A Practical Approach to Prescribe The Amount of Used Insulin of Diabetic Patients

Mehran Mazandarani*, Ali Vahidian Kamyad**
*M.Sc. in Electrical Engineering, Ferdowsi University of Mashhad, Iran, me.mazandarani@gmail.com
**Full Professor, Faculty of Mathematical Sciences, Ferdowsi University of Mashhad, avkamyad@yahoo.com

Abstract: *To assess of diabetes mellitus, extensive mathematical studies have been done to date. Up to now, many crisp mathematical models have described this phenomenon, but with the aim of controlling and modelling diabetes mellitus in more realistic and practical form, the models that consider most aspects of the problem should be considered. This kind of attitude to the disease can be modelling with mathematics called fuzzy mathematics. In this paper, modelling of diabetes mellitus type 2 has been studied by using IF-Then fuzzy rules based on the medical information of diabetic patients of Parsian clinic in Mashhad-Iran who were treated during October 2009-February 2010, and then by using the defuzzification method the prescribable amount of insulin to diabetic patients type 2 would be determined. This approach will provide a better control possibility of blood glucose level stability in patients despite the uncertainty in the data and information of patients due to disturbances of body system.*

Keywords: Diabetes Mellitus Type 2; Fuzzy Logic; Modelling.

1. Introduction

In recent years diagnosis and treatment of diabetes has been the subject of discussion in many scientific circles because more than 117 million people are suffering from diabetes in the world and it is expected that this figure be reach to more than 300 million people by 2025[1]. A person with diabetes needs four times more than non-diabetic person to facilities and medical activities. As the number of patients is constantly growing, the cost of treatment and control of diabetes has been doubled during the past decade too. In the past years we have witnessed an increased incidence of diabetes and in future years we will face with its pandemic. Statistics show that the number of diabetic patients in the world from about 100 million people in 1994 has been reached to about 180 million in 2000 and it is forecasted that this figure be reached to about 250 million people by 2010 that most of this increase is related to diabetes type 2, which constitutes about 90 to 95 percent of total diabetes [2]. The most common type of diabetes is diabetes type 2 or Non Insulin Dependent Diabetes Mellitus [NIDDM] Approximately 90 to 95 percent of diabetic people suffer from this type of diabetes mellitus. In this type of diabetes, the pancreas normally secrete enough insulin and it can still produce insulin, but for unknown reasons the body cannot effectively use the insulin and the body's cells do not response appropriately to insulin in the blood. This is a situation that is called resistance to insulin that after several years the insulin production is reduced [3]. Extensive mathematical studies to assess and control of diabetes mellitus have been done. So far many crisp mathematical models have been presented to assess and describe of diabetes mellitus that among them the models with form of ordinary differential equations, see [3]-[9], models with form of delay differential equations, see [10]-[13], models with form of integral differential equations, see [14]-[19], and models with form of partial differential equations, see [20]-[25] can be mentioned, but to justify the exact fact of this problem many of these models cannot review every aspect of the disease, because human beings, as a unique system, are not measurable in terms of physiological characteristics, weather conditions and living environment etc. Thus, with the aim of reviewing the diabetes mellitus prevalence process in more realistic and practical form, the models that consider most aspects of the problem should be considered. This kind of attitude to the disease can be modelling with mathematics called fuzzy mathematics [26], [27]. In this paper, modelling of diabetes mellitus type 2 has been studied by using the IF-Then fuzzy rules based on the medical information of diabetic patients of Parsian clinic in Mashhad-Iran. Mamdani approach has been used for fuzzy reasoning and determining the amount of insulin, because Mamdani approach, with having simple structure of applying min, max is widely used [28], [29].

2. Modelling the Diabetes Mellitus Type 2 Based on the IF-Then Fuzzy Rules

2.1 Determining of the Membership Functions

To modelling diabetes mellitus type 2, by cooperating and counselling with Parsian clinic in Mashhad, we used medical information of diabetic patients that their insulin level has been determined according to their blood glucose stabilization and their blood glucose level has been stable. Information needed to implement the IF-

Then rules include age, blood pressure, Body Mass Index (BMI), fasting blood glucose and non-fasting blood glucose of the patient as the system inputs and the amount of patient's insulin use is as the fuzzy model output. The significant point here is that the data used in this article are related to patients that their blood glucose is controlled stably i.e. their blood glucose level has reached to an acceptable level that in the long term this level has remained stable with minor changes. To express the membership functions, at first we cluster the input and output variables of fuzzy model as follows:

1. **Clustering of Age (year)**: young, middle-aged, old

Patients' age membership functions curve based on the above clustering is defined as follows:

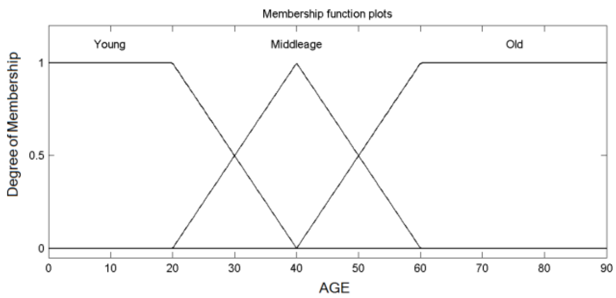

Fig.1: Age Membership Functions

2. **Clustering of Blood Pressure ($mmHg$)**: Low, Normal, High.

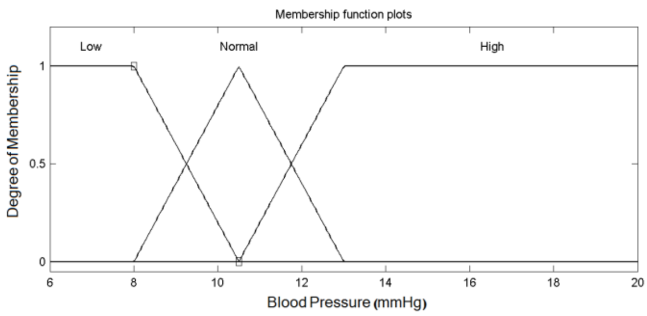

Fig.2: Blood Pressure Membership Functions

3. **Clustering of BMI (kg/m^2)**: Low, Medium, High, Very High.

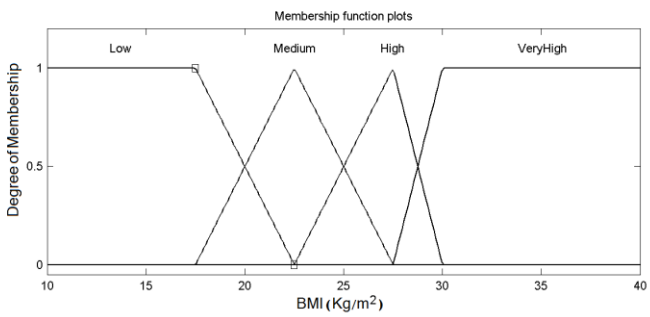

Fig.3: BMI Membership Functions

4. **Clustering of Fasting Blood Glucose (mg/dl)**: Good, Very Good, Bad.

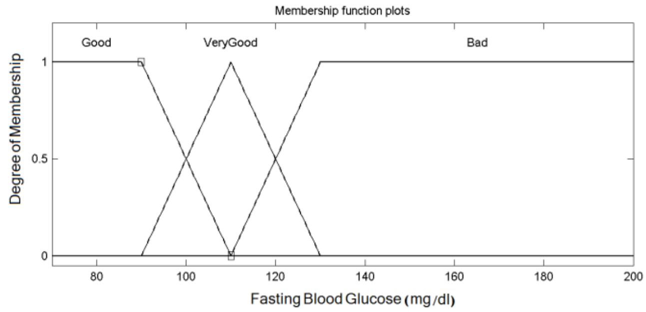

Fig.4: Fasting Blood Glucose Membership Functions

5. **Clustering of Non-Fasting Blood Glucose (mg / dl)**: Good, Bad

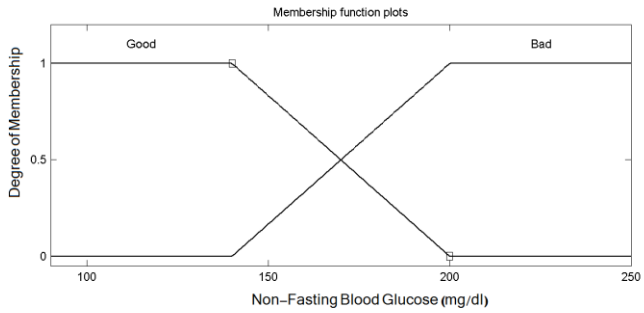

Fig.5: Non-Fasting Blood Glucose Membership Functions

6. **Clustering of Amount of Insulin (μu / ml)**: Low, Medium, High.

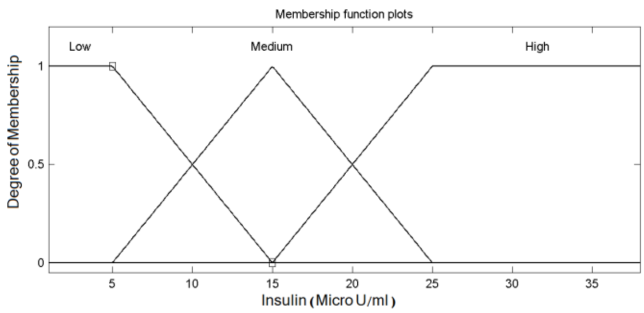

Fig.6: Insulin Membership Functions

2.2 The IF-Then Rules of Diabetes Mellitus Type 2

Now by using of numerous articles in the field of diabetes mellitus type 2 and also the obtained information from medical record of the patients of diabetes Parsian clinic in Mashhad-Iran and guidance of diabetes specialists, the IF-Then rules has been prepared as follows:

1. **IF** the patient is young with normal blood pressure, with medium BMI, and with good fasting blood glucose, **Then** he/she uses a medium amount of insulin.
2. **IF** the patient is young with high blood pressure, with very high BMI, and with good fasting blood glucose, **Then** he/she uses high amounts of insulin.
3. **IF** the patient is young with high blood pressure, with high BMI, and with bad fasting blood glucose, **Then** he/she uses high amounts of insulin.
4. **IF** the patient is young with high blood pressure, with medium BMI, and with good fasting blood glucose, **Then** he/she uses a medium amount of insulin.
5. **IF** the patient is middle-aged with normal blood pressure, with high BMI, and with bad fasting blood glucose, **Then** he/she uses high amounts of insulin.
6. **IF** the patient is middle-aged with normal blood pressure, with medium BMI, and with good fasting blood glucose, **Then** he/she uses a medium amount of insulin.
7. **IF** the patient is middle-aged with normal blood pressure, with medium BMI, and with bad fasting blood glucose, **Then** he/she uses a low amount of insulin.
8. **IF** the patient is old with normal blood pressure, with medium BMI, and with very good fasting blood glucose, **Then** he/she uses a medium amount of insulin.
9. **IF** the patient is old with high blood pressure, with very high BMI, and with bad fasting blood glucose, **Then** he/she uses high amounts of insulin.
10. **IF** the patient is old with high blood pressure, with high BMI, and with good fasting blood glucose, **Then** he/she uses high amounts of insulin.
11. **IF** the patient is old with high blood pressure, with high BMI, and with bad fasting blood glucose, **Then** he/she uses high amounts of insulin.
12. **IF** the patient is old with normal blood pressure, with very high BMI, and with good fasting blood glucose, **Then** he/she uses high amounts of insulin.
13. **IF** the patient is old with high blood pressure, with very high BMI, and with very good fasting blood glucose, **Then** he/she uses high amounts of insulin.
14. **IF** the patient is young with normal blood pressure, with medium BMI, and with good non-fasting blood glucose, **Then** he/she uses a medium amount of insulin.
15. **IF** the patient is young with high blood pressure, with very high BMI, and with good non-fasting blood glucose, **Then** he/she uses high amounts of insulin.
16. **IF** the patient is middle-aged with normal blood pressure, with medium BMI, and with bad non-fasting blood glucose, **Then** he/she uses a low amount of insulin.
17. **IF** the patient is middle-aged with normal blood pressure, with high BMI, and with bad non-fasting blood glucose, **Then** he/she uses high amounts of insulin.
18. **IF** the patient is old with normal blood pressure, with medium BMI, and with good non-fasting blood glucose, **Then** he/she uses a medium amount of insulin
19. **IF** the patient is old with high blood pressure, with very high BMI, and with bad non-fasting blood glucose, **Then** he/she uses high amounts of insulin.
20. **IF** the patient is old with high blood pressure, with high BMI, and with good non-fasting blood glucose, **Then** he/she uses high amounts of insulin.
21. **IF** the patient is old with high blood pressure, with high BMI, and with bad non-fasting blood glucose, **Then** he/she uses high amounts of insulin.
22. **IF** the patient is old with normal blood pressure, with high BMI, and with good non-fasting blood glucose, **Then** he/she uses high amounts of insulin.

3. Description of Mamdani Method

Mamdani reasoning approach can be expressed in three steps as follows:

First, we assume that we have n rules that their antecedent part of the IF-Then rules include m input

Rule 1**:** If x_1 is in A_1^1 and ... and x_m is in A_1^m, then y is in B_1.

⋮

Rule n**:** If x_1 is in A_n^1 and ... and x_m is in A_n^m, then y is in B_n.

Step 1: First, we assume that x_1^0 and ... and x_m^0 are respectively the inputs for variables x_1, ... and x_m of antecedent part. We measure compatibility of every rule for above input as follows:

Compatibility of rule 1: $w_1 = \mu_{A_1^1}(x_1^0) \wedge \dots \wedge \mu_{A_1^m}(x_m^0)$

⋮

Compatibility of rule n: $w_n = \mu_{A_n^1}(x_1^0) \wedge \dots \wedge \mu_{A_n^m}(x_m^0)$

Step 2: By using the compatibility of step 1 we obtain the fuzzy sets in result part and the result of each rule:

Result of rule 1: $\mu_{B_1'}(y) = w_1 \wedge \mu_{B_1}(y)$

⋮

Result of rule n: $\mu_{B_n'}(y) = w_n \wedge \mu_{B_n}(y)$

Step 3: We totalize the result of each rule that has obtained in Step 2 and obtain the final result as follows:

$$\mu_B(y) = \mu_{B_1'}(y) \vee \dots \vee \mu_{B_n'}(y)$$

The final result obtained in Step 3 is in a fuzzy set that this result is not applicable because we need a certain amount as the reasoning output, so we should return the fuzzy set to a certain number. The return operation of a fuzzy set to a certain amount is called defuzzification that in this article the centroid defuzzification has been used as follows:

$$y_0 = \frac{\int \mu_B(y) y \, dy}{\int \mu_B(y) \, dy}$$

4. Practical results

At this stage, by using the Mamdani approach we combined the IF-Then rules and determined the proposed insulin amount by using the centroid defuzzification. The obtained results based on the fuzzy model presented in section 2 to determine the amount of insulin use were

TABLE I. THE PRESCRIBED AND PROPOSED AMOUNT OF INSULIN.

Patient	Age	Blood Pressure	BMI	Fasting Blood Glucose	Non-Fasting Blood Glucose	The amount of insulin prescribed by a doctor	The proposed amount of insulin by using fuzzy model
1	23	$^{117}/_{78}$	26.4	203	220	26	24.4
2	23	$^{120}/_{75}$	22.3	87	106	16	15
3	45	$^{144}/_{85}$	30.8	80	141	23	19.5
4	46	$^{124}/_{74}$	24.2	109	127	24	23
5	27	$^{106}/_{74}$	20.3	81	105	15	15
6	29	$^{140}/_{90}$	34.2	96	110	26	27.9
7	39	$^{140}/_{96}$	34.5	98	110	24	26.7
8	54	$^{148}/_{78}$	27.6	97	110	27	28.2
9	20	$^{105}/_{75}$	23	110	147	14	15
10	37	$^{110}/_{72}$	27.5	95	110	19	19.5

Verified to a large extent by the relevant doctor in Parsian diabetes clinic in Mashhad-Iran and has had an acceptable conformity to the amount of insulin use of patients who are under the control of clinic. For example, for **a patient who is 45 years old** with **blood pressure 13**, **BMI 25**, **fasting blood glucose 135** and **Non-fasting blood glucose 170** the amount of **insulin prescribed by a doctor is 26** units and the amount of the **proposed insulin by using the presented fuzzy model has obtained 26.8** units a day that these two amounts have very little difference. Table I shows some examples of the results obtained based on fuzzy model presented in this article compared to the amount of insulin prescribed by a doctor for diabetic patients type 2 that their blood glucose level has been stably controlled. This database is related to medical records of the patients who were treated in the clinic during October 2009 - February 2010.

5. Conclusion

The fuzzy model presented in this article that has obtained based on the information of diabetic patients type 2 has achieved an acceptable success due to the potential use of human knowledge for modelling diabetes mellitus type 2 despite the uncertainty of biological system of appropriate adjustment glucose-insulin. The results obtained from this model that some of them presented in Table I indicate their acceptable conformity with the amount of patients' insulin use that are under control in the clinic that these results have been verified by the relevant doctor too. Although the obtained results from the proposed fuzzy model has indicated an acceptable difference to the amount of insulin use in the studied diabetic patients type 2 and perhaps this model can be used when the doctor is not available to determine the amount of insulin use in the studied diabetic patients type 2 in this paper, but to obtain more accurate and comprehensive model we should have access to many of diabetic patients type 2 information to be able to obtain better results.

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