Control Scheme for Arterial Blood Pressure Regulation in Hypertensive Patients

(Blood pressure regulation)

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Abstract—**Sodium nitroprusside (SNP) is used to reduce the mean arterial pressure (MAP) in ICCU patients. During infusion of the drug, automatic infusion is found to be more efficient than manual infusion. The fuzzy control logic has been used. The range within which the blood pressure usually varies and the rate of change in pressure given to the controller. The safe range of drug has been given to the patient. PID controller was also implemented and the comparative study has been done. The results of fuzzy controller were found satisfactory. The main advantage of this controller is that the output of the controller can be directly given to the patient.Simulation studies are carried out in MATLAB-Simulink environment.**

Keywords—mean arterial pressure; sodium nitroprusside; *fuzzy controller*; *PID controller*

I. INTRODUCTION

After cardiac operation, severe complications may occur in patients due to hypertension. It may damage heart cells, causes excessive bleeding, bursting of veins in brains etc. To decrease the chances of complication, the mean arterial pressure (MAP) must be maintained at a desired level. This is achieved by intravenous infusion of suitable vasodilator drugs such as sodium nitroprusside (SNP), Nitroglycerin, etc., which are commonly used for treatment for the treatment of hypertensive cardiac patients [1]. The infusion of these drugs will generate Nitric Oxide (NO) and there by reduces the MAP. It causes widening of blood vessels and has fewer side effects [2]. Clinically the drug injection is achieved using manual drug delivery. Manual control may be time consuming, and of poor quality. Due to disturbances that perturb pressure, the changing conditions of patient, and the wide range of response characteristics, determining the right drug infusion may be difficult [3]. So an automatic drug delivery system can be employed for drug delivery. The main aim of this paper is to control the drug infusion rate suchthat the mean arterial pressure (MAP) is regulated within desired limits.

II. PATIENT MODELING

J. B. Slate in 1980, have developed a model based design of a controller for infusing nitroprusside during postsurgical hypertension [4]. In this, the patient's response to SNP drug was successfully modelled. A dynamic model of patient MAP to SNP infusion rate is given by,

$$MAP = MAP_0 + \Delta MAP + MAP_n \quad (1)$$

where MAP is the mean arterial pressure, MAP_0 is the initial blood pressure, ΔMAP is the change in blood pressure due to infusion of SNP, MAP_n is the plant background noise. $MAP_0$is usually 140-160mmHg. A continuous-time model describing the relationship between the change in blood pressure and the SNP infusion rate is given by,

$$\frac{\Delta MAP}{SNP(s)} = \frac{K\ e^{-T1s}(1+\alpha e^{-T2s})}{1+\tau s} \quad (2)$$

where, K is the drug sensitivity, α is the recirculation constant, T_1 represents the initial transport lag from injection site, T_2 is the recirculation time delay, i.e. time required for drug to flow through the body [5]. The parameter τ is the lag time constant resulting from the uptake, distribution and biotransformation of the drug. The parameter range of the model is given in [6] table I.

TABLE I. PARAMETERS OF SLATE'S MODEL

Parameter	**Parameter value and unit**		
	Range of parameter	***Normal value***	***Units***
K	$0.25 \le K \le 8$	5	mmHg/ ml/h
A	$0 \le \alpha \le 0.4$	0.1	-
T_1	$20 \le T_1 \le 60$	25	Sec
T_2	$20 \le T_1 \le 60$	35	Sec
τ	$40 \le \tau \le 60$	50	Sec

III. CONTROLLER DESIGN

Consider the system described by the equations (1) and (2). The input is the drug i.e. Sodium nitroprusside (SNP) and the output is the mean arterial pressure [7].

A.PID Controller

The PID controller can be tuned by Ziegler- Nichols method [8]. The PID controller is a weighted sum of the input signal, derivative and the integral of the input signal.

$$G_c(s) = K(1 + \frac{K_I}{s} + K_D s) \quad (3)$$

The tuning of PID controller is done by Ziegler Nichols method. It is a closed loop tuning method. It is performed by setting the gains K_D(derivative) and K_I (integral) gain to zero. The proportional gain, $K_P$is then increased (from zero) until it reaches the ultimate gain, $K_U$at which the output of the control loop oscillates with a constant amplitude K_U and the oscillation period $T_U$are used to set K_P , K_D and $K_I$gains.

$$K_P = 0.6 * K_U \quad (4)$$

$$T_I = T_u/2 \quad (5)$$

$$T_D = T_u/4 \quad (6)$$

The critical gain K_U was found to be 1.25 and the oscillation period T_u obtained was 77 sec. The result is given in results and discussion.

B. Fuzzy Controller

A fuzzy control system is a control system based on fuzzy logic that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1. It consists of an input stage, a processing stage, and an output stage. The input variables in a fuzzy control system are mapped by sets of membership functions, known as fuzzy sets [9]. The process of converting input value to a fuzzy value is called fuzzification. The fuzzy rule sets usually have severalantecedents that are combined using fuzzy operators- AND, OR, and NOT. AND, uses the minimum weight of all the antecedents, while OR uses the maximum value. NOT operator subtracts a membership function from 1 to give the complementary function. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value. The process of converting fuzzy value to output value id called defuzzification. The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement [10].

The fuzzy controller used with this system has two inputs and an output. The error and rate of change of error are the inputs and the drug infusion rate is the output. The error *E(t)* and the rate of change of error *R(t)* are given by,

$$E(t) = MAP_C(t) - MAP(t) \quad (7)$$

$$R(t) = E(t) - E(t-1) \quad (8)$$

The range of error will be in the range,

$$0 \leq E(t) \leq 100mmHg$$

The tolerance limit of error is within

$$0 \leq E(t) \leq 10mmHg$$

The error is divided into seven segments, from E1- E7, for controller design

The rate of change of MAP determines the patient sensitivity, i.e. it gives a measure of how blood pressure varies in different patients, which is a measure of sensitivity to that drug, for the patient [11].

$$|\Delta MAP(t)| = |MAP(t) - MAP(t-1)| \leq 25mmHg \quad (10)$$

The rate of change of MAP ids divided into five sections, namely, Positive(P), Middle(M), Negative Small(NS), Negative Big(NB), Negative very big(NVB), for controller design.

On the output, the pressure should not drop more than 20mmHg below the set point. Since the set point given is 100mmHg, the minimum acceptable value of the blood pressure is 80mmHg.Fig 1 shows the surface view of fuzzy controller.

The output is the SNP infusion rate (D) and the range of output varies [11] between,

$$0.5 \leq SNP(t) \leq 10mcg/Kg/min$$

To ensure safety the drug dosage has been limited to

$$0.5 \leq SNP(t) \leq 7mcg/Kg/min$$

The output is divided into nine segments, from D0-D8.
Table 2 shows the fuzzy control algorithm.Mamdani- type fuzzy controller is used.

TABLE II. FUZZY CONTROLLER RULES

Error (mmHg)	**Rate of change of MAP(mmHg/sec)**				
	P	***M***	***NS***	***NB***	***NVB***
E1	D2	D1	D1	D1	D0
E2	D2	D2	D2	D1	D1
E3	D4	D3	D3	D2	D2
E4	D5	D5	D4	D3	D3
E5	D6	D5	D5	D4	D4
E6	D7	D7	D6	D6	D5
E7	D8	D8	D7	D6	D6

The table II, can be explained, by considering the third column and fourth row. If the error is in E4 range and rate of change of error is negative but small, then the dosage of dug is in the range D4.

IV. Results And Discussions

The PID controller has been tuned using Ziegler – Nichols method and the response is plotted in Fig 2. The system is found to be oscillatory in nature but the amplitude of oscillation is found to be within the desirable range (±10 mmHg) [12]. As the system here is a patient, the oscillatory nature of the controller is not acceptable. The need for a modern controller rather than conventional controller arises in this case.

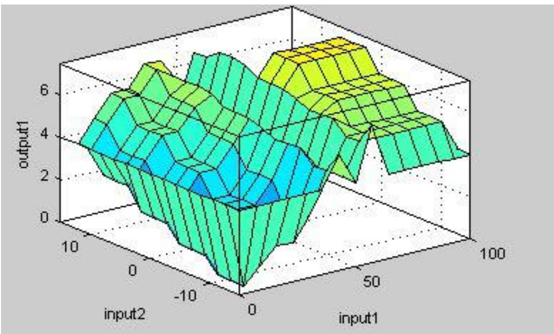

Fig 1.Surface view of fuzzy controller.

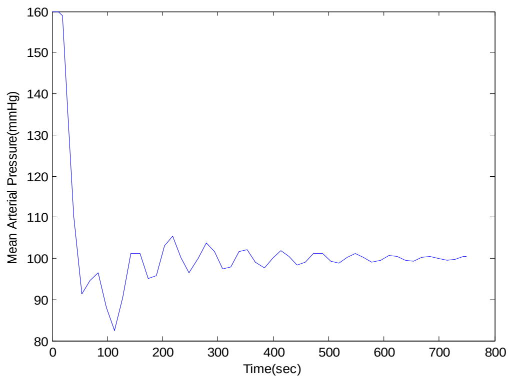

Fig 2. Patient response with PID controller

The second controller used is the fuzzy controller. The inputs to the controller are error and variations of the mean arterial pressure. The output is the drug concentration. The response obtained for an initial pressure of 160mmHg is plotted in Fig 3.

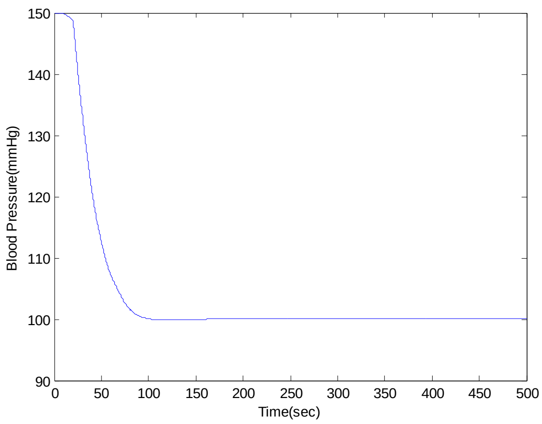

Fig 3 Patient responses with fuzzy controller

The response is found to settle within 100 sec. The response is fast and satisfactory. It has fewer oscillations and settles faster than other controllers. The output can also be constrained, directlyusing fuzzy controller as large infusion of drug has toxic effects. The main advantage of this controller is that the output of the controller can be directly given to the patient.

V. Conclusion

Mean arterial pressure can be brought to the reference pressure by controlled infusion of vasodilator drug sodium nitroprusside. The Slate's model has been controlled by using PID controller and Fuzzy controller. Fuzzy controller has been found better than PID controller. Using fuzzy controller the patient sensitivities can be considered. The drug infusion rate can also be limited without use of complex controllers.

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References

[1] K. E. Barrett, S. M.Barman, S. Boitano, H. L. Brooks, "Ganong's review of medical physiology" 23rd ed. New York: McGraw-Hill, 2010, pp. 489-569.

[2] D. L. Kasper,.et.al., " Harrison's principles of internal medicine" ,16th ed.,New York: McGraw-Hill , 2005, pp 312- 892.

[3] Michael C. K. Khoo, "Physiological control systems-analysis, simulation and estimation", in biomedical engineering, New York: IEEE press, 2000, pp 13- 271.

[4] J. B. Slate, L. C. Sheppard, "Automatic control of blood pressure by drug infusion", IEEE Proc on Phy. Sci. Vol. 129, pp.639-645, 1982.

[5] S. Isaka, "Control strategies for arterial blood pressure regulation", IEEE trans. on Biomed. Eng. vol. 40,pp 352-363, Apr, 1993.

[6] Y. Gao and M. J. Er, "An intelligent adaptive control scheme for postsurgical blood pressure regulation", IEEE Trans. Neural Netw., vol 16,pp 475-483, Mar, 2005.

[7] H. Zheng, K. Zhu, "Automated post-operative blood pressure control", J. Contr. Theo. Appln, vol 3,no.3,pp 227-212, Aug, 2005.

[8] V. S. Manju, S. Maka, "Design of drug delivery system for blood pressure control", Int. Conf. Microelcectro.Commun.Renw.Energy, Kanjirappally, Ker., India, 2013, pp 1-5.

[9] K. Ogata, "Modern control engineering", 5th ed., New Jersey: Prentice Hall,2010, pp 477-576.

[10] H Ying,,M. Micheal, D. W. Eddleman, L. C Sheppard., "Fuzzy control of mean arterial pressure in postsurgical patients with sodium nitroprusside infusion" , IEEE Trans. On Biomed. Eng., vol 39,pp 1060-1070, Oct, 1992.

[11] G APajunen, M Steinmetz, R Shankar, "Model reference adaptive control with constraints for postoperative blood pressure management", IEEE Trans, on Biomed. Eng., vol. 37, pp 679-687, Jul, 1990.
[12] K. Y. Zhu, H. Zheng, J. Lavanya, "An adaptive PI controller for regulation of blood pressure of Hypertension patients", Int.Conf. Automa.Sci.Eng., Edmonton, Alberta, 2005, pp 67-72.