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Insulin Control System for Diabetic Patients by Using Adaptive Controller

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ABSTRACT

Diabetes is one of the most important medical problems during which the body's production and use of insulin is impaired, causing glucose concentration level to increase in the bloodstream .This paper focuses on designing a controller with observer to improve the performance of the insulin control for type 'I' diabetic patients. Since the dynamic model of glucose levels in diabetic patients is a nonlinear model, therefore fuzzy controller is a good choice for controlling of insulin in blood. Simulation results show the performance of fuzzy controller to produce a stable control signal in comparison to PID controller.
KEYWORDS: Pump, insulin, controller, and diabetes.

1. INTRODUCTION

Several organs, hormones and enzyme systems are involved in the regulation of the blood glucose Levels in human body. Insulin is a hormone that is necessary for converting the blood sugar, or glucose, into usable energy. The human body maintains an appropriate level of insulin. Diabetes is caused by lack of insulin in the body. There are two major types of diabetes, called type 'I' and type 'II' diabetes. Type 'I' diabetes are called Insulin Dependent Diabetes Mellitus (IDDM), or Juvenile Onset Diabetes Mellitus (JODM). Type 'II' diabetes are known as Non-Insulin Dependent Diabetes Mellitus (NIDDM) or Adult-Onset Diabetes (AOD) [1-7]. The lifestyles of type 'I' diabetes are often severely affected by the Consequences of the disease. Because of the insulin producing B-cells of the pancreas are destroyed, patients typically regulate glucose manually. The patient is totally dependent on an external source of insulin to be infused at an appropriate rate to maintain blood glucose concentration. Mishandling this task, potentially lead to a number of serious health problems including heart and blood vessel disease, kidney disease, blindness. Deviations below the basal glucose levels (hypoglycaemic deviations) are considerably more dangerous in the short term than positive (hyperglycaemic) deviations, although both types of deviations are undesirable [8, 9]. Large efforts are undertaken in pharmacology and biomedical engineering to control glucose concentration by proper insulin dosing [10]. The insulin infusion rate to a diabetic patient can be administrated based on the glucose (sugar) level inside the body. Over the years many mathematical models have been developed to describe the dynamic behaviour of human glucose-insulin systems. The most commonly used model is the minimal model introduced by Bergman [11-16]. The minimal model consists of a set of three differential equations with unknown parameters. Since diabetic patients differ dramatically due to variations of their physiology and pathology characteristics, the parameters of the minimal model are significantly different among patients. Based on such models, a variety of control technologies have been applied to glucose/insulin control problems [17-20]. Therefore, the closed loop control techniques are developed to maintain physiological glucose level [10].

2 Metabolic process models

In Fig. 1 (Sorensen, 1985) the behavioural difference among diabetic and normal patients for the blood glucose concentration (Fig. 1a) and the plasma free insulin concentration (Fig. 1b), when a meal is taken, is shown.

The model used in this study is a multi-compartment model constituted by lots of differential equations where glucose and insulin are transferred into the compartments with a convective transport by the blood plasma. A detailed analysis of the model can be found in Sorensen (1985). The output of the system, used for the control proposed in this study, is the peripheral interstitial blood glucose concentration Gpi (set-point value = 80.7 mg/dl). Two inputs are considered: the intravenous release of insulin to the patient that represents the manipulation variable and the meal that instead represents the disturbance to the system. The Sorensen model does not include a module for the meal metabolism and considers as input the rate of gut oral glucose absorption determined by the assumption of a standard amountò (100 g) of glucose, as shown in Fig. 2 (Sorensen, 1985). The control target is to obtain for a diabetic patient a glucose concentration, after a meal, comparable to that of a healthy person.

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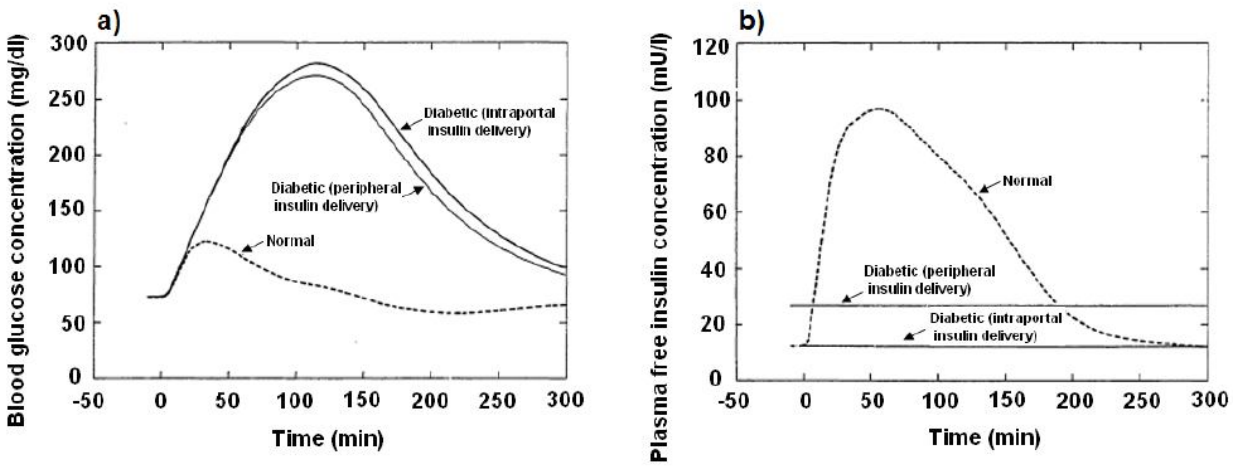

Fig. 1: a) Blood glucose concentration and b) Plasma free insulin concentration for normal and diabetic persons (peripheral and intraoral insulin delivery).

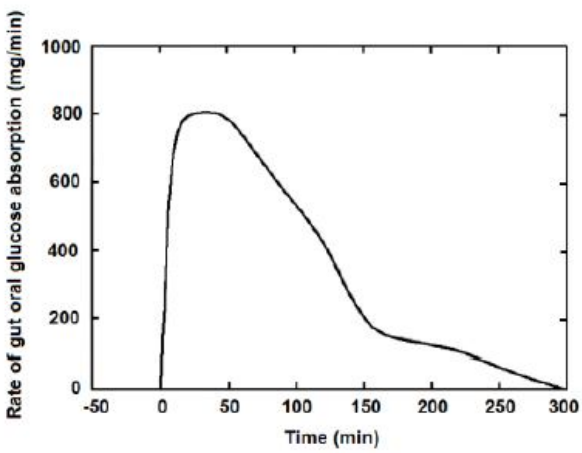

Fig. 2: Rate of gut oral glucose absorption vs time.

2. Control process model

2.1 An insulin pump control system

An insulin pump is a medical system that simulates the operation of the pancreas (an internal organ). The structure of this system is an embedded system, which collects information from a sensor and controls a pump that delivers a controlled dose of insulin to a user. People who suffer from diabetes use the system. Diabetes is a relatively common condition where the human pancreas is unable to produce sufficient quantities of a hormone called insulin. Insulin metabolises glucose (sugar) in the blood. The conventional treatment of diabetes involves regular injections of genetically engineered insulin. Diabetics measure their blood sugar levels using an external meter and then calculate the dose of insulin that they should inject. The problem with this treatment is that the level of insulin required does not just depend on the blood glucose level but also on the time of the last insulin injection. This can lead to very low levels of blood glucose (if there is too much insulin) or very high levels of blood sugar (if there is too little insulin). Low blood glucose is, in the short term, a more serious condition as it can result in temporary brain malfunctioning and, ultimately, unconsciousness and death. In the long term, however, continual high levels of blood glucose can lead to eye damage, kidney damage, and heart problems. Current advances in developing miniaturized sensors have meant that it is now possible to develop automated insulin delivery systems. These systems monitor blood sugar levels and deliver an appropriate dose of insulin when required. Insulin delivery systems like this already exist for the treatment of hospital patients. In future, it may be possible for many diabetics to have such systems permanently attached to their bodies. A software-controlled insulin delivery system might work by using a micro-sensor embedded in the patient to measure some blood parameter that is proportional to the sugar level. This is then sent to the pump controller. This controller

computes the sugar level and the amount of insulin that is needed. It then sends signals to a miniaturised pump to deliver the insulin via a permanently attached needle.

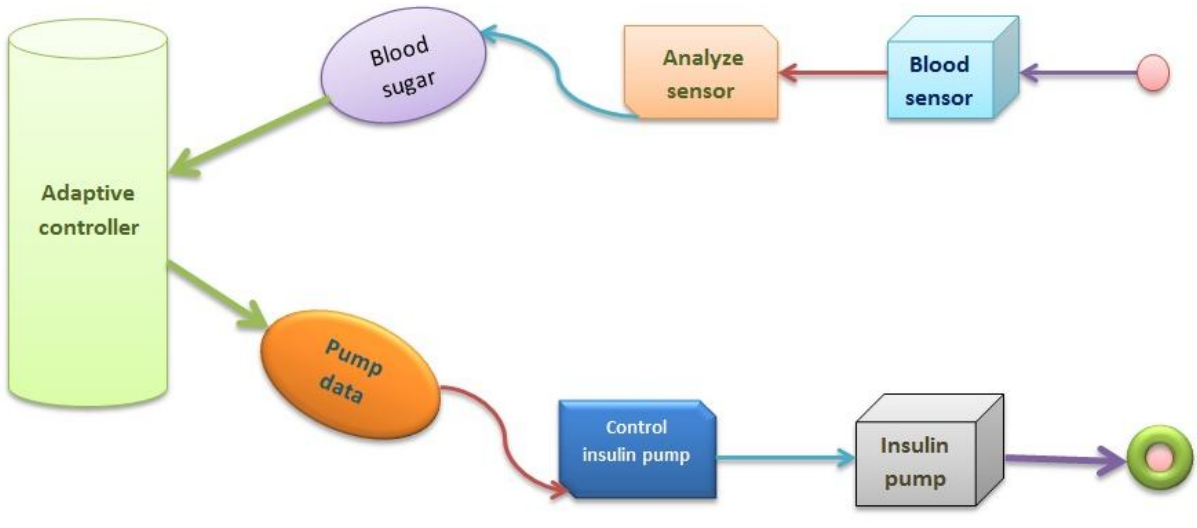

Fig 3: Adaptive controller applicable in insulin pump control system

Figure 3 is an activity model that illustrates how the system transforms an input blood sugar level to a sequence of commands that drive the insulin pump. Clearly, this is a safety-critical system. If the pump fails to operate or does not operate correctly, then the user's health may be damaged or they may fall into a coma because their blood sugar levels are too high or too low. There are therefore two essential high-level requirements that this system must meet:

1. The system shall be available to deliver insulin when required.
2. The system shall perform reliably and deliver the correct amount of insulin to counteract the current level of blood sugar.

The system must therefore be designed and implemented to ensure that the system always meets these requirements. More detailed requirements and discussions of how to ensure that the system is safe are discussed in other supporting documents.

2.2 Adaptive used controller

Takagi and Sugeno proposed the T-S fuzzy model in 1985. Students called it as Sugeno fuzzy model. The Sugeno fuzzy model is a nonlinear model. It can actualy express the dynamic characteristic of complex systems. Furthermore, it is the fuzzy inference model that is in the most common use. A typical fuzzy rule in a Sugeno fuzzy model has the format:

If x is A and y is B, Then z = $f(x, y)$

Where A and B are fuzzy sets in the antecedent; z = $f(x,y)$ is a crisp function in the consequent. When $f(x, y)$ is a first-order polynomial, we have the first-order Sugeno fuzzy model. Consider a first-order Sugeno fuzzy inference system, which contains two rules.

Rule 1: If x is A_1 and y is B_1Then $f_1 = p_1x + q_1y + r_1$

Rule 2: If x is A_2 and y is B_2Then $f_2 = p_2x + q_2y + r_2$

Adaptive controller is created through the concepts of fuzzy sets and the Sugeno fuzzy inference system which imitates the human decision making. The advantage of controller is to immediately calculate output. It is not necessary to create the complex mathematical model. This controller can learn from the sample data such as the input output sets from the system and can adapt parameters inside its network. In this paper we assume that the controller has five layers. In this model, the output of ith node in layer l is denoted as $O_{l,i}$.

Layer 1: Every node i in this layer is an adaptive node with a node function

$$O_{1,i} = \mu_{A_i}(x) = exp\left[-\left(\frac{x - m_i}{\sigma_i}\right)^2\right] \quad for\ i = 1,2\ or \qquad (1)$$

$$O_{1,i} = \mu_{B_{i-2}}(x) = exp\left[-\left(\frac{x - m_i}{\sigma_i}\right)^2\right] \quad for\ i = 3,4 \qquad (2)$$

where $\{m_i, \sigma_i\}$ is the parameter set. These are called premise parameters.
Layer 2: Every node in this layer is a fixed node, whose output is the product of all the incoming signals.

$$O_{2,i} = w_i = \mu_{A_i} * \mu_{B_i} \quad for\ i = 1,2 \qquad (3)$$

Layer 3: Here, the ith node calculates the ratio of the ith rule's firing strength to the sum of all rule's firing strengths.

$$O_{3,i} = \overline{w}_i = \frac{w_i}{w_1 + w_2} \quad for\ i = 1,2 \qquad (4)$$

Layer 4: Every node i in this layer is an adaptive node with a node function

$$O_{4,i} = \overline{w}_i f_i = \overline{w}_i (p_i x + q_i y + r_i) \qquad (5)$$

where $\overline{w}_i$ is a normalized firing strength from layer 3 and $\{p_i, q_i, r_i\}$ is the parameter set of the node. These parameters are referred to as consequent parameters.
Layer 5: The single node in this layer is a fixed node, which computes the overall output as the summation of all incoming signals:

$$O_5 = f = \sum_i \overline{w}_i f_i \qquad (6)$$

3. Comparison Between PID Algorithm and Fuzzy Logic Technique

Various therapeutic situations are related to control problems. Although the early medical systems appeared at the same time as the article by Zadeh (1965), there has been little communication between the research fields, but recently this has changed due to the developments in computer systems, and rapid development of the literature searching methods motivated by the internet and the World Wide Web. Many systems are being developed which utilize fuzzy logic and fuzzy set theory.

Fuzzy logic control is also an advanced process control, which imitates the logic of human thought, and much less rigid than the calculations computers generally perform. There are three steps for the process of a fuzzy logic algorithm: fuzzification, rules, and defuzzification. In this paper, it is assumed that there are two different inputs of the concentration of glucose and the change rate of

Concentration and one output of the change rate of insulin injection. Fuzzy logic controller is designed according to the structure of Mamdani.

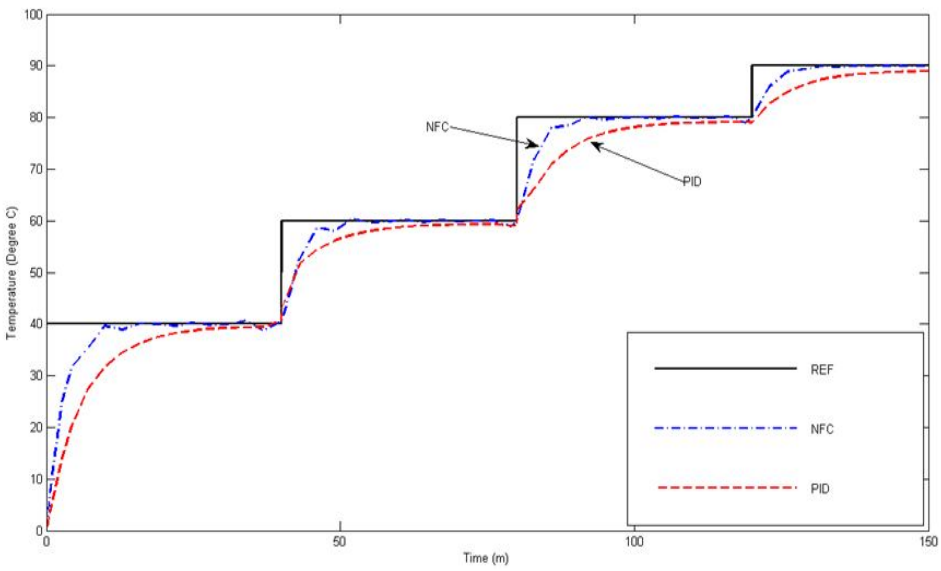

Fig. 4: Performance of the NFC and PID Controller

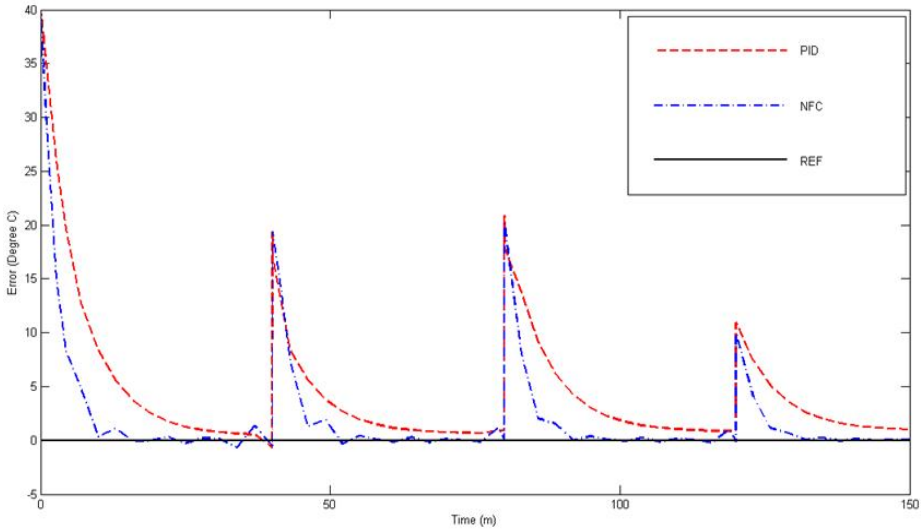

Fig. 5: The error curves of NFC and PID controller

For the aforementioned simulation results, Figure 4 has shown that the Fuzzy Controller has better performance than PID Controller.

5. Conclusion

In this paper we have discussed a new method to control insulin in human body. The diabetes management is one of the challenging control problems. We have used Fuzzy controller which is a good choice for nonlinear systems. Simulation results show that the fuzzy controller produces a stable control signal than PID controller which is very important factor for insulin control system.

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