CONTROLLING OF BLOOD GLUCOSE INCLUDING THE EFFECT OF FFA DYNAMICS

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ABSTRACT

Diabetes is a chronic disorder because of the secretion of insulin was not sufficient. Due lack of insulin, the amount of blood glucose will be increased and cause diabetes, this paper provides the closed loop control using the Bergman's extended minimal model with fuzzy logic controller. The controller takes the corrective action even for the maximum disturbance and it brings back the glucose level into around 70mmHg which is a basal value. By using this proposed model the level of glucose is continuously monitors and the corrective action will be takes place according to the defined rules.

Key words - FFA dynamics, blood glucose control, fuzzy logic controller, diabetes.

I. INTRODUCTION

Diabetes have two types type one diabetes and type two diabetes in that type one diabetes is because the lack of secretion of insulin from pancreatic β cells. This type one diabetes is a genuine issue and one of the common disease worldwide. The diabetes cannot be cured but it can be regulated by continuous monitoring and treatment, for this a closed loop monitoring system is introduced and it may be called artificial pancreas. The sensor measures the level of glucose regularly and the controller calculates the required insulin, then con-trol action will take place. In this paper, the controller designed was fuzzy logic based controller. Many patient models were developed and published [1, 2, 3] in that Bergman's minimal model is used here because its complexity is optimal it gives glucose insulin feedback relationship and proved in [8] as effective, in addition to that minimal model FFA dynamics also added. FFA influences glucose insulin metabolism greatly and it is one of the major energy provider, FFA cause insulin resistant for all major insulin target organs and it will vary while doing exercise and in rest [4]. Adding FFA dynamics to minimal model is nece-ssary to calculate the accurate insulin requirement. The closed loop insulin delivery system was represented in Fig 1.

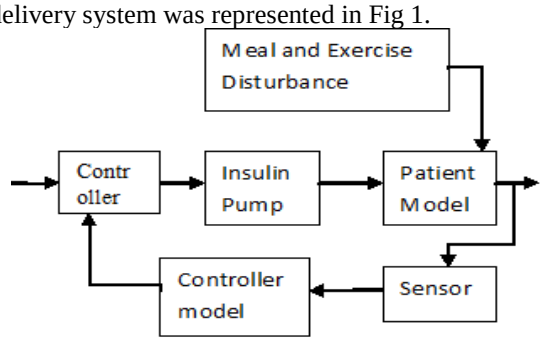

Figure 1 Closed loop regulation for level of glucose

The extended minimal model consists of FFA, insulin and glucose interactions and it was proposed in [6], this consists of interconnected subsystems which is represented in Fig. 2. Table 1 provides the relationship between parameters, the values are calculated using goodness of fit method and published in [6].

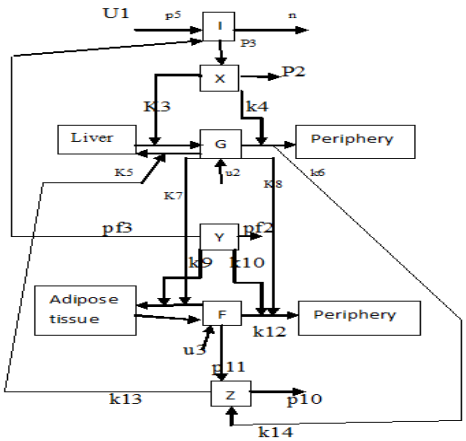

Figure 2 Block diagram of extended minimal model

Table 1 parameter relationship

Parameter	Relation
P1	K5+k6
P4	K3+k4
P6	K13+k14
P7	K11+k12
P8	K9+k10
P9	K7+k8

II. Mathematical Model

Bergman's minimal model

Bergman's minimal model consists of three com-partments which is I(t) plasma insulin ($\mu U/ml$),X(t) remote insulin($\mu U/ml$) and G(t)in (mg/dl) plasma glu-cose concentration. This model represents the insulin dependent diabetic patient by making the assumtion that the insulin is infused exogenously and it is given by

$$\frac{dI(t)}{dt} = -nI(t) + p5u1(t)$$

$$I(0)=Ib=\frac{p4}{n}u1b \qquad (1)$$

$$\frac{dX(t)}{dt} = -p2X9t) + p3[I(t) - Ib]$$

$$x(0)=0 \qquad (2)$$

$$\frac{dG(t)}{dt} = -p1G(t) - p4X(t)G(t) + p1Gb + \frac{u2(t)}{VolG} \qquad (3)$$

$$G(0)=Gb$$

Where Ib and Gb are basal insulin and glucose concentrations respectively, n is clearance of plasma insulin.The parameter values are p1=0.068, p2=0.037,

p3=0.000012, p4=1, p5=0.000568, n=0.142, gb=98 and VolG=117.

Extended minimal model

Same as Bergman minimal model the assumption here is insulin is not secreted endogenoulsy. In addtiion to the previous equations(1) and (2) for I(t) and X(t) the following equations were added for inclusion of FFA dynamics. These equations are given by

$$\frac{dG(t)}{dt} = -p1G(t) - p4X(t)G(t) + p6G(t)Z(t) + p1Gb - p6GbZb + \frac{u2(t)}{VolG} \quad (4)$$

The additional parameter p6 is FFA action on glucose uptake. The remote insulin with FFA dynamics involves the effect of lipolysis in the insulin of unaccessible compartment Y(t), lipolysis means the free fatty acid release in the circulatory system. The transfer function for Y(t) is represented by

$$\frac{dY(t)}{dt} = -pF2Y(t) + pF3[I(t) - Ib] \quad (5)$$

The parameters pF2 and pF3 is the rate of disapperance and apperance of insulin from the remote insulin respectively.

The plasma FFA dynmaics are represented by

$$\frac{dF(t)}{dt} = -p7F(t) - p8Y(t)F(t) + p9(g)F(t)G(t) + p7Fb - p9(G)FbGb + \frac{u3(t)}{VolF} \quad (6)$$

Where Fb and VolF is basal FFA concentration and distribution respectively. External lipid infusion is represented by u3(t), p8 is anti-lipolytic effect of insulin, p7 tracts the FFA consumption in adipose tissue and periphery without affecting the insulin and p9(G) is lipolytic effect and it is given by

$$p9(G(t)) = ae^{-bG(t)} \quad (7)$$

The FFA from circulatory system enters the unaccessible compartment z(t) which is remote FFA and it is represented by

$$\frac{dz(t)}{dt} = -k2[z(t) - Zb] + k1[F(t) - Fb] \quad (8)$$

Basal remote FFA concentrations is represented by Zb and the parameters k1,k2 tracks the disapperacne and apperance of FFA in Z(t) compartment. The values for the parameters are p6=0.00006, p7=0.03, p8=4.5, a=0.21e^{-3}, b=0.0055, k1=0.02,k2=0.03, pf2=1.7, pf3=0.00001, F_b=380, VolF=11.7 and the remaining values are same as minimal model values.

III. Controller design

The controller used in this paper is fuzzy logic controller, two inputs are assigned one is glucose measued by the sensor and the other one is glucose devia-tion and the output is insulin. The quantity of member-ship functions defined was 9 for both the inputs and output. The number of defined rules were 80, the sur-face graph of rules were shown in Fig. 3. The defuzzi-fication method used here is centroid method, with this number of rules even a minimum deviation in glucose level also controlled by secreting the required insulin, Fig. 4 represents the simulink model which consists of subsystems for glucose, insulin and FFA dynamics.

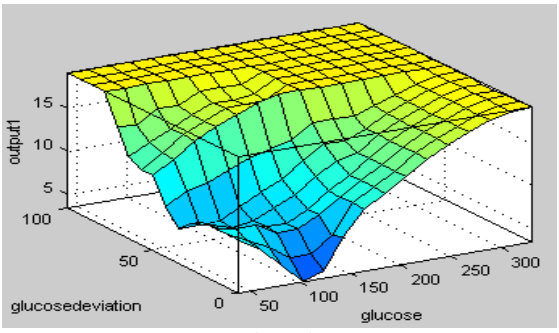

Figure 3 Surface of Fuzzy rules

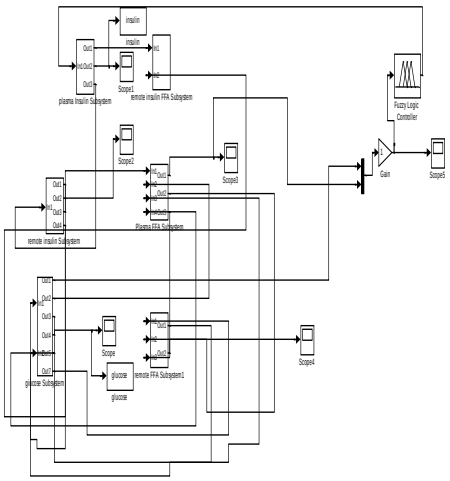

Figure 4 simulink model

IV. Results and validation

The proposed model was tested for maximum disturbance, for that also the controller takes the corrective action and the glucose level reached its normal basal value like normal persons as shown in Fig. 5. After the meal intake the amount of glucose in blood goes to 310 and it comes to normal basal value 70 by using this fuzzy controller. By comparing the results with [6,9] the time of response is very much reduced which is 4s.

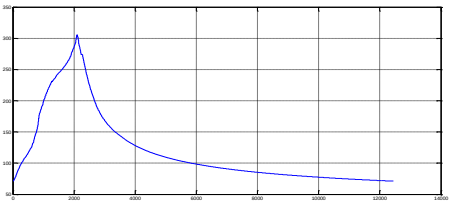

Figure 5 Glucose output controlled using fuzzy logic controller

Open loop response of type one diabetic patient is shown in the Fig. 6, where the glucose level reaches maximum of 370 and there is no control action the glucose level fluctuates between 275 to 325 which is known as hyperglycaemia it leads to “ketoacidosis” it may cause coma even death.

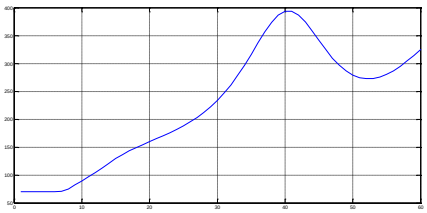

Figure 6 open loop response

V. Conclusion

Blood glucose level should be maintained to 70-120mg/dl for healthy life, if not maintained it leads to diabetes. In this paper, a fuzzy based closed loop control for the level of blood glucose regulation system was developed. For patient model, extended Bergman's minimal model was used i.e., including the FFA dynamics with Bergman's minimal model. The result was compared with open loop output of the system and it shows very good response. The response time is also reduced and it avoids both hyperglycaemia and hypoglycaemia.

Reference:

1. Ackerman, E., Gatewood, L.C., Rosevear, J.W. and G.D. Molnar, Model Studies of Blood-Glucose Regulation, The Bulletin of Mathematical Bio-physics, 27(Suppl.): 21 (1965). American Diabetes Association, Economic Costs of Diabetes in the U.S. in 2002. Diabetes Care 26(3): 917-932 (2003).
2. Bergman, R.N., Phillips, L.S. and C. Cobelli, Physiologic Evaluation of Factors Controlling Glucose Tolerance in Man. Journal of clinical investigation 68: 1456 (1981).
3. Bolie, V.W., Coefficients of Normal Blood Glucose Regulation. Journal of Applied Physiology 16: 783 (1961).
4. Obesity and Free Fatty Acids (FFA), Guenther Boden, M.D. Laura H. Carnell Professor of Medicine and Chief, Division of Endocrinology/ Diabetes/ Metabo-lism, Temple University School of Medicine, Phila-delphia, PA.
5. A Fuzzy Controller for Blood Glucose-Insulin System Ahmed Y. Ben Sasi, Mahmud A. Elmalki, The College of Industrial Technology, Misurata, Libya.
6. Thesis of Dynamic modeling of free fatty acid, glucose, and insulin during rest and exercise in insulin dependent diabetes mellitus patients by Anirban Roy B.S., University of Pittsburgh, 2008.
7. Regulation of Blood Glucose Concentration in Type 1 Diabetics Using Single Order Sliding Mode Control Combined with Fuzzy On-line Tunable Gain, a Simulation Study Soudabeh Taghian Dinani, Maryam Zekri1, Marzieh Kamali Isfahan University of Medical Sciences, Isfahan, Iran.
8. Cobelli, C., G. Pacini, G. Toffolo, and L. Sacca, Estimation of insulin sensitivity and glucose clearance from minimal model: New insights from labeled IVGTT. Am. J. Physiol., 250: E591–E598, (1986).
9. Active Insulin Infusion Using Fuzzy-Based Closed-loop Control, Sh. Yasini, M. B. Naghibi-Sistani, A. Karimpour, Department of Electrical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran. Proceedings of 3rd international conference on intelligent system and knowledge engineering (2008).