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RESEARCH ARTICLE

BIOINSPIRED ALGORITHM FOR THE CONTROL OF CARDIAC PACEMAKER

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ABSTRACT

Designing the controller for the control of cardiac pacemakers to maintain the heart rate in a efficient way is very challenging. Proportional - Integral - Derivative control schemes continue to provide the simplest and effective solutions to most of the control engineering applications today. However, tuning of these controllers is time consuming, not easy and generally lead to poor performance especially with non-linear systems. This paper presents a Bioinspired optimization (BIO) algorithm for tuning the (PID) controller parameters for the control of pacemaker. This approach has superior features, including easy implementation, stable convergence characteristic and good computational efficiency over the conventional methods. The PID conventional controller had been applied and results were compared with the automatic tuning BIO-PID for the pacemaker using Matlab coding .The proposed algorithm is used to tune the PID parameters and its performance has been compared with the conventional Ziegler Nichols method. The results obtained reflects that use of heuristic algorithm based controller improves the performance of pacemaker in terms of time domain specifications, set point tracking and regulatory changes and also provides an optimum stability. This paper discusses in detail, the Bioinspired technique and its implementation with PID tuning for a controller of a pacemaker. Compared to other conventional PID tuning methods, the result shows that better performance can be achieved with the soft computing based tuning method. The ability of the designed controller in terms, of tracking set point is also compared and simulation results are discussed.

INTRODUCTION

Cardiovascular diseases are major causes of morbidity and mortality in the developed countries. One of the cardiac diseases, bradycardia sometimes results in fainting, shortness of breath, and if severe enough, death (Kenneth *et al*., 2005; Sthlberg *et al*., 2011). In case of bradycardia, the electrical signals in the heart are ineffective to cause lower heart rate that is not enough for physiological needs, unless it is interrupted by an external stimulus generated by implantable cardiac devices, such as pacemakers, and then a normal heart rhythm is quickly restored. With heart disease still the number one cause of death in the United States, the development and improvement of medical devices is of great importance. It is well known that pacemaker as one of the implantable cardiac devices for medical treatment of heart diseases has been widely used nowadays (Haddad *et al*., 2006). Pacemakers are used to treat arrhythmias that are problems with the rate or rhythm of heartbeat and they provide electric pulses that mimic the natural pacing system of the heart, maintain an adequate heart rate by delivering controlled, rhythmic electrical stimuli to the chambers of the heart, and prevent human from being harmed by low heart rate (Petrutiu *et al*., 2007). Modern pacemakers with sensors are applied to make the measurements of diagnostic data and to provide continuous cardiac monitoring (Shepard and Ellenbogen, 2009). Due to the uncertainties contain imprecise information by combining the physiological demand, controller realization for the pacemaker systems has been developed (Kligfield *et al*., 1996). However, the conventional PID control algorithm needs much improvement to achieve better adaptation of regulating the pacing rate to the physiological requirement for each particular patient. In addition, the mathematical complexity in the nonlinear nature of pacemaker and physiological behaviour makes the formulation of a tuning mechanism an extremely complex problem. Exact mathematical modeling of system is required for the control and the performance of the system is questionable if there is parameter variation (Nabil, 2005), however the PID controller is still extensively used in the industry this is due to its simplicity and the ability to apply in a wide range of situations. On the other hand tuning a PID controller is rather difficult and can be a time consuming process (Heno, 2002; Raghhavan, 2005; Jyoti Yadav *et al*., 2011; Wei Vivien Shi and MengChu Zhou, 2013). In recent years, many intelligent algorithms are proposed to tune the

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PID parameters. Tuning PID parameters by the optimal algorithms such as the Simulated Annealing (SA), Genetic Algorithm (GA), and Particle Swarm Optimization (PSO) algorithm are carried out in this paper . Chent *et al*. proposed a method to tune PID parameters by Sino Atrial node (Chent *et al*., 1998), however, it is slow to search the best solution. PSO, is one of the modern heuristics algorithms and it was developed through simulation of a simplified social system, which is robust in solving continuous non-linear optimization problems. (Zwe-Lee Gaing, 2004). This paper discusses a novel method to build a simplified bioinspired model based on a closed-loop tuning for PID controller to calculate regulation parameters.

PID Controller

The PID feedback control system is illustrated in Fig. 1 consists of the PID controller with Proportional, Integral and Derivative gains where r, e, y are respectively the reference, error and controlled variables. Where K_p is proportional gain, K_i is integral gain and K_d is derivative gain.

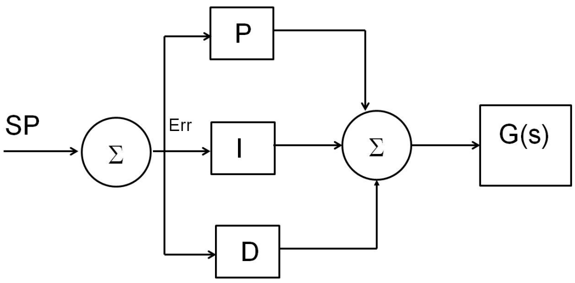

Figure 1. Feedback PID Controller

In Fig.1, G(s) is the plant transfer function and C(s) is the PID controller transfer function that is given as:

$$C(s) = K_p + \frac{K_i}{s} + K_d s \tag{1}$$

Where K_p ,K_i, K_d are the parameters of the PID controllers that are going to be tuned using Bioinspired algorithm.

Neural Network PID Control

Neural network could be used to regulate the parameters of the PID controller. The PID control system based on back Propagation (BP) neural network was composed by the conventional PID controller and BP neural network, its structure is shown in Figure 2, are regulated by the neural network.

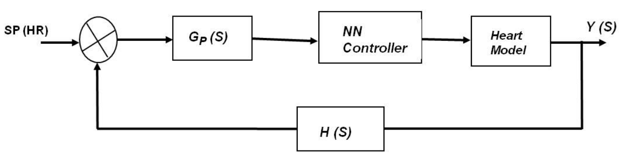

Fig. 2 Closed loop Neuro Controller for HR

The BP neural network can contain different hidden layers. But it is theoretically proved that three layered network with unlimited nodes can fit any non linear mapping. The number of input layer neurons assigned as two namely I_1 and I_2 that is Heart rate set point (HR_S), Heart rate output (HR_O).

The output of the network is PID controller output O_1. Therefore the number of neurons in the output layer is one. The hidden layer has three neurons and they represented as H_1 (P-neuron), H_2 (I-neuron) and H_3 (D-neuron). According to the block diagram in Figure 4, the actuating error HR_{err} can be expressed as,

$$HR_{err} = HR_S - Hr_O$$

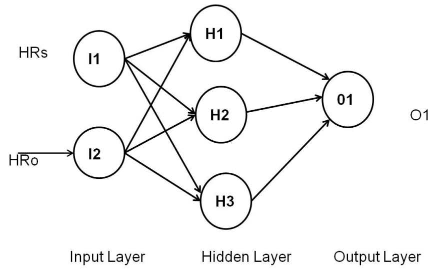

Figure 3. Architecture of Proposed BP NN control scheme

In the conventional BP multi-layered neural network, the learning algorithm is the gradient descent algorithm in which the gradient is calculated by back propagation method, according to the rules of windrow-Hoff. BP algorithm is used for weighting coefficients. The aim of the algorithm is to minimize the error in order to recover the system quickly from the effects of the external disturbance by tuning of PID parameter. BP neural network learning algorithm is described as follow:

$$e_k = 0.5 * (HRs - HRo)^2$$

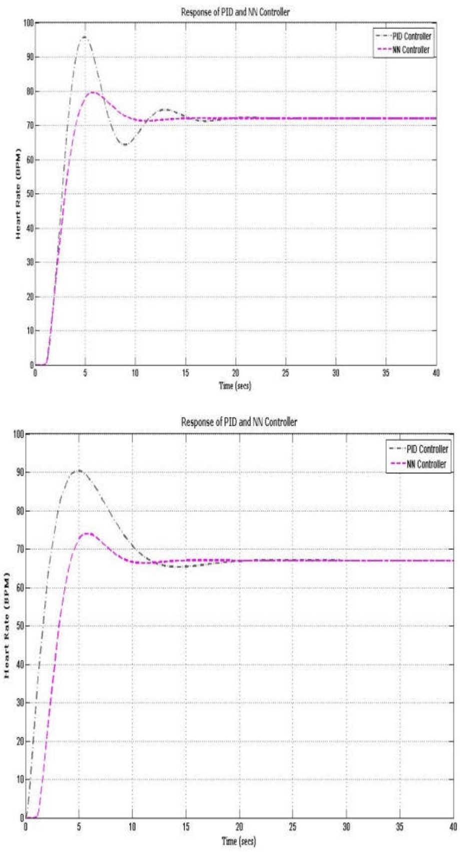

Figure 4. Response of PID and NN controller for 67 and 72 bpm

The weights of hidden nodes are adjusted by BPNN algorithm based on steepest descent online training process. It is done in terms of adjusted weights of hidden layer to output layer and input layer to hidden layer. The increments of weight in hidden to output connection are updated by gradient descent method. The responses of both the controllers are given in Figure 4. It is observed from the above response that the performance criteria such as peak over shoot, settling time are too high. In order to bring the performance indices within the stipulated limit, the Conventional PID controller parameters are tuned using the proposed Bioinspired optimization algorithm.

Bioinspired Algorithm

Bio inspired Algorithm is one of the newest representatives of SI-based algorithms. Since 2010, its reputation and visibility are highly rising. Bat algorithm is easy to implement and applicable to various applications. It offers solid results by solving of the low-dimensional problems and that is one of the reasons to be applied to tune the parameters of PI-controller. Thus, high convergence of the BA algorithm is expected.

Fundamentals of BA

Fundamentals of Bat algorithm Bats are night animals. Nature has given them ability to navigate in darkness, using a so-called sonar, named echolocation. This phenomenon consists of generating an ultrasonic pulse, which echoes from obstacles and prey, bouncing back to the bat, who calculates the distance to either obstacle or prey. More information on bats behaviour and their abilities can be found The BA algorithm treats bats as a swarm of bats, searching for a prey. Since bats search for the prey individually, BA emphasizes the phenomena of echolocation by converging the whole swarm by approaching the found prey. This means that one random individual can achieve the whole swarm to divert for food. From the engineer's point of view, more food means higher fitness function and better solution of the problem. The whole swarm is converging to the best solution during generations by changing their current positions.

RESULTS AND DISCUSSION

The cardiovascular system is considered to be a closed loop system with filter and controller with unity negative feedback. Figure5 shows a simplified model of a closed loop control system for regulating the heart rate HR of a patient in an efficient way.

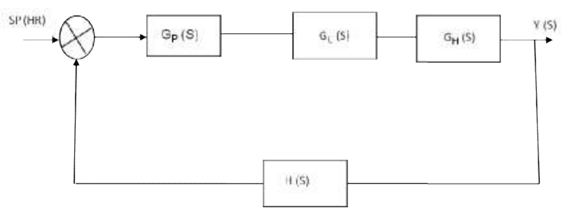

Figure 5. Block diagram of Cardiovasuclar Control Scheme

GP (S) = Transfer function of Pacemaker = $\frac{9}{s+9}$
GC(s) = Transfer function of controller
GH (s) = Transfer function of Heart = $\frac{169}{s^2+20.8s}$
SP = Actual heart rate
H(s) = Unity Feedback
Y (s) = Desired heart rate

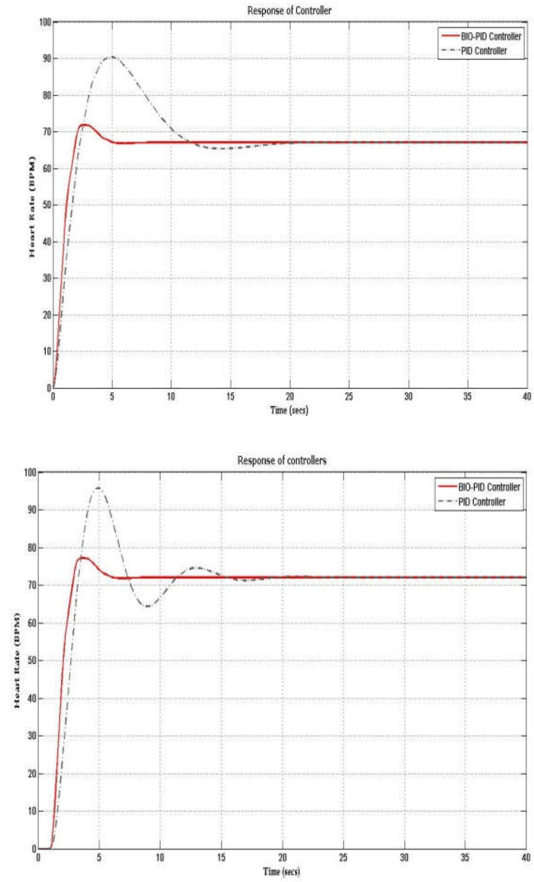

Figure 6. Response of PID and Bioinspired tuned controller

Method	Heart Rate (bpm)	Rise time (sec)	Settling time (Sec)	% Over Shoot
ZN PID Controller	67	2.67	22.34	31.76
	72	2.98	18.97	32.88
Bioinspired tuned PID Controller	67	1.96	5.67	6.26
		1.87	6.29	5.93

The cardiovascular system including the heart can be modelled as an under damped second order system and hence the mathematical model of the heart simulated (16) is as described Heart transfer function. Usually heart rate of humans varies between 60-100bpm. The normal heart rate of humans is around 72 beats/min. Heart rate decreases to around 62bpm in old age. The heart rate can increase/decrease in order to supply oxygen according to physical demands. The ZN based PID controller and Bioinspired PID controllers are used for regulating the heart rate and their responses are given in Figure

Conclusion

This paper introduced a novel tuning method for the PID controller parameters using Bioinspired Optimization algorithm (BOA) based heart rate regulation. The objective function of the proposed BOA designed according to the required control characteristics of cardiac system. The proposed BOA tuning method has better performance compared with the conventional ZN tuning method. The results of the simulating cardiac pacemaker system is proved to be better than the tuning the controller after approximation or by any traditional existing methods.

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