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Diabetes Mellitus Patients Analysis (DMPA-MGO) by Modified Grasshopper Optimization Algorithm

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ABSTRACT

The Modified Grasshopper Optimization Algorithm is the optimization algorithm, which is utilized for selecting the optimized tuning parameters of the Proportional Integral Derivative controller, which solves the nonlinear system parameter identification problem. The novelty of the proposed study is to stabilize the glucose level in the blood for type 1 diabetic patients thereby the infusion of insulin time is reduced with optimal quantity. The controller is used to analyze the type 1 diabetic patients that automatically connect to the glucose monitoring and insulin injection, without any patient intervention. In this work, the Proportional Integral Derivative controller calculates an error value as the difference between the measured variable and the setpoint. Therefore, the research based on blood glucose control needs to concentrate on advanced patient modeling, control optimization, and control performance evaluation under realistic patient-oriented conditions. The simulation results show that substantial improvement in the performance of the proposed algorithm that achieves better results than the other conventional controllers such as Particle swarm optimization - Proportional Integral Derivative and Elephant Herding Optimization-Proportional Integral Derivative.

Keywords: Type 1 diabetes mellitus system, Hypoglycemia, Modified Grasshopper Optimization Algorithm, and Proportional Integral Derivative controller.

I. INTRODUCTION

Recently, more than 346 million peoples are affected by diabetes based on the survey of the World Health Organisation (WHO) [1]. Diabetes disease does not normalize the glucose amount in the blood of the body and it is the major issue in the glucose-insulin diagnosis system, which is called hyperglycemia [2]. This system was stemming from the failure of the pancreas that maintains the concentration of blood glucose between the range of 70-110 mg/dl (0.7–1.1 mg/ml) [3]. The two major kinds of diabetes are type 1 insulin-dependent diabetes mellitus (IDDM) and type 2 (non-IDDM) [4]. The pancreatic β-cells are not able to prevent the regulatory hormone insulin, which is called type 1diabetes [5]. When the system becomes dysfunctional, the β-cells do not produce enough insulin or insulin resistance, which is called diabetes type 2 [6].

An insulin-titrating protocol/algorithm needs to be safe, efficacious, and efficient [7]. Type 1 diabetes mellitus (T1DM) patients deal with this disease by several blood glucose measurements a day [8]. The glucose concentration is maintained by releasing the external insulin with an insulin infusion device [9]. The control strategies of diabetes treatment can be categorized as open-loop control, semi closed-loop, and closed-loop control [10]. For insulin-dependent diabetes, the current treatment methods are subcutaneous insulin injection or continuous infusion of insulin resultant the significant. Sometimes, it is a frequent process with glucose concentration variation due to their inherently open-loop nature [11]. Sedaghat’s model [12] provided the basic simulation of several most accepted mechanisms of the insulin signal transduction pathway, including the activation of phosphoinositide 3-kinase (PI3K) and the translocation of glucose transporter to the plasma membrane.

A diabetes model with a single delay term for describing the delayed hepatic glucose production process in the patient’s liver was suggested by Tolic [13]. Another diabetes model with two-time-delay terms for better fitting to glucose-insulin dynamics was proposed by Li et al. [14]. The physiological delays of insulin secreted by β-cells in the pancreas and the hepatic glucose production (HGP) process in the patient’s liver are emphasized. A new model applying to Type 2 diabetes detection with 31 varying model parameters has presented by Man et al. [15]. This technology requires the intervention of mathematical modeling processes that quantitatively characterize the system and the measurement of biological variables involved in the homeostatic system [16]. Initially, it focuses on two mechanistic, physiologically based classes of models such as the minimal (coarse) and maximal (fine-grain) models [17]. However, the main disadvantage of this model is simply because it is established based on several assumptions and the significant components of glucose-insulin interactions are neglected [18].

A direct application of these models can be glucose prediction in T1DM patients, but the parameters of these models are in general time-varying, even for a patient under constant treatment and environment conditions [19]. In control engineering, the risk of getting a hypoglycemia state caused by a wrong insulin dose imposes two design conditions such as to avoid large overshoot. By applying the use of adaptive control algorithms may increase efficiency when unexpected disturbance or parameter variations may appear [20].

II. RECENT RESEARCH WORKS: AN OVERVIEW

Some recent research works for the diabetes mellitus system are overviewed as follows. The glucose control with closed-loop (CL) versus threshold-low-glucose-suspend (TLGS) insulin pump delivery in prepubertal children with type 1 diabetes is investigated by Eric Renard *et al.* [21] with supervised hotel conditions. A Size of the food, Chewing style and Swallow time (SCS) method to regulate glycemic index without exercise through changing the eating method have proposed by S.Krishna Kumari and J. M.Mathana [22]. The proposed SCS eating method consists of Size of the food, Chewing style, and SCS of the food to regulate glycemic index. Furthermore, the proposed SCS method evaluates and validates through the acoustic signal acquired and processed with a deep learning algorithm to analyze the chewing pattern of food to formulate a standard procedure for eating style and to reduce the glycemic level. A model predictive control (MPC) based on artificial neural networks (ANNs), which combines ANN for blood glucose level (BGL) prediction based on inputs have developed by SaeidBahremand*et al.* [23-46]. Initially, a mathematical model was developed for diabetic rats, which was used to identify individual virtual subjects by fitting to empirical data collected through an APS including BGL data, insulin injection, and food intake. Then, the virtual subjects are used to generate datasets for training ANNs. The NN-MPC determines control actions (insulin injection) based on BGL predicted by the ANN.

The development of the third-generation type open circuit potential (OCP) principle-based glucose sensor with direct electron transfer FAD-dependent glucose dehydrogenase complex (FADGDH) immobilized on gold electrodes using a self-assembled monolayer (SAM) have presented by Inyoung Lee *et al.* [24]. By employing the algorithm, high reproducibility of measurement and sensor preparation was achieved. Backstepping-based adaptive controllers for integration in the artificial pancreas have been proposed by Iftikhar Ahmad *et al.* [25]. Controller design has been based on Bergman's minimal model which represents the dynamics of the blood glucose-insulin system of the human body. The glucose effectiveness factor has been treated as an unknown parameter and its value has been adapted using Lyapunov based adaptive backstepping control approach. The effects of meal disturbance, physical non-linearities, and sensor noise have also been considered in the controller design. The design of observer-based nonlinear control of blood glucose concentration (BGC) of T1DM patients in a Linear Matrix Inequality (LMI) framework has developed by Anirudh Nath *et al.* [26]. The controller design relies on the information of the states obtained from a nonlinear observer. The control law is derived by using feedback linearisation and regional pole placement technique. The proposed controller can deliver a robust closed-loop response of BGC within a specified range of parametric uncertainty and meal disturbances owing to the appropriately tuned bound of LMI region parameters.

In the last decades, several types of numerous control algorithms based on both linear and nonlinear models, including fuzzy-based control, physiological and empirical model-based control, PID, and MPC have been proposed for the blood glucose regulation of T1DM patients. Conventional PID control schemes were developed according to robust and adaptive control algorithms. Among these, MPC is popular due to its advantage of handling receding horizon control as a constrained optimization problem. However, the models identified in MPC are usually difficult to implement in real-time due to their complexity and requirement of initializing all variables. Furthermore, other internal and external factors may affect glucose homeostasis and thus make modeling and control difficult. An ANN can be used to model complex nonlinear systems by computing units (neurons) interconnected with each other with certain numeric weights. The weights can be adjusted by a training algorithm applied to the dataset. This learning ability as well as its versatility, nonlinearity, and adaptability of ANN make it appropriate for developing complex BGL prediction models. Several studies showed ANN performed well by predicting hypo-/hyper-glycemia based on inputs such as insulin dosage, nutritional intake, and daily activities. The literature reveals that a vast majority of control algorithms are either based on a linearized version of the nonlinear physiological model or time-series model.

The linearization of the original nonlinear system results in significant loss of the nonlinear characteristics of the system resulting in the deterioration of the control performance at operating points other than the equilibrium point.

The major difficulty with the time-series models is that it becomes difficult to express important physiological factors in terms of the model parameters directly. Further, the model-based control algorithms explicitly use the information of all the state variables (related to both blood glucose and insulin), but the measurement of all states is not practically possible in APS because of high cost and reliability issues. Also, the computational aspect of the nonlinear control technique is another point of concern. Thus, the main motivations behind the proposed work are to first design a nonlinear controller that utilizes BGC information only. Secondly, the computational aspect of the controller gain should be simple, efficient yet robust enough.

III. RESULTS

This section discusses the blood glucose control system by utilizing the proposed MGOA based PID controller. The performance of the PID controller is enhanced by MGOA. The proposed system is designed and simulated using Intel(R) Core (TM) i5 processor, 4GB RAM, and MATLAB/Simulink 7.10.0 (R2015a) platform. Then simulated results are evaluated by using different algorithms such as PSO and EHO. The Bergman minimal nonlinear model is utilized for simulating the diabetic patient's dynamics. The effectiveness and robustness of MGOA optimized PID and some traditional controllers are considered by testing under different uncertainty parameters, meal disturbances, and sensor noise. The robustness to the uncertainties makes this controller attractive in designing the insulin supplying pumps by adjusts the PID parameter values until the system is stable.

In this section, the PID controller design using the classical method and MGOA is presented. The blood glucose-insulin regulation model is designed based on the nonlinear Bergman minimal model. A simple simulation experiment of the PID control algorithm is applied to the identification of the T1DM minimal model, which is trying to emulate the insulin secretion of a healthy pancreas. The simulation conditions as present during the intravenous glucose tolerance test (IVGTT) have been replicated the identified model received an equal amount of glucose. The PSO based PID controller simulation results can be illustrated in figure 3. At the time of the initial glucose peak, the PID controller tries to keep glucose concentration within normal glucose range resulting in insulin rise with the peak. The simulation experiment represents the regulation process of T1DM subject in 48 h.

The discrete PID controller is used to control the blood glucose concentration of the T1DM model and its gain parameters are described in table 1. The primary objective of glucose concentration control is keeping its level. which describes the glucose level, meal concentration, and insulin injection. Based on the simulated results, the proposed controller regulates the glucose level and stabilizes the insulin injection level.

Table1: Gain parameters of controllers

Parameters	PSO-PID	EHO-PID	Proposed (MGOA-PID)
KP	0.6052	0.7246	0.4587
KI	1.0248	0.8153	0.7785
KD	0.3231	0.7625	0.6953

The provision of the proposed controller is based on the comparison analysis, which is described in figure 6. Table4 shows the average blood glycemic level before the proposed method and after following the proposed method of swallowing about 10 days for 10 diabetic persons who have diabetes for 4 years. In this comparative analysis, the insulin injection and the convergence of the proposed controller and the existing controllers are evaluated. Based on the comparative analysis, the proposed MGOA optimized PID controller is better than the other existing controllers. Finally, the proposed blood glucose control system with nonlinear Bergman minimal model for type-1 diabetic patients is concluded as follows.

IV. CONCLUSION

This study presents the blood glucose control system based on the MGOA utilized PID controller with nonlinear Bergman minimal model for type-1 diabetic patients. The controller regulates the patient's glucose level using both basal and bolus insulin. The basal updates can stabilize blood glucose, and the bolus can reduce glucose undershoot and prevent hypoglycemia. The proposed nonlinear Bergman minimal model system is developed using the MATLAB/Simulink model. The simulation results of the proposed controller, the optimal reinforcement learning, and the PID controller on a type-1 diabetes model show that the proposed algorithm is the most effective. As their response depends on the accuracy of the internal model, control performance degradation is caused by model-induced system simplification and neglected adaptation to the individual patient's glucose metabolism. The proposed controller is exposed from the simulated results that MGOA utilized the PID controller outperforms the other existing PID controllers. The MGOA optimizes the PID controller to gain parameters for stabilizing the type-1 diabetic patient's glucose level. The simulated result shows the correctness of MGOA-PID to efficiently stabilize the glucose level in the blood for type-1diabetic patients. Additionally, the

MGOA-PID may be explored on more accurate models that consist of the absolute dynamics of type-1 diabetic patients. The results show that the control algorithm is able to keep the blood glucose at a healthy level although uncertainties create variations in the blood glucose responses. The future scope of this study will be designed the controller by different algorithms and the complete closed-loop system will be considered and designed for real-time glucose values.

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