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Blood Glucose Control in Type Ⅰ Diabet Patients with Adequate Insulin Injection Using Feedback Linearization Method

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***Abstract*— In recent decades, the theory of control system has been used in many industrial, medical and other issues. Obtaining an appropriate injection rate of insulin for type 1 diabetic patients, is always important issue. The goal of controlling and treating diabetes is to keep blood glucose in normal level. In diabetic patients, the glucose regulation system does not perform properly, so it should replace by a control algorithm to regulate blood glucose levels. To develop an effective algorithm, it is essential to know how the glucose regulation system works in a healthy person. In this paper, a minimal Bergman model is used to describe the nonlinear dynamics of the glucose-insulin system for type 1 diabetes patients. Then, the feedback linearization method is proposed to determine the rate of insulin injection. The results of simulations show that the proposed controller can successfully adjust blood glucose level with proper rate and insulin injection true amount, which confirms the efficiency of the controller and its high accuracy through simulations.**

Keywords—component; feedback linearization, Type 1 Diabetes, Blood Glucose Concentration, Insulin Injection Rate, Minimal Bergman Model.

I. INTRODUCTION

Detection and treatment of diabetes have been studied in recent years .Diabetes is a metabolic disease in which insulin, secreted from beta cells located in the pancreas whose main role is to reduce blood glucose which is not produced adequately [1]. In the closed loop control method, which acts like an artificial pancreas, blood glucose concentration is measured by the glucose sensor and after comparing with the optimal amount of insulin dose required by the appropriate control algorithm and is often subcutaneous injection [2-3]. Since the patient's body is sensitive to changes in glucose levels, the time required to reach normal blood glucose levels is very important for design of the controller [4]. On the other hand, the main problem of physiological models is the manipulate patient in order to determine the parameters of the model [5]. It should be noted that even a small change in model parameters can affect the functionality of the closed loop system and even result in patient death [6]. Therefore, the purpose of this study is to design a controller that is Resist against changing model parameters and disturbances and ability to control the patient's blood glucose level with proper sitting time.

In recent years there have been many studies in this field. In the minimal glucose model of Bergman was used to design a model predictive control or MPC to control glucose levels in a diabetic patient [7-8]. In the model of the minimal glucose from Bergman was designed for an optimal semi-closed loop control system for controlling glucose levels in diabetic patients [9]. The rest of this paper is as follows: in Section 2, nonlinear model of type 1 diabetes will be presented. In Section 3, the new closed loop control strategy will be presented to stabilize the blood glucose level of type 1 diabetic patient in a normal range using the feedback control linearization algorithm. Finally, Sections 4 and 5, the results of simulation and Conclusion will be presented.

II. NONLINEAR MODEL OF TYPE 1 DIABETES

Type 1 diabetes is an autoimmune disease. In Type 1 diabetes, which is included 10-15% of all cases of diabetes, due to the loss of insulin-forming cells, insulin production from the pancreas stops [10-11]. The normal range is the concentration of blood glucose is about $6 - 120\,\frac{mg}{dl}$ [12]. In this paper, we considered the Bergman model [13] of blood glucose in type 1 diabetic patients for Matlab Simulink.

$$\dot{G}(t) = -\big(p_1 + X(t)\big)G(t) - X(t)G_b + \frac{G_{meal}}{v_1} \quad (1)$$

$$\dot{X}(t) = -P_2X(t) + P_3I(t) \quad (2)$$

$$\dot{I}(t) = -n\big(I(t) + I(b)\big) + \frac{u(t)}{v_1} \quad (3)$$

In the above equations $G(T)$ is difference between glucose concentration and its normal state G_b. Also, $I(t)$ is difference between plasma free insulin concentrations with its normal amount of I_b. x(t) It is proportional to the insulin concentration in the lumen.

p_1, p_2, p_3 are parameters of the minimal model, which models the interactions of plasma glucose and insulin dynamics effects. n is the rate of insulin loss, v_1 is the rate of insulin release from the pancreas and u(t) is the rate of insulin injection [13-14]. The values of the parameters that used for simulation in equations (1) to (3) are given in Table (1).

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TABLE 1

Parameters	Value
G (Nominal)	81.5 $m.Mol\ L^{-1}$
I (Nominal)	10.5 mUL^{-1}
X (Nominal)	0.00546 min^{-1}
G_b	4.5 $m.Mol\ L^{-1}$
v_1	12 L
p_1	0 min^{-1}
I_b	4.5 $mU\ L^{-1}$
p_2	0.025 min^{-1}
p_3	0.000013 $mU\ L^{-1}min^{-2}$
n	5.54 min^{-1}
G_{meal}	5.54 mol $L^{-1}min^{-1}$
u	16.5 $mU\ L^{-1}min^{-1}$

III. Method of Linearization Feedback State

In the simplest form, the linearization feedback can be summarized in deletion of a nonlinear system such that the closed loop dynamics[15-16]. The system is represented in the standard form:

$$\dot{x} = f(x) + g(x)u \quad (4)$$

$$x = [G, X, I] \quad (5)$$

$$f = [f^1, f^2, f^3] \quad (6)$$

$$g = \left[0, 0, \frac{1}{v_1}\right] \quad (7)$$

The extension and bracket lee, and Lee derivative, are defined in relations (8) to (10).

$$ad_f^i = [f \ \ ad_f^{i-1}g], \qquad ad_f g = g \quad (8)$$

$$[f \ g] = L_f g - L_g f \quad (9)$$

$$L_f g = \nabla g.f \quad (10)$$

To check the possibility of using this control method, the following two conditions will apply:

1. Fields of vectors $[g\ ad_f\ g\ ad_f^2 g]$ in the area of Ω can be Linear Independent. Since the matrix rank is full, below conditions is available:

$$\begin{bmatrix} 0 & 0 & -\frac{p_3 * (G_b + x_1)}{v_1} \\ 0 & -\frac{p_3}{v_1} & -\frac{n * p_3}{v_1} - \frac{p_2 * p_3}{v_1} \\ \frac{1}{v_1} & \frac{n}{v_1} & \frac{n^2}{v_1} \end{bmatrix}$$

2. Set of $[g\ ad_f g]$ is non-conventional, so when the following matrix elements are constant, this condition is available [17].

$$\begin{bmatrix} 0 & 0 \\ 0 & -\frac{p_3}{v_1} \\ \frac{1}{v_1} & \frac{n}{v_1} \end{bmatrix}$$

We define the new state variables in equation (11) to (13).

$$z = [z_1, z_2, z_3] \quad (11)$$

$$z_1 = x \quad , \quad z_2 = L_f z_1 \quad , \quad z_3 = L_f \quad (12)$$

$$u = \frac{1}{L_g z_3} * (v - l_f z_3) \quad (13)$$

The linearized model is obtained in equation (14).

$$\begin{cases} \dot{z}_1 = z_2 \\ \dot{z}_2 = z_3 \\ \dot{z}_3 = v \end{cases} \quad (14)$$

IV. Matlab Simulink Simulation Result

The proposed system is simulated in Matlab Simulink. As shown in Figure 1, Diabetes was modeled in the first block. In the second block, the feedback linearization method is applied, after determining the optimum values of z for PID control. One noteworthy point is pay attention to limitation of insulin injected at the level of glucose in the blood. We simulate and compare the blood glucose and insulin levels of diabetic patients at different intervals with their controlled state.

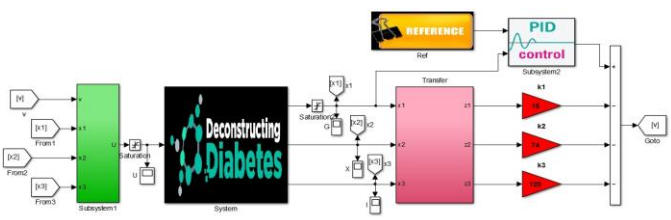

Figure 1- Simulated Blood glucose control components

First, we examine the condition of the patient in the absence of any drug injection, as shown in Figure 2, the level of blood glucose in the patient is increasing rapidly. This figure indicates that type 1 diabetes has been modeled without the controller. So it completely out of the desired range of the healthy person.

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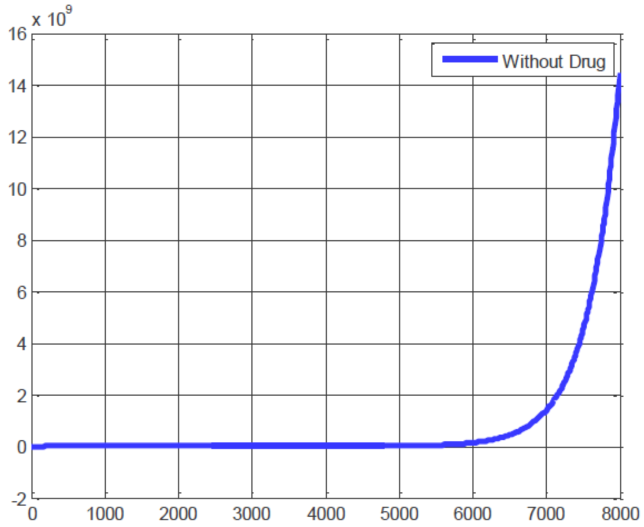

Figure 2- Blood glucose level of diabetic patient without insulin injections

After employing the controller and using the linearization feedback method, as shown in Fig. 3, the blood glucose level is always in an optimal range. After the appropriate injection of insulin to the patient in accordance, the blood glucose level of the patient will be controlled according to figure 4.

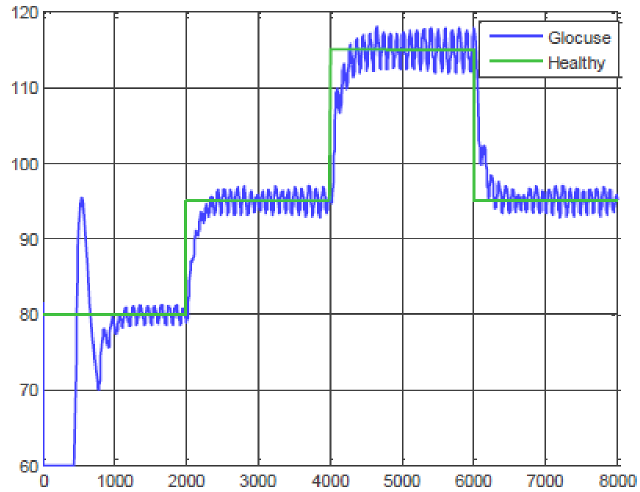

Figure 3- Blood glucose level of diabetic patient with insulin injections

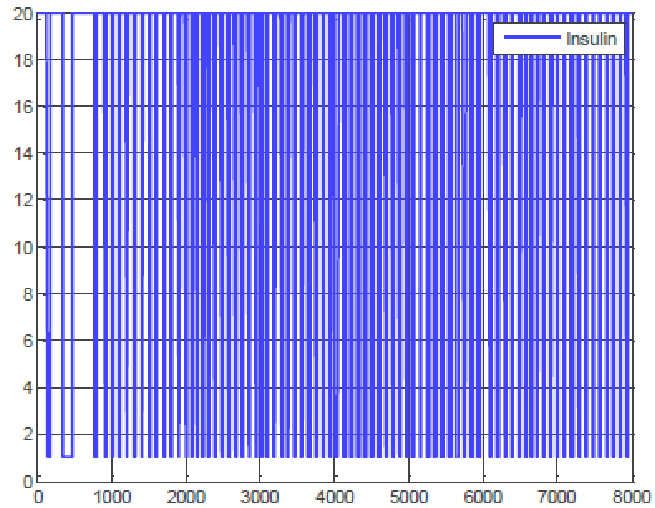

Figure 4- The limitation of insulin injected at different times

The level of glucose in the initial intervals of insulin injection is fundamental part. In paper [18] injection of glucose level is very low and close to zero, which is not vindication at all and patient death is definite. According to simulation results of proposed method, insulin control strategy, the level of glucose in the optimum range from the beginning to the end of the insulin injection.

Also, in the paper [18], the amount of insulin injection is not limited at all and the injection rate and injection amount not specified for certain time intervals. In this paper, insulin injections have been limited between 1 and 20 at specific timescales. Now we discuss the simulation result without insulin injection limits, as shown in figure 5. The level of blood glucose is completely in the desired range, and there is no small change in the previous results. Figure 6 shows the amount of insulin injections, which is very inadequate.

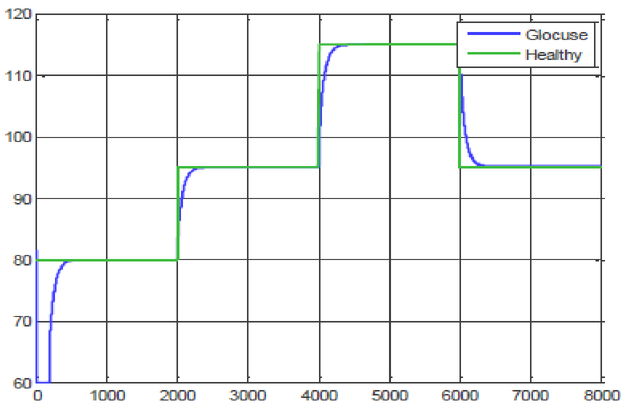

Figure 5- Blood glucose levels under uncontrolled injection of insulin

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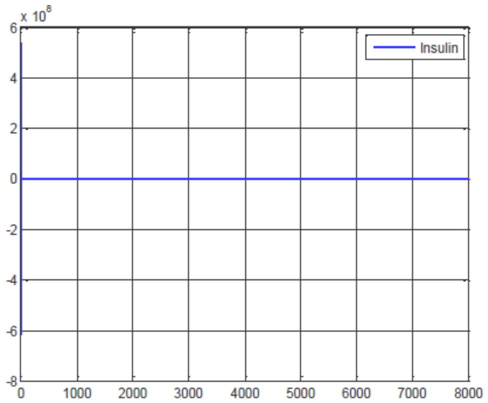

Figure 6- Unlimited injection rates of insulin in different time's periods

V. CONCLUSION

In recent years, different type of controllers have been used to inject insulin properly for recovery of diabetic patients faster. Proposed system equations is nonlinear. In this paper, we proposed controller based on linearization feedback. By implementing this controller on the glucose minimal model of type 1 diabetic patients, researchers observed that their glucose levels are monitored and controlled. For improving the PID performance, it's recommended to choose optimal controller parameters or use other optimization methods. Also, for future works we can replace the Minimal Bergman model to the PSO algorithm, And evaluating the PSO result.

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