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AUTOMATION OF MEAN ARTERIAL PRESSURE CONTROL BY INFUSION OF SODIUM NITRRO PRUSSIDE USING INTERNAL MODEL CONTROLLER

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ABSTRACT

Cardiovasular system is one of the main physiological system in human bodies. Monitoring and controlling of mean arterial pressure during the cardiac surgery is extensively difficult task and determining manually the right drug infusion rates may also be difficult. This is a problem where automatic drug delivery can provide a solution, especially if it is designed to adapt to variations in the patient's model. In this paper it is aimed to control the mean arterial pressure by infusing the sodium nitroprusside. The mean arterial pressure is regulated by Zeigler-Nichols PI, Fuzzy logic controller and Neural network-Internal model controller. Simulations are carried out by making use of a mathematical model describing the effects of drugs infusion rates on controlled variables. Due to the automation consumption of drugs are reduced. In addition, the physician can concentrate in controlling other parameters and the treatment period is shortened.

KEY WORDS: *Mean arterial pressure (MAP) , Drug infusion rate, Cardiovascular system, Internal Model Controller.*

I. INTRODUCTION

In clinical emergency situations require simultaneous observation and control of a large number of hemodynamic and respiratory variables, for enough medical and clinical procedures. The post surgery patients require intravenous administration of suitable drugs to maintain key physiological variables such as blood pressure within desired limits. Hence, introducing automatic control of key physiological variables is beneficial for better patient care and reducing workload of healthcare staff [1]. The regulation of MAP in post cardiac surgery patient is an example where automation is particularly attractive. In such patients, patient's blood pressure is measured and the infusion of the fast-acting vasodilator - sodium nitroprusside (SNP) is adjusted as necessary. Different drugs may result in different time of regulation and has different sensitivity. To decrease the elevated blood pressure required the continuous infusion of vasodilator drugs, such as SNP or Nitroglycerin can quickly lower the blood pressure in most patients [2].

Automation of drug infusion is possible because of available of programmable pumps. Once the programming is done it doesn't rely on manual intervention, and requires physician intervention to respond to changes in the patient's condition. This is the open loop procedure, a usual operating procedure in most hospitals. In other words, there is no automatic feedback mechanism is present. In case of automation physician intervention is not needed even if the patient condition varies. In this work, an attempt is made to control MAP by means of vasodilator drug (SNP). Early investigations were conducted by [3] Koivo et al. who studied the automatic control of blood pressure in rabbits and dogs [4]. Their controller did not consider the delay in the patient response explicitly and produced oscillatory response under certain conditions. Sheppard and co-workers [5]-[7] developed a computer-based system for control of MAP in post surgical patients. Their system has been used in treating a large number of patients successfully. However, their clinical experience indicated that the system needed a significant improvement for patients with high or low sensitivity to SNP [8]. Slate and Sheppard [9] devised a heuristic adaptive control scheme to rectify the problem of patient drug sensitivity. While the results from treating post cardiovascular surgery patients with the adaptive scheme have been satisfactory [9], the controller is specifically tuned to treat this category of patients. Therefore, its performance in other applications such as hypotensive surgery cannot be predicted [17].

Recognizing the need for an adaptive controller, other investigators have explored the use of more systematically derived adaptive control algorithms. Specifically, Martin et al. [2] and Kaufman et al. [10] used a model reference approach while Meline et al. [11] and Walker et al. [12] applied other forms of adaptive controllers. The adaptive or self-tuning controllers are advantageous, as they seek to minimize the deviation of MAP from the desired level and attempt to accommodate changes in the characteristics of the patient response. The self tuning algorithms used by the above did not consider optimizing the amount of infused medication.

In this paper, A continuous-time model describing the relationship between the change in blood pressure and the SNP infusion rate is used to investigate the performance of Zeigler-Nichols PI, Fuzzy logic controller and Internal model controllers. Matlab Simulink Toolbox is used to design and simulate the proposed control system.

II. MODEL OF CARDIOVASCULAR PHARMACOLOGICAL SYSTEM

Automatic control of arterial blood pressure by infusing the drug SNP is used for the treatment of elevated blood pressure after open-heart surgery at the cardiac Surgical Intensive Care Unit. A (Slate, J. B. and L. C. Sheppard, 1982) model is developed relating the arterial pressure and its response to SNP. This model is a linear first-order transfer function with two time delay components,

$$\frac{\Delta MAP(s)}{SNP(s)} = \frac{Ke^{-T_1 s}(1+\alpha e^{-T_2 s})}{1+\tau s} \qquad (1)$$

K is the sensitivity to SNP, -0.72 for the patient.

T_1 = 30 second the transport time lag between a SNP injection site and the receptors.

T_2=50 second is the recirculation time delay of SNP in Sec.

α=0.4 is the recirculation fraction of SNP.

τ=40 second is the time constant representing the uptake and distribution of SNP.

III. DESIGN OF CONTROLLER FOR DRUG INFUSION

The model shown in equation 1 is modeled in closed loop by controller method like Zieler Nichols, Fuzzy logic controller (FLC) and internal model controller (IMC). The descriptions of the controllers are given in the sub section A, B and C.

A. DESIGN OF PI CONTROLLER USING ZIEGLER-NICHOLS (ZN-PI) METHOD

Ziegler Nichol's has proposed an open-loop tuning method called process reaction curve method. Optimum control setting can be obtained for various modes of control by using process reaction method. Process reaction curve method is to approximate a higher order process as first order with dead time. The open-loop response of the process is obtained as 'S' shaped curve or sigmoid curve as shown in Figure 1.

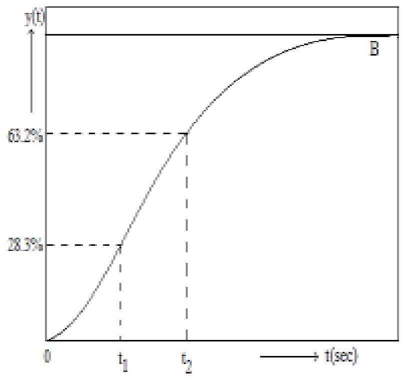

Fig.1. Typical process reaction curve.

The process parameters are obtained using two point method [13] (Wayne Bequette, 2010).

Time constant $\tau = 1.5(t_2 - t_1)$

Dead time $t_d = t_2 - \tau$

Process gain $K_p = \frac{\Delta Output}{\Delta Input}$ (2)

B. DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy logic control technique has found many successful industrial applications and demonstrated significant performance improvements. Fuzzy controller design remains a fuzzy process due to the fact that there is insufficient analytic design technique in Contrast with the well developed linear control systems .In standard procedure the design consist of three main parts Fuzzification, Fuzzy logic rule base, and Defuzzification. A Mamdani type with Seven Gaussian membership functions is used for each input which results in 25 rules and minimum operation is used for implication process and Centre of Gravity (COG) defuzzification method [14]. The selection of these rules are based on the knowledge of the behavior of the system response. The characters NB, NM, NS, Z, PS, PM, PB are the linguistic variables of the inputs and output fuzzy sets. The letters N, P, Z, B, S, M, represent Negative, Positive, zero, Big, Small and Medium respectively. M is the certainty of the membership. The rule base is explained in Table I. The selection of rules shown is based on the knowledge of the behavior of the error equation.

TABLE I: RULE TABLE FOR FLC WITH TRIANGULAR MEMBERSHIP

		Change in Error				
		NB	NS	Z	PS	PB
Error	NB	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PB
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

C. DESIGN OF INTERNAL MODEL CONTROLLER

The Internal Model Control (IMC) philosophy relies on the internal model principle which states that if any control system contains within it, implicitly or explicitly, some representation of the process to be controlled then a perfect control is easily achieved. In particular, if the control scheme has been developed based on the accurate model of the process then perfect control is theoretically possible [15] & [16].

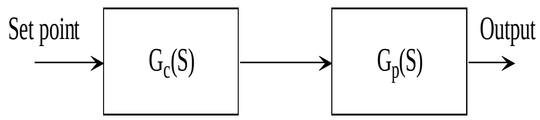

Fig.2.Open loop IMC strategy.

For above open loop control systemOutput = Gc . Gp . Set-point (4)

Gc = controller of process

Gp = actual process or plant

Gp* = model of the actual process

A controller Gc is used to control the process Gp. If one have complete knowledge about the process (as encapsulated in the process model) being controlled, one can achieve perfect control. This ideal control performance is achieved without feedback which signifies that feedback control is necessary only when knowledge about the process is inaccurate or incomplete. In practical case the actual process differs from the model of the process i.e. process model mismatch is general due to disturbances entering into the system. Due to which open loop control system is difficult to implement so a control strategy is required to achieve a perfect control. Through IMC strategy shown in Figure 2 perfect control can be expected.

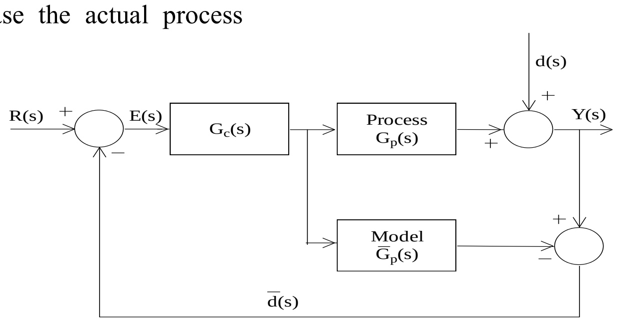

Fig.3.IMC control statergy.

In the above figure 3, d(s) is the unknown disturbance affecting the system. The manipulated input u(s) is introduced to both the process and its model. The process output, y(s), is compared with the output of the model resulting in the signal d*(s). The feedback signal send to the controller as shown in equation 5.

$$d^*(s) = [Gp(s) - Gp^*(s)].u(s) + d(s) \quad (5)$$

In case d(s) is zero then feedback signal will depend upon the difference between the actual process and its model.

If actual process is same as process model i.e Gp(s) = Gp*(s) then feedback signal d*(s) is equal to the unknown disturbance. So for this case d*(s) may be regarded as information that is missing in the model signifies and can be therefore used to improve control for the process. This is done by sending an error signal to the controller. The error signal R'(s) incorporates the model mismatch and the disturbances and helps to achieve the set-point by comparing these three parameters. It is send as control signal to the controller and is given by

$$R'(s) = r(s) - d^*(s) \quad (6)$$

And output of the controller is the manipulated input u(s). It is send to both process and its model.

$$u(s) = R''(s) \cdot Gc(s) = [r(s) - d^*(s)]\, Gc(s) \quad (7)$$

Hence, closed loop transfer function for IMC scheme can be derived as

$$y(s) = \{Gc(s) \cdot Gp(s) \cdot r(s) + [1 - Gc(s) \cdot Gp^*(s)] \cdot d(s)\} / \{ 1 + [Gp(s) - Gp^*(s)]\, Gc(s) \} \quad (8)$$

Now if Gc(s) is equal to the inverse of the process model and if Gp(s) = Gp*(s) then perfect set point tracking and disturbance rejection can be achieved.

IV. RESULTS AND DISCUSSIONS

The open loop response of the system is shown in the Figure 4. The model shown in equation 1 is studied in closed loop for PI controller separately. Figure 5 shows the MAP response to drug infusion of SNP. From the Figure 5 it is observed that the under shoot and overshoots present in output. This variation will lead to varying the blood pressure of the patient. Since the variation is not feasible for the patient, ZN-PI controller cannot be used [17] for controlling the MAP practically.

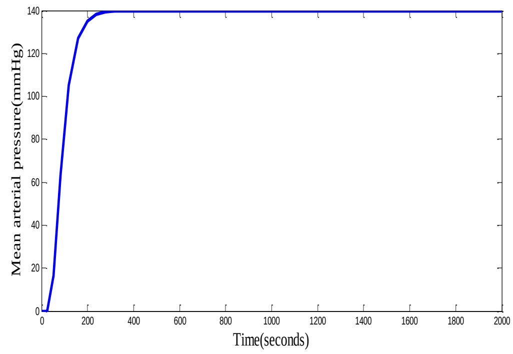

Fig.4.Open loop response of the model.

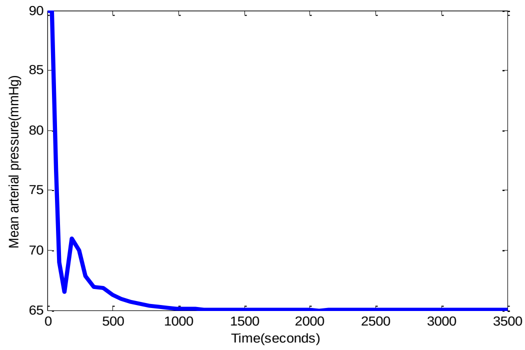

Fig.5.MAP response to ZN-PI controller

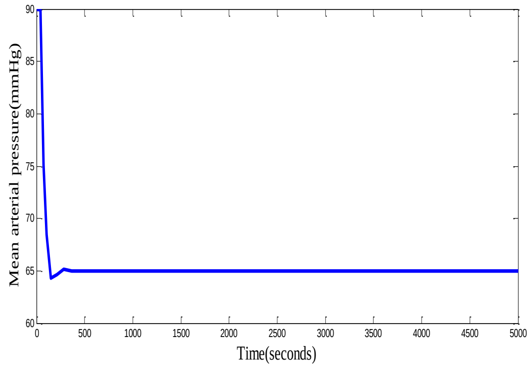

Fig.6.MAP response to FLC controller

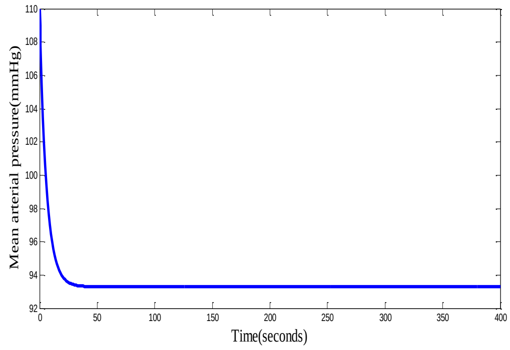

Fig.7.MAP response to IMC controller

To eliminate the overshoot and under shoot in the output FLC is proposed. Figure 6 show the fuzzy logic response of SNP. Figure 7 shows the response of MAP to IMC controller.

For showing the superiority of IMC, the performance of Z-N PI, fuzzy controller and IMC are measured using Integral Square Error (ISE) and Integral Absolute Error (IAE) criteria which are tabulated in table II.

TABLE II: Performance measures of Z-N PI, FLC and IMC

Controller	ISE	IAE
ZN-PI	$1.149X10^{7}$	3390
FLC	$4.012X10^{6}$	2003
IMC	$2.780X10^{5}$	1757

From the table II it is observed that IMC is having less ISE and IAE values compared to Z-N PI and FLC which also indicates that IMC improves the performance.

V.CONCLUSION

In this paper, control of drug delivery system based on ZN-PI, FLC and IMC is proposed and applied to control MAP using SNP. Simulation results demonstrate the effectiveness of the proposed IMC to improve the performance of the closed loop control system. Performance of the controllers is also compared by their performance indices (ISE & IAE), which shows that the IMC is performing better than the other two controllers.

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