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Fuzzy control design for blood glucose and free fatty acid regulation in diabetes patients

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Abstract

This paper presents a method for controlling the blood glucose and free fatty acid (FFA) of body in type 1 diabetes patients in order to obtain the appropriate value in case of insulin limited. First, the nonlinear system of blood glucose and free fatty acid model can be explained by using a model of Takagi-Sugeno (TS) fuzzy. The controller for this system under sufficient condition is given based on a linear matrix inequality (LMI) and H∞ control approach. Finally, the simulation results demonstrate the effectiveness of this controller design. According to the results, it has been presented that this proposed work could be well used with the diabetic patients and other related diseases.

Keywords: Blood glucose; Free Fatty acid; Takagi – Sugeno fuzzy controller; H∞ control; LMI approach

1. Introduction

Diabetes Mellitus (DM) is a kind of the diseases in which the body cannot produce and respond to insulin requirement of body adequately. The diabetes patients are certainly in high blood glucose level which is known as hyperglycemia. When the high level of glucoses exists in our bloodstream for a long time, it is dangerous and may cause other complications. However, if the level of blood glucose is too low, the patients can be in coma situation. So far, there have been many researchers studied and modeled to understand the system of the blood glucose [1]. The amount of glucose and insulin are the main roles that the researchers have played the attentions. However, some

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researchers have found that there are other factors which can affect the system body such as free fatty acids (FFA) [2]. The human body can convert sugar to starch within the body and make glucose stay in the bloodstream. In addition, the amount of fatty acid can possibly cause the high blood glucose level as well. Most diabetes therapies can be done by injecting the insulin in order to control the amount of glucose in bloodstream.

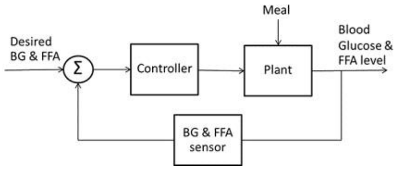

Fig. 1. Block diagram of the closed-loop control system of the blood glucose and FFA regulation in diabetes patient.

The block diagram of closed-loop control system of the blood glucose and FFA regulation in diabetes patient is shown in Figure 1. The closed-loop control system will act as the pancreas of normal body while the controller will control the blood glucose and FFA in the proper level close to normal person after dinning.

The objective of this research work is to present a method that can control both the blood glucose and FFA in the human body so that the acceptable levels can be reached in case of insulin limited instead. First, we descript the nonlinear system of blood glucose and free fatty acid model by using the model of Takagi-Sugeno (TS) fuzzy [3-4]. Then, a set of sufficient conditions of the proposed controller for this system will be obtained via a linear matrix inequality (LMI) approach, and H∞ control approach [3-4]. Finally, the simulation results will demonstrate the effectiveness of this controller design for the blood glucose and free fatty acid (FFA) of body in type 1 diabetes patients.

2. Modeling of insulin, glucose and free fatty acid

The equation of insulin, glucose and FFA dynamics are [2]:

$$\begin{aligned}
\dot{x_1}(t) &= -nx_1(t) + 0.1w_1(t) + \rho_5 U_1(t) \\
\dot{x_2}(t) &= -\rho_2 x_2(t) + \rho_3 x_1(t) + 0.1w_2(t) \\
\dot{x_3}(t) &= -\rho_{F2} x_3(t) + \rho_{F3} x_1(t) + 0.1w_3(t) \\
\dot{x_4}(t) &= -\rho_1 x_4(t) - \rho_4 x_2(t)x_4(t) + \rho_6 x_4(t)x_6(t) + 0.1w_4(t) + \frac{U_2(t)}{Vol_G} \\
\dot{x_5}(t) &= -\rho_7 x_5(t) - \rho_8 x_3(t)x_5(t) + \rho_9 x_5(t)x_4(t) + 0.1w_5(t) + \frac{U_3(t)}{Vol_F} \\
\dot{x_6}(t) &= -\rho_{10} x_6(t) + \rho_{11} x_5(t) + 0.1w_6(t) \\
z(t) &= x_4(t) + x_5(t)
\end{aligned} \tag{1}$$

where $x_1(t) = I(t)$ is plasma insulin (μU/ml), $x_2(t) = X(t)$ is the first interstitial insulin (μU/ml), $x_3(t) = Y(t)$ is the second interstitial insulin (μU/ml), $x_4(t) = G(t)$ is the plasma glucose (mg/dl), $x_5(t) = F(t)$ is plasma FFA (μmol/l), $x_6(t) = Z(t)$ is the interstitial FFA (μmol/l), U_1 is the exogenous insulin infusion (μU/ml), U_2 and U_3 are the control input which are the dietary absorption or external infusion of glucose and FFA (g/min) respectively, Vol_G and Vol_F are the distribution space of glucose (dl) and FFA (l) respectively, I_b, X_b, Y_b, G_b, F_b and Z_b are the base value and ρ_1-ρ_{11} and ρ_{F2}-ρ_{F3} are the parameters for type 1 diabetic, $w_1(t)$ ... $w_6(t)$ are the input disturbance of system, and $z(t)$ is the regulated output.

3. Nonlinear fuzzy model

In this section the fuzzy system model is used to describe the part of nonlinear systems:

Plant Rule i: IF $x_1(t)$ is M_{i1} and … and $x_v(t)$ is M_{iv}

THEN $\dot{x}(t) = A_i x(t) + B_w w(t) + B_i u(t)$, $\quad z(t) = C_i x(t) + B_w w(t)$ (2)