N.Sivaramakrishnan et al /J. Pharm. Sci. & Res. Vol. 9(4), 2017, 465-469

ISSN:0975-1459
Journal of Pharmaceutical Sciences and Research
www.jpsr.pharmainfo.in

Optimal Model Based Control for Blood Glucose Insulin System Using Continuous Glucose Monitoring

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Abstract

The level of glucose control in the human body is very important, because increase in glucose level in diabetic patients for long time causes blindness and cardiovascular problem. In this paper, closed loop insulin system for diabetic patients is proposed to regulate the blood glucose level. Hence, continuous monitoring and control of glucose level is necessary for Type 1 diabetes patients. In this paper, Bergeman minimal model is consider and then closed loop system is developed with insulin pump. This closed loop system essentially acts as an artificial pancreas. The closed loop control parameters are optimally tuned to control the blood glucose level most effectively. The Internal model control (IMC) and proportional derivative (PD) controller are implemented and the control parameters are tuned optimally. The comparative simulation results are compared and analysed.

Keywords: *IMC control, PID, Genetic Algorithm, Blood Glucose level.*

1. INTRODUCTION:

Blood glucose level is regulated by production of insulin by the pancreas. Type 1 diabetes mellitus patients cannot produce any insulin and they must administer insulin shots several times a day to regulate their blood glucose level. Type 1 diabetics disease mostly affecting the health of children. The continuous monitoring of glucose level is required to control the glucose level in the blood. There are some advanced techniques are introduced to monitor and control of glucose level. Insulin pump device and glucose monitoring devices are integrated to form an automatic insulin pump device. The digestion process considered as slow process (dead time process) while consume the food, automatically the blood glucose level in the blood is changed, for type 1 diabetic to injection of insulin from insulin pump in exact quantity. The blood glucose sensor monitoring the continuous value of glucose and Insulin pump injects the insulin based on lag of blood glucose. A genetic algorithm based PID control algorithm is proposed to control blood glucose level effectively in type 1 diabetics.

The artificial pancreas (a closed loop control system) enables diabetic patient to maintain normal glucose level by providing the right amount of insulin at the right time with no need for human interaction when it comes to decision making.[1] A controller has been proposed for decision making. A PID controller regulates the glucose level in type -1 diabetic patients , an active sliding table is used to prescribe insulin infusion rates[2] The bio-inspired method for in-vivo is used to model a pancreatic-cell and this system implemented using analogue integrated circuits[3]. In some advanced control techniques to combined the two types of controllers like proportional integral derivative (PID), and fuzzy logic controllers (FLC) and control the blood glucose level.[3] a closed-loop system which utilizes modified glucose insulin interaction model is considered. The modified model was derived by adding an exogenous insulin infusion term. Two control algorithms are used for exogenous insulin infusion: a Mamdani type fuzzy logic controller (FLC), and a fuzzy-PID controller [5] The tuning is complex in PID controller and the optimum tuning value is not achieved in fuzzy logic controller. In this paper a genetic algorithm based fuzzy PID controller proposed for closed loop blood glucose system to increase the performance.

2. MATHEMATICAL MODEL:

Various mathematical models have been proposed to understand the Diabetes dynamics and to correlate the relation between glucose and insulin distribution models that helps in designing of model for control of diabetics. All these models are taken considerations at specific rules and procedures to design these models. Our body system is entirely the non linear system and this model can be compared with the Brownie motion which has various stochastic processes in our body system for various factors. So by taking certain parameters with assumption of some steady state condition, the appropriate model can be designed. These models have many limitations in predicting blood glucose in real time clinical situation because of the essential requirement of frequently updated information about the models like glucose loads, insulin availability, and necessary standatise glucose sensor based system [4]. Reference model charts of change of biosignals with amount of insulin injected. Consider a mathematical model comprised of glucose level G, glucose uptake activity X and insulin level I. Many parameters has to be taken into account. Based on these values a mathematical model can be formed using these parameters. This model includes the basal values also i.e. Gb and b I .

The human body inherent much system to do their function one of important function is the blood glucose level system. After having meal .Insulin is taken by cell to break down the glucose. If glucose is not breakdown it is increase it tends to hyperglycemia (high blood sugar) it can lead to blindness and some heart problems.Type-1 diabetic patients the pancreas is not functioning and it is not injecting the insulin naturally so artificially to inject the insulin for those patients to regulate the glucose level. Insulin pump are plays vital role, it act as artificial pancreas it monitored the continuous glucose level and injects the exact quantity of insulin in the human body. To development of artificial pancreas system a human body blood glucose system is represented as dynamic equations. This model is Bergman "minimal model" (Bergman et al.,1981) it is expressed as,

$$\frac{dG}{dt} = -p_1 G - X(G + G_b) + \frac{G_{meal}}{V_1} \quad (1)$$

$$\frac{dX}{dt} = -p_2 X + p_3 I \quad (2)$$

$$\frac{dI}{dt} = -n(I + I_b) + \frac{U}{V_1} \quad (3)$$

Where G and I indicate the change in blood glucose and insulin concentration respectively. Here the X is proportional to the insulin concentration in "remote" areas. The inputs are G_{meal}, a meal is disturbance that increases the glucose concentration in body levels slowly as per health condition of person and U , the manipulated insulin infusion rate . The parameters include p_1, p_2, p_3, n, V_1(which represents the blood volume). Other parameters are $G_d and\ I_b$, the " basal" (baseline or steady state) values of blood glucose and insulin concentration. These values can be used to find the basal infusion rate of insulin necessary to maintain a steady state.

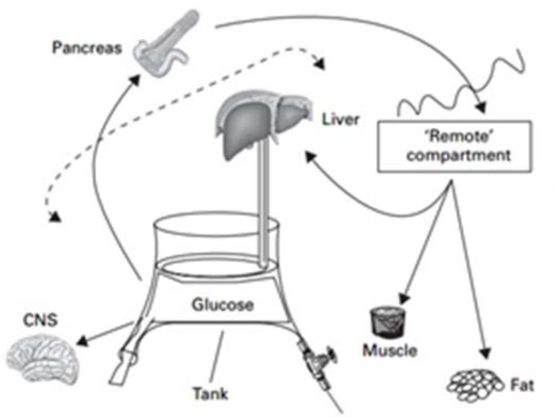

Figure 1 Bergmann's Minimal Model

Consider a diabetic that is modelled using following set of parameters (Lynch and Bequette 2001)

Process Transfer function,

$$\text{Gp}(s) = \frac{-3.79}{(40s+1)(10.8s+1)} \quad (4)$$

Meal disturbance transfer function is considered as

$$\text{Gd}(s) = \frac{8.44}{s(20s+1)} \quad (5)$$

The meal disturbances is given as pulse and assume that 1 50 g glucose meal is consumed over a 15- minute period; the pulse then has a magnitude of 3.33g/minute of a duration of 15 minutes.

3. CONTROLLER DESIGN

3.1. PD control

The PD controller inherent the advantages of proportional and Derivative controller the Proportional controller produces an instantaneous response to control the error and its magnitude is proportional to output and error signal. A derivative controller differentiates the error signal and produces the controller signal. It used to find the future error signal and it reduces the peak overshoot to achieve the transient response of output with in small settling time. The equation of PD controller as,

$$u(t) = K_p e(t) + K_D \frac{de}{dt} \quad (6)$$

$e(t) - Error\ signal$

$K_p - Proportional\ Cosntant$

$K_D - Derivative\ Constant$

$u(t) - \ Controller\ output$

3.2. Internal Model Controller (IMC)

The IMC controller has good tracing performance to track and regulate the blood glucose level It has good set-point tracking in many process control applications and rejection the disturbance for the stable processes to include a filter with this controller to act as a good disturbances rejection for unstable processes. Thus, an appropriate IMC filter to design an IMC controller for better set-point tracking in unstable processes. Normally in PD controller its is complex to tune the controller parameters K_p and K_I and PD controller is not suitable for unstable process to overcome this tuning complexity IMC Controller is proposed for blood glucose system. This IMC controller contains a single tuning parameter λ, so tuning is simple compare with PD controller.

Glucose Model is,

$$p(s) = \frac{K}{\tau s + 1} e^{-\theta s} \quad (7)$$

The IMC controller q(s) is,

$$q(s) = P(s)^{-} * f \quad (8)$$

where p(s)$^-$ is a invertible model without dead time and right hand zero.

$$p(s)^{-} = \frac{\tau s + 1}{K} \quad (9)$$

The filter f(s) is

$$f(s) = \frac{1}{\lambda s + 1} \quad (10)$$

Here,The IMC control for blood glucose model is,

$$q(s) = G_p^{-}(s).f(s) \quad (11)$$

The Filter for blood glucose model is selected as,

$$f(s) = \frac{1}{(\lambda s + 1)^3} \quad (12)$$

Therefore, the IMC controller q(s) is,

$$q(s) = \frac{(40s+1)(10.8s+1)}{(-3.79)(\lambda s+1)^3} \qquad (13)$$

The filter time constant λ is the only tuning parameter of IMC controller. The genetic algorithm based tuning optimization concept is proposed to tune the parameter λ to minimization of ISE(Integral Square Error).

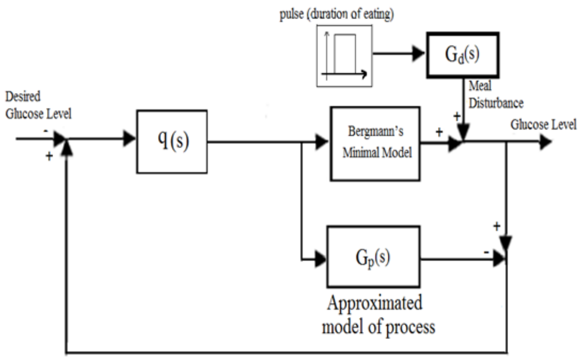

Figure 2. The IMC based Control for Blood Glucose insulin system

The objective function of optimization (J) is given as,

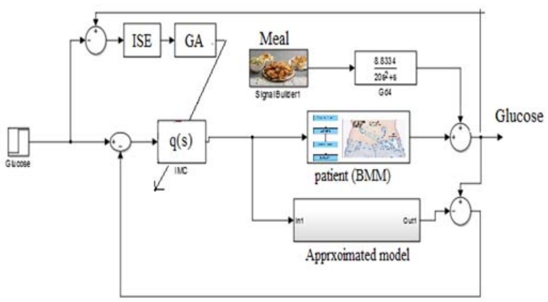

Figure 3 Closed loop GA based IMC control of blood Glucose system

4. Genetic Algorithm

The Genetic algorithm (GA) is used to solve highly complex problems, the solution of a problem is expressed as set of parameters and this parameters are regarded as genes of a chromosome and it's structured by a string of concatenated values. This is called as encoding scheme, based on data values these variables are expressed as binary values, real number values and some other codes values. Initially chromosomes are randomly generated this chromosome consist of K_p ,K_i, K_d parameters with value bounds varied depend on the delay and objective functions used. The value bounds are set using Ziegler-Nichols rule value

The fitness of each chromosome is assessed and a survival of the fittest strategy is applied. In this work, the error value is used to assess the fitness of each chromosome. There are three main operations in a genetic algorithm: reproduction, crossover, and mutation.

Genetic Algorithm Steps

Step 1. Initialize the parameter with a population of random solutions, such as crossover rate, mutation rate, number of clusters, and number of generations. Determine the coding mode.

Step 2. Compute and evaluate the value of the fitness function.

Step 3. Proceed with crossover and mutation operation and make up the new cluster.

Step 4. Repeat Step 2, till the best value is obtained.

4.1 Coding and Decoding:

Genetic algorithms work with a population of strings or chromosomes, instead of considering parameters directly. Hence, to solve our problem, the controller parameter vector should be coded to a string called chromosome. For convenience and simplicity, the binary coding method is chosen. Based on the binary coding method, every element of the parameter vector is coded as a string of length, which consists of zeros and ones for the desired resolution.

4.2 Fitness

Fitness is a measure to evaluate the suitability of a chromosome. By the principle of survival of the fittest, a chromosome with higher fitness value has a higher probability of contributing one or more offspring in the next generation. By employing genetic algorithm, the performance criterion is related to fitness function and optimal PID parameters are derived by minimizing an objective, which inculcates a weighted combination of ISE.

4.3 Crossover

Reproduction is a basic operator of genetic algorithm. It is operated on the basis of the survival of the fittest. In each generation, the chromosome of the current population is reproduced or copied into the next generation, according to the reproduction probability, which is defined in where is the population size.

4.4 Reproduction

Reproduction directs the search of genetic algorithm towards the best individuals. Crossover operation is performed to exchange the information between any two chromosomes via probabilistic decision in the mating pool and to provide a mechanism to mix chromosomes with the splice point.

4.5 Mutation

In genetic algorithms, however, the gene pool tends to become more and more homogeneous as one better gene begins to dominate after several generations and leads to premature convergence of non optimal solution. To overcome this undesirable convergence, the third genetic operator mutation is introduced in genetic algorithm with appropriate probability. Mutation is an occasional alternation of the gene from zero to one or from one to zero with the mutation point determined uniformly at random.

The population size for optimisation is set as 20 and iteration is set as 100.

5. Simulation results & discussion:

The following simulation results show that the desired objectives of achieving minimum ISE are achieved. The simulation started with time t=0 , without any disturbance.

The controller tracking the set point of 80 mg/decilitre level and then the meal disturbance with magnitude of 3.33g/minute is applied at 400^{th} minute as a pulse which raises the glucose level of patient. The GA-IMC based controller rejects the meal disturbance effectively than GA-PID control. The GA-IMC regulates the glucose level within 40 minutes after having meal whereas GA-PD takes longer time to regulate the glucose level.

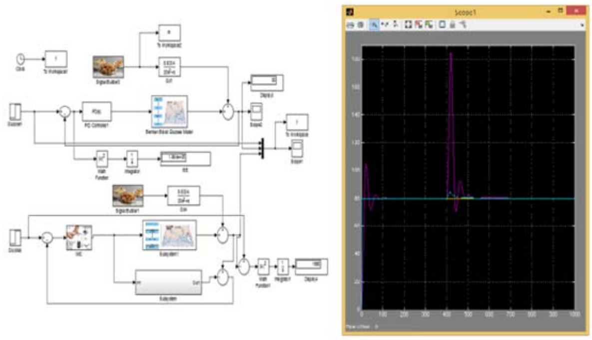

Figure 4 simulation of closed loop GA-PD, GA-IMC controller for blood glucose system

The optimised control value for minimum ISE is tabulated for GA-PD and GA-IMC in table 1,2.

Table.1 GA-PD Controller

	kp	ki	ISE
GA-PD	-0.0527	-2.37	1666

Table.2 GA-IMC controller

	λ	ISE
GA-IMC	-0.12	45810

The blood glucose level has to maintain a particular level while it increases, naturally pancreas inject the insulin to our body to maintain the glucose level whereas for type-1 diabetic patients pancreas doesn't inject the insulin so insulin pump injects the insulin The glucose sensor continuously monitoring the blood glucose level after a meal the glucose level is increases drastically it has refers to input disturbances to the process. The Process is first order with dead time process. The genetic algorithm based single loop PD controller is used for control the blood glucose system. Insulin pump there is a stepper motor it coupled with a injection needle shaft. If the glucose level increases the ID controller produces a control signal in terms of voltage to drive a stepper motor. The displacement of shaft is equivalent to injection of insulin into human body. The PD controller tuned using GA to achieve minimum ISE. The PD control signal affects the insulin system due to its oscillatory response; the time take to regulate the blood glucose is high. To overcome this complexity genetic algorithm based (GA) IMC controller is used.

In practice, the glucose level does not enter the blood stream immediately. Meals take some time to reach it into blood stream. Assume, the patient is taking 50g meal over 15 minutes. Hence 3.3g/minutes pulse is applied in simulation for 15 minutes. The glucose level increases suddenly due to the meal, and it is gradually reduced by applying insulin.

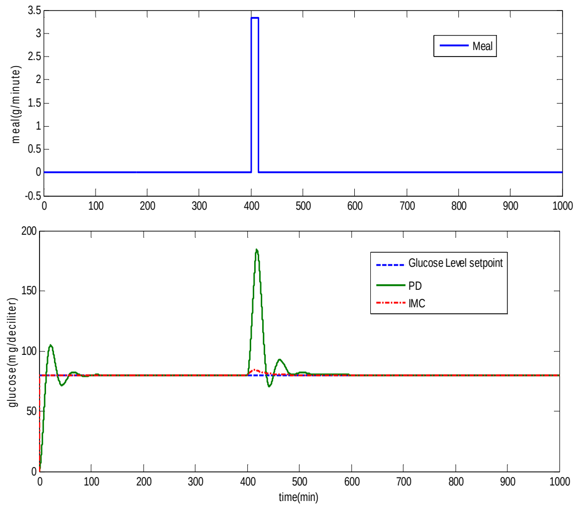

Figure 5 Comparison of GA-PD response, GA-IMC response to meal disturbance

6. CONCLUSION:

In this paper GA based PD controller proposed for blood glucose system The simulation part was done by taking Bergmann's minimal model as a reference model from which glucose and insulin kinetics where referred and then it is simulated. In the simulation, Glucose (meal) is taken as a disturbance which has to be controlled by infusing the insulin in blood of the patient which maintains the glucose level in blood as normal. It is inferred that GA-IMC and GA-PD controllers are compared. The superiority of GA-IMC is shown and discussed. The optimal selection of filter constant in IMC regulates the blood glucose level effectively.

There is major research effort to develop implantable glucose sensors and insulin pumps. The IMC is a model based control which requires exact model of blood glucose system, but the modelling varies patient to patient. The modelling has to be done for each patients using his glucose level data.

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