A FUZZY LOGIC CONTROLLER FOR EMULATION OF SUITABLE INSULIN DOSE IN TYPE II DIABETIC PATIENTS

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Summary

Since traditional control systems are not fully effective in complex nonlinear systems, we tried to find a fuzzy logic controller (FLC) to predict required insulin doses in diabetic patients. While fuzzy logic control is still intuitive and at a very early stage, it has already been implemented in many biological fields and reported results are very promising. In fact, FLC is based on human expertise and on desired output characteristics, and hence does not require precise mathematical models. This observation makes fuzzy rule-based technique very suitable for biomedical systems. The goal of this paper is to determine the dose of insulin which must be injected into the patient's body according to the measured blood glucose level. The algorithm was implemented in MATLAB/SIMULINK software and its performances was considered finally

Key words: Diabetic patients; Fuzzy logic controller; Insulin

Introduction

Diabetes mellitus is a metabolic disorder of endogenous insulin allowing excessive amount of glucose to stay in blood. In general, blood glucose is transformed into energy required by human activities, such as, walking, and this transformation requires insulin functionality [1]. However, in type II diabetes, since a human body partially is resistant to insulin, unchanged glucose remains in blood. Type II diabetes is characterized by insulin being appropriately produced by the by body cells. This kind of diabetes is more common than type I, and is characterized by late occurrence (adult stage).

As body is very sensitive to variations of blood glucose level and even a small change from normal level for a long period can lead to serious complications such as cardiovascular disease, time in which glucose level back to normal level is critical [2-3]. On the other hand the patient characteristics are very different and individual response to same stimuli is not similar, thus, it is necessary to change the parameters in a mathematical model. Therefore, we used fuzzy logic controller in which changing in parameters or oscillations can not influence on it and can control the level of glucose with a suitable settling time [4].

Many mathematical studies for the assessment and control of diabetic have been carried out. The classical and crisp mathematical models for the description of this phenomenon mostly cannot investigate all the aspects of this problem; because, we cannot assume the body of peoples as a unique system physiologically. Thus, a Model to investigate all the human parameters looks at all the sides is really a fuzzy model [5-6]. In recent decades, mathematical articles about fuzziness and uncertainty and especially in fields such as system modeling and optimization and control in medicine sciences have been developed extensively. Furthermore, because of more than 117 million people all over the world are diabetic and it is expected for its increase to more than 300 million up to 2025 [7], a number of researches used fuzzy theory to consider diabetic have been done [8]; because, the diagnosis and control of diabetic has been the topic of discussion in scientific meetings in recent years, many mathematical models for dynamic description of the diabetic are presented.

The proposed of this paper is to design a controller to stabilize the blood glucose level in patients with type 2 diabetes in normal values.

Material and methods

Fuzzy Logic Controller

The basic structure of a Fuzzy Logic Controller (FLC) is shown in figure1.

The Fuzzification process

Fuzzification is a process of mapping inputs to the FLC into fuzzy set membership values in the various input universes of discourse [9]. Decisions need to be made regarding:

a) Number of inputs

b) Size of universes of discourse

c) Number and shape of fuzzy sets

2.1.2. The fuzzy rulebase

The fuzzy rulebase consist of a set of antecedent-consequent linguistic rules of the form

IF e is PS AND ce is NS THEN u is PS

This style of fuzzy conditional statement is often called a Mamadani-type, after Mamadani (1976) who first used it in a fuzzy rulebase to control steam plant.

A mathematical model for blood glucose

For designing the 'Mamdani'-type rule in fuzzy control we used the information of twenty diabetic patients that have been under medical consideration and the level of glucose in their blood was stable and their disease was controlled. The necessary parameters for our model are age, blood pressure, BMI, insulin dose, FBS, non-FBS. The main objective of the designed method of a Fuzzy logic control is to predict the suitable insulin dose in terms of patient characteristics. “Age, blood pressure, BMI and FBS” are considered as input parameters and the “Insulin dose” is the output parameter. The input triangular membership functions are young, middle age and old for age, Low, Normal and High for blood pressure, Low, Normal, High and Very High for BMI and very good, good and bad for FBS. The output triangular membership functions are Low, Mild, and High.

Fuzzy relations for inputs (age, blood pressure, BMI, FBS, non-FBS) and output (dose of insulin administered for patients) that consider as table 1. the membership functions for output is shown in figures2. In figure 3 the process of fuzzification in Matlab is presented .This model is completely feasible, for example for a patient with 45 years old, blood pressure 13, BMI 25, FBS 135 and non -FBS 170 ,insulin dose will be 26.8, that correlates with administered dose of insulin by physician . In figure 4 some different surfaces of our model regarding to this case was shown.

Results

The numerical simulation was implemented in MATLAB/Simulink using the Fuzzy Logic Toolbox [10]. The result compared with the administered doses of insulin and is shown in table 2.

The linear regression equation for fuzzy logic is

$F_{fuzzy}(x) = 0.008x + 21.5205$ (figure 5)

The linear regression equation for administered doses of insulin that is near to the rule of fuzzy logic control:

$F_{near}(x) = 0.27218x + 17.9421$ (figure 5)

Finally to find how our model can predict the insulin dose we calculate the difference between the linear regression equation for fuzzy logic and linear regression equation for administered doses of insulin that is near to the rule of fuzzy logic control.

$$Error = \frac{\int_1^{20} |F_{fuzzy}(x) - F_{near}(x)| dx}{20} = 1.30$$

As it was shown the error is low and thus our model is reliable.

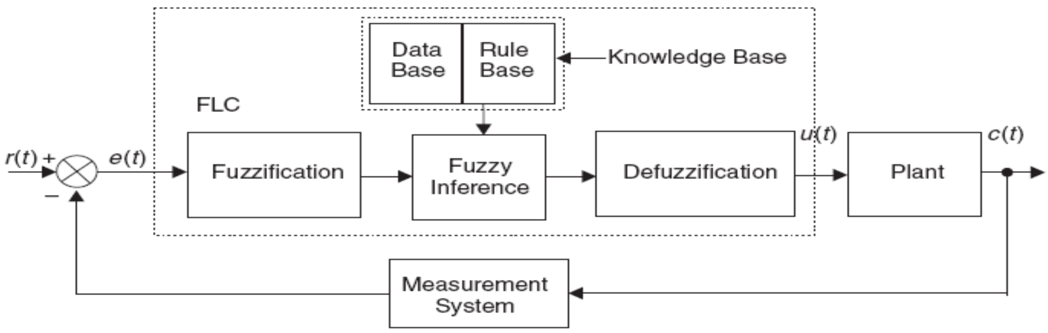


Figure 1.Fuzzy Logic Controller

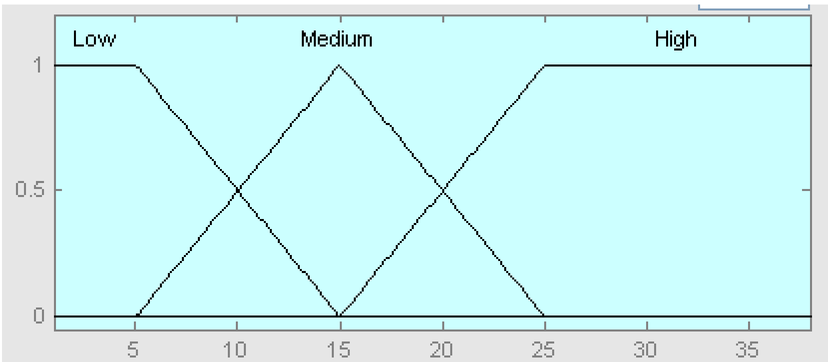


Figure 2. Membership functions. . The Horizontal axis is insulin

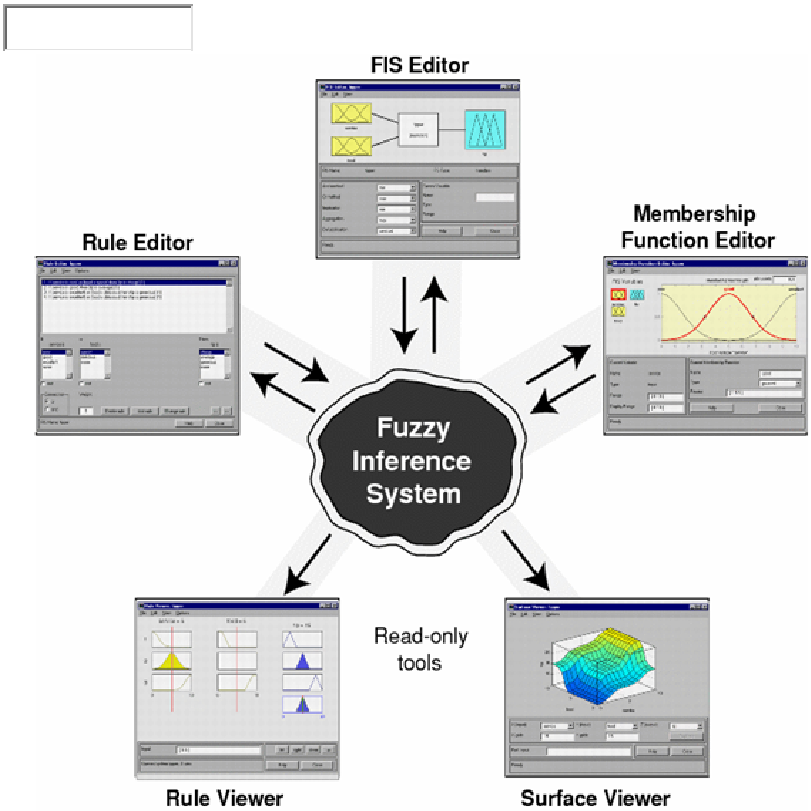
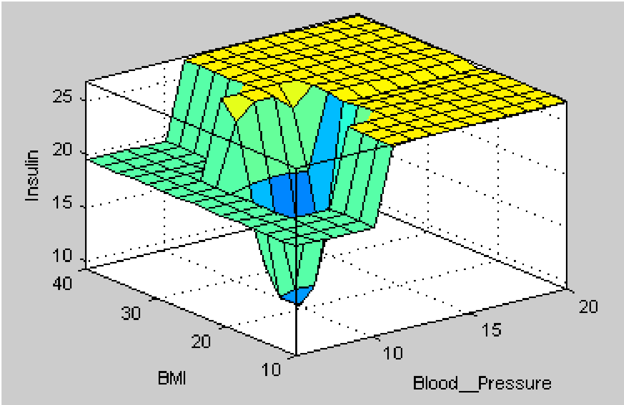


Figure 3. Diagram of fuzzification



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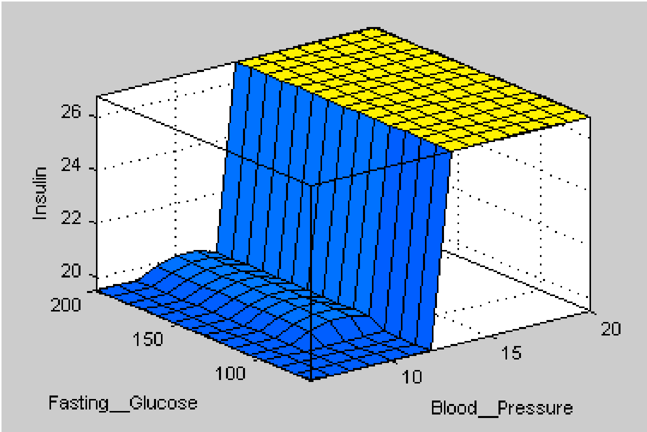

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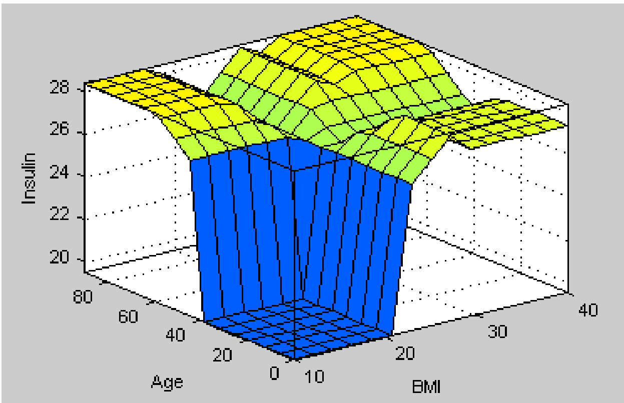

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Figure 4. Some different surfaces of our model regarding to an individual patient.

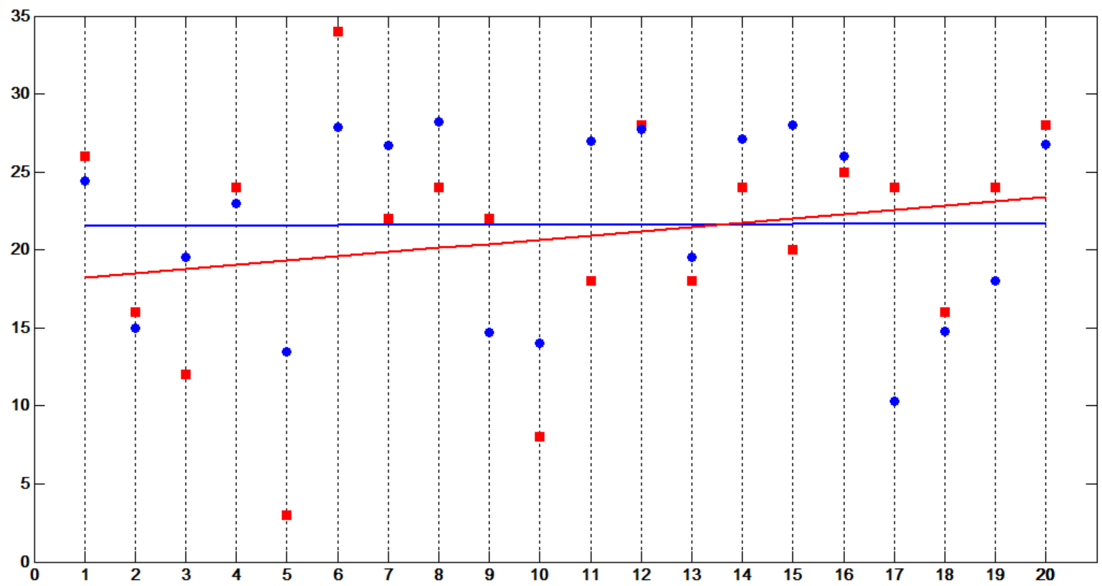

Figure 5. Insulin doses obtained from fuzzy logic (blue circles) and the nearest administered doses of insulin (red squares) for each patient.

Table 1. Fuzzy relations for inputs (age, blood pressure, BMI, FBS, non-FBS) and output (dose of insulin administered for patients)

Age	Blood pressure	BMI	Blood Sugar	Insulin dose
Young	Normal	Normal	Good (FBS)	Medium
Young	High	Very high	Good(FBS)	High
Young	High	High	Bad(FBS)	High
Young	High	Normal	Bad (FBS)	Mild
Middle age	Normal	High	Bad (FBS)	High
Middle age	Normal	Normal	Good (FBS)	Mild
Middle age	Normal	Normal	Bad(FBS)	High
Middle age	Normal	High	Bad (FBS)	High
Old	Normal	Normal	Very Good (FBS)	Medium
Old	High	Very High	Bad (FBS)	High
Old	High	High	Good (FBS)	High
Old	High	High	Bad (FBS)	High
Old	Normal	Very High	Good (non-FBS)	High
Old	High	Very High	Very Good (non-FBS)	High

Young	Normal	Normal	Good (non-FBS)	Medium
Young	High	Very High	Good (non-FBS)	High
Middle age	Normal	Medium	Bad (non-FBS)	Low
Middle age	Normal	Very High	Bad (non-FBS)	High
Old	Normal	Medium	Good (non-FBS)	Medium
Old	High	Very High	Bad (non-FBS)	High
Old	High	High	Good (non-FBS)	High
Old	High	High	Bad (non-FBS)	High
Old	Normal	High	Good (non-FBS)	High
Old	Normal	Normal	Good (non-FBS)	Low

Table 2. Insulin dose administred by physician and emulated insulin dose by fuzzy logic controller.

Patients No.	Administered insulin dose range	Emulated insulin dose by fuzzy logic controller
1	18-26	24.4
2	16-24	15
3	12-34	19.5
4	8-24	23
5	3-36	13.5
6	34	27.9
7	12-22	26.7
8	14-24	28.2
9	22-31	14.7
10	8-22	14
11	18	27
12	4-28	27.7
13	18-22	19.5
14	24-36	27.1
15	10-20	28

16	25	26
17	24-38	10.3
18	16-19	14.8
19	24	18
20	18-28	26.8

Discussion and Conclusion

In this study, a fuzzy logic controller has been proposed to achieve suitable doses of insulin for diabetic patient of type II. The controller is based on patient characteristics [11]. In order to incorporate knowledge about patient treatment, the controllers are designed using a Mamdani-type fuzzy scheme. Numerical simulation results show the effectiveness of structure. In this study, remarkable results also can be achieved with introduction of new model of diabetic using fuzzy logic and identification of fuzzy parameters; because obtained results have good accuracy and high reliability and it shows considerable improvement comparing with prior researches regarding parametric uncertainty in patient [12] model and the strength of method has been confirmed to great extent using some real data which they are mentioned in paper.

As shown in this paper, the fuzzy logic framework has the potential to predict the suitable doses. Moreover, in future work, the inclusion of an exercise regime and also diet in the overall model in order to have a more realistic simulation will be considered.

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