MEAN ARTERIAL PRESSURE CONTROL USING NEW PI-PD SMITH PREDICTOR BASED ON FIREWORKS ALGORITHM

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Abstract— Mean arterial pressure (MAP) is a simple parameter that can be non-invasively acquired to assess an individual's cardiovascular health. The control of MAP, therefore, is of utmost importance in medical science. Although the hybrid of proportional-integral controller (PI), proportional-derivative controller (PD), and Smith predictor has been effectively used in controlling systems with long dead time, its application in MAP control has not been reported. By combining the hybrid fireworks algorithm and the reference model, the present study aimed at evaluating the effectiveness of MAP control by comparing the proposed system with a published controller that used a hybrid algorithm between particle swarm optimization (PSO) and Boids (PSO-BOIDS) for Proportional-Integral-Derivative controller (PID) optimization. The simulation process was carried out using MATLAB/Simulink. The results showed that the proposed approach substantially shortened the response time and prevented MAP overshoot compared with the PID controller using PSO-BOIDS algorithm, highlighting enhanced effectiveness of the proposed system in MAP control.

I. INTRODUCTION

Although modern development of science and technology has contributed greatly to the advances in medical care, the demand for better health care remains insatiable because of the ever-improving quality of life and the accompanying cardiovascular diseases in the developed world. Therefore, innovations and optimization of existing technologies have become keys to the improvement of modern health care. Currently, the most common global causes of death are vascular in origin, including coronary arterial disease and stroke [1, 2]. These diseases are the results of chronic dysfunction of the vascular system such as hypertension. A key parameter for clinicians to keep track of vascular health is mean arterial pressure (MAP) which should be meticulous controlled [3, 4]. In this way, elevation in MAP is sometimes suppressed by infusing a vasodilator such as sodium nitroprusside (SNP) into intravenous lines. In fact, many engineering approaches have previously been proposed for MAP control, such as model predictive controller [4, 5], fuzzy logic controller [6-9], multiple-model adaptive control [10], neural network [11-14], and so forth. The most common drawback of these nonlinear controllers is their complexity in designing procedure. Some linear controllers such as PID are also employed to control MAP [15, 16]. However, in order to design these controllers, the system is approximated into the first order plus time delay system or the second order plus time delay system, then using some conventional approaches or optimization algorithms such as PSO-BOIDS to determine PID controller parameters [16]. In this way, these controllers are imperfectly designed for original process because of uncertain model. In this study, a novel method is proposed for MAP system using PI-PD Smith predictor controller [17, 18]. Smith predictor was used to treat time delay component in system. After that, the hybrid PI-PD controller was employed for tracking control. To enhance performance of the whole system, a typical swarm intelligence optimization algorithm [19] inspired by fireworks explosion phenomenon known as fireworks algorithm (FWA) [20] was proposed to optimize the four parameters of PI and PD controllers. Through combining this optimization method with model reference control, the present study investigated the effectiveness of the proposed method by testing the closeness of the system response to the desired response. This paper is organized as the follows. Section 2 describes mathematical modeling of the mean arterial pressure (MAP). Section 3 shows the main methodology. The simulation results and discussions are demonstrated in Section 4. The conclusion is given in Section

II. MATHEMATICAL MODELING

The SNP drug infusion system model of MAP control is shown in Figure 1 [4, 6].

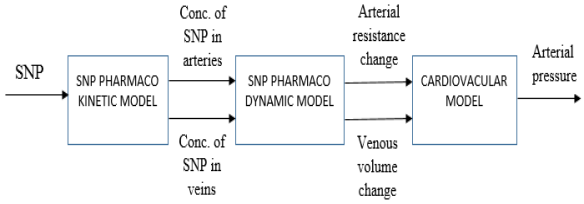


Figure 1. Block diagram of the SNP drug infusion system model of MAP control

MAP system is constructed by three sections, including SNP pharmacokinetic model, SNP pharmacodynamics model and cardiovascular model.

Output of the system, namely arterial blood pressure, is controlled by infusing SNP into intravenous lines at the input side.

The transfer function for the mean arterial pressure (MAP) is as follows [15, 16]:

$$G_{MAP}(s)=\frac{Y(s)}{U(s)}=\frac{K(\tau_3 s+1)e^{-\theta s}}{[(\tau_3 s+1)(\tau_2 s+1)-\alpha](\tau_1 s+1)}, \quad (1)$$

where is the arterial pressure, P0 is the reference pressure, Y(s) is actual pressure, U(s) is the drug infusion rate, K is the system gain, is time delay of the system; are time constants and is the fraction of SNP recirculated.

The system parameters are chosen as follows [15, 16]: Therefore, the transfer function of this model is obtained as follows:

$$G_{MAP}(s)=\frac{5(30s+1)e^{-60s}}{1+130s+4600s^2+30000s^3}. \quad (2)$$

Clinical constraint of the drug infusion rate:

During surgery, the value of MAP must be rapidly reduced by infusing sodium nitroprusside (SNP) into intravenous lines. However, an overdose of SNP would lead to the production of toxic metabolites. Therefore, the maximum rate of drug infusion must be carefully monitored. This value is calculated by the following function:

$$U_M = W_p i_M C_s^{-1} \quad (3)$$

where is weight of patient (kg), Cs is the SNP concentration (5000), and im is the maximum recommended dose (600).

Assume that the average weight of each person is 70 kg, then the maximum value of the drug infusion rate into the patient is 8.4 ml/hr.

A. New PI-PD Smith Predictor

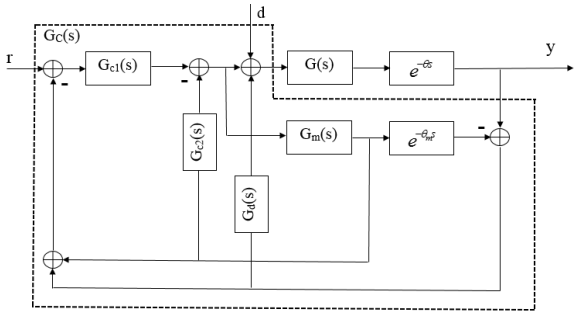


Figure 2. Block diagram of a PI-PD Smith predictor

Figure 2 describes the block diagram of a new PI-PD Smith predictor, where Gc1 and Gc2 are PI and PD controller, respectively; Gd is a disturbance rejection controller. Smith predictor is usually known as one of the most effective dead time compensators for stable systems with long dead time. Using PI-Smith predictor controller can give better closed loop response [17]. In order to modify the pole locations for a stable system, a PD controller was employed in the inner loop. Both controllers Gc1 and Gd were employed for target tracking control and regulatory control, respectively, in the present study.

B FIREWORKS ALGORITHM (FWA)

In 2010, the fireworks algorithm was proposed by Y. Tan. Similar to the fireworks explosion phenomenon, a shower of sparks will local space around a firework when it is set off. By this way, the explosion process of a firework can be viewed as a search in the local space around a specific point where the firework is set off through the sparks generated in the explosion. At the beginning of FWA, n fireworks are set off at n pre-chosen locations. After each firework explosion, the location of sparks are determined. The fitness values at these sparks are evaluated. During this process, the performance of explosion must be controlled by explosion operator. To guarantee diversity of the population, Gaussian mutation operator was also employed. In the case that some new sparks beyond the feasible space, mapping rule is used to get them back to the search space. In the next step, the quality of these locations are verified by using selection strategy. The best fireworks are kept for the next generation. This process is continuous until the terminal conditions are met. The Figure 3 shows the framework of FWA program [20].

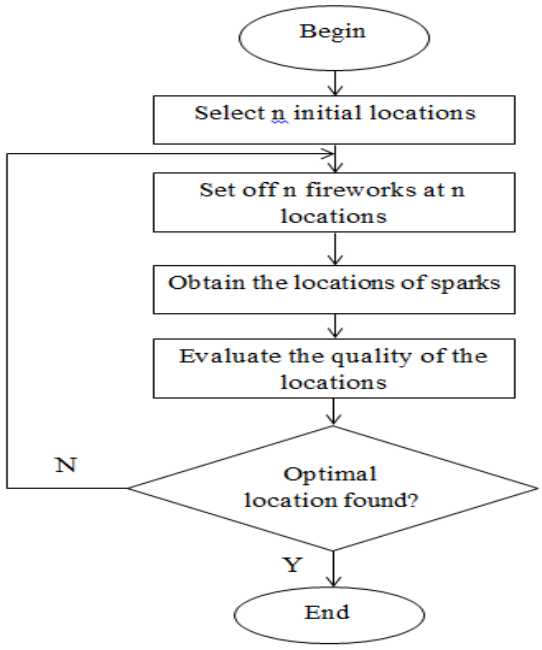


Figure 3. Framework of FWA

The two most important factors strongly affects to optimization result are the number of sparks and amplitude explosion.

C NUMBER OF SPARKS

The performance of a fireworks explosion depends on the number of sparks. The fireworks with better fitness values produce more sparks, and vice versa. From this point, the fireworks with worse fitness values should be manipulated to explore the feasible space and to prevent the algorithm from premature convergence.

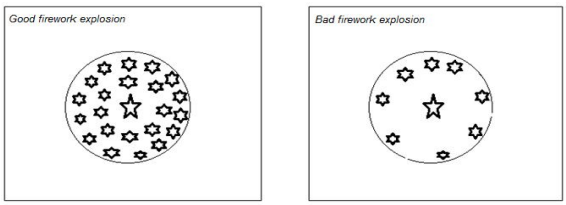


Figure 4. Good and bad firework explosions

Assume a general optimization problem can be stated as:

$$Min\, f(x) \in R, x_{min} \le x \le x_{max}$$

where x represents a location in the searching space, f(x) is a cost function, and x_min and x_max are the bounds of the potential space.

The number of sparks generated by each firework xi is shown as follows [20]:

$$s_i = m \cdot \frac{y_{\max} - f(x_i) + \gamma}{\sum_{i=1}^{n}\left(y_{\max} - f(x_i)\right) + \gamma} \qquad (4)$$

where:

m : Maximum number of sparks

y_max : The maximum value of object function, (y_max=max(f(x_i))).

γ : The smallest constant to avoid zero division zero.

To avoid overwhelming effects of splendid fireworks s_i is defined in a range as below:

$$\hat{s}_i = \begin{cases} round(a.m) & if\ s_i < a.m \\ round(b.m) & if\ s_i > b.m \\ round(s_i) & otherwise \end{cases} \qquad (5)$$

where a and b are constants, $a < b < 1$.

D AMPLITUDE OF EXPLOSION

After calculating the number of sparks, the amplitude of explosion is also determined. In explosion operator, a good firework explosion with better fitness values produces more sparks within smaller amplitude and vice versa. Therefore, the firework algorithm must be controlled to reduce the amplitude of explosion gradually.

The amplitude of explosion is generated as the following formula [20]:

$$A_i = \hat{A} \cdot \frac{f(x_i) - y_{min} + \gamma}{\sum_{i=1}^{n}\left(f(x_i) - y_{min}\right) + \gamma} \qquad (6)$$

where

Aˆ : The maximum explosion amplitude.

y_min : The minimum value of the objective function:

E PROPOSED HYBRID FWA-MRC OPTIMIZATION METHOD

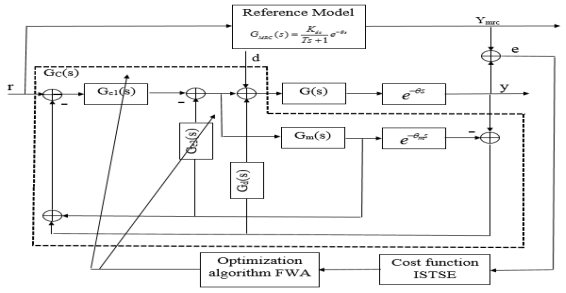


Figure 5. Proposed optimization structure of hybrid FWA-MRC method

In order to optimize parameters of PI and PD controllers in the PI-PD Smith predictor configuration, a combination of FWA and model reference control (MRC) is proposed. The reference model has transfer function in the form of a first order plus dead-time process as shown as follows:

$$G_{MRC}(s) = \frac{K_{dc}}{Ts+1} e^{-\theta s} \qquad (7)$$

where is DC gain whose value is equal to set point, is desired time constant of the reference model.

The hybrid FWA-MRC optimization method is developed from the idea of function approximation, in which the fireworks algorithm optimizes error between output of process and output of reference model. In this way, designing controller is completely active in guaranteeing system performance as expected.

A performance criterion based on error variable, namely ISTSE, is chosen as the cost function.

Integral of Square Time Multiplied by Square Error (ISTSE):

$$ISTSE = \int t^2 e^2(t)\, dt \qquad (8)$$

where t is simulation time, is error variable between output of process and output of reference model . .

E SIMULATION RESULTS AND DISCUSSION

Figure 6 and Figure 7 show the simulation models of optimization process and the control configuration, respectively. The "FWA_optim" block is a function used to optimize four parameters of both PI and PD controllers.

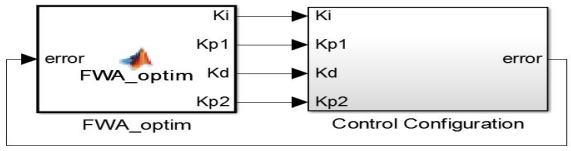


Figure 6. Simulation model of optimization process

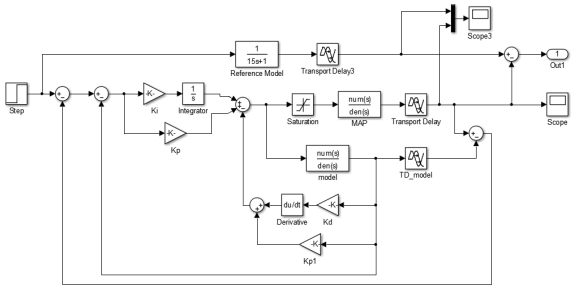


Figure 7. Simulation model of control configuration

RESULTS

Figure 8 and Figure 9 display the performance comparison in target tracking control and control signal (the rate of infusion drug) between the proposed method and a published method of Oliveira et al. [16], in which PSO-BOIDS was used to optimize PID controller parameters after approximating system model. Table 1 summarizes some performance criteria

in system response of both methods. Table 2 shows the optimized parameters of PI-PD controller.

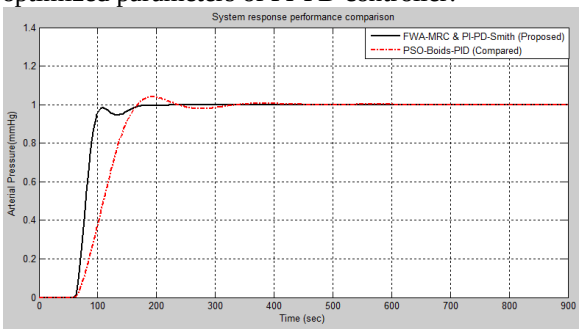


Figure 8. Target tracking performance comparison between the proposed method and the published method (PSO-BOIDS-PID)

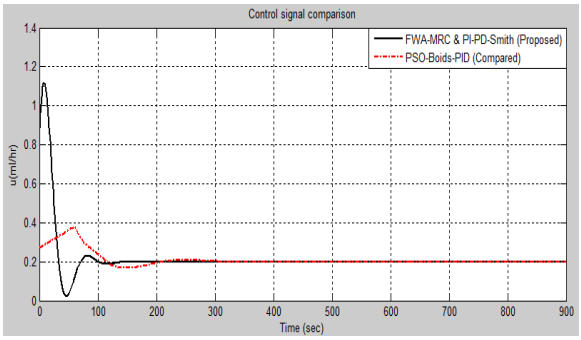


Figure 9. Control signal (drug infusion rate) between the proposed method and PSO-BOIDS &PID

Table 1: System performance comparison

Controller Schemes	System Performance Comparison			
	P.O. (%)	T_s (s)	T_r (s)	Maximum control signal (ml/hr)
FWA- MRC & PI-PD-Smith Predictor (Proposed)	0	152	27.30	1.12
PSO-Boids-PID	4	209	72.08	0.38

Table 2: Optimized PI-PD controller parameters

Controller	PI controller		PD controller	
	K_i	K_p	K_p	K_d
Values	0.0869	0.81998	1.7756	2.7372

The above simulation results demonstrate that the proposed method produced a system response with zero overshoot and much faster response time as compared with that of the published method of Oliveira et al. [16]. Combining reference model (MRC) with fireworks algorithm significantly reduced optimal solution searching time. In addition, this hybrid optimization method guarantees matching of performance of designed controller with that of the desired reference model.

CONCLUSION

This paper proposes a hybrid optimization method of reference model and fireworks algorithm in designing parameters of the PI-PD Smith predictor controller. Not only was there no overshoot, but the response of MAP system with the proposed method was also very fast and smooth. Moreover, the drug infusion rate was very small and suitable for clinical application. Applying reference model significantly enhanced the optimization performance of fireworks algorithm, including shortening searching time, and controlling system performance. Besides, the simulation results showed that the performance of the proposed controller is much better than that of the published method.

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