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Modeling of Patient of Type 1 Diabetes for Blood Glucose Control

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ABSTRACT

The recent development in the insulin delivery system is the automatic one .The blood glucose levels are controlled by the feedback loop. The initial success with the simple models in normalizing blood glucose level led to the improvement of the devices including variety of control system. The insulin delivery system to diabetic is a tedious job and doesn't ensure proper performance and leads to various complications if the delivery of insulin is not proper. The system which is a portable one used to control the blood glucose concentration. In this paper theoretical analysis has been performed to regulate blood glucose insulin concentration on the basis of some mathematical models. The closed-loop insulin delivery system is composed of three essential components: a stable glucose sensor for measuring the glucose concentration, a control system regulating external insulin infusion based on the glucose-insulin system and a safe and stable insulin pump. The goal is to control and analyze two controllers which were designed to control the plant which is diabetic patient for this paper and the controllers analyzed are proportional integral derivative (PID), and fuzzy logic controllers (FLC). Mathematical modeling of a patient is shown in this paper. Simulation would be performed in MATLAB software.

Keywords: PID, Fuzzy Control, Type 1 Diabetes, Modeling of Diabetic Patient.

I. INTRODUCTION

Diabetes Mellitus is an autoimmune disease around the world, which can induce various other diseases and would cause death on large scale. The World Health Organization estimates that there are more than 180 million people suffering from diabetes, and the number may double by 2030. Diabetes can be mainly divided as Type 1 and Type 2 diabetes. Type 1 diabetes, often occurring among children and young, makes up 5% to 10% of diabetes cases, and is characterized as inability of producing any insulin by their bodies. While Type 2 diabetes, usually developing in middle aged or later, is associated with high insulin resistance, which results in unused glucose cumulating in body to cause hyperglycemia and tissue damage over time In type 1 diabetes, scientists have been researching by various ways to replace the missing and vitally necessary hormone insulin. With the development of the computer era, new chances have opened up to explore and develop different treatment method.

High blood glucose level can cause high pressure exerted by the circulation of blood through a se mipermeable membrane which separates two solutions with different concentrations of solute in the extracellular fluid resulting notable cellular dehydration and high level of glucose would cause glucose reduction in the urine, which is followed by osmotic dieresis which leads to consumption of fluids and electrolytes of the body. A significant increase in high blood glucose can damage blood vessels and tissues. The normal fasting blood sugar level is 70-99mg/dL. Low glucose concentration that is 45-55 mg/dL for a long time may bring about brain function tremors and may cause attack or fit. An ultimate remedy would be insulin therapy which can reduce the risk of complications resulted from diabetes. As a result hyperglycemia can be minimized and hypoglycemia can be avoided by proper insulin delivery. The traditional therapy of diabetes is multiple subcutaneous insulin injections using long or short acting insulin analogues after glucose level measurement by glucose monitor and other device such as insulin pen which are also a convenient way. There are other routes of insulin delivery such as inhaled insulin, orally

administered insulin, transdermal (through skin) insulin delivery and so on. In order to regulate blood glucose concentration, continuous subcutaneous insulin infusion using external insulin pump has been applied. A closed-loop insulin delivery system consisting on a continuous glucose sensor, insulin infusion pump and an advanced control algorithm can be developed to control blood glucose concentration automatically.

The control algorithm can optimize insulin dose to be delivered to the patient by insulin pump in order to maintain glucose concentration within the normal range. Difference between measured glucose level and reference value multiplied by proportional constant, integrated over a period of time, and its derivative are used to control the insulin input. Although the simple control approach is easy to implement, it cannot provide insight into the physiological meaning of the metabolic system, and human expertise is needed to ensure the successful operation, which restricts greatly the functioning of this approach. Due to the complexity of nonlinear dynamics of glucose-insulin metabolic system, fuzzy control taking advantage of detailed process models and information regarding process constraints or limitations is more advantageous in regulating blood glucose concentration. Advanced control algorithm is one of the three important factors developing closed-loop insulin delivery system and has been established to aid in the diabetes treatment [1],[2]

II. METHODS AND MATERIAL

A. System Description

The closed-loop insulin delivery system, which is also called artificial pancreas, is composed of three essential components: a stable glucose sensor for measuring the glucose concentration, a control system regulating external insulin infusion based on the glucose-insulin system and a safe and stable insulin pump. In closed loop control a feedback is taken from the body by placing the sensor which senses the glucose level in body. The output of the sensor is given to the controller and based on the error the controller pumps the required amount of insulin to the body. The closed loop control is shown in the following figure 1[3].

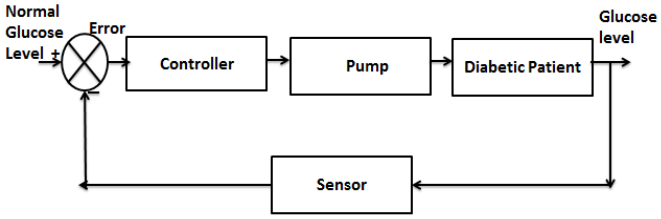

Figure 1 : Block diagram of Glucose Insulin regulation system[3]

A closed loop system monitors glucose levels and supplies insulin accordingly. The ideal closed-loop system should contain three basic elements(i)a safe-delivery device that stores and releases insulin reliably and accurately (insulin pump),(ii)an accurate glucose-sensing.(iii)a control system modulating insulin delivery, glucose and maybe glucagon or amylin according to blood glucose levels (continuous monitor).

B. Mathematical Modeling

The human glucose-insulin system model used in this study was based on initial work by Guyton et al. (1978) which was updated by Sorensen (1985)[4]. The current work modified the Sorensen model to include generalized meal disturbances as well as parameters for uncertainty analysis. Utilizing compartmental modeling a technique, the diabetic patient model is represented schematically in Figure 2[5].The model is comprised of three sub-systems: glucose, insulin, and glucagon. Eleven ODEs are used to define the glucose sub-system, seven define the insulin sub-system, and one models the glucagon dynamics. Individual compartment models were obtained by performing mass balances around tissues important to glucose or insulin dynamics. This resulted in a six-compartment representation, where the compartmentalized organs were the brain, heart/lungs, gut, liver, kidney, and periphery.

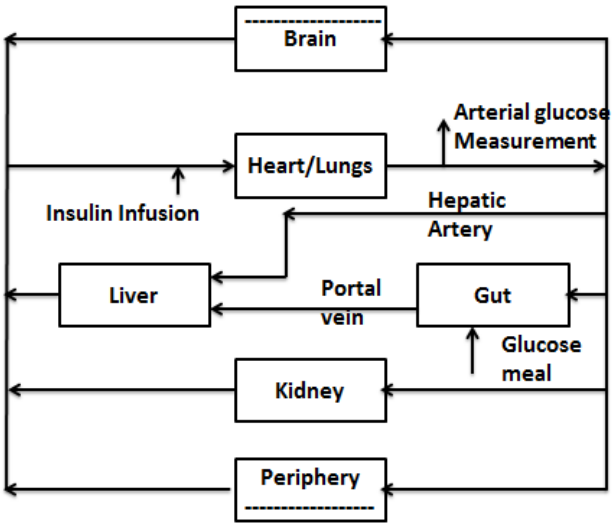

Figure 2 : Compartmental diagram of the glucose and insulin systems in a diabetic patient [4].

Following are the physiologically-based model equations along with the nomenclature (Table 3.1) and parameter values (Table 3.2) and (Table 3.3) adapted from [5]

Brain:

$$\dot{G_B^C} = \left(G_H^C - G_B^C\right)\frac{q_B}{v_B^C} - \left(G_B^C - G_B^T\right)\frac{v_B^T}{T_B v_B^C} \qquad (3.1)$$

$$\dot{G_B^T} = \left(G_B^C - G_B^T\right)\frac{1}{T_B} - \frac{\Gamma_{BU}}{v_B^T} \qquad (3.2)$$

Heart and lungs:

$$\dot{G_H^C} = \left(G_B^C q_B + G_L^C q_K + G_K^C q_K + G_P^C q_P - G_H^C q_H - \Gamma_{RBCU}\right)\frac{1}{v_H^C} \qquad (3.3)$$

Gut:

$$\dot{G_S^C} = \left(G_H^C - G_S^C\right)\frac{q_S}{v_S^C} + \frac{\Gamma_{Meal}}{v_S^C} - \frac{\Gamma_{SU}}{T_B v_S^C} \qquad (3.3)$$

Liver:

$$\dot{G_L^C} = \left(G_H^C q_A + G_S^C q_S + G_L^C q_S + G_L^C q_L\right)\frac{1}{v_L^C} + \frac{\Gamma_{HGP}}{v_L^C} - \frac{\Gamma_{HGU}}{v_L^C} \qquad (3.5)$$

Kidney:

$$\dot{G_K^C} = \left(G_H^C - G_K^C\right)\frac{q_K}{v_K^C} - \frac{\Gamma_{KE}}{v_K^C} \qquad (3.6)$$

Muscle:

$$\dot{G_P^C} = \left(G_H^C - G_P^C\right)\frac{q_P}{v_P^C} + \left(G_P^T - G_P^C\right)\frac{v_P^T}{T_P^G v_P^C} \qquad (3.7)$$

$$\dot{G_P^T} = \left(G_P^C - G_P^T\right)\frac{1}{T_P^G} - \frac{\Gamma_{PGU}}{v_P^T} \qquad (3.8)$$

Table 3.1 Model variables[5]

PARAMETER
A=auxiliary equation state (dimensionless).
B=fractional clearance(L/min)
G=glucose concentration(mU/dL)
N=glucagon concentration(normalized)
Q=vascular plasma flow rate (L/min)
q= vascular blood flow rate (dl/min)
T= transcapillary diffusion time constant
V=volume(L)
v=volume(dL)
Γ=metabolic source or sink rate (mg/min or mU/min)

Table 3.2 Parameter Values for the Diabetic Patient [5]

PARAMETER	PARAMETER
$v_B^C = 3.5dL$	$q_B = 5.9dL/min$
$v_B^T = 4.5dL$	
$v_H^C = 13.8dL$	$q_H = 43.7dL/min$
$v_S^C = 11.2dL$	$q_S = 10.1dL/min$
$v_L^C = 25.1dL$	$q_L = 12.6dL/min$
	$q_A = 2.5dL/min$
$v_K^C = 6.6dL$	$q_K = 10.1dL/min$
$v_P^C = 10.4dL$	$q_P = 15.1dL/min$
$v_P^T = 67.4dL$	
$V_B^C = 0.265L$	$Q_B = 0.45L/min$
$V_H^C = 0.985L$	$Q_H = 3.12L/min$
$V_S^C = 0.945dL$	$Q_S = 0.72L/min$
$V_L^C = 1.14L$	$Q_L = 0.9L/min$
	$Q_A = 0.18L/min$
$V_K^C = 0.505L$	$Q_K = 0.72L/min$
$V_P^C = 0.735L$	$Q_P = 1.05L/min$
$V_P^T = 6.3L$	
$V_N = 9.93dL$	$F_{PNC} = 0.910L/min$

Table 3.3 Glucose Sub and superscripts [5]

PARAMETER
A=hepatic artery
B=brain
BU=brain uptake
C=capillary space
G=glucose
H= heart and lungs
HGP=hepatic glucose production
HGU=hepatic glucose uptake
IHGP=Insulin effect on HGP
IHGU=Insulin effect on HGU

IVI=Intravenous insulin infusion
K=kidney
KC=kidney clearance
KE=kidney excretion
L= liver
LC=liver clearance
N=glucagon
NHGP=glucagon effect
P=periphery(muscle/adipose tissue)
PC=peripheral
PGU=peripheral glucose uptake
PIR=peripheral insulin release
PNC=pancreatic glucose clearance
PNR=pancreatic glucagon release
RBCU=red blood cell uptake
S=gut/intestine
SIA=insulin absorption into blood stream from subcutaneous depot
SU= gut uptake
T=tissue space

III. RESULTS AND DISCUSSION

Implementation of Patient Model

The figure 3 shows the topmost model, the model for the diabetic patient and MATLAB/Simulink is used. It consists of five submodels this is the topmost model. It consists of five submodels which are shown in the following figures. Dark green blocks represent submodels. Green blocks represent scopes that display the calculated quantities as a function of time. Magenta blocks define model parameters that can be changed by the user.

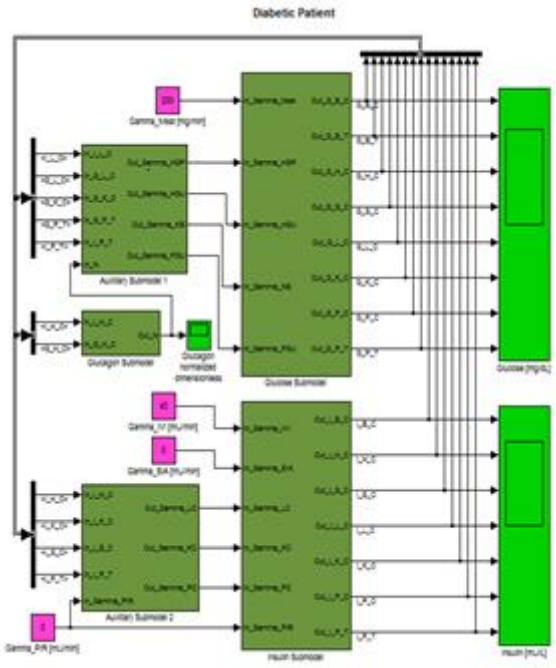

Figure 3 : Simulink model of diabetic patient (Sorensen)

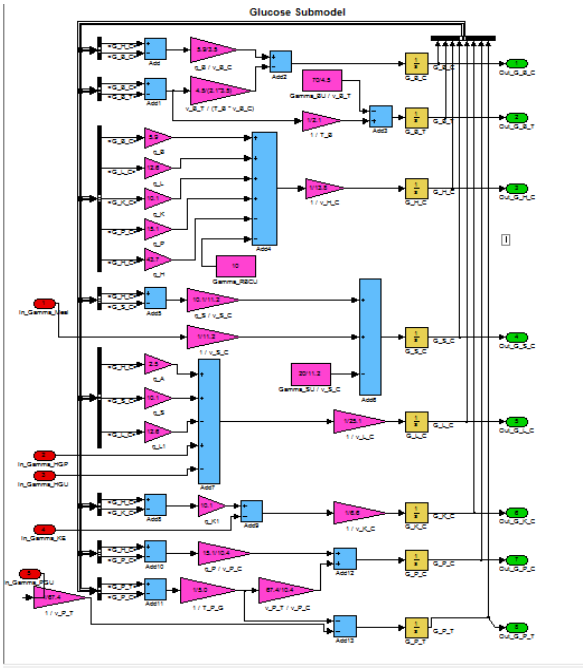

Figure 4 : Simulink Model of Glucose Submodel

Figure 4 shows the glucose submodel. It implements the glucose differential mass balance equations that are given by 3.1 to 3.8.Green rounded rectangles represent output ports.Red rounded rectangles represent input ports. Magenta blocks define model parameters that can be changed by the user.Blue blocks implement mathematical model functions . The yellow blocks are the integrators.

IV. CONCLUSION

In this paper, the Sorensen patient model is considered with compartments was considered. The mathematical modeling of model is designed using MATLAB/SIMULINK. The control strategy can be applied that is PID and fuzzy to control with proper insulin to patient which can prevent the risk of high or low level glucose level but far better control one can go for other control.

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