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Design and Tuning of Control system for blood Glucose level with artificial pancreas using harmony search Algorithm

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ABSTRACT--*Diabetes adds psychosocial issues to every day of life. Stress can be a major obstacle to effective glucose control. The artificial pancreas developed to control the glucose level effectively than manual injection. The closed loop controller algorithm designing procedure is proposed in this paper by considering the Bergman Minimal Model as a diabetes dynamic. Two Control strategies are designed such as proportional & Derivative controller (PD) and Internal Model Controller (IMC), and then the controller gains are optimally tuned using harmony search algorithm. The performance of controller algorithm is compared and analyzed by the closed loop simulation results.*

Keywords--*psychosocial; diabetes; stress; IMC control, PID, Harmony Search Algorithm, Blood Glucose level.*

I. INTRODUCTION

Psychological Impact of Diabetics: The psychological impact of diabetes is huge and it can be lead to depression and emotional distress. The obligation regarding overseeing diabetes lies on the whole in the hands of the individual with this long lasting condition. Individuals with various kinds of diabetes frequently have particular psychosocial needs. The individual expenses for those with type 2 diabetes are many. It can affect on connections, on working and public activity, and on mental prosperity, with a resulting impact on in general personal satisfaction. Consistent checking, following a sound eating regimen and discovering time for exercise would all be able to prompt improved mental and passionate wellbeing [1]. Individuals with diabetes may likewise encounter diabetes-related passionate pain and in spite of the fact that there is a solid relationship among trouble and misery, numerous individuals just report either. Manifestations of diabetes-related pain incorporate continually agonizing over blood glucose levels or the danger of getting diabetes complexities, feeling furious about living with diabetes, and feeling remorseful when going off course with overseeing diabetes self-care. Recognizing side effects of

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discouragement or diabetes-related pain through conversation with the diabetes medical caretaker or GP, can assist with choosing what the most fitting follow-up care ought to be advertised.

Figure 1: The cyclical nature of the relationship between depression and diabetes (adapted from Diabetes UK) [1]

Insulin and glucagon are the principle hormones engaged with the blood glucose guideline. If there should arise an occurrence of high blood glucose focus, the pancreas secretes insulin. Insulin advances the take-up of glucose in the body cells and the capacity of glucose in the liver as glycogen. On the off chance that the blood glucose is lower than ordinary, the pancreas begins to create glucagon. Glucagon has the inverse impact, ie. advances the breakdown of glycogen into glucose.

The blood glucose regulation in healthy people is shown in the Figure 1. The beta cells pancreas generates the insulin to control the level of glucose and generate energy for the human body. Type 2 diabetic patients beta cell defect the results in reduced insulin generation which leads to hyperglycaemia.

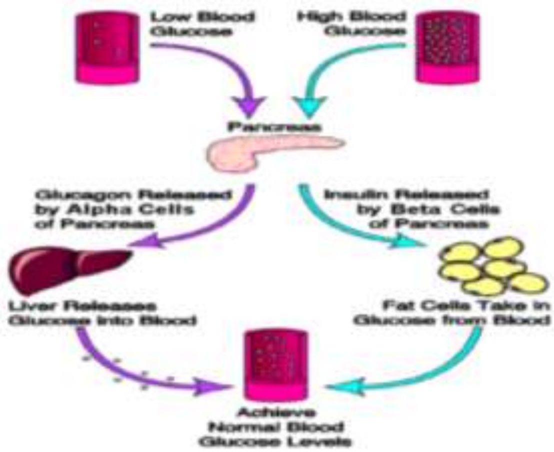

Figure 2: Blood glucose regulation in healthy people [2].

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Regardless of modern improvements within diabetes administration such as speedy performing insulin, continuous glucose monitors (CGM) and insulin pumps, tight blood glucose control still remains a challenge. A completely robotic closedloop controller, also known as an artificial pancreas (AP), has the capability to ease the life and trim down the threat of acute and chronic diabetic complications.[3]

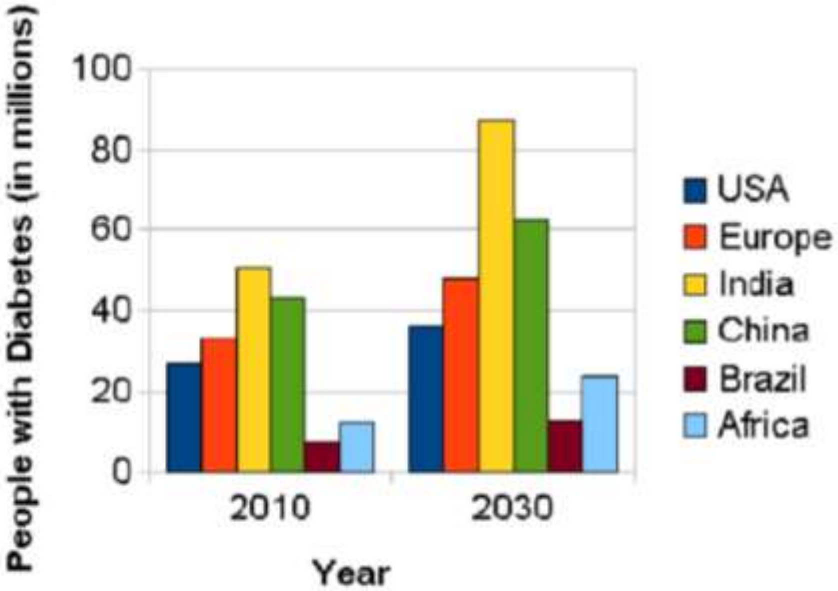

Figure 3: Estimation of the number of people with diabetes in the usa, europe, india, china, brazil and africa in 2010 and 2030 (boiroux et al 2012) [3].

The Artificial pancreas allow diabetic patient to keep up ordinary glucose level by giving the perfect measure of insulin at the ideal time with no requirement for human collaboration with regards to choice making.[4] A controller has been proposed for dynamic. A PID controller directs the glucose level in type - 1 diabetic patients , a functioning sliding table is utilized to recommend insulin implantation rates[5] The bio-propelled technique for in-vivo is utilized to demonstrate a pancreatic-cell and this framework executed utilizing simple coordinated circuits[6]. In some propelled control strategies to joined the two sorts of controllers like relative necessary subordinate (PID), and fluffy rationale controllers (FLC) and control the blood glucose level. The feedback control algorithm and internal model based control are designed and controller parameters are tuned using algorithm [7]. It is demonstrated that genetic algorithm based proportional integral controller regulate the glucose level than the ZN based controller. [7].

II. MATHEMATICAL MODEL

Different mathematical replica has been proposed to recognize the Diabetes dynamics and to correlate the relation between glucose and insulin distribution models. Bergman’s minimal model is illustrated as the section together with basal concentration of insulin and glucose intensity in the body. Glucose energy portrays how the convergence of blood glucose responds with blood insulin , where as insulin energy depicts how the centralization of blood insulin responds with blood glucose by taking both the information's of insulin and glucose as input [8].

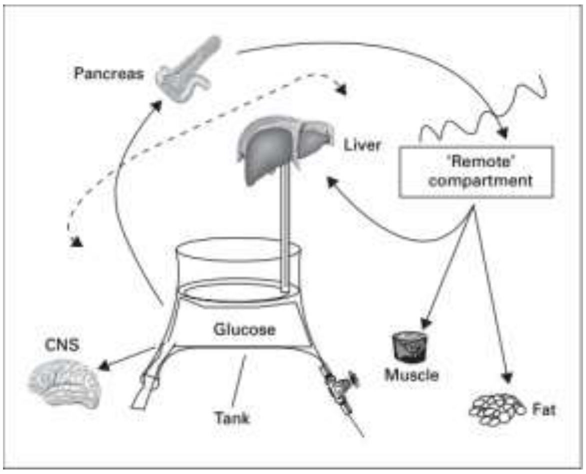

Figure 4: Bergmann's Minimal Model

The model is defined as:

$$\frac{dG}{dt}=-m_1G+m_2I+m_1G_{b.} \quad (1)$$

$$\frac{dX}{dt}=-m_2X+m_3I-m_3I_b+m_6I_b. \quad (2)$$

$$\frac{dI}{dt}=-m_3I+m_4G+m_4m_5-m_6I+m_6I_6. \quad (3)$$

$$\begin{aligned} dG/dt &= p1G - X(G+Gb) + Gmeal/V1 \\ dX/dt &= p2X + p3I \\ dI/dt &= -n(I+Ib) + U/V1 \end{aligned} \quad (4)$$

G – blood glucose deviation

I – insulin concentration

X – is equivalent to the concentration of insulin within a remote area

Input are Gmeal and U

Gmeal – meal disturbance i/p of glucose

U – manipulated insulin injection rate

By using this value we can determine basal rate of infusion in insulin for maintaining a steady state [17].

Linearised state space model

This model helps to develop control system design the state, i/p, o/p variable (in deviation form) define as,

$$\begin{bmatrix} x1 \\ x2 \\ x3 \end{bmatrix} = \begin{bmatrix} G \\ X \\ I \end{bmatrix} \begin{bmatrix} u1 \\ u2 \end{bmatrix} = \begin{bmatrix} U-Ub \\ Gmeal-0 \end{bmatrix} y = G \quad (5)$$

The state space model of the process is given as follows

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$$A=\begin{bmatrix} -P1 & -G1 & 0 \\ 0 & -P2 & P3 \\ 0 & 0 & -n \end{bmatrix} \quad B=\begin{bmatrix} 0 & 1/V1 \\ 0 & 0 \\ 1/V1 & 0 \end{bmatrix}$$

$$C=\begin{bmatrix}1 & 0 & 0\end{bmatrix} \quad D=\begin{bmatrix}0 & 0\end{bmatrix} \tag{6}$$

Example set of parameter

Imagine a diabetic patient is modelled with the help of following parameters (lynch and bequette,2001)

G_b = 4.5mmol/liter

Ib = 4.5mU/liter

V_1 = 12 liters

P_1 = 0 min^{-1}

P2 = 0.025 min-1

P_3 = 0.000013mU/liter

n = 5/54 min^{-1}

notice that concentration is in mmol/liter unit and glucose disturbance in gram unit so it should be simply conversion factor 5.556 mmol/g to Gmeal. The state space model at steady state is given in equation

$$A=\begin{bmatrix} 0 & -4.5 & 0 \\ 0 & -0.025 & 0.000013 \\ 0 & 0 & -5/54 \end{bmatrix} \quad B=\begin{bmatrix} 0 & 0.04630 \\ 0 & 0 \\ 1/12 & 0 \end{bmatrix} \tag{7}$$

$$C=\begin{bmatrix}18 & 0 & 0\end{bmatrix} \quad D=\begin{bmatrix}0 & 0\end{bmatrix} \tag{8}$$

The process transfer function is

$g_p(s) = -3.79/(40_s+1)(10.8_s+1)$ (9)

$g_d(s) = 8.334/s(20s+1)$ (10)

Likewise, numerous chemical process disturbance, a pulse imagine containing 50 g glucose meal is consumed on a 15-minute interval ;then the pulse has a greatness of 3.333 g/minute for a length of 15 minutes. [9]

III. CONTROLLER DESIGN

PD control:

The PD controller intrinsic the compensation of proportional and Derivative controller. The proportional controller generate control signal based on the e=deviation between feedback sensor signal and reference setpoint signal. The derivative of the deviation from the setpoint is taken into account to generate some control action, which act as the predictive control action based on the predictive error.

The equation of PD controller as,

$$u(t) = K_p e(t) + K_D \frac{de}{dt} \tag{11}$$

$e(t) - Error\ signal$

$\frac{de}{dt} - \ derivative\ Error\ Signal$

$K_p - Proportional\ Cosntant$

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$K_D - Derivative\ Constant$

$u(t) -\ manipulated\ input\ to\ the\ system\ (controller\ output)$

Figure 5: Design of an artificial pancreas (boiroux et al 2012) [5].

Internal Model Controller (IMC)

Internal model controller is like open loop controller. It was initially developed with the principle of inverse model control. It was like open loop control. The controller performance fully depends on the model accuracy. It was very difficult to generate 100% accurate model, also, if there any external dynamical disturbance acts on the model may increase the model accuracy from the mathematical model. To compensate this disturbance the feedback output is taken and the deviation of model accuracy is given as feedback signal to the IMC controller. The IMC controller generate the manipulate controller output to compensate the model deviation.

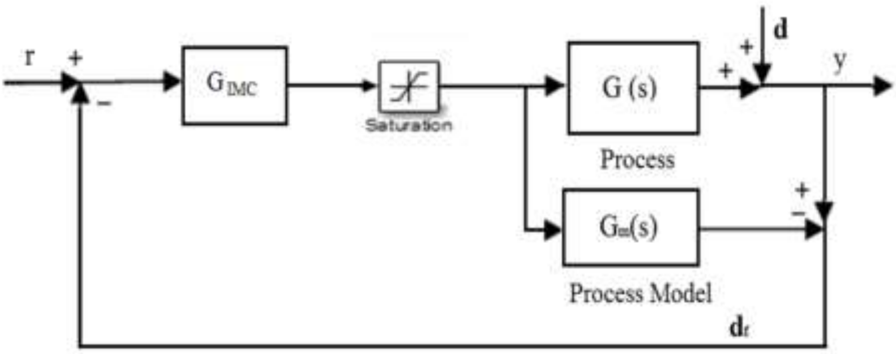

Figure 3.2: IMC control scheme

The IMC controller $C_{IMC}(s)$ is as given in equation 12

$$G_{IMC}(s)=\frac{1}{G_m^-(s)}F(s) \tag{12}$$

where F(s) is a low pass filter which is included to construct IMC controller appropriate. The filter transfer function is given in equation 13

$$F(s)=\frac{1}{(1+\lambda s)^{n}} \tag{13}$$

IV. HARMONY SEARCH OPTIMIZATION ALGORITHM.

This Harmony search algorithm (HS) is inspired by the jazz artist's impromptu creation process. The Hs calculation previously romanticized by the accompanying strides of performers. At the point when artists making a music, the person in question follow the beneath steps, at first he play any renowned music and afterward he attempt to ad lib by modifying pitch of instrument.

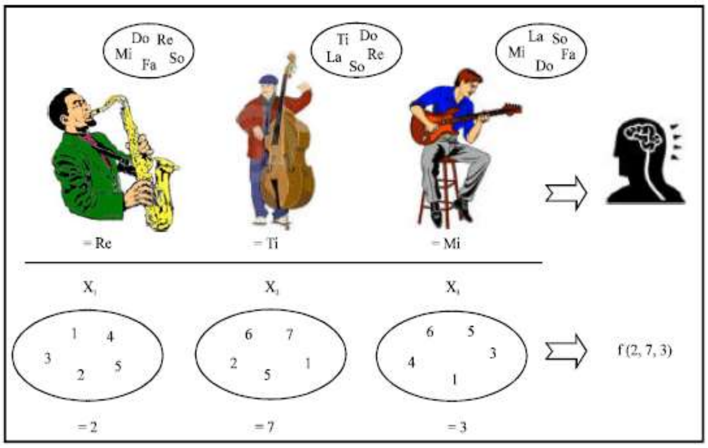

Figure 6: Musicians tries randomly try to impress the audience.

The point of artists is to make the satisfying amicability as dictated by tasteful norm; this procedure of accomplishing ideal condition of congruity can be improved by altering pitch ranges.

The artists resemble choice factors and they change instrument's pitch range and melodic sounds are extemporized to make awesome wonderful congruity to dazzle crowd (target work). At each attempt performer store the amicability as a main priority and extemporize by tuning pitch, this alludes to the emphasis of streamlining. The best created satisfying concordance for ideal pitch ranges are considered as best satisfying amicability (last worldwide target esteem). The flow chart of harmony is shown in the figure

The pitch manipulated by pitch bandwidth *brange* and a pitch adjusting rate *rpa*. The pitch solution x_{new} *updated and stored in harmony memory after the adjusting action.*

$$xnew = xold + brange*\xi \tag{14}$$

ξ is a random number generator in the range of [-1,1]. Randomization is also like pitch adjusting but it used for the global search of system to bring new global solution.

The probability of randomization is,

$$P_{random} = 1 - r_{accept} \tag{15}$$

The actual probability of pitch adjustment is

$$P_{pitch} = r_{accept} - r_{pa} \tag{16}$$

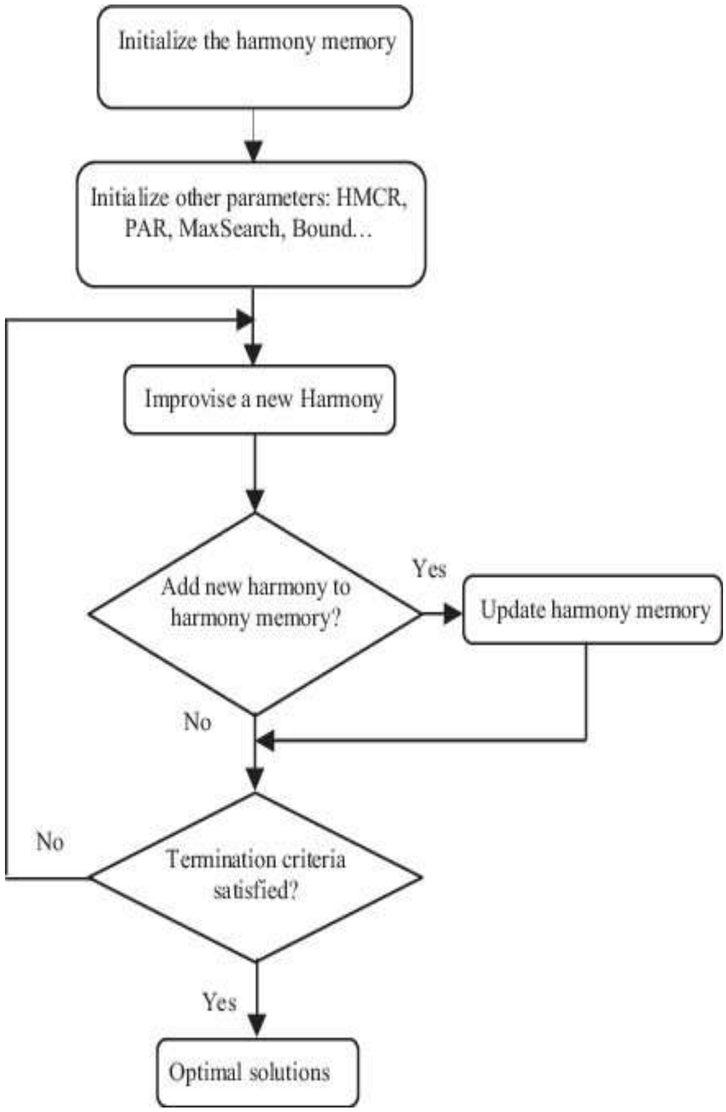

Figure 7: Flow chart of Harmony Search Algorithm [10]

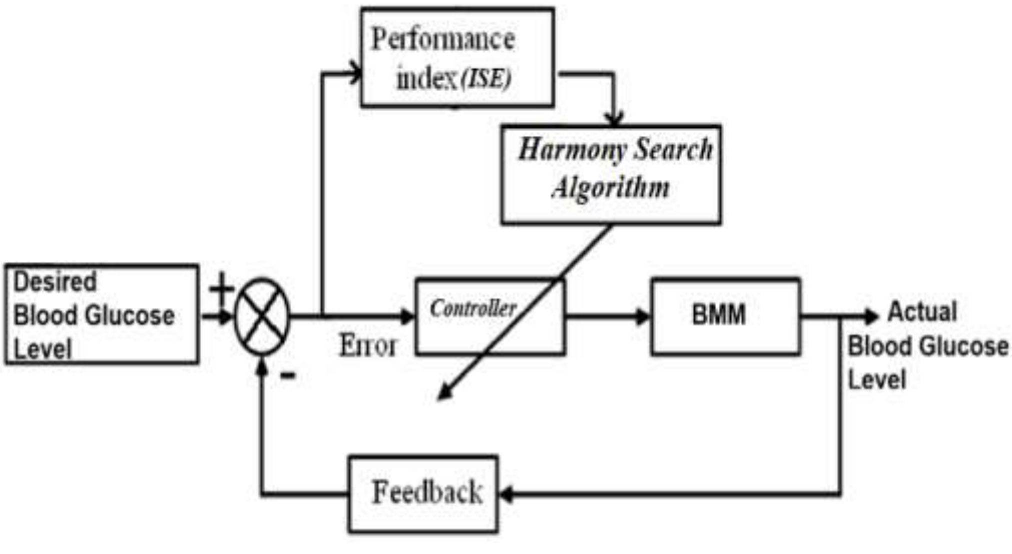

Figure 8: Closed loop block diagram for HS tuning of controller (PD/IMC) .

The optimization problem is transformed into control problem. The objective function for controller design problem is formulated using Integral squared error which is a deviation from the setpoint and feedback signal.

$$J = \int_{0}^{T} \left[\left(e_1(t) \right)^2 \right] dt \tag{17}$$

V. SIMULATION RESULTS & DISCUSSION

The simulation results demonstrate that the required goal of reaching minimum ISE is obtained. The simulation started with time t=0, not including disturbance. The controller tracking the set point of 120 mg/decilitre level and then the meal disturbance with magnitude of 3.33g/minute is applied at 400th minute as a pulse which raises the glucose level of patient. The HS-IMC based controller rejects the meal disturbance effectively than HS-PID control. The HS-IMC regulates the glucose level within 40 minutes after having meal whereas HS-PD takes longer time to regulate the glucose level.

Table 1: Comparison of performance measures of servo and regulatory response of controllers

Controller	Controller parameter		ISE
HS-PD Controller	Kp	Kd	1528.4
	-0.015	25.12	
HS-IMC Controller	λ		855.3
	0.142		

In practice, the glucose level does not enter the blood stream immediately. A meal takes some time to reach it into blood stream.

Figure 9: Servo controller responses of controllers

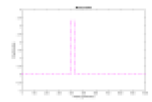

Figure 10: 1 Disturbance (Meal intake)

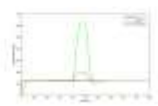

Figure 10.2: Regulatory responses of controllers

VI. CONCLUSION

The psychosocial issues of diabetes are discussed in this paper. The artificial pancreas with closed loop control system is designed by PD and IMC controller. The controller tuning parameters are optimally tuned using the harmony search algorithm. From the simulation study, it is clearly shown that harmony search based internal model control (HA-IMC) performance was superior in servo tracking and glucose level regulation than the HA based PD Controller. Recently, researcher community attempt to develop implantable glucose sensors and insulin pumps for diabetics.

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