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Controlling of Mean Arterial Pressure by Modified PI-ID Controller Based on Two Optimization Algorithms

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Abstract*:* High blood pressure is one of the diseases that most people suffer from, and it becomes a serious disease when it is not controlled precisely, especially during the surgical procedure. There must be anesthesiologists during the operation to monitor the pressure during the operation. It is not good and expensive, for patient safety and injection of the patient with the required dose, and it accurately requires an intelligent control to control the patient's pressure This paper presents nonlinear control system, to regulate the Mean Arterial Pressure (MAP) system. This controller is designed based on slate model that represent the mathematical equation that clarifies relationship between blood pressure and vasoactive drug injection. In this work Squirrel Search Algorithm (SSA) and Bacterial Foraging Optimization (BFO) are considered to optimize the controller parameters. Also nonlinear gain is used in PI-Id controller rather than fixed gain to make the controller much more sensitive to small value of error. Two algorithms applied to the controller to optimize its parameters to compare their results and determine which gives better results. The comparison results show best improvement when using the suggested controller based on SSA Algorithm. the results have no undershot with less (800s) settling time and low error.

Index Terms: Mean Arterial Pressure, Modified PI-ID Controller, Squirrel Search Algorithm, Bacterial Foraging Optimization.

1. Introduction

High blood pressure can occur during surgical operations Mean Arterial Pressure (MAP) is an important factor that can rise during surgery. There are several risks that caused by blood pressure such as: memory loss, Heart attack, brain attack, Sudden loss of kidney function. ..etc [1].

To reduce the serious symptoms caused by high blood pressure complications, the blood pressure must be controlled in an intelligent controller way. One way to achieve this is to apply the Infusing vasoactive drugs can be used to low the blood pressure to desired level such as Sodium Nitroprusside (SNP), The sensibility to the drug differs from patient to patient (three type of patient: normal, sensitive and insensitive patient) [2].

The infusion of vasoactive drugs will generate Nitric Oxide (NO) which reduces the MAP, it causes expansion of blood vessels and has less side effects. The control mechanism is carried using the manual control using rate limiters in the syringe pump. This process is not accurate and Consume a lot of time. moreover, when the patients are kept in ICU for postsurgical treatments, the pressure has to be monitored by Anaesthesiologists continuously for many hours. So, an Automatic Drug Delivery System is useful to carry out the control of drug infusion in a proper manner [3].

The infusion system is an integrated system contains of injection materials as per the medical standards, which will be sensing the blood pressure level and calculate the desired amount of vasoactive drug (such as SNP sodium nitroprusside) required and injection the human body by the desired amount of drug with the help of automatic pump [4].

A formal research for the development of automatic control schemes for regulation of postoperative hypertension dates back to the late 1970’s when Slate at (1979) presented an experimentally validated mathematical model relating the patient’s blood pressure response to the injection of Sodium Nitroprusside (SNP) drug [5].

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The Proportional-Integral-Derivative (PID) controller is consider as one of the most widely used to regulators the MAP therefore many contributions were made towards fixed gain Proportional-Integral-Derivative (PID) controllers for postoperative hypertension regulation like pid controller with Ziegler Nichols method suggested by Manju V S, Srinivasu Maka et al [6], The PSO Boids algorithm is proposed to perform both system identification and PID controller design. The advantage over a standard particle swarm optimization algorithm is the promotion of the diversity of the search procedure this suggested by Paulo B. de Moura Oliveira1, Joana Durães2, and Eduardo J. Solteiro Pires et al [7], Shabana Urooj and Bharat Singh design Control of Mean Arterial Pressure Using Fractional PID Controller, PID controller having fractional order can give better result to reduce the MAP in cardiac patients at el [8], G.C.Sowparnika and V.M.Sivakumar they sugusted PI and PID controllers for MAP system and tuning these controller with various tuning rules such as ISE, IAE and ITAE at el [3], D.Sathish, Alamelu Nachiappan developed A control system using PI, PID, IMC, These controllers effectively control the blood pressure of the patients to the preferred level and carry out strongly in the occurrence of deviations in the patient response at el [9].

The goal of this research to design controller for regulating blood pressure during surgery at desired level with optimum time and desired amount of drug. the sensitivity to the drug is different from patient to patient , therefore the traditional control algorithm cannot perform efficiently. A modified PI-ID controller is suggested in this paper with nonlinear gain function for controlling the mean arterial blood pressure regulation, the attractive feature of this controller is its capacity to optimize the quantity of infused medication. The parameter of this controller optimized by Squirrel Search Algorithm (SSA) and Bacterial Foraging Optimization (BFO) based on the least-square error (LSE) criterion. The suggested controller is easy to design and gave better results compared with classical PID controller.

The rest of this paper is outlined as follows: section II presents the mathematical model of a mean arterial pressure. Section III describes the suggested (PI-ID) controller, while section IV illustrates the SSA and BFO algorithms. Section V addresses the simulation results and comparison between algorithms, and section VI provides the final conclusion.

2. Mean Arterial Pressure Modelization

The most common used mathematical model of the mean arterial pressure (MAP) of a patient and very popular introduced in 1980 by slate [10, 5] after more studies on patients which leaded to the following mathematical equation:

$$MAP(t) = \Delta pd(t) + p \tag{1}$$

MAP is the mean arterial blood pressure, $\Delta pd(t)$ is the change in blood pressure after injected the patient with SNP given in mmHg, p_0 is the initial blood pressure. The transfer function of $\Delta pd(t)$ relating to SNP infusion rate is [11]:

$$\frac{\Delta pd(s)}{I(s)} = \frac{K\, e^{-Ti\, s}(1+\alpha e^{-Tc\ s})}{1+\mathrm{T}s} \tag{2}$$

where I(s) is infusion rate, K is the drug sensitivity, α is the drug fraction recirculation, Ti is the initial transport lag from injection site, Tc is the time consuming by the drug to flow through the patient's body, T is the time required for distribution and biotransformation of the drug.

3. Modified Pi-Id Controller

The blood pressure control system measures the mean arterial pressure (MAP) using a pressure sensor then the measured value is compared with the desired pressure level. The error between measured MAP and desired MAP, e is given to a controller. The controller finds the amount of vasoactive drug (such as SNP sodium Nitroprusside) that need to be injected into the human body to bring the desired amount of pressure change in the human body [6].

The suggested controller combines (PI) and (ID) controller with replace the constant gain with nonlinear gain as shown in Fig (1).the control signal is:

$$U(t) = u1(t) + u2\,(t) \tag{3}$$

$$u1(t) = Kp\; e(t) + Ki \int e(t)dt \tag{4}$$

$$u2(t) = K_i \int e(t)\; dt\; + K_d \frac{de}{dt} \tag{5}$$

$$U(t) = Kp \times \left(e + \frac{1}{Ti} \int e + \frac{1}{Ti} \int e + Td\; \acute{e}\right) \tag{6}$$

The constant *kp* gain replaced with nonlinear gain. The transfer function nonlinear gain is:

$$Kp = K1 + \frac{K2}{1+e^{(m*e^2)}} \tag{7}$$

where *K1*, *K2* and *m* are constants value, the benefit of the nonlinear gain term is to make the controller much more sensitive to small value of error, when $e = 0$, then $Kp=K1+K2/2$, Moreover, as e goes sufficiently large, then $Kp \approx K1$. The nonlinear gain Kp term is bounded in the sector $[K1,\ K1+K2/2]$ [12].

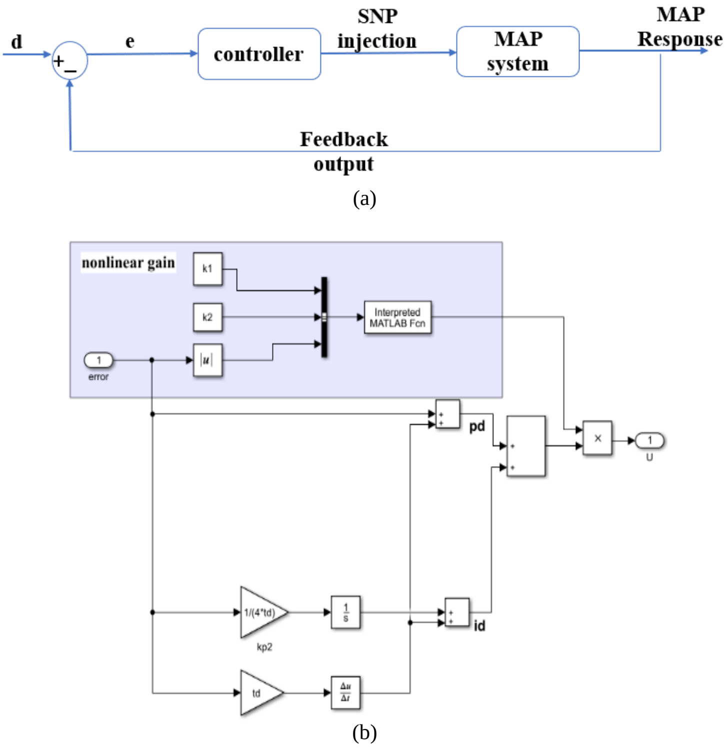

Fig.1. (a) block diagram explains the relation between the system and controller (b) block diagram of the controller.

4. Optimazation Algorithm

The parameters of controller *K1, K2, m*are optimized using SSA and BFO algorithm as illustrate in following subsection.

A. The Squirrel Search Algorithm

The squirrel search algorithm (SSA) proposed by Mohit Jain, et al. in 2019 was a novel nature-inspired algorithm for optimization, (SSA) algorithm consist of four the search processes of flying squirrels: (i). there are *n* flying squirrels and *n* trees and only one squirrel on one tree, (ii). each flying squirrel is tries to find the food so each one searching for food individually, (iv). there are only three types of trees such as normal tree, oak tree and hickory tree (which is the favour tree) in forest only three oak trees and one hickory tree in the forest [13]. The following steps explained the operation of this algorithm [14]:

Step 1: Initialization Let that the number of the population is N, the upper and lower bounds of the search space are fsu and fsl, and start the loop iteration, N individuals arerandomly produced according to equation:

$$fsi = fsl + rand(\,1, D) - (fsu - fsl) \tag{8}$$

Step2: Evaluate the fitness value for each individual.

Ranking the fitness values of the individuals in ascending order, the squirrels are classified into three types: (i).Fh squirrels located at hickory trees (the best food resource for the squirrels), (ii). Fa squirrels located at acorn trees (takessecond place food resource for the squirrels), (iv). Fn squirrels located at normaltrees (no food).

Step3: Update the Position (winter strategiah)

All squirrels try to move to the hickory trees or acorn trees, they update their The positions of each squirrel updated according to the updating equation:

$$\begin{matrix} & if \quad p > pdp \\ fsi(t+1) = & fsi(t) + dg\ Gc\ (fth - fsti) \\ Random\ location & & otherwise \end{matrix} \quad (9)$$

$$\begin{matrix} & if \quad p > pdp \\ fsi(t+1) = & fsi(t) + dg\ Gc\ (fta - fsti) \\ Random\ location & & otherwise \end{matrix} \quad (10)$$

where pdp represents the predator appearance probability, Gc is the constant with the value, dg is the gliding distance which can be calculated by this equation:

$$dg = \frac{hg}{tan(\Phi)\, sf} \quad (11)$$

Where hg the constant, sf the constant, Tan (Φ) is the angle of gliding which can be calculated as shown below:

$$tan(\Phi) = \frac{D}{L} \quad (12)$$

$$D = \frac{1}{2\ p\ v\ s\ CD} \quad (13)$$

$$L = \frac{1}{2\ p\ v\ s\ CL} \quad (14)$$

Where *p, V, S, CL* and *CD* are all the constants.

Step4: Seasonal Transitionwhether the season changes is judged according to these equation.

$$S_c^t = \sqrt{\sum_{k=1}^{D} (F_{ai,k}^t - F_{h,k}^t)} \ \ i = 1,2, \dots, Nfs \quad (15)$$

At the beginning of each iteration, the whole population is in Winter, so all the individuals are updated in the way introduced step (3) When the season turns to summer, the individuals updated location, by these equations:

$$FS_{inew}^{t+1} = FSL + Le' vy(n)\ (FSu - FSl) \quad (16)$$

$$Le' vy(n) = 0.01 \times \frac{r_a \times \sigma}{|r_b|^{1/\beta}} \quad (17)$$

$$\sigma = \left(\frac{\Gamma(1+\beta)\ sin\frac{\beta\pi}{2}}{\Gamma\left(\frac{1+\beta}{2}\right)\beta\ 2^{\frac{\beta-1}{2}}}\right)^{\frac{1}{\beta}} \quad (18)$$

where $\Gamma(x) = (x1)!$

Step5: Stopping criteria: If all iteration will be finished,stop the search and display the values. Else, repeat step 2 to step 4 until the specified iterations are completed

B. Bacterial Foraging Optimization Bacterial Foraging Optimization

Bacterial Foraging Optimization **(**BFO) algorithm is one of the natures inspired heuristic method proposed by Passino in 2002. In this method, a group of artificial bacteria work together to find the potential solution in the D-dimensional search space during the optimization exploration.The foraging strategy of Escherichia coli bacteria present in human can be described by four processes, namely chemotaxis, swarming, reproduction, and elimination dispersal Implementation of the BFO has following steps [15]:

Step 1: Initialization: assign the number of bacteria's, Number of chemotactic steps NCLimits the length of a swim NS, number of reproduction steps Nre, number of

elimination-dispersal events Ned, number of bacteria reproductions (splits) pergeneration Sr=s/2, Theprobability that each bacterium will beeliminated/dispersed Ped.

Step 2: (i). Start of the chemotaxis loop (j=1..NC), (ii). Star of the reproduction loop (kk=1..Nre), (iv) Start of the swimming or tumbling operation (i=1…NS), (iii). Start of theelimination- dispersal loop (ell=1..Ned).

Step 3: Evaluate the cost function: The objective function values of the bacteria's are Evaluated using the performance criteria. let J is a matrix which store each cost valuefor each bacterium at each iteration.

Step 4: Update the position of each bacteria according to the Tumble operation and Evaluate the cost function for each bacterium after updating its position:

$$p(i,j,kk,ell) = p(i,j,kk,ell) + c(i,kk) \times \frac{delta(:,i)}{sqrt(delta(:,i)'delta(:,i))} \tag{19}$$

$$delta(:,i) = \left(2\, round\left(rand(p,1)\right) - 1\right) .\times \text{rand}\,(\text{p},1)) \tag{20}$$

$$c(:,1) = 0.05 \times ones(NS,1) \tag{21}$$

Step 5: Update the position of each bacteria accordingthe Swim operation using equation (19) and Evaluate the cost function for each bacterium after updating itsposition.

Step 6: Sorts the cost value for each bacterium in order of ascending.

Step 7: the most fit ones split into two identical copies in the reproduction step.

Step 8: Elimination and dispersal the least fit one this operation can be doing using randomFunction.

Step 9:Stopping criteria: If all iteration will be finished, stop the search and display thevalues. Else, repeat step (3) to step 8 until the specified iterations are completed.

5. Simulation and Results

The simulation results of the suggested controllers based on the (SSA) algorithm and (BFO) algorithm for controlling MAP model have been presented in this section. The MAP response without controller has no reached the desired level and there is an error, the parameters of the model given by the table (1), and the input to the system is the reference value without noise (desired value [90 - 120]):

Table 1. Parameters values of patient model [16,17]

Parameter	Sensitive	Normal	Insensitive
K	-9	-0.7143	-0.1786
α	0	0.4	0.4
Ti	20	30	60
Tc	30	45	75
T	30	40	60

When the system controlled with classical (PID) controller, noticed that the response has large setting time and under shot value as shown in the Fig (2).

The system controlled with suggested controller. The controller parameters optimized with (SSA) and (BFO) algorithms. The parameters of controller are shown in table (2) and (3):

Table 2. The controller parameters optimized with (SSA) algorithm

patient	*K1*	*K2*	*m*	*Td*
Normal	-0.0125	0.00036	1	0.64
Sensitive	-0.0021	0.0001	1	0.55
Insensitive	-0.0450	0.0003	1	1

Table 3. The controller parameters optimized with (SSA) algorithm

patient	*K1*	*K2*	*m*	*Td*
Normal	-0.0115	0.0008	1	0.58
Sensitive	-0.0019	0.0002	1	0.44
Insensitive	-0.04433	0.00066	1	1

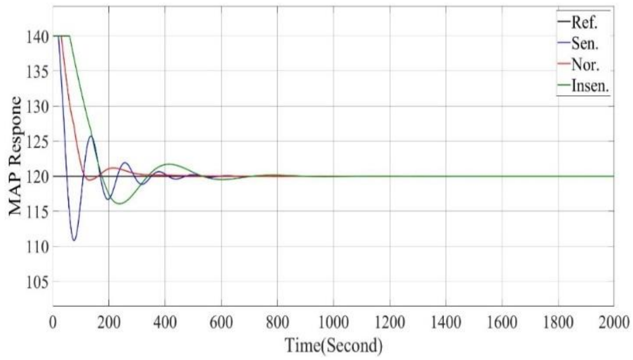

Fig.2.MAP response using classical (PID) controller.

Fig (3) and Fig (4) show the response of MAP and the SNP injection (control signal) when the parameter of controller optimized with (SSA) algorithm respectly. Fig (5) and Fig (6) show the response of MAP and the SNP injection (control signal) when the parameter of same controller optimized with (BFO) algorithm respectly. It can be noticed from the figures the controller satisfies the design requirement by making the MAP system follows the desired Level with small steady state error (e.s.s), settling time (ts), and under shot (MP).

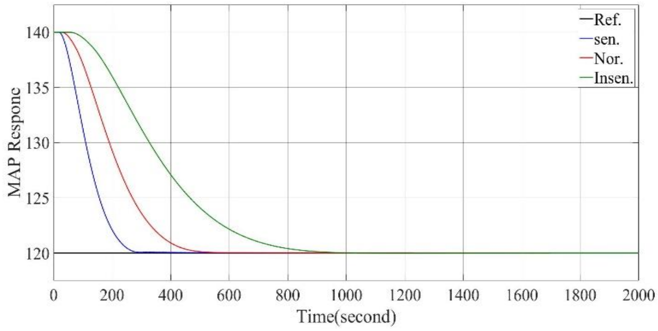

Fig.3.MAP response using the proposed controller with (SSA) algorithm

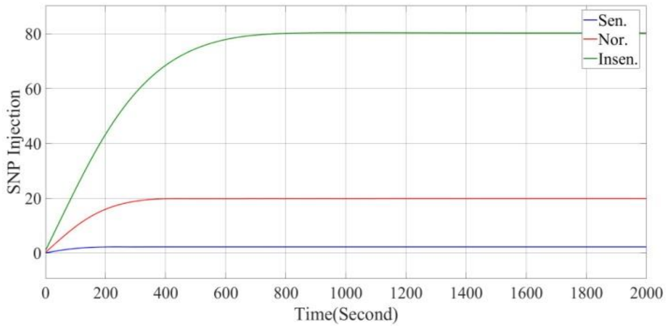

Fig.4.SNP injection using the proposed controller with (SSA) algorithm

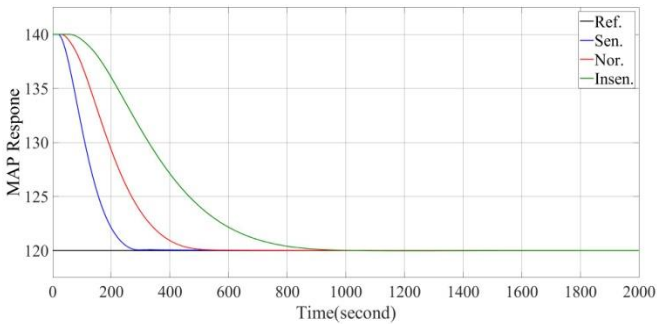

Fig.5.MAP response using the proposed controller with (BFO) algorithm

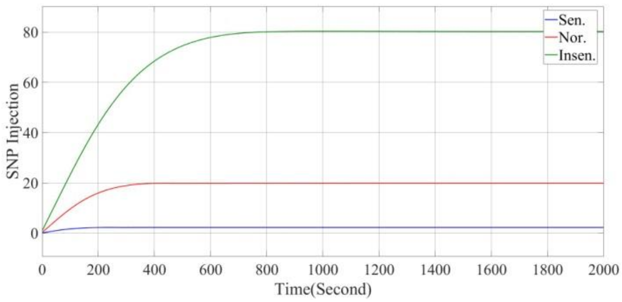

Fig.6.SNP injection using the proposed controller with (SSA) algorithm

From the above figures and table (4) it was noted that the two algorithms gave good results, also it be noted that the controller when optimized with SSA algorithm give better results (less error steady state) when comparison with second method see table (4).

Table .4. comparison between (SSA) and (BFO) algorithms.

SSA Algorithm				
Patient type	Erro steady state(mmHg)	Sett-ing time (s)	Under shoot (mmHg)	SNP inject-ion(ml/h)
Normal	2.61×10^{-5}	450	0	20.01
Sensitive	2.58×10^{-5}	240	0	2.2221
Insensiti-ve	0.00044	770	0	80.26
BFO Algorithm				
Patient type	Erro steady state(mmHg)	Sett-ing time (s)	Under shoot (mmHg)	SNP inject-ion(ml/h)
Normal	0.0039	448	0	20.01
Sensitive	0.00026	240	0	2.01
Insensiti-ve	0.0017	850	0	80.25

Through the results above, it was noted that the controller achieved the required results the mean arterial pressure follows the desired level with low amount error ,low settling time and under shoot.

6. Conclusion

In this paper, modified PI-ID controller is suggested instead of the traditional discrete PID controller to regulate the MAP system. The mathematical model MAP has been considered. In order to improve the characteristics of the suggested controller, (SSA) and (BFO) algorithms have been applied to the controller. The simulation results show that the suggested controller gave good results comparison with classical (PID) controller. In spite of classical (PID) controller gave response with small error but the system output suffer from large setting time and under shot. The suggested future work is using same controller with multi input and multi output system to regulate the pressure and cardiac output using two drugs dopamine and nitroprusside.

References

[1] A. Luiz, D. E. O. Cavalcanti, and A. L. Maitelli, “Design of an Intelligent Adaptive Drug Delivery System for Arterial Pressure Control,” vol. 10, pp. 704–712, 2015.

[2] H. A. Silva, C. P. Leão, and E. A. Seabra, “Parametric Sensitivity Analysis of a Multiple Model Adaptive Predictive Control for Regulation of Mean Arterial Blood Pressure,” vol. 1, no. Icinco, pp. 520–526, 2018.

[3] G. C. Sowparnika, V. M. Sivakumar, M. Thirumarimurugan, and S. N. Saranya, “Metaphorical analysis of tuning rules for PI and PID controllers in modeling an automatic drug delivery system to control mean arterial blood pressure,” 2017 4th Int. Conf. Adv. Comput. Commun. Syst. ICACCS 2017, pp. 0–4, 2017.

[4] A. A. Basha, S. Vivekanandan, and P. Parthasarathy, “Evolution of blood pressure control identification in lieu of post-surgery diabetic patients: a review,” Heal. Inf. Sci. Syst., vol. 6, no. 1, 2018.

[5] J. B. Slate, L. C. Sheppard, V. C. Rideout, and E. H. Blackstone, “Model for Design of a Blood Pressure Controller for Hypertensive Patients.,” J. Sound Vib., vol. 12, no. 8, pp. 285–289, 1979.

[6] V. S. Manju and S. Maka, “Design of drug delivery system for blood pressure control,” 2013 Annu. Int. Conf. Emerg. Res. Areas, AICERA 2013 2013 Int. Conf. Microelectron. Commun. Renew. Energy, ICMiCR 2013 - Proc., 2013.

[7] Á. Herrero et al., “Preface,” Adv. Intell. Syst. Comput., vol. 239, pp. v–vi, 2014.
[8] S. Urooj and B. Singh, “Control of mean arterial pressure using fractional PID controller,” Proc. 10th INDIACom; 2016 3rd Int. Conf. Comput. Sustain. Glob. Dev. INDIACom 2016, pp. 1556–1559, 2016.
[9] D. Sathish and A. Nachiappan, “Automatic drug delivery system for the drug adrenaline using Pi, Pid, Imc & Mpc controllers,” Int. J. Recent Technol. Eng., vol. 7, no. 6, pp. 2043–2047, 2019.
[10] J. B. Slate and L. C. Sheppard, “Model-Based Adaptive Blood Pressure Controller.,” IFAC Proc. Vol., vol. 2, no. 4, pp. 1437–1442, 1983.
[11] S. Saxena and Y. V. Hote, “A simulation study on optimal IMC based PI/PID controller for mean arterial blood pressure,” Biomed. Eng. Lett., vol. 2, no. 4, pp. 240–248, 2012.
[12] A. J. Humaidi and I. K. Ibraheem, “Speed Control of Permanent Magnet DC Motor with Friction and Measurement Noise Using Novel Nonlinear Extended State Observer-Based Anti-Disturbance Control,” Energies, vol. 12, no. 9, 2019.
[13] H. Hu, L. Zhang, Y. Bai, P. Wang, and X. Tan, “A Hybrid Algorithm Based on Squirrel Search Algorithm and Invasive Weed Optimization for Optimization,” IEEE Access, vol. 7, pp. 105652–105668, 2019.
[14] Y. Xiaobing, Y. Xianrui, and C. Hong, “An improved gravitational search algorithm for global optimization,” J. Intell. Fuzzy Syst., vol. 37, no. 4, pp. 5039–5047, 2019.
[15] R. Sivakumar, P. Deepa, and D. Sankaran, “A study on BFO algorithm based PID controller design for MIMO process using various cost functions,” Indian J. Sci. Technol., vol. 9, no. 12, pp. 1–6, 2016.
[16] S. A. Nirmala, R. Muthu, and B. Veena Abirami, “Model Predictive Control of Drug Infusion System for Mean Arterial Pressure Regulation of Critical Care Patients,” Res. J. Appl. Sci. Eng. Technol., vol. 7, no. 21, pp. 4601–4605, 2014.
[17] S. Urooj and B. Singh, “Fractional-order PID control for postoperative mean arterial blood pressure control scheme,” Procedia Comput. Sci., vol. 152, pp. 380–389, 2019.

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