Designing of Digital PID Controller for blood glucose level of Diabetic patient by using various tuning methods

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***Abstract*- The aim of this paper is to design the digital PID controller for injecting insulin externally to the diabetic patient for maintaining the healthy blood glucose level. We have designed PID controllers using various tuning rules for examining the best performance in terms of different time response parameters like Overshoot, Settling time & rise time etc. Various tuning methods used for designing PID in this paper are Ziegler Nichols method and IPDT method. An approximate mathematical modelling of blood glucose level is also done. Finally the designed conventional PID controller is converted into digital PID controller.**

***Keywords*- Ziegler Nichols, IPDT, diabetic patient, MATLAB simulation.**

I. INTRODUCTION

Now a day's Blood sugar or we can also say Diabetes is a common disease in the world. The recent data is observed that in 2014 report, 29.1 million people are suffering from diabetes. Diabetes is basically a systemic endocrinal disorder which is characterized byHyperglycemia and Glycosuria with Ketonuria. The higher blood glucose level of the diabetic patient which is abovethe 180 mg/dl is the type of patient suffering from Hyperglycemia and another terminology is Hypo-glycemia which is caused by less than 70 mg/dl blood glucose level of the diabetic patient. Hyperglycemia causes long term disease like heart attack, kidney damage, eye related problem and nervedamage. [1]

Diabetes is generally of two different types. The one which is commonly affected is Type 1 Diabetes mellitus and the other one is Type 2 Diabetes mellitus.[3]

Type 1 Diabetes mellitusis caused by absence of Beta cells in pancreas. Due to absence of beta cell in pancreasdeficiency of insulinin human body is created. That's why we provide the external insulin to maintain the blood sugar(glucose) level at the healthy range i.e.3.8 mmol/L to 5.6mmol/L(or in terms of mg/dl is 70 to 120 mg/dl).It is also referred as Insulin Dependent Diabetes Mellitus (IDDM).[3]

Type 2 Diabetes Mellitus starts with insulin resistance. Due to this insulin resistance condition Beta cell doesn't produce insulin in proper amount which required the diabetic patient. It can begenerated in those persons having excess amount of body weight. It is also referredas Non-insulin Dependent Diabetes Mellitus (NIDDM).[2]

Therefore in Type 2 Diabetes a low probability exists that externally injected insulin can cure it. But in Type-1 Diabetes appropriate amount of externally injected insulin can maintain a healthy level of blood glucose. Here comes the various ways of external process to inject the insulin. One process is to inject the insulin through the injection by any human being and the otherprocess is to inject insulin by using automatic digital PID controller. This controller detects the actual glucose level of patient & compares it with healthy level which is the set point. Depending upon the difference of the actual & healthy levelof blood glucose, PID controller injects the amount of insulin which is needed for the blood glucose level of diabetic patient for coming to the normal range.[6]

II. MATHEMATICAL MODELING OF HUMAN BLOOD GLUCOSE LEVEL

In the blood of the human being the amount of insulin present decides the level of Glucose. If more insulin is present then Glucose level remains in a healthy level.

The approximate mathematical modeling of blood glucose can be verified from the given differential equation. The differential equation of blood glucose is shown below – [2]

$$r(t)=\frac{d^3c(t)}{dt^3}+6\frac{d^2c(t)}{dt^2}+5\frac{dc(t)}{dt} \qquad (1)$$

Where, r (t) is the response of blood glucose-insulin systemi.e. the amount of insulin input to the system and c (t) is input of blood glucose – insulin system i.e. the actual measured level of glucose in blood. [2]

This above differential equation (1) is toconvertinto the Laplace domain by using forward transform technique with zero initial condition.

$C(s) \rightarrow L\{c(t); t \rightarrow s\}$ (a)

$$R(s) \rightarrow L\{r(t); t \rightarrow s\} \qquad (b)$$

Now equation (a) and equation (b) put in equation (1) we get the equation in the term of S domain is –

$$R(s) = s^3C(s) + 6s^2C(s) + 5sC(s) \qquad (2)$$

Now taking C(s) common in the above equation (2) and solving the equation in term of R(s)/C(s) the transfer function which is denoted by $G_c(s)$ becomes.

$$Gc(s) = \frac{1}{S^3+6S^2+5S} \qquad (3)$$

This above equation (3) showsthe Transfer function of blood glucose equation for diabetic patient.[2]

Above equation (3) is converted using Triangle approximation (modified first order hold) into discrete function in Z- domain as shown below:

$$G_C(z) = \frac{3.707e^{-005}z^3+0.003635z^2+0.00032252z+2.587e^{-005}}{z^3-2.511z^2+2.06z-0.5488} \qquad (4)$$

The input step response of the blood glucose-insulin system which is shown in figure 1, the stability plot is shown in figure 2 and bode plot of this above equation (3) is shown in figure 3.

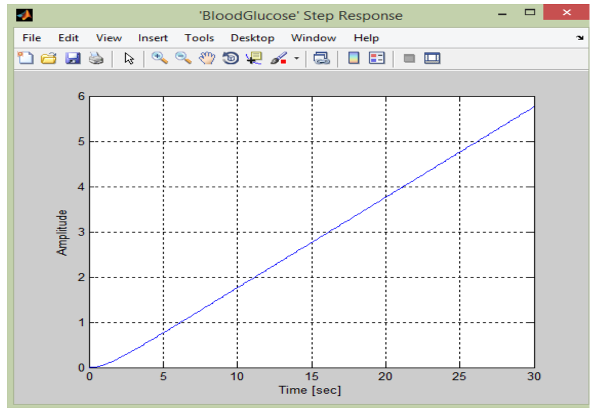

Fig.1Input step response of blood glucose-insulin system.

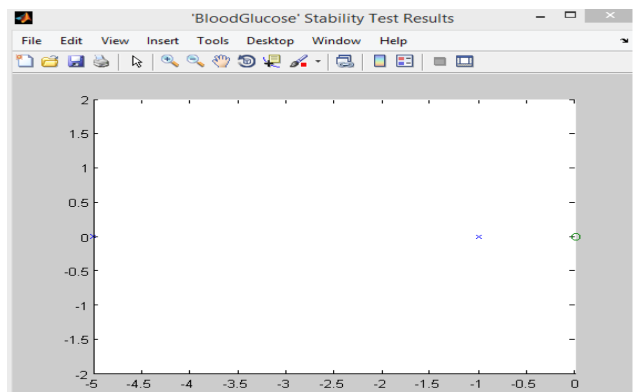

Fig.2Stability plot of equation (3)

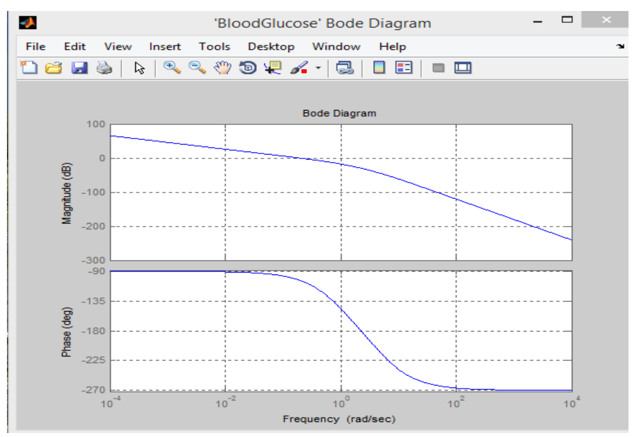

Fig.3Bode plot of blood glucose equation (3).

From the above figure it is revealed that although the system is a stable system but the settling time and overshoot is very high. So practically when it will be implemented the insulin injection amount may increase a lot instantaneously which can create serious problems in human body. It also may take a very large amount of time to bring a steady level of glucose and injected insulin. Therefore PID controller is designed in the next section for improvement in the time response parameters like overshoot and settling time.

III. DESIGNING OF DIGITAL PID CONTROLLER

Digital PID controller is widely used application in industries and it can also be used in medical purpose. This PID controller is used 90 percent in industrial sector because it gives less settling time, improved transient response, less overshoot time and it should be reliable. The equation of PID controller is –

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t) \quad (5)$$

Where u(t) is controller output response , K_p is proportion gain of the system , $K_d$is derivative gain of the system ,K_i is the integral gain of the system stand for error which is SP-MV(SP is set point and MV is measured value) , t is instantaneous time and τ is integral variation from 0 to t.
And the PID controller in Laplace domain is-

$$L(s)=K_p+\frac{K_i}{s}+K_d s \quad (6)$$

Where, L in S domain which represent the complex number of frequency. [8]

By using this blood glucose equation (3) in digital PID controller we find out the PID parameter by using various tuning method like Ziegler Nichols and IPDT tuning method.

IV. ZIEGLER-NICHOLS TUNING METHOD

Ziegler and Nichols method is used to determine PID controller parameters. It was formed by two empirical methods in the year of 1940.

1. Non-first order plus dead time situations.
2. Involved intense manual calculations.

To calculate the tuning parameters of PID controller we use the following procedure:
For feedback loop or closed loop, we follow these steps:

a. The action of integrator and derivative are removed to find the value of K_u, a large value (or 999) is set for Integral time (T_i) and derivative controller (T_d) is kept at zero value.
b. Small disturbance is created due to change of the set point in the loop till the oscillations have common amplitude, the proportional gain is kept adjusting by increase or decrease in value.
c. The gain (K_u) and the oscillation period (P_u) are recorded.
d. The necessary parameters of the PID controller are determined by putting the appropriate values in the Ziegler-Nichols.[4]

TABLE 1 CLOSED LOOP CALCULATION OF K_c, T_i , T_d.

	K_c	T_i	T_d
PID	$0.58K_u$	$0.83P_u$	$0.125P_u$
PI	$0.45K_u$	$0.5P_u$	
P	$0.5K_u$		

For open loop:
Process Reaction method has the ability to test the process of open-loop reaction, for the change in the output control variable.

These steps are as follows:
(i) Open loop step response test is performed.
(ii) Process reaction curve is studied. Dead time or transportation lag (τ_{dead}) is the time for response to change or the time constant (τ), and the value at which the system reaches the steady state (M_0) for a step change X_0.

$$K_0 = \frac{X_0}{M_u} * \frac{\tau}{\tau_{dead}} \quad (7)$$

To calculate the tuning parameters of the PID controller put the values ofreaction time andlag rate into the Ziegler-Nichols open loop tuning equation.[4]

TABLE 2 OPEN LOOP CALCULATION OF K_c, T_i, T_d.

	K_c	T_i	T_d
PID	$1.2K_o$	$2\tau_{dead}$	$0.5\tau_{dead}$
PI	$0.9K_o$	$3.3\tau_{dead}$	
P	K_0		

A. Digital PID controller tuning with Ziegler-Nichols.

For finding the digital PID controller by using the tuning method of Ziegler Nichols method, the block diagram of digital PID controller with blood glucose equation which is shown in figure 1

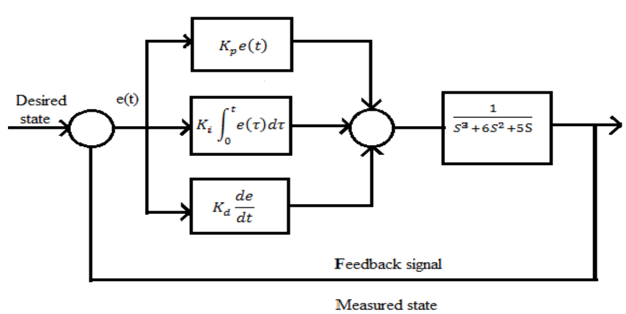

Fig.4 Block diagram of PID controller with blood glucose-insulin system.

The related parameters of PID controller by using Ziegler Nichols method are-

Kp=3.25316, Ki=0.882044, Kd=2.99957

Kp,Ki,Kd are put in the equation, the equation of Ziegler-Nichols for blood glucose level is obtained, then Triangle approximation (modified first order hold) is used & the equation is converted into discrete domain with sampling time of 0.1sec. We get $G_z(z)$ –

$$\frac{0.0004436z^4 + 0.007341z^3 - 0.02238z^2 + 0.007553z + 0.003113}{z^4 - 3.488z^3 + 4.527z^2 - 2.588z + 0.5488} \quad (8)$$

The parameters show the improvisation in the settling time, and the overshoot value becomes bit large but the performance of the system remains efficient. [5]

V. IPDT Tuning Method

This method has large number of industrial models that can be approximated in integer plus time delay. The IPDT is the combination of integer process with time delay or dead time. The IPDT equation which is shown below:[7]

$$G_{IPDT}(s) = \frac{K}{s}e^{-Ls} \quad (9)$$

Where K is gain factor and L is time delay or dead time. To finding the value of K ,where K is the ratio of change in output to change in input and also finding the value of L, $L = T_2 - T_1$ where T_1 and T_2 are the time instances in seconds which is taken from the step response obtained having a particular steady state gain.

In IPDT tuning method, there is no need to requirement of integrator to remove the steady state error. To minimise the overshoot time we can use the PD controller. [7]

After getting the value of K and L, putting these value in equation (9) we get the value of $G_{IPDT}(s)$.After that the approximate modelling of IPDT using the Ziegler-Nichols method we find out the value of K_p, K_i and K_d .

A. Digital PID controller tuning with IPDT method.

We find out the value of PID parameter K_p, K_i, K_d by using the tuning method of IPDT. By using the tuning method of IPDT method in digital PID controller of blood glucose-insulin system, those parameters value are-

Kp=5.70833, Ki=3.19258, Kd=4.0415

By applying the parameters Kp, Ki, Kd, the equation for IPDT of blood glucose level is obtained, this is converted into discrete domain with the use of Triangle approximation (modified first order hold) where the sampling time becomes 0.1sec & we get $G_i(z)$–

$$\frac{0.006024z^4 + 0.01034z^3 - 0.03009z^2 + 0.0098z + 0.004159}{z^4 - 3.479z^3 + 4.511z^2 - 2.581z + 0.5488} \quad (10)$$

This parameter value shows that its settling time of the system is less, it means it takes less time to settle down the response or we can also say that it is fast or without time consuming system.

VI. Result

A. By using Ziegler-Nichols method results

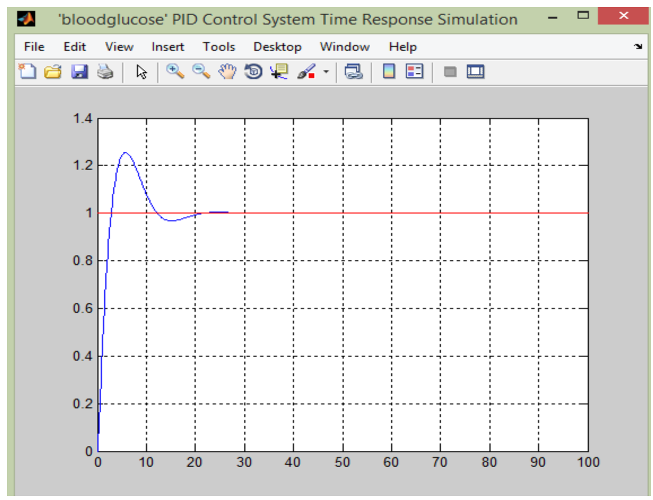

Fig.5 Step response of blood glucose insulin system after the use of Ziegler-Nichols method.

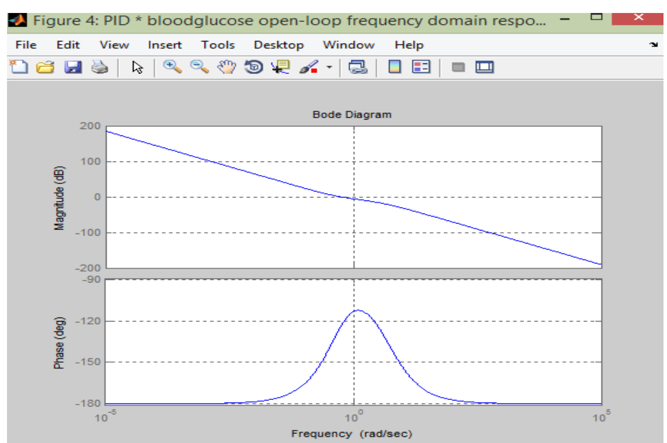

Fig.6 Open loop bode plot of blood glucose insulin system after the use of Ziegler Nichols.

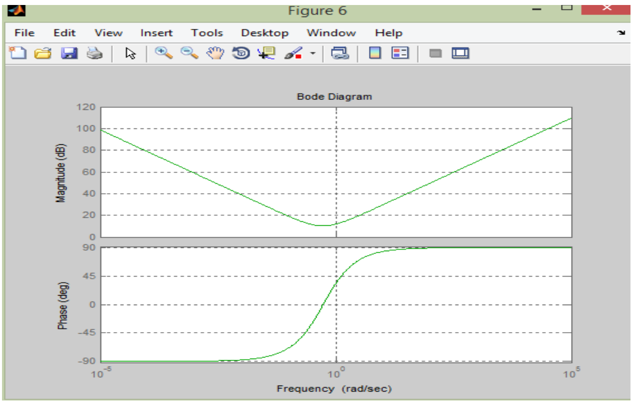

Fig.7 Continuous- time approximation bode plot for blood glucose insulin system after the use Ziegler Nichols.

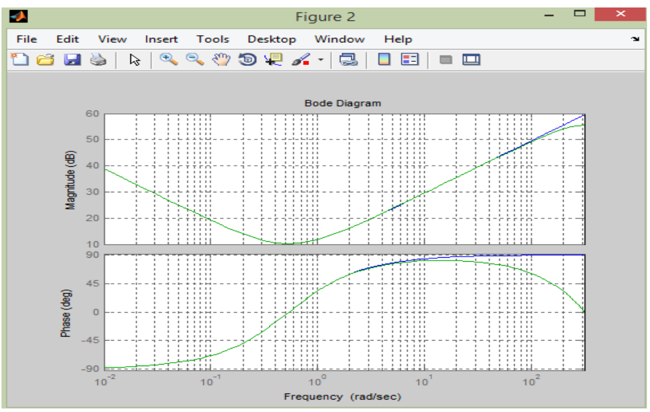

Fig.8 Discrete- time approximation bode plot of blood glucose insulin system after the use of Ziegler Nichols

B. By using IPDT method results

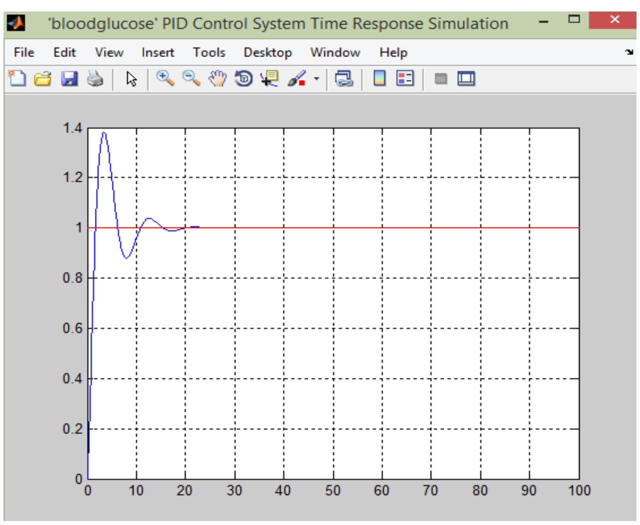

Fig 9 Step response of blood glucose insulin system after the use of IPDT method.

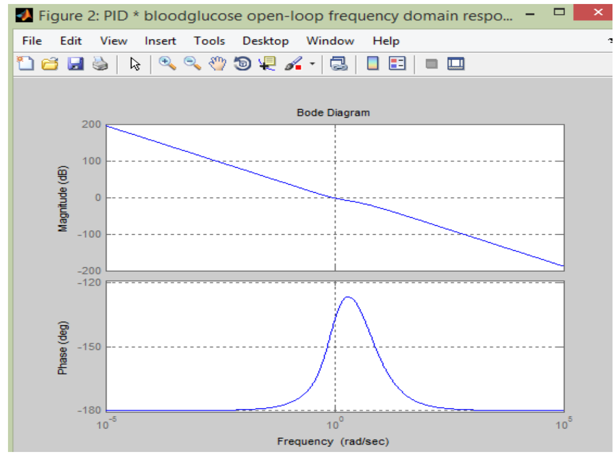

Fig.10 Open loop bode plot of blood glucose insulin system after the use of IPDT method.

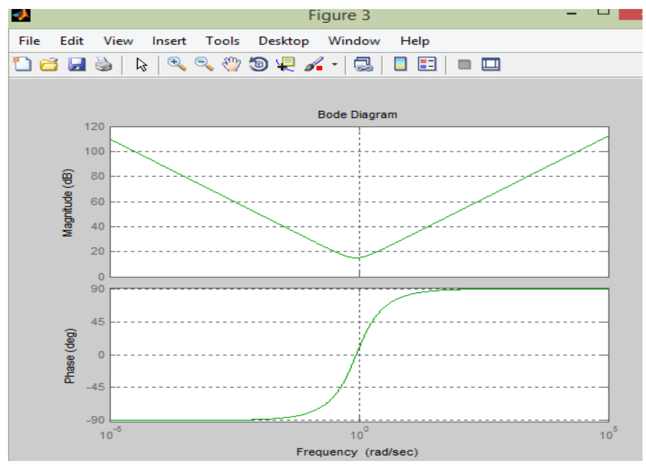

Fig.11 Continuous- time approximation bode plot of blood glucose insulin system after the use of IPDT.

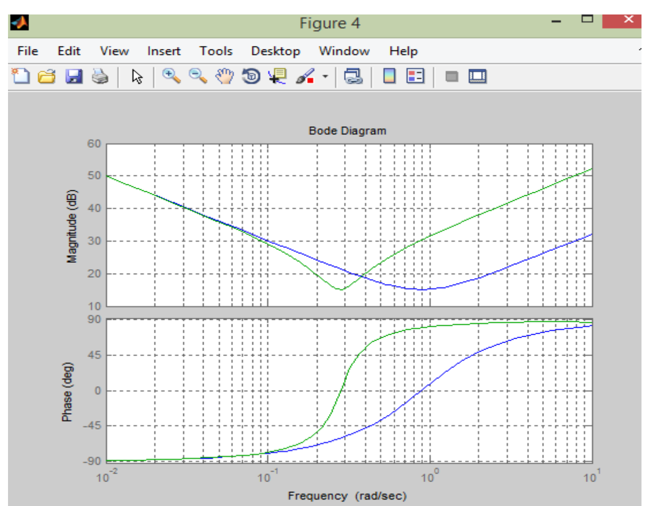

Fig.12 Discrete-time approximation bode plot of blood glucose insulin system after the use of IPDT.

VII. DISCUSSION

For the blood glucose system the overshoot and settling time is very high but when the PID is designed and tuned using IPDT the overshoot is limited to 41.68% and settling time is also minimised up to 14.2469sec. Whereas PID which is tuned using Ziegler-Nichols method result in very low overshoot of 26.67% and slightly higher settling time of 17.9192 sec. Finally the blood glucose system converted into discrete domain using Triangular approximation (modified first order hold) method.

VIII. CONCLUSION

While designing a PID controller for blood glucose maintenance by injecting external insulin the time response parameter must be kept in the mind. As we have discussed that overshoot of PID controller designed using Ziegler-Nichols method is very less it is suitable for tuning PID. But in IPDT tuning the PID which is designed imparts a very high overshoot where as the settling time becomes comparative less. Therefore IPDT can not used for tuning as it may endanger the life of patient by injecting a very large amount of insulin initially due to overshoot. After tuning the PID it is essential to convert the analog PID to digital PID as we known hardware implementation of digital PID is very easy in minimized area. Further tuning of PID after implementation also become very easy and the system also becomes very accurate.

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