Model Reference Adaptive Control on Glucose Regulation

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Abstract: ***ICU patients can suffer from stress induced hyperglycemia, which differs from diabetes mellitus. Glucose variations can be balanced using online optimization of parameters. This is a challenging fact because of less number of individualized model in ICU. Model Reference Adaptive Control is used to deal with this problem. Hovorka model is used as patient model and the glucose level is controlled using Liaponov method in MRAC controller***

Keywords: Model Reference Adaptive Control (MRAC), Lyapunov theory, Glucose regulation

1. Introduction

Diabetes Mellitus is a common disease around the world and it can induce various diseases and can cause high mortality. It can be grouped into type 1 and type 2 diabetes. Recently many developments are introduced for the development of artificial pancreas. Artificial pancreas is an automated closed loop control system for glucose regulation of patients with type 1 diabetes. There are different control strategies for closed loop artificial pancreas, which are based on different controllers such as MPC, SMC, PID, ILC etc…Here Model Reference Adaptive Control is use for glucose regulation. There are two mathematical models for virtual patient, UV simulator and Hovorka model. Here Hovorka model is used since second order function with delay element is considered as system model.

Human body uses glucose as primary source of energy and glucose molecules are broken down within cells in order to synthesis ATP molecules which drives various processes in living cells. In a human being the Blood Glucose (BG) level ranges in between 70-110mg/dL. Glucose regulation is mainly done by the production of Insulin and Glucagon. Alpha cells secretes glucagon and beta cells secrets insulin. When glucose level fall below the normal level, insulin is secreted by pancreas and when glucose is higher than a normal level glucagon is secreted by pancreas

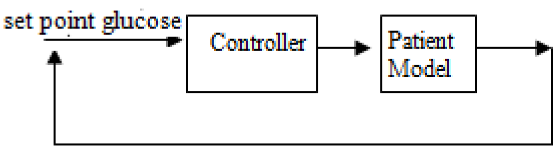


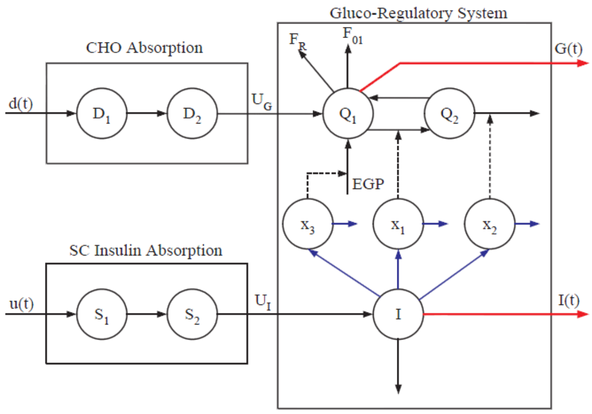
Figure 1.1: block diagram of system

The variation of glucose level becomes unpredictable and can cause mortality so appropriate insulin injection is predicted by using artificial models and controllers and proper value of in insulin to be injected is determined. Insulin injection is done by insulin pumb. Here MRAC Controller is used for glucose regulation.

Using Hovorka model, a patient model is introduced which shows huge variation of glucose level in patient body which I regulated and settled to a reference point by MRAC.

2. Patient Model

Hovorka and coworkers developed the nonlinear model to represent virtual patient model.



Usually second order functions with delays are represented by hovorka model.

$$H(s) = \frac{G(s)}{I(s)} \tag{1}$$

$$H(s) = \frac{k\, e^{-T_d \theta s}}{s^2 + 2\varepsilon w_n + w_n^2} \tag{2}$$

Where T_d the delay time and the value ranges from .2 to .3. Substituting the values for θ, ε, T_d, and w_n $H(s)$ becomes

$$G(s) = e^{-.0287s} * \frac{1.136}{s^2 + 1.007s + 101.3} \tag{3}$$

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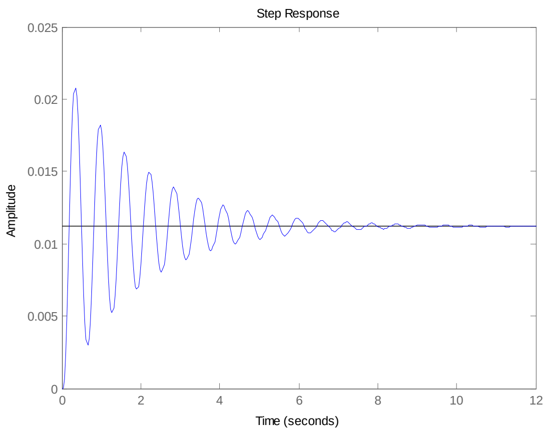

Figure 2.2: step response of the system

3. Model Reference Adaptive Control

Sometimes conventional feedback controllers may not perform well online because of the variation in process dynamics, changes in environmental conditions and disturbances that affects the system therefore an adaptive control adjusts the controller parameters so that the output of the actual plant tracks the output of a reference model having the same reference input.

Model Reference Adaptive control (MRAC) is an adaptive control strategy which has some adaptive control parameters (θ_i) and an adjusting mechanism to adjust these controller parameters and in MRAC, desired behavior of system is specified by a model as shown in fig.3.1. The difference between model output and plant output is termed as error and thearameters of controller are adjusted based on the error with same reference input given to both controller and model.

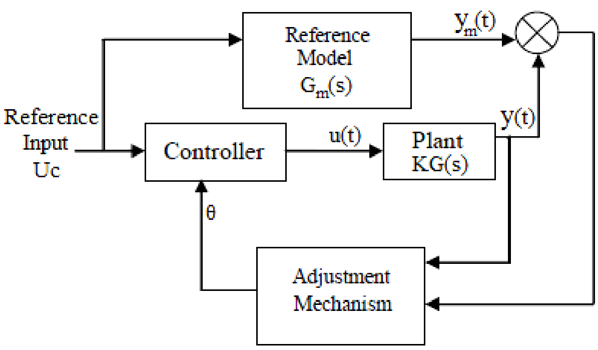

Figure 3.1: Model reference adaptive controller

Here, model output is compared to the actual plant output, and the difference is used to adjust feedback controller parameters. The basic block diagram of MRAC system is shown in the fig.3.1. As shown in Fig.3.1, y_m(t) is the output of the reference model and y(t) is the output of the actual plant and difference between them is denoted by e(t).

e(t) = y(t) - y_m(t). Mathematical techniques like MIT rule, Lyapunov theory and theory of augmented error can be used to develop the adjusting mechanism. In this paper Lyapunov rule are used for glucose regulation.

3.1 Lyapunov Method

Assume a Lyapunov function

$$V(e,\theta_1,\theta_2) = \frac{1}{2}\left(e^2 + \frac{1}{b\gamma}(b\theta_2 + a - a_m)^2 + \frac{1}{b\gamma}(b\theta_1 - b_m^2)\right) \quad (4)$$

For the function to qualify as Lyapunov function, the derivative must be negative definite.

$$\frac{dV}{dt} = -a_m e^2 + \frac{1}{\gamma}(b\theta_2 + a - a_m)\left(\frac{d\theta_2}{dt} - \gamma y e\right) + \frac{1}{\gamma}(b\theta_1 - b_m)\left(\frac{d\theta_1}{dt} + \gamma u_c e\right) \quad (5)$$

3.2 Model Reference Adaptive Controller Design

The model transfer function is represented as $G(m)$

$$y_m = G(m).U_c \quad (6)$$

$$y_m = \frac{64}{s^2 + 16s + 64} U_c;\ \varepsilon = 0.95 \quad (7)$$

3.3 Lyapunov Rule

$$\frac{d\theta_1}{dt} = -\gamma u_c e \quad (8)$$

$$\frac{d\theta_2}{dt} = \gamma y e \quad (9)$$

γ_1 and γ_2 values are taken as 12 and 4 by trial and error method.

4. Simulation Results and Discussion

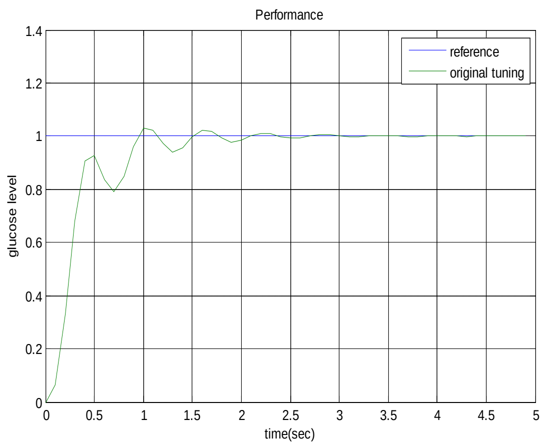

Figure 4.1: response using MRAC controller

Settling time of glucose level is almost 2.5 seconds using MRAC controller

5. Conclusion

A detailed discussion on MRAC scheme using Lyapunov theory is done in this paper and the performance evaluation is carried out by means of simulations on SIMULINK. Responses of MRAC is obtained. For Lyapunov rule, the suitable range of γ is 3< γ <15. The complicacy is reduced in MRAC with Lyapunov rule. Also Lyapunov rule can give better response.

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