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Research Article

Comparative Analysis of PID Tuning Techniques for Blood Glucose Level of Diabetic Patient

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Abstract: The robustness and ease of execution has attention the use of Proportional, Integral and Derivative (PID) controllers in the field of biomedical engineering. One of the applications of PID controllers in field of Biomedical Engineering is to control the Blood Glucose Level of Diabetic Patient. PID works on the principle of closed loop system mechanism. The closed loop IDS (Insulin Delivery System) consist of 3 components: A glucose sensor, a control system for controlling insulin infusion and insulin pump. Several tuning methods are present for tuning of PID controllers; each one of it has its advantages and disadvantages. This paper deals the process for obtaining the controller technique of IDC using diverse tuning techniques and performance comparison of PID controller based on Process Reaction Curve tuning process and PID controller tuned with Ziegler-Nichols (Z-N), Integral of Time multiplied by Absolute Errors (ITAE), Approximate constrained Integral Gain Optimization (AMIGO) and Chien-Hrones-Reswick (CHR). The response shows that CHR-PID gives the flexibility of regulate for given desired performance in assessment to other tuning methods.

Keywords: PID tuning, Diabetic Patient, Ziegler-Nichols, Cohen-coon (CC) AMIGO, Chien-Hrones-Reswick (CHR), Integral of Time multiplied by Absolute Errors (ITAE)

1. Introduction

Ambiguity constitutes one of the most difficult aspects in biomedical and control systems that aim to capture the physiology of a patient through mathematical modeling. A Disease that generally lasts for three months or longer and may get poorer over time called chronic disease (CD) [1]. CDs are extended forms of medical conditions that are usually progressive. Diabetes is a type of chronic disease. Diabetes mellitus (DM) is a metabolic disorder in which the human body is unable to manufacture or use insulin properly. Diabetes mellitus is a metabolic condition in which the body is unable to manufacture or use insulin properly. The pancreas produces insulin, which controls blood glucose levels (BGL). To regulate the level of glucose in the blood, nonstop observation of the level of glucose is required. There are several sophisticated methods [17][18] for measuring and regulating the amount of glucose. To build an automatic insulin pump system, the insulin pump device and glucose monitoring systems are combined. Insulin and glucagon, two pancreatic hormones concealed by β -cells and alpha-cells, respectively, are answerable for keeping a normal blood glucose (BG) concentration. T1DM (Type-1diabetes mellitus), T2DM (Type-2 diabetes mellitus) and Gestational diabetes (GD) are the 3 types of diabetes.

The dearth or fatalities of the β-cells typify T1DM. Hyper-gly-caemia is a disorder in which the BGL abnormally elevated (more than 110 mg/dL) when it becomes less than 70 mg/dL in human body then is called Hypo-gly-caemia for T1DM. The β-cells are answerable for the development of insulin; TIDM requires external insulin injections to control the amount of BG. When the human body is not-able to use its own insulin then it’s called T2DM. Some pregnant women grow GD, which is similar to T2DM. BG rating in a human body is shown in table 1.

Table 1. BG Rating for insulin system

BG Rating	**BG Range**
Normal Glucose	70 to 90 mg/dL
Pre Diabetes	100 to 125 mg/dL
Diabetes	< 126 mg/dL

The deliverance of closed-loop managed drugs is becoming an actuality in anaes-thesia (hypnotic depth and analgesia control) as well as in diabetes (BGL control). Presently lots of models are available [2,3] related to drug delivery system. The AP (A Method of Closed-Loop-Control) helps diabetic patients to keep up a usual level of glucose by providing the exact quantity of insulin at the precise moment, without required for human intervention when decision-making is concerned [4]. For decision-making, a controller has been suggested. In T1DM, a PID controller controls the BGL and a lively downhill bench is employed to set down rates of IDS [5].

To represent a pancreatic cell, the bio-inspired in-vivo approach is used, and this structure is executed via analog integrated circuit. In various highly developed control methods, PID and fuzzy logic controllers (FLC) are combined to control BGL [6]. A CLS based on an updated glucose insulin interaction model is under consideration. By incorporating an exogenous term for insulin infusion, the amended model was derived. For exogenous insulin infusion, two controlling methods are used: a Mamdani style FLC and a fuzzy-PID controller [7] [19] [20]. In a PID controller, tuning is difficult, and in a FLC, the desired tuning value is not reached. The controller is being fine-tuned using a number of sophisticated conventional methods. Because of its cleanness and feasibility, the traditional method of Z-N tuning is still commonly used for Linear Time Invariant (LTI) systems [15].

On the other hand, in Non-Linear (NL) and Time-Varying (TV) systems, the standard PID tuning method obtains a long time and costs a lot of money. It too creates a major overshoot, which is inappropriate. As a result, various methods can be integrated into the PID tuning as it improves the system performance. AMIGO, Z-N, ITAE and CHR tunings tend to be identical. The Z-N tuning approach was first developed in the 1940s and is still widely used today. Constants L and T define the time response and are used to measure controller constraint. CHR tuning method was introduced in 1952 and offers a further effective technique to choosing a sensor for BG system applications. For more reliable control intervention, an adequate collection of a time domain output index forms simple error minimization criteria. In this paper, a comparative analysis of traditional PID tuning methods is employed for closed loop BGS. The following is how the paper is organized: Section 2 expresses the Mathematical modeling of IDS, accompanied by PID Controller Tuning for IDS. In Section 3 Traditional PID Tuning is discussed. Finally, in section 4 the result and discussion are discussed. In section 5 conclusion is discussed.

2. Mathematical Modeling of IDs

Drug delivery (DD) MM and drug release inevitability is an area of gradually growing academic and industrial significance with tremendous possibility for the future. The “in-silico” optimization of novel DD systems can be expected to dramatically increase the precision and ease of application due to the substantial developments in information technology. Professor **Takeru Higuchi** is regarded as the "Father" of DD-MM. He presented his renowned equation in 1961, enabling a remarkably simple explanation of the release of drugs from a liniment base that shows a significant first surplus of non-dissolved drugs inside an inert matrix with film geometry (Higuchi, 1961). This was the start of quantitative drug release treatment from prescription dosage types. Since then, countless models have been proposed like Stolwijk-Hardy’s glucose-insulin regulation model published by Khoo [8]. When analyzed in terms of mathematical complexity, it is one of the simplest models. The third order transfer function of the insulin delivery system which is generally used for simulation studies for conventional data specification is given as below. By using this transfer function, different controllers would be designed to enhance the performance of the system [9].

$$G_c(s) = \frac{R(s)}{C(s)} = \frac{1}{s^3 + 6s^2 + 5s} \qquad (1)$$

3. PID Controller Tuning

The process of finding the values of a PID controller's parameter (P, I and D) gains to attain desired efficiency and meet design specifications is known as PID tuning. Regardless of the system used, the control elements, sensor noise and process instability, load disruption, and reference signals must all be addressed. Zeigler-Nicholas pioneered the most well-known tuning approach (Z-N). For over a century, this approach has been proven to be a dominant tuning method for PID controllers. Selecting the numeric value for the PID coefficient is what PID tuning means. As a consequence, practical regulations and principles for controlling the PID controller are typically feasible. The Z-N trials offered statistical rules for determining PID parameter values based on the system's time reaction distinctiveness. AMIGO, Z-N, ITAE and CHR are common tuning methods for finding PID controller using Reaction Curve Process technique. Errors can be decreased, and output pushed closer to the necessary value by implementing effective tuning methods. In a variety of cases where systems aren't working correctly, traditional PID tuning methods may produce worldwide most favorable results [14]. The PID has 3 controlling parameters: First is “P” depend on present changes in the error, second is “I” depend on the past errors, third is “D” depend on the future errors [11]. By adjusting all 3 parameters, researchers get desired system outcome according to need [12]. Equation 2 determines the control operation.

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{d}{dt} e(t) \qquad (2)$$

$u(t)$ = The output of PID controller

K_p = Present-Error (Proportional Gain)

K_i = Past-Error (Integral Gain)

K_d = Future-Error (Derivative Gain)

The closed-loop method, which constantly tracks the output and compute the fault indication, involves the application of the controller. The key technique for designing a model-based controller is the PID controller. The key advantages of this controller are simplicity, reliability, uniformity, and broad applicability. After the invention of Continuous glucose monitoring (CGM) system in the 1980s, patients were given algorithms to amend their dose of insulin [13]. Closed-loop AP systems consist: a CGM sensor, an insulin pen, and a control method (PID) that calculates the insulin dose, were later executed with the assist of superior control approach. Figure 1 depicts a control related AP system in which a glucose sensor is used to measure BG level in patient's body.

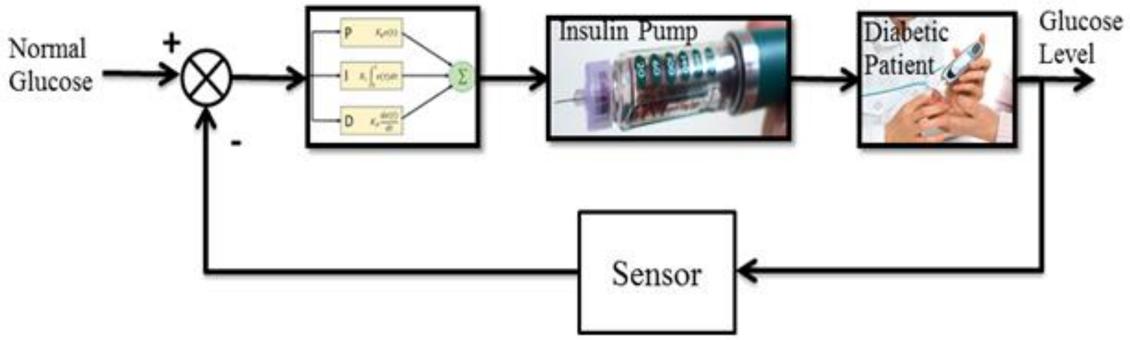

Figure 1. AP system using PID controller for Diabetics.

4. Traditional PID Tuning

The tuning process starts with BG system modelling, followed by closed loop system transfer-function and PID-tuning methods pedestal on the system phase reaction. If a machine isn't tuned correctly, it can perform poorly. As a result, it should be noted that these parameters have been fine-tuned to ensure the best possible results. The BG-IDS answer tends to be regarded as an s-shaped Process Reaction Curve. Two constants: time constant *T* and delay time *L* will characterize the S-shaped response, which are determined by sketching a tangential track at the inflection spot of the graph and obtaining the junctions with steady-state line and x-axis of the tangent mainline. The response of the BG-IDS looks like a S-shaped is known as Process Reaction Curve. The S-shaped response can be described by two constant, time constant *T* and delay time *L*, these are calculated by sketching a tangential track at the inflexion spot of the graph and getting the junctions of the tangent mainline with steady-state line and x-axis. The *T* is determined by evaluating the time span inside the spots where the highest slope line crosses the beginning and ending answer lines using the highest slope line. Primarily, the system's performance curve is reached. The absence of dominant conjugate poles in the system causes the S-shaped curve, the trajectory of the unit phase response, and this arch has two parameters, *T* and *L*, as shown in Figure 2. Various PID tuning techniques are uses a series of equations to calculate the PID constraint shown in Table 2.

Where $a = \dfrac{KL}{T}$

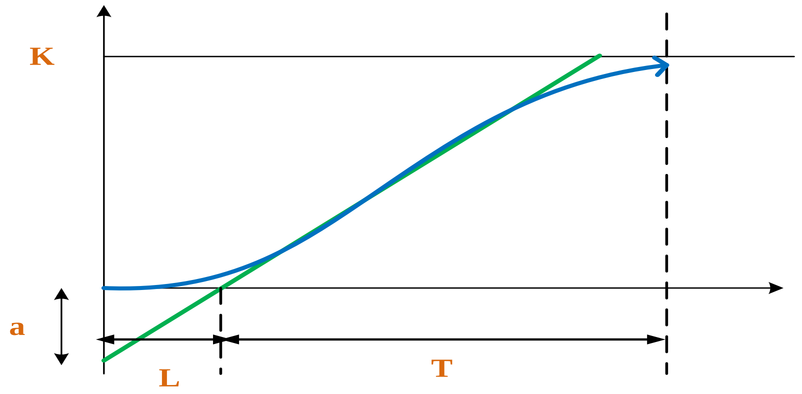

Figure 2. Process reaction curve for a response change

Table 2. The tuning parameters of the PID: AMIGO, Z-N, ITAE and CHR

Controller Parameter	T_i	K_p	T_d
AMIGO	$\frac{0.4L + 0.8T}{L + 0.1T} L$	$1/K[0.2 + 0.45\left(\frac{T}{L}\right)]$	$\frac{0.5LT}{0.3L + T}$
Z-N	2L	1.2/a	0.5L
ITAE	$\frac{T}{(0.796 - 0.147\frac{L}{T})}$	0.965 / $K(\frac{T}{L})^{0.855}$	$0.308T(L/T)^{0.929}$
CHR Overshoot 20 %	1.4T	0.95/a	0.47L

5. Result and Discussion

The BG-IDS was model and simulated in MATLAB tool and controlling done by application of traditional PID methods. The system time-responses were traced and examine. Unit-step response of the BG system is described by 3 constraints: K (Gain), T (Time Constant) and L (Time Delay) with values calculated as 0.9999, 6.4180 sec and 0.8010 sec respectively. Figure 3 shows the time-response plots of closed-loop BG-IDS with different PID tuning methods, and Tables 3 list the equivalent PID constraints. The resulting method using Z-N and AMIGO approaches has a higher overshoot in the response plot which is inappropriate. BG-IDS system needs to go through a series of enhanced tuning methods before getting a satisfactory result. For the purpose of analyzing tuning approaches time response stipulations such as peak time, settling time, overshoot and rise time were measured and characterized in Table 4. Comparison shows that CHR and AMIGO had the fastest settling times with values of 9.5046 and 10.1627 seconds respectively.

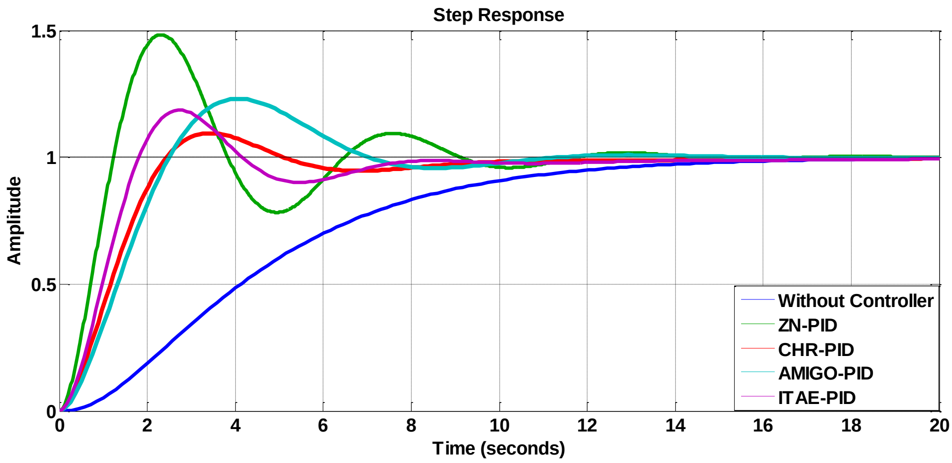

Figure 3. Comparative analysis of BG-IDS performance with diverse PID Tuning Methods

Table 3 PID constraints of AMIGO, Z-N, ITAE and CHR for BG-IDS

Control Techniques / **Constraints**	**AMIGO-PID**	**Z-N PID**	**CHR-PID**	**ITAE-PID**
K_p	3.8060	9.6150	4.8080	7.0416
K_i	1.2568	6.0019	0.7491	0.8532
K_d	1.4693	3.8508	1.9256	2.0138

Table 4 Association of diverse PID Tuning methods for response stipulation

Control Techniques	**Without**	**Z-N PID**	**CHR PID**	**AMIGO PID**	**ITAE-PID**

Response Parameters	**controller**				
Rise time(sec)	8.3344	0.8571	1.6759	1.7591	1.2426
Overshoot (%)	0	48.2785	9.5046	23.0564	18.5692
Peak time(sec)	37.0932	2.3187	3.4423	4.0190	2.7046
Settling time(sec)	15.0125	11.1845	9.5046	10.1627	12.1404
Settling time (sec.) Min./Max.	0.9002/ 1.0000	0.7828 / 1.4828	0.9165 / 1.0950	0.9186 / 1.2306	0.9009 / 1.1857
Undershoot (%)	0	0	0	0	0
Peak	1.0000	1.0100	1.0950	1.2306	1.1857

6. Conclusion

As a result, it is observed that development of traditional PID controllers with different tuning techniques for diabetic patients' BGL; provide better result, than without controller. Table 3 shows that, the CHR-PID is provided better set point tracking and produces the desired results for BG-IDS. It also decreases oscillation and allows for quicker responses. Z-N and AMIGO showed elevated over-shoots with longer settling times in various situations while system produces a very lethargic performance in case of without controller. Therefore, CHR tuning method is better suited for BG-IDS when it operates within the steady state area, but at the same time it will be unsafe to tune AMIGO and Z-N PID control methods for systems that operate exterior of the steady state area..

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