Design of Automatic drug infusion system for mean arterial blood pressure control using cuckoo search algorithm

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Abstract:

The paper presents the optimal control design for an automatic drug infusion system to control the physiological sate such as Mean Arterial Pressure (MAP) by manipulating Sodium Nitroprusside (SNP). The design of multi delivery drug system is very difficult to design due to the patients' sensitivity and dynamics. This paper presents the designing procedure for optimal controller for drug delivery system using cuckoo search algorithm. The simulation result shows the superiority of the proposed controller design.

Keywords: *Blood Pressure Control; Drug Delivery System; optimal Control; cuckoo search algorithm; Intelligent techniques*

I. Introduction:

Mean arterial blood pressure (MABP) is a significant physiological parameter which should be unequivocally controlled in numerous clinical conditions. Keeping up the endorsed MABP level is significant during the cardiac surgery to confine intra-operative bleeding and also in post-surgery conditions to promote healing [1][2]. In the course of recent years, various methodologies have been researched. Many have concentrated on the single-input single-yield (SISO) control frameworks to bring down the patients' circulatory strain and keep up it at wanted level utilizing single medication especially sodium nitroprusside. Ebiya S et al (2011) proposed Model reference algorithm for blood pressure control. It was demonstrated that MRAC is potentially helpful for regulating the MAP and CO by calculating the DPM and SNP infusion rate.

Due to the advancement of control system, the development of automatic biomedical health care instruments is increased. The precision and control strategy are improvement by incorporating the intelligence algorithm into it. The automatic drug delivery system is widely used device in the hospitals, which play a very

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crucial role during the operations. The control system has to be optimally tuned because the patients dynamics are mostly non linear and unpredicted. The control system needs to take some regulatory action in the faster manner. During surgery, many abnormal disturbances such as surgical stimulus, skin incision, tabulation etc. Hence, the control has to be in the position to take corrective action based on the sensed and estimated parameter to take necessary action. Many control strategy and tuning algorithm for automatic drug system is proposed in the literature. Sondhi S and Hote YV (2015) proposed a fractional order PI controller with specific gain margin algorithm to improve the control performance for the automatic drug delivery system. The required controller fractional integral order parameter is obtained from the gain-phase stability region.

Bibian, S., et al 2005, proposed a improved feedback control algorithm for Automated Drug Delivery in Clinical Anesthesia by considering the large inter and intra-patient variability in terms of patients response to drug administration [4]. Urooj, S, and Singh B (2019) presented a method of designing fractional order controller for blood pressure control system. That paper discusses a technique for factional-order PID control approach for blood pressure control using sodium nitroprusside throughout surgical duration. A entire summary of special models detailed in literature, different constraints of control have been studied. SISO model is considered and fractional PID controller is used to control the drug infusion rate to control the MABP.

II. Blood Pressure control in post operative Patients

Health care is a significant zone that can profit by control systems techniques. For instance, in the wake of experiencing open-chest surgery, (for example, cardiovascular detour or lung surgery), numerous patients have a higher than wanted pulse; one explanation that a lower blood pressure is required is to diminish bleeding from sutures. Ordinarily, a basic consideration medical attendant will set up a persistent infusion of the drug sodium nitroprusside to diminish the patient's blood pressure. The medical attendant must make visit checks of blood pressure and change the drug infusion rate to keep up the ideal blood pressure. As it were, the medical caretaker is filling in as a feedback controller. There is a reasonable inspiration to build up a mechanized input control framework, where a blood pressure sensor imparts a sign to a pulse controller, which modifies the speed of a drug infusion pump. Notwithstanding giving more tightly guideline of blood pressure, this procedure frees up the nurse to spend more time monitoring patients for other problems. The drug infusion closed loop control system is shown in the figure 1.

A 70-kg patient exhibits the following input-output behavior for the effect of sodium nitroprusside (SNP) on mean arterial pressure (MAP):

$$Gp(s) = \frac{-1.0}{0.67s+1} e^{-0.5s} \tag{1}$$

where the pressure unit is mm Hg, the drug flow units are ml/hr and the time unit is minutes. The initial MAP (with no SNP infused) is 175 mm Hg. The desired MAP setpoint is 100 ± 15 mm Hg, and the maximum allowable (short-term) SNP infusion rate is 150 ml/hr. The desired settling time (time for the MAP to remain within limits) is 5 minutes. [7].

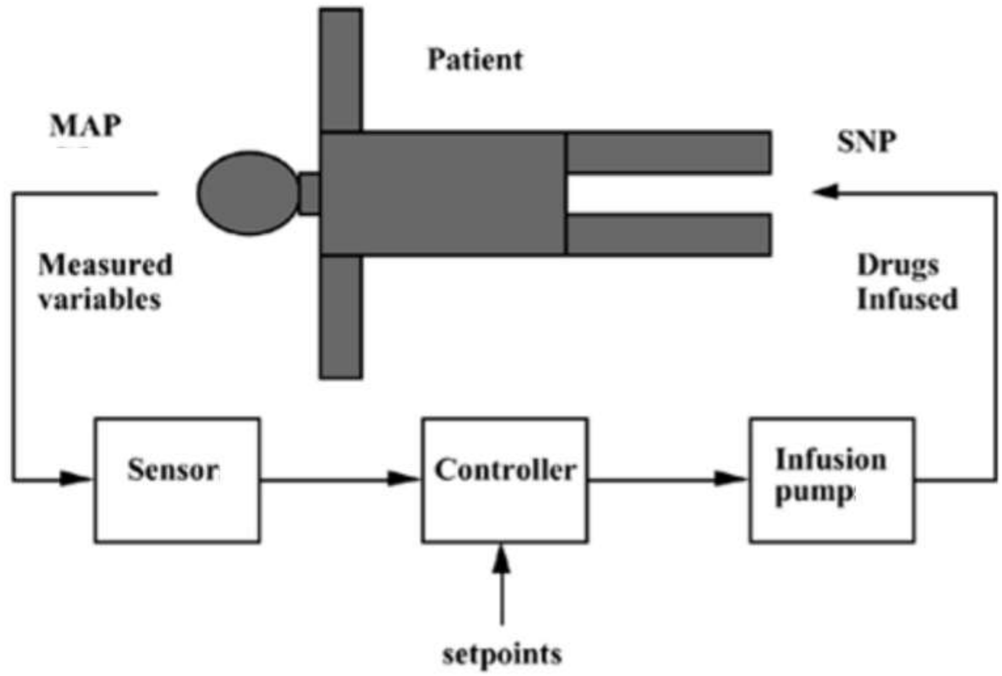
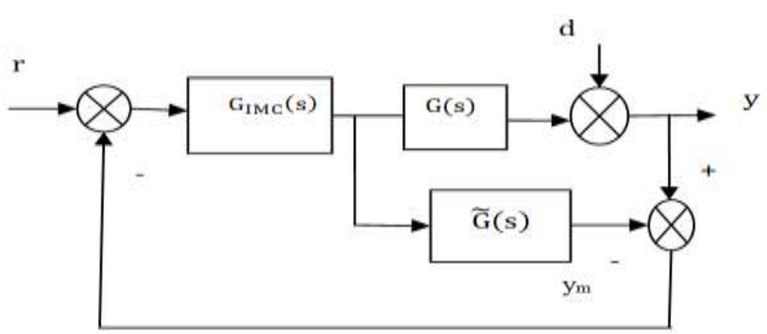


Figure 1. Drug infusion control

III. MC – PI CONTROLLER DESIGN

The IMC control scheme as illustrated in the Figure 1, the approximated model ( ) response y_m , is obtained by applying the manipulated controller output ‘u’. The difference between process model (G(s)) output y and approximated model output (y_m (s)) is given as a feedback signal to the IMC controller. If there are external disturbances, the model output y and approximated model output y_m will not be equal.



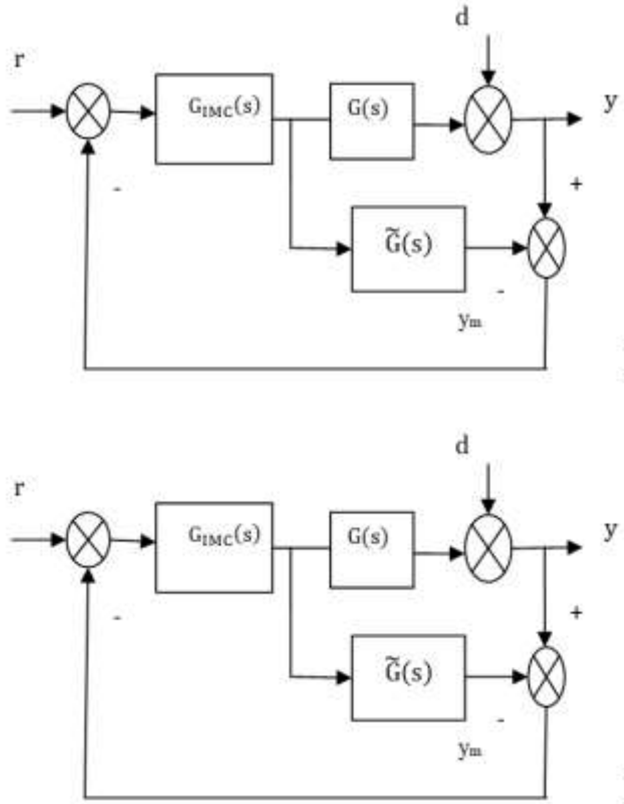


Figure.2. General internal model control structure

The feedback closed loop control system is shown in the figure 2. The diagrams shown in fig.1 and fig.2 are equal ifthe controller G_c (s) and $G_{I\ MC}$ (s) satisfies the relation: (1)

$$G_c(s) = \frac{G_{IMC}(s)}{1 - G_{IMC}(s)\tilde{G}(s)}$$

(2)

Thus, it can be concluded that any IMC controller, $G_{I\ MC}$ (s) is comparable to a standard feedback controller G_c(s), and vice versa.

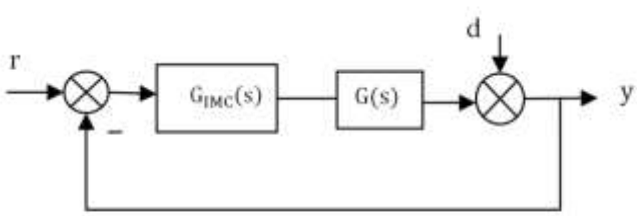


Figure. 3 Conventional Feedback control

The PID controller G_c (s) is given as, (3)

$$Gc(s)=Kp+ki/S \quad (3)$$

Where, K_p is a Proportional gain, K_i is the Integral gain of the controller

3.1. ZN Tuning rules

The Ziegler–Nichols tuning method is developed by John G. Ziegler and Nathaniel B. Nichols. It is carried out by setting the *I* (integral) and *D* (derivative) gains to zero. The proportional gain, (K) is then increased (from zero) until it reaches the ultimate gain (Ku), which is the largest gain at which the output of the control loop has stable and consistent oscillations; higher gains than the ultimate gain have diverging oscillation. The oscillation period Pu are then used to set the K_P, K_i gains directly using the analytical methods.

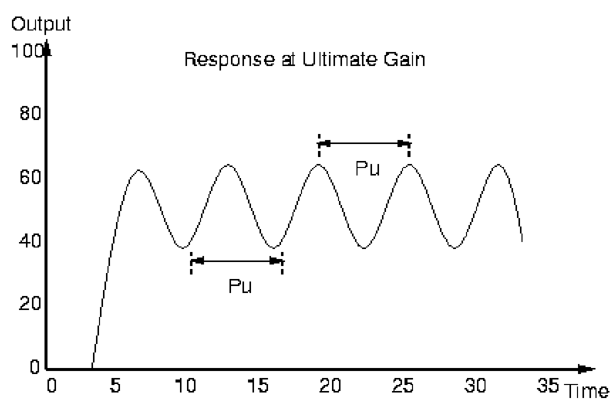


Figure.4 ZN closed loop PI Controller tuning

The tuning formula based on the closed loop tuning method is give in equation 4.

$$Kp= 0.45*Ku \; ; \; Ki=0.54*Ku/Pu \quad (4)$$

IV. Cuckoo Algorithm

Swarm intelligence techniques like Bee colony optimization, ant colony optimization, bat algorithm, etc are gaining popularity in the recent past in the areas of control engineering. Xin-She Yang and Suash Deb proposed a metaheurtistic optimization technique named Cuckoo search algorithm, based on the breeding behaviour of cuckoo species. Cuckoo's characteristic of mimicing the color and pattern of eggs give rooms for them to lay eggs in other bird's nest. Cuckoo's search for other bird's nest where the bird's have just laid their eggs such that the cuckoo's eggs hatch earlier than their host eggs which helps in their reproduction and survival. Some host birds identify the foreigner eggs and either throw them out or abandon their nest. Finding the best nest location is the theme for cuckoo search.

The rules for the cuckoo search algorithm are as follows:

1. Each cuckoo lays single egg and places it in an arbitrarily chosen nest.
2. The best nests carry the potential solution which will move on to the next generation.
3. The available host nests are limited and a host bird can find the foreign eggs by a probability 'p' which ranges between [0,1].

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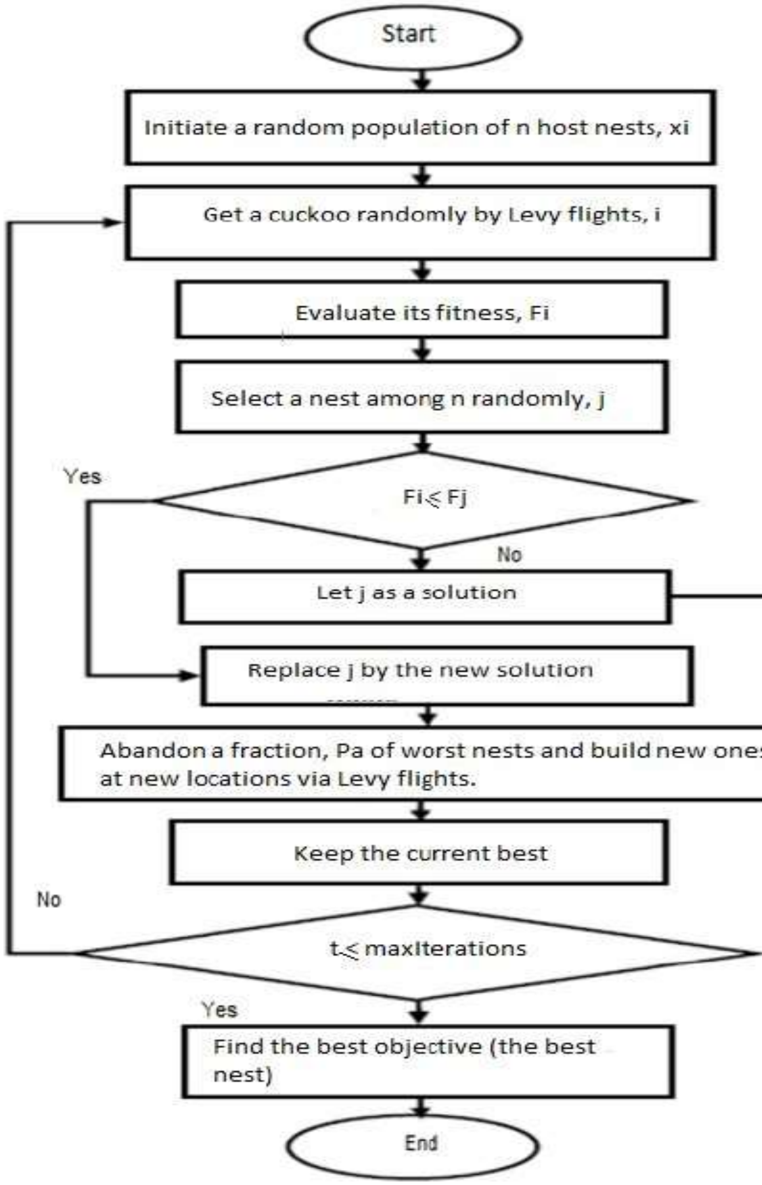

Figure 5. Flowchart of Cuckoo search Algorithm

4.1. Cuckoo's Algorithm for PI tuning (CS-PI)

1.Generate the initial population of n host nests x_i(comprising parameter λ) initial generation.

2.Evaluate fitness $F_j$optimization by determining the objective function (Fj = ISE)

3.Get a cuckoo randomly by Levy flights

4.Evaluate its quality/fitness F_i

5.Choose a nest among n (say j) randomly

6.If Fi>Fj, then replace j by the new solution

7.A portion of worse nests are abondoned and new ones are built

8.Keep the best solutions (or nests with quality solutions);

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9.Rank the solutions and find the current best

10. Repeat steps 3 to 9 till maximum generation or stop criterion is met

11. Post process results and visualization.

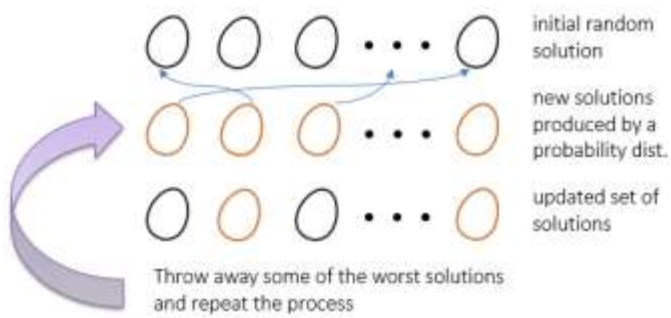

Figure. 6. Cuckoo selection process

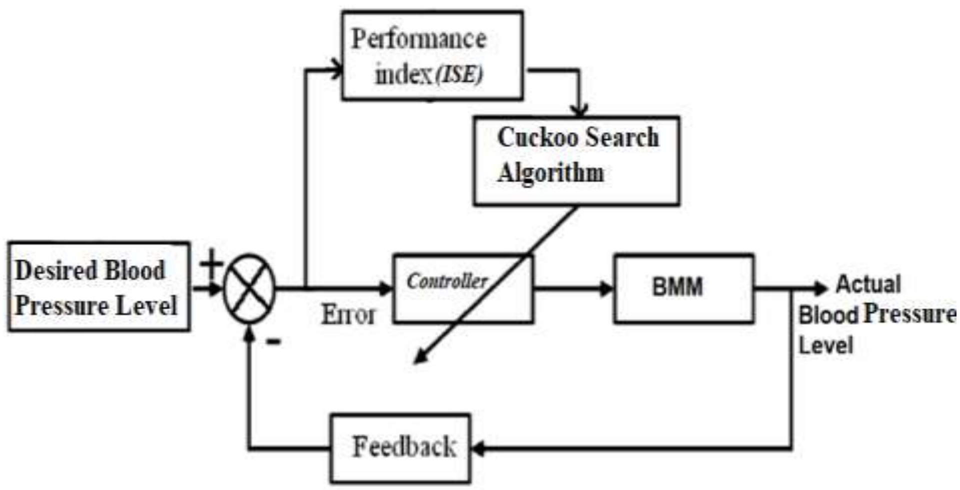

Figure 7. Closed loop block diagram for CS –PI tuning of controller.

The optimization problem is transformed into control problem. The objective function for controller design problem is formulated using Integral squared error which is a deviation from the setpoint and feedback signal.

$$\mathbf{J} = \int_{0}^{T} \left[\left(e_1(\mathrm{t}) \right)^2 \right] dt \tag{4}$$

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V. Simulation results & Discussion:

The simulation results demonstrate that the required goal of reaching minimum ISE is obtained. The simulation started with time t=0, not including disturbance. The controller tracking the nominal set point and disturbance rejection performance for nominal step disturbance also shown in the figure 8 and 9. The frequency response of closed loop control for the tracking and disturbance rejection is shown in figure 10. The controller parameter obtained by cuckoo search algorithm and conventional ZN based method is tabulated in the Table 1.

Table.1 Comparison of performance measures of servo and regulatory response of controllers

Controller	Controller parameter		ISE
	Kp	Ki	
CS-PI Controller	-0.998	-1.148	0.7431
SIMC PI Controller	-0.67	-2.3	1.069

In practice, the glucose level does not enter the blood stream immediately. A meal takes some time to reach it into blood stream.

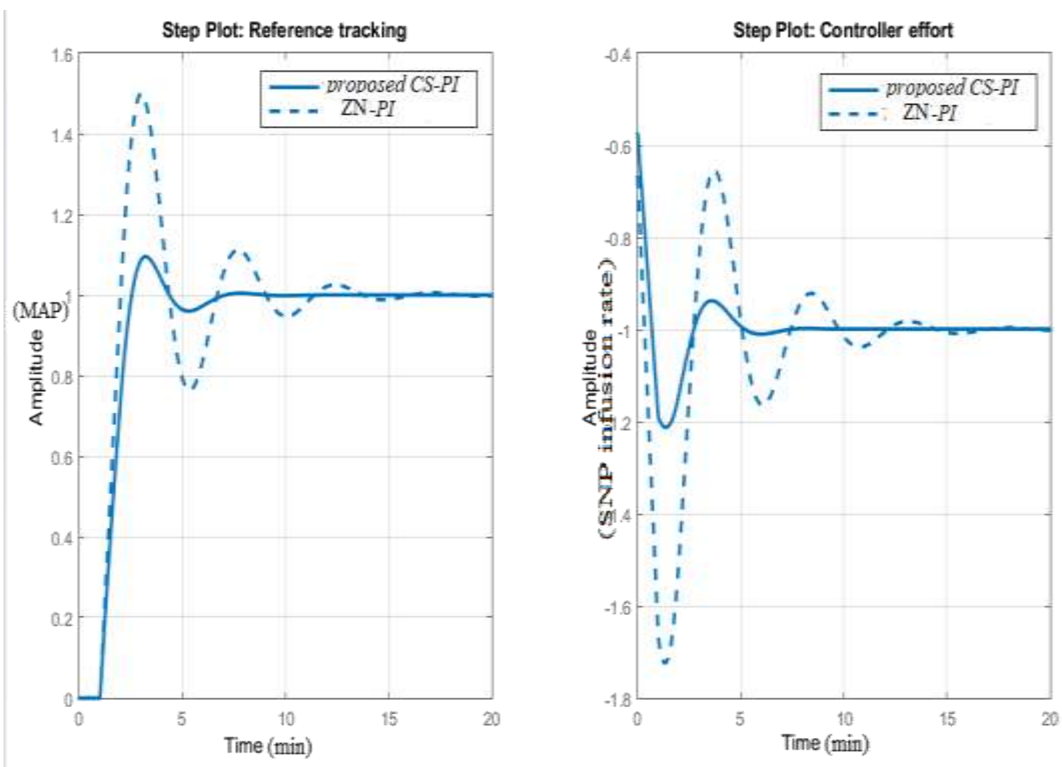

Figure 8. Reference tracking and Controller effort plot for nominal reference point

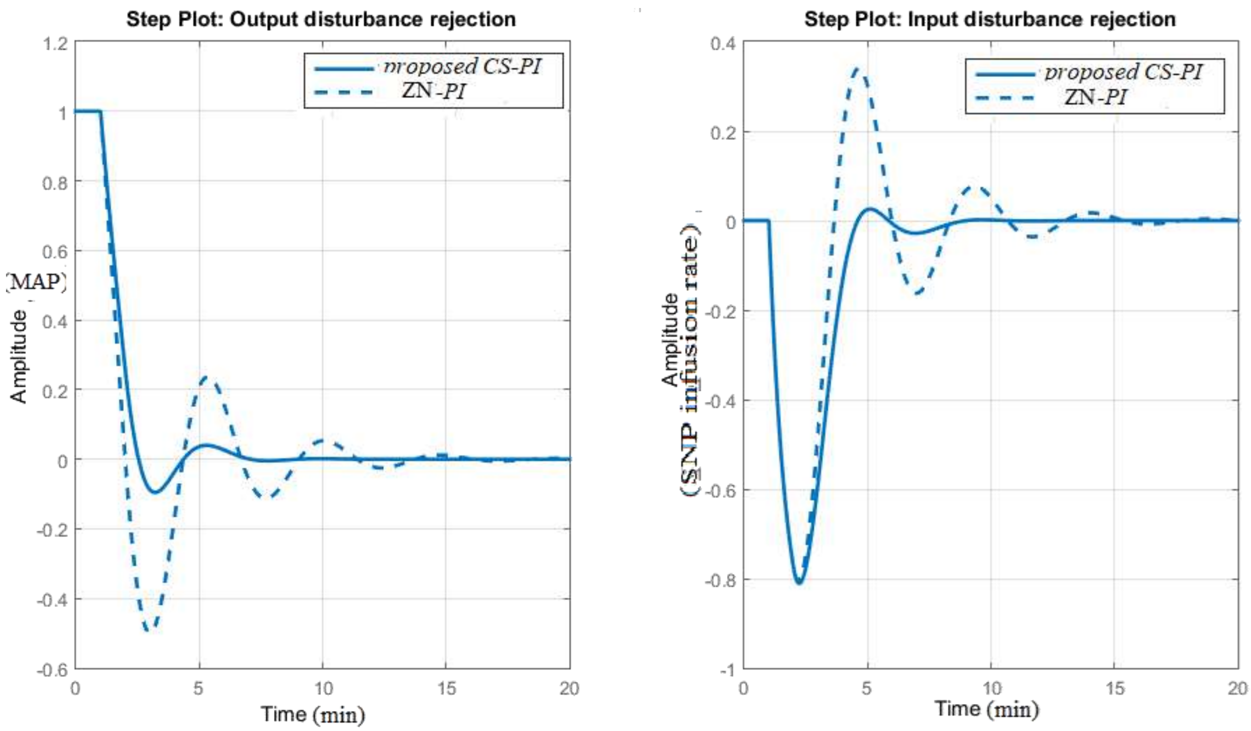

Figure 9. Output/Input disturbance rejection

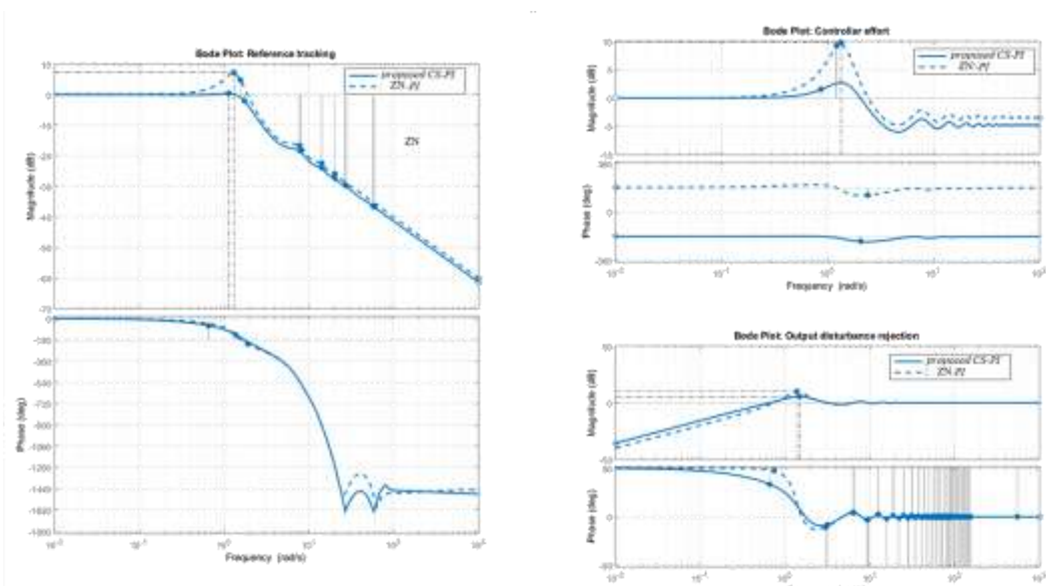

Figure 10. Frequency response of Reference tracking and Controller effort plot for nominal reference point

Figure 11. The servo tracking of mean arterial pressure

The blood pressure reference is set as 120 mm hg, 90 mm hg, 115 mm hg and 100 hg in the 25 minutes sample intervals. The CS-PI controller tracks the controller with faster settling time and minimum overshoot. The peak overshoot of proposed controller is 9.5% and ZN-PI based is 50%, the minimum overshoot of CS-PI yields the better controller response. The integral error such as Integral Time Absolute Error (ITAE) , Integral Absolute Error (IAE) and Integral Square Error (ISE) for CS-PI controller for nominal setpoint is 0.690, 0.9822 and 0.7431 which is lesser than the ZN-PI controller ITAE, IAE and ISE values 4.198,1956 and 1.069. The minimum of integral error values yield the faster controller response. The performance comparison matrics are tabulated in table 2. The CS-PI based controller rejects the disturbance effectively than ZN-PI control. The CS-PI regulates the blood pressure level faster than the ZN-PI controller.

Table 2. controller performance metrics

	ZN-PI	Proposed CS-PI Controller
Rise Time	0.799 Seconds	1.16 seconds
Settling Time	12.9 Seconds	6.22 Seconds
Overshoot	50%	9.54%

peak	1.5	1.1
Gain Margin	3.92 dB@1.57 rad/s	7.09 dB@1.73 rad/s
Phase Margin	32.7 deg@1 rad/s	60 deg @ 0.661 rad/s
Closed loop stability	Stable	Stable
Integral Time Absolute Error (ITAE)	4.198	0.6909
Integral Absolute Error (IAE)	1.956	0.9822
Integral Square Error (ISE)	1.069	0.7431

VI. Conclusion:

In this paper we have presented results for control of blood pressure by manipulating SNP variables in critical care patients using a feedback control strategy. The paper presents an optimal design control procedure for blood pressure control. The controller parameters proportional gain and integral gains are obtained by cuckoo search algorithm. The optimal tuning parameter is obtained for minimum integral square error. The proposed scheme was designed and evaluated in simulation study to main the mean arterial pressure by manipulating the SNP. The comparative simulation results of proposed algorithm shows the superiority in the servo tracking and regulating the blood pressure.

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