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RESEARCH ARTICLE

ADAPTIVE FUZZY BACKSTEPPING CONTROL FOR BLOOD GLUCOSE REGULATION

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Abstract

In this paper, we propose an adaptive type-2 fuzzy backstepping controller for blood glucose regulation. To mimic at best the behavior of a real pancras, the nonlinear Bergman minimal model is adopted. To deal with the strict feedback form of this model, we use backstepping algorithm. To overcome the knowledge of the several parameters of model to deduce the control laws, we use adaptive type-2 fuzzy systems to obtain the control signals. The stability of the closed loop system is proven using Lypunov theory. A simulation example with a comparative study is given to schow the performances of the proposed approach.

Introduction:-

Diabetes is a serious threat to global health which increasing at a very high rate. This metabolic disease, which ischaracterized by hyperglycemia resulting from defects ininsulin secretion, insulin action or both, can lead to frequent hospital admissions and premature death[1]–[2]. According to the American Diabetes Association, there are four types of diabetes entailing: type 1, type 2, gestational diabetes (diabetes while pregnancy), and specific types of diabetes (such as genetic defects in insulinaction). Type-1 diabetes is a chronic condition in which pancreatic β-cell destruction typically culminates and can be controlled by injecting insulin daily. technological developments in terms of sensors and actuators have made it possible to develop prototypes of artificial pancreas. The objective to establish a closed loop for glucose regulation.

Thus, several methods including the proportional–integralDerivative (PID) controllers [3], LQG control algorithm [4] and combined PI-Fuzzy techniques[5] are adopted into the control process. Dispite the good results, these linear methods uses several simplifying assumptions with not reflects the non-linear glucose-insulin dynamic.

The backstepping methodis among the popular controller methods which can be applied to non linear systems [6]. It is a recursive design procedure that links the choice of a control Lyapunov function with the design of a feedback controller and guarantees global asymptotic stability of strict feedback systems. The active backstepping control method is a practical tool to overcome the limitations of the feedback linearization approach in the control literature [7].

In this work, we propose to combine backstepping control with type 2 fuzzy logic to blood glucose regulation. Indeed, the backstepping allows to exploit the abiklity of this approach to control non linear systems and then reduce used assuptions to maintain the non linear bahavior of the model. To overcome the problem of knowledge of the system paraters we propose to use adaptive fuzzy type 2 systems. This choice is motivated by the fact that type-2 fuzzy logic allows to take in account modeling uncerytainties [8]. Furthermore these systems will be updated

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according to adaptation laws dediced from the stability analysis and then reduce the knoledge of the system for control design. To illustrate the performances of the proposed approach, a simulation example is given.

Mathematical model of type-1 diabetes:-

The non-linear extended model for type 1 diabetic patientshas been proposed in [9]. Meal disturbance to the blood glucose level which was consideredas fixed value in Bergman's minimal modelare defined as a fourth state of thesystem given as:

$$\begin{cases} \dot{x}_1 = -p_1(x_1 - G_b) - x_1.x_2 + x_4 \\ \dot{x}_2 = -p_2 x_2 + p_3(x_3 - I_b) \\ \dot{x}_3 = -p_4(x_3 - I_b) + U(t) \\ \dot{x}_4 = -p_5 x_4 \end{cases} \tag{1}$$

Where:

- x_1, x_2, x_3 and x_4: are glucose concentration, remote insulin concentration, plasma insulin concentration and Fisher's Meal disturbance respectively.
- G_b: is the basal plasma glucose.
- I_b: is the basal plasma insulin.
- p_1: is the glucose effectiveness factor .
- p_2: is the delay in insulin action .
- p_3: is the patient parametter .
- p_4: is the insulin degradation rate .
- p_5: is the meal disturbance .

$U(t)$ represents the insulininfusion rate, which will be deduced using the proposed control approach in the next section.

Proposed contront approach:-

To elaborate the proposed approach base on combination of backstepping and type-2 fuzzy logic, we introduce the calculus used a classical backstepping control and then we give the proposed algorithm.

The synthesis of the first virtual control law is obtainedvia the expression of the following error:

$$e_1 = x_1 - x_{1d} \tag{2}$$

If we consider the following Lyapunov function for stability analysis:

$$V_1 = \frac{1}{2} e_1^2 \tag{3}$$

Thefollowing virtual control allows us to attain our objctive

$$x_{2d} = x_1^{-1}(-p_1(x_1 - G_b) - \dot{x}_{1d} + c_1 e_1 + k_1 sign(e_1)) \tag{4}$$

A second tracking error, resulting from the expression ofthe first virtual control law, is added to the control process:

$$x_2 = x_{2d} + e_2 \tag{5}$$

Then, the time derivative of the Lyapunovfunction becomes:

$$\dot{V}_1 = -c_1 e_1^2 - x_1 e_1 e_2 - e_1(k_1 sign(e_1) - x_4) \tag{6}$$

The stability condition $\dot{V}_1 < 0$ is ensured as long asc_1> 0 and $|x_4| < k_1$, with the residual term $x_1 e_1 e_2$, mustbe compensated in the second step.

So, let's consider the second Lypunov finction:

$$V_2 = \frac{1}{2}(e_1^2 + e_2^2) \tag{7}$$

As in the case of the previous step, the second virtual control law is taken as:

$$x_{3d} = p_3^{-1}(p_2 x_2 + p_3 I_b + \dot{x}_{2d} + x_1 e_1 - c_2 e_2 - k_2 sign(e_2)) \tag{8}$$

Which introduces the following third error term:

$$x_3 = x_{3d} + e_3 \tag{9}$$

Consequently, the time derivative of the Lyapunov equation (7) is given by:

$$\dot{V}_2 = -c_1 e_1^2 - e_1(k_1 sign(e_1) - x_4) - c_2 e_2^2 - e_2(k_2 sign(e_2) - p_3 e_3) \tag{10}$$

Again we have a residual term which must be eliminated in the next step.

For this, we consider the gloval Lypunov function:

$$V_3 = \frac{1}{2}(e_1^2 + e_2^2 + e_3^2) \tag{11}$$

If we choose the global control law as:

$U(t) = p_4(x_3 - I_b) + \dot{x}_{3d} - p_3 e_2 - c_3 e_3 - k_3 sign(e_3)$ (12)
The time derivative of the Lypunov function (11) becomes:
$\dot{V}_3 = -c_1 e_1^2 - e_1(k_1 sign(e_1) - x_4) - c_2 e_2^2 - k_2 c_3 e_2^2 e_3^2 - k_3 e_3^2$ (13)
Wich ensures the the asymptotic stability ofthe closed loop system via a judicious choice of parameters.

Analysing the expressions of the virual and global control laws, we remark that the good knowledge of the system paramters is required to attain the regulation objevctives. To overcome this probme, we propsoe to aproximate the unknown terms by adaptive type-2 fuzzy systems in the form [10]:
$\psi^T(x_1, x_2, x_3).\Phi$ (14)
Wher $\psi(x_1, x_2, x_3)$ and Φ represent respectively the regressive vector and the adaptive parameters vector.
In this case the, the control laws become:
$x_{2d} = \psi_1^T(x_1, x_2, x_3).\Phi_1 + x_1^{-1}(c_1 e_1 + k_1 sign(e_1))$ (15)
$x_{3d} = \psi_2^T(x_1, x_2, x_3).\Phi_2 + p_3^{-1}(c_2 e_2 + k_2 sign(e_2))$ (16)
$U(t) = \psi_3^T(x_1, x_2, x_3).\Phi_3 - c_3 e_3 - k_3 sign(e_3)$ (17)
Where the adaptation laws are given by the following expressions:
$\dot{\Phi}_1 = \gamma_1 \psi_1^T(x_1, x_2, x_3) e_1$ (18)
$\dot{\Phi}_2 = \gamma_2 \psi_2^T(x_1, x_2, x_3) e_2$ (19)
$\dot{\Phi}_3 = 3\, \psi_3^T(x_1, x_2, x_3) e_3$ (20)
With $\gamma_i\, (i = 1,2,3)$ are the learning scalars.

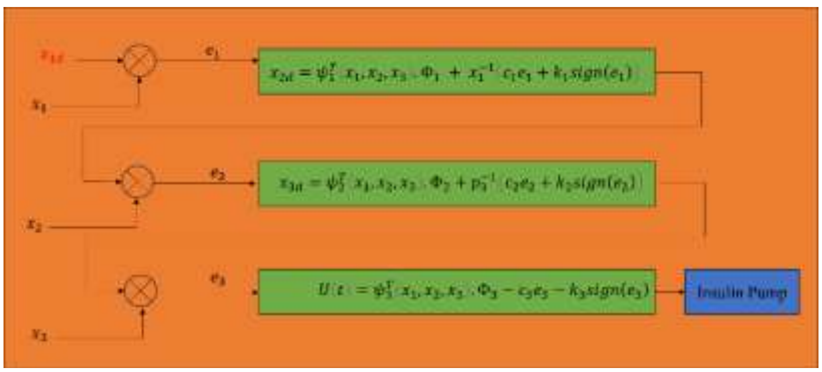

Figure 1:- Diagram block of the proposed approach.

Results and Discussion:-

The simulation has beendone for a patient with the followinh parameters: $G_b = 90\, mb/dl$, $p_1 = 0 l/min, p_2 = 0.0142 l/min$, , $p_3 = 15.10^{-6} ml/\mu U/min$ and $p_4 = 0,2814 l/min$. The simulations are done starting from fasting glucose level (no foodtaken for at least 8 h) at 7 A.M. The meals are taken at 7 A.M. as breakfast, 1 P.M. as lunch, and 7 P.M. as dinner. We assume that effects of foods of lunch meal amount is more than dinner while dinner ismore than breakfast. Figure 2 gives the Blood glucose level evolution using the proposed method and a classical backstepping. We remark that the proposed approach allows to obtain the objective quickly. Also, it makes it possible to quickly limit the increase in the level of glucose in the blood, which makes it possible to avoid possible hyperglycemia, unlike a conventional backstepping control.

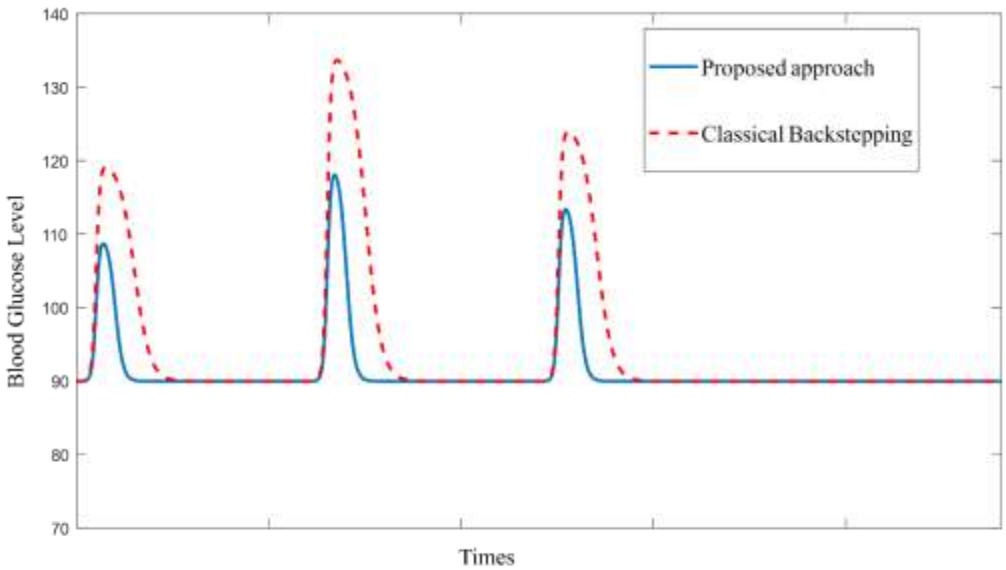

Figure 2:- Blood glucose level for a nominal patient under the control algorithm.

Conclusions:-

In this paper, a blood glucose regulation for type-1 diabete is treated. Based on a nonlinear model, a backstepping controller has been developed. To overcome the problem of the well-knowledge of the patient parameters, adaptive type-2 fuzzy sysems have been used. These systems are updated on line according to adaptation laws deduced from the stability analysis to reduce the dependence of control implementation of the perfect knowledge of the patients. Obtained simulation results schow that the proposed approach allows to obtain a good regulation and avoid to attain hyperglycemia. As future works, we propose to simplify the design procedure by reducing the involved parameters.

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