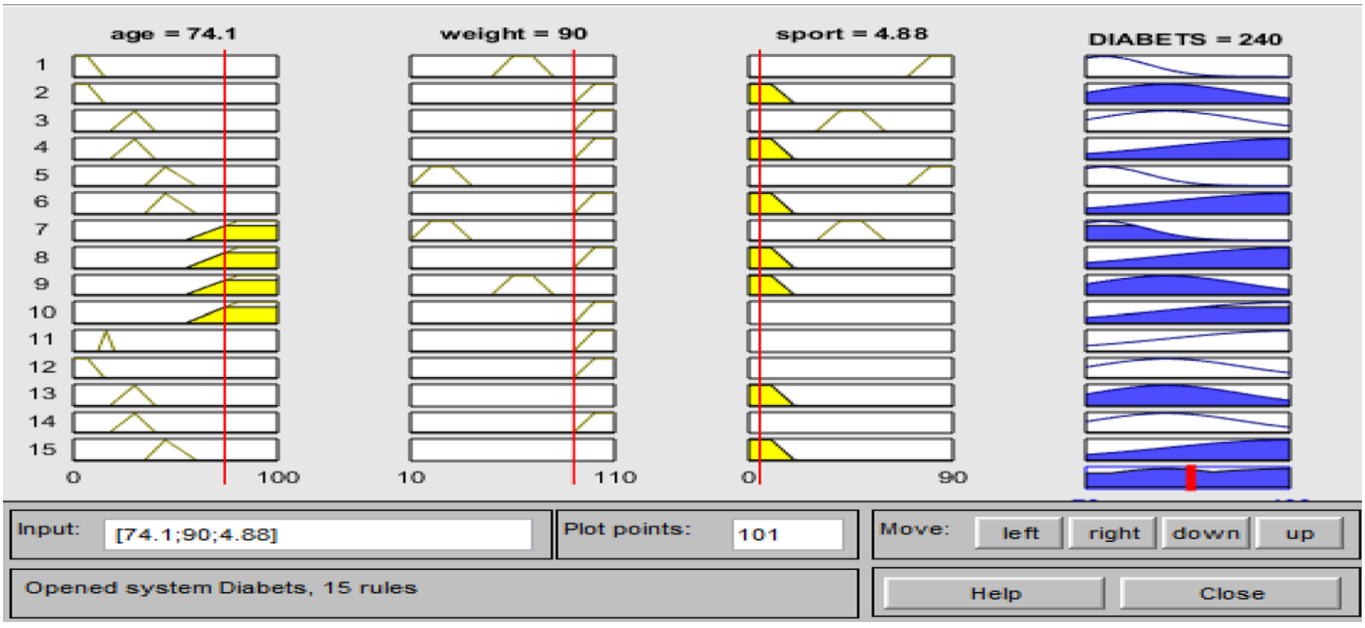

Fig. 9. The results of a case for the proposed model

Figure 10 shows the surface diagram of relationships between people's weight, age and amount of sports as input variables and diabetes as output variable of the fuzzy expert system. With increasing age, weight and also decreasing physical activity in people, the height of the diagram increases and the risk of diabete increases.

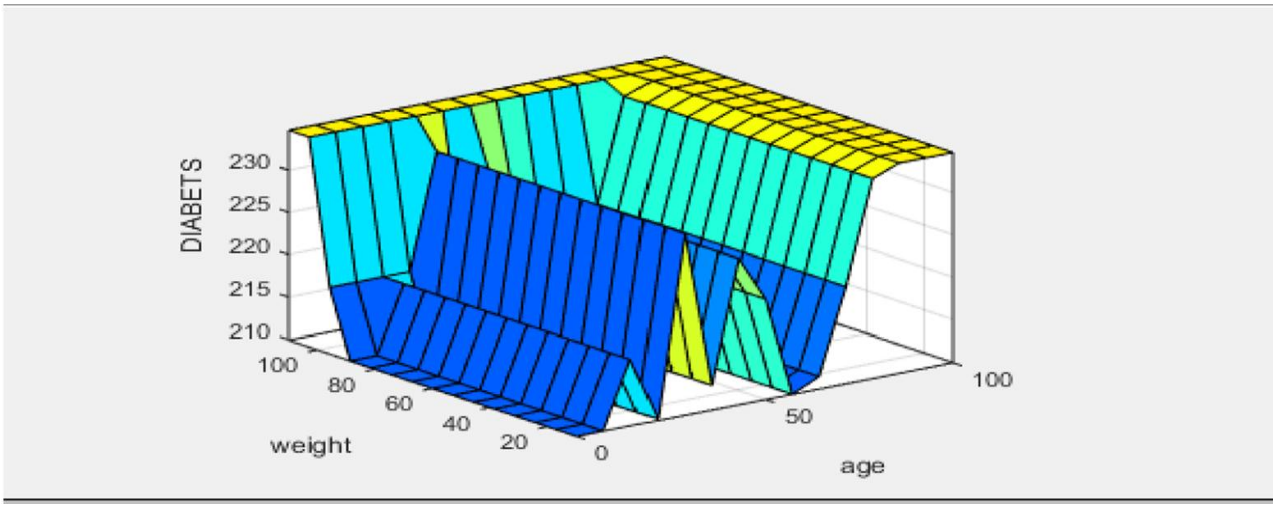

Fig. 10. Surface diagram for input and output variables

7. Conclusion

In this paper, a fuzzy expert system was presented in order to determine the status of people from the society who are at risk of diabetes. For this purpose, in the proposed model, three input variables including the age, weight and amount of sports of the people and one output variable including the type of diabetes were defined and then 15 rules were defined for the fuzzy expert system and the output of each rule was shown as a diagram and with examples real analyzed. The most successful models used to diagnose and treat diabetes are based on fuzzy expert system methods that simulate blood sugar factors with a non-linear viewpoint and suggest the required amount of insulin. The main reason for the popularity of this approach is related to learning models, which propose the most optimal amount of insulin for the patient after receiving the input data. In this research, despite the uncertainty and many complications, considering the necessity of diabetes control for patients, a novel method based on fuzzy expert system was presented. The obtained results are significantly improved compared to previous research. Also, compared to the results of doctors, it shows a good performance in predicting the accuracy of blood sugar concentration. For future research, one can work on presenting a system with more applicability and efficiency in diagnosis of diabetes. In this regard, the applicability of the proposed model could be justified by considering a stochastic programming approach and exploring the output results with the current fuzzy-based one.

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