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SIMULATION AND REALIZATION OF DRUG INFUSION BASED CARDIOVASCULAR SYSTEM MODEL

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Abstract - *The anesthesiologist or physician is required to observe and control a broad range of physiological states such as mean arterial pressure, cardiac output, carbon dioxide and oxygen levels, blood acidity, fluid levels, heart contractility, renal function and more. The surgeons regulate the patient states around satisfactory operating ranges by infusing various drugs and/or intravenous fluids. Additionally, throughout the surgical procedures physicians is required to administrate anesthetics and monitor the depth of anesthesia. In this view, it is aimed to automate the Mean Arterial Pressure regulation. Dopamine and Sodiumnitroprusside were infused, open loop response is obtained. PI and IMC controller were studied and found that IMC is behaving better and produces stable output. IMC is being realized in real time for validating simulated output.*

Key Words: Mean arterial Pressure, IMC, Dopamine and Sodiumnitroprusside

1.INTRODUCTION

A survey estimates that physician consumes time on adjusting the drug infusion rate up to 26% of the total duration. Automating this process may reduce the work load of the physicians, permitting them to enhanced supervising of the other secondary parameters. A manual control of arterial blood pressure during surgery may often be of meager quality or even dangerous [1]. The physician can use his knowledge to diagnose the patient, specify set values or ranges of values for the states to be controlled choose the drugs best suited to obtain the objective, and authorize the permissible infusion rates. Initial research in this area focused on single input-single output control of MAP. A powerful medication for control of MAP is sodium nitroprusside (SNP) that appears to emerge as an effective vasodilator. The research are being coterie to explore the control of several hemodynamic variables by the infusion of multiple drugs SNP and dopamine (DP), and deduce hypnosis and analgesia as the vital parameters to be regulated.

2. MULTIDRUG MODEL OF CVS

The SNP and DP are selected to increase ventricular contractility and decrease resistance to blood flow respectively. The drugs DP and SNP are interchangeably infused into the CVS model as shown in Fig 1. The target sites of SNP are considered to be the main parameters which affect the arterial blood pressure in the CVS such as the $V_{us,v}$ and R_{sys}. Both $E_{max,lv}$ and R_{sys} (R_{0s} of CVS) are modified by the pharmacological effects of DP. The DP is inotropic in nature, in the sense it increases ventricular contractility and mainly affects $E_{max,lv}$. SNP is a vasodilator and decreases resistance to blood flow by decreasing R_{sys} and increasing $V_{us,v}$. The drug infusion therefore affects the controlled variable MAP by these body parameters. An increase in DP infusion increases MAP and an increase in SNP infusion reduces MAP. The therapeutic range of SNP (0.0-10.0 µg/kg/min) is used for both hypertension and acute congestive heart failure. An intermediate infusion range of DP (2-6 µg/kg/min) is used for its inotropic effects and safety provide during acute congestive heart failure [3].

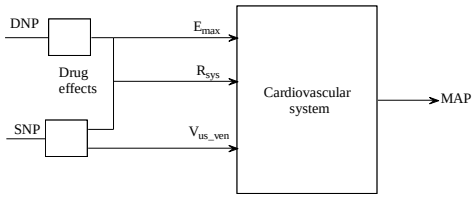

Fig.1.Conceptual diagram of the cardiovascular system with drug effects

3. OBTAINING MODEL BY TWO POINT METHOD

The open-loop response of the process is obtained as 'S' shaped curve or sigmoid curve as shown in Fig 2.

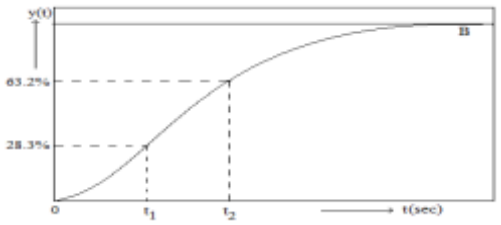

Fig.2. Typical process reaction curve.

The process parameters are obtained using two point method [2] and the constants we defined as in Eqn 1 to 3.

Time constant

$$\tau = 1.5(t_2 - t_1) \qquad (1)$$

Dead time

$$t_d = t_2 - \tau \quad (2)$$

Process gain

$$K_p = \frac{\Delta \text{Output}}{\Delta \text{Input}} \quad (3)$$

The Time instant t_2 is obtained from 63.2% of the final steady state value. Similarly t_1 is obtained as 28.3% of the final steady state value (B).

The drug effects of SNP and DP are modeled with the four compartmental CVS modeled. The SNP is infused at the 9th second and travels to lower the MAP. Meanwhile DP is infused on 19th second and serves to increase the MAP. The effect of SNP and DP on MAP is shown in Fig 3.

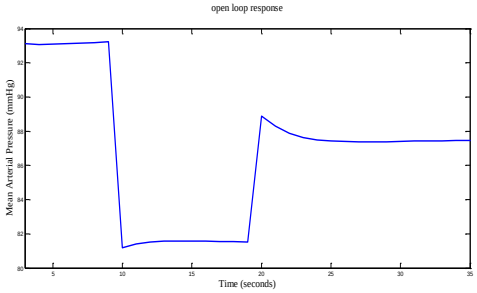

Fig.3. CVS model output with drug effects.

$$\frac{\Delta MAP}{SNP} = \frac{-11.68}{0.51s+1} e^{-0.18s} \quad (4)$$

$$\frac{\Delta MAP}{DP} = \frac{16.27}{0.98s+1} e^{-0.2s} \quad (5)$$

From the open loop response the models are obtained which are depicted in Eqns 4 and 5. The ZN tuning method of PI controller settings are identified and reported in Table 1.

Table 1. Controller Parameters Based on ZN Tuning Rules

Controller	Controller Settings	
	K_c	T_i (s)
ZN-PI SNP	-0.2183	-0.5994
ZN-PI DP	0.27	0.6660

4. RESULTS AND DISCUSSIONS

A closed loop performance of the CVS drug infusion model is studied from the obtained ZN settings. In this study it is aimed to maintain the constant MAP during the pre/post-operative and anesthetic (surgical) state. During the pre/post-operative state the range of MAP may be in the range between 100 to 160mmHg. At this stage SNP and DP are infused to maintain the MAP at 93.3mmHg.

During the anesthetic state (cardiac surgery) the pressure will be drop down to the range of 65 to 80mmHg in order to relieve the patient from perceiving pain during surgery. The pre/post-operative pressure state is scenario is simulated by keeping the initial MAP as 110mmHg. The Fig 4 shows the response of SNP on MAP which bring back MAP to the nominal value. Similarly the Fig 5 shows the effect of DP on MAP with initial MAP being considered as 65. The DP has increased the MAP and maintains it in the nominal value.

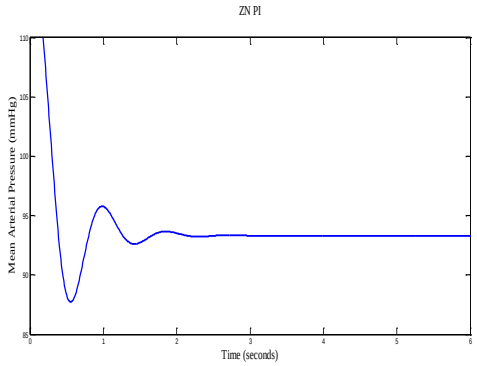

Fig.4. MAP response to SNP infusion under pre/post-operative condition.

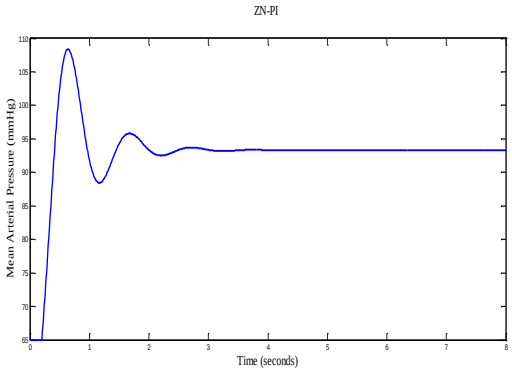

Fig.5. MAP response to ZN-PI based DP infusion under pre/post-operative condition.

The Controller output (infusion rate) of SNP and DP is shown in Fig 6 and Fig 7 respectively.

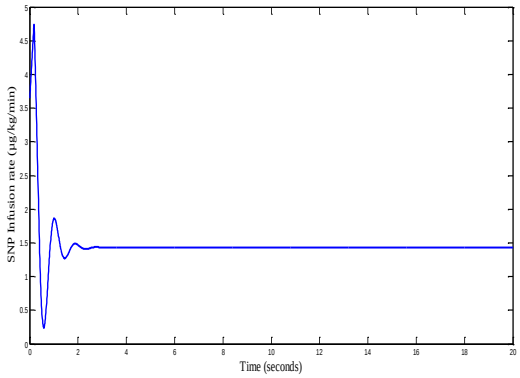

Fig.6. ZN-PI Controller output for SNP under pre/post-operative condition.

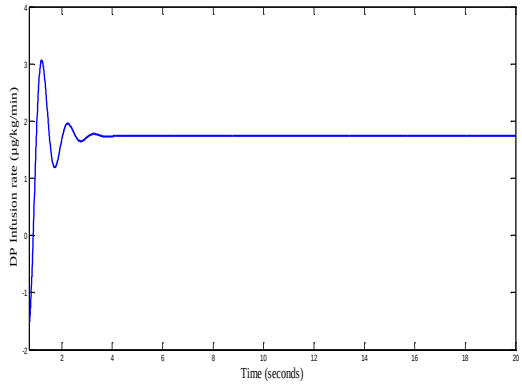

Fig.7. PI Controller output for DP under pre/post-operative condition.

It is observed that from figures 4 and 5 responses contain overshoot and under shoot which is not feasible for the patient in the operating conditions.

The IMC is implemented as shown in the Fig 8 to control the CVS drug infusion. The responses of MAP on SNP and DP to IMC controller are shown in Figures 8 and 9.

It is noticed from the figures 8 and 9 that the output of the IMC doesn't exhibit overshoot and undershoot. The performance of the controller is measured using Integral Square Error (ISE), percentage overshoot and settling time, tabulated in Tables 2 for pre/post operating condtion.

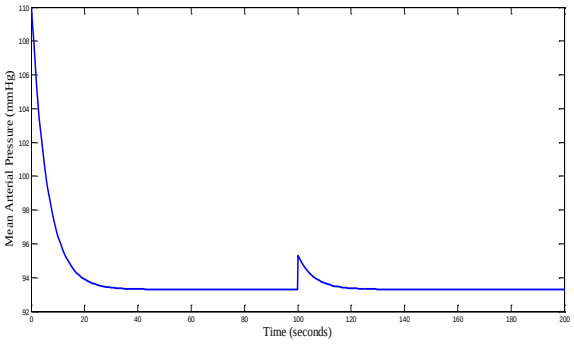

Fig.8. MAP response to IMC based SNP infusion under pre/post-operative condition.

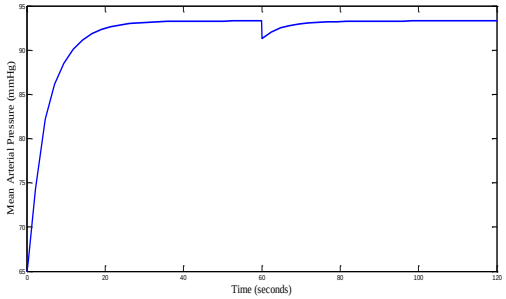

Fig.9. MAP response to IMC based DP infusion under pre/post-operative condition.

Table2. Perfomance criteria of controllers for pre/post-operative condition.

Controller	ISE	% Overshoot	Settling time (seconds)
PI (SNP)	76.79	6.0021	4.6
IMC (SNP)	11160	0	74
PI (DP)	286.20	16	6.7
IMC (DP)	16200	0	56

It is noted from the Tables 2, that IMC do not produce overshoot. It is seen that the FLC offers having less ISE value when compared to IMC and ZN-PI controllers. A steady decrease of MAP is to be attained in the pre/post-operative or surgical environment indicating that the settling time should be more. It is registered from the Table 2 that settling time is more for IMC than ZN-PI which reveals the steady decrease of MAP. It is concluded from the Tables 2, that among the controllers, IMC control strategy performing well at pre/post-operative conditions.

The design of switching control strategy (Arefeh Moridi *et.al*. 2011), (Asarin *et.al.* 2000) is shown in Fig 10 guaranteeing that, at each instant of time, only one control is activated. When the error is greater than zero, the SNP

based controller is activated. While the error is less than zero, the DP based controller is activated.

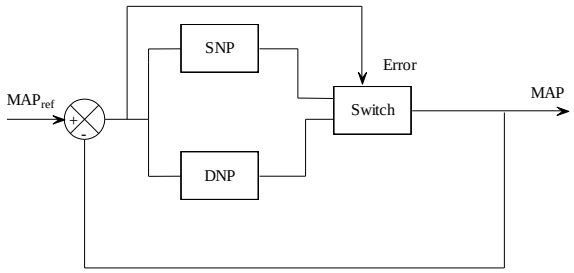

Fig.10. Block diagram of Switching of controller.

The Fig 11 shows the response of switch mode control technique for controlling MAP by IMC controller. It is noted from Fig11, it is observed that when the pressure is decreased intentionally at 1000 second, at that time DP acts and increases the MAP, whereas when the pressure is increased intentionally at 2000 second it is seen that SNP decreases the MAP and maintains the nominal pressure. The Fig 11, exhibits that the switch mode control technique performs well for both pre/post-operative condition.

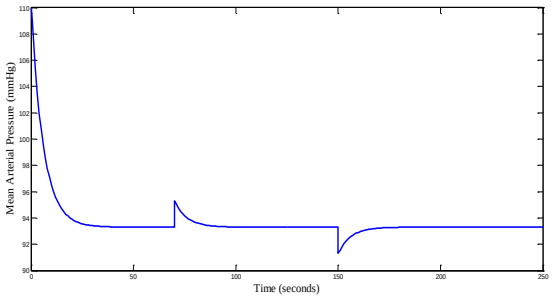

Fig.11.MAP response to switching of IMC controller for pre/post operative condition.

4.1. Realization of the SNP and DP model- Experimental set up

The experimental setup of SNP model is shown in Figure 12. The pressure output of the model in terms of voltage signal is given to PC based control system through ADC port of VMAT01 interface board. The voltage signal is processed and the real time control signal is transmitted to process through DAC port of VMAT01.

Fig.12. Experimental setup of SNP model.

4.1.1. VMAT 01 Plug in Data Acquisition and Control Board

The Data Acquisition and Control boards (or called ADD-ON cards) represents the heart of the control unit system. The card is a high performance, multifunction high speed analog to digital (ADC) and digital to analog (DAC) interface card. It is compatible for personal computer, which can be plugged on to the serial port in PC. The VMAT - 01 control board is specially designed for real time interface for MATLAB simulink software. The pin details of VMAT-01 are given in Fig 13

Fig.13. pin details of VMAT-01

The model show in Eqns 4 and 5 are realized with operational amplifier (OP-AMP) circuit shown in Fig 14 and 15. The Figs 14 and 15 shows the circuit for realization of SNP and DP effect model.

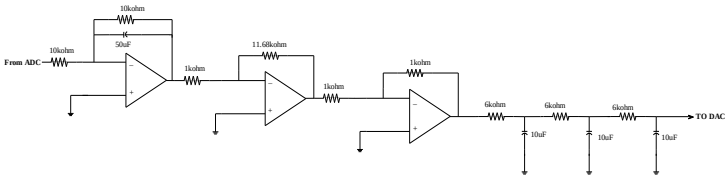

Fig.14. Electronic equivalent model of SNP.

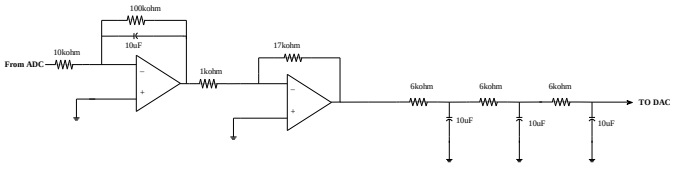

Fig.15. Electronic equivalent model of DP.

The gain of the amplifier is set by inverting mode of the amplifier as shown in Figs 14 and 15. The lag term is realized by second OP-AMP as integrating amplifier. The delay in the transfer functions (Eqn 4 & 5) are realized by cascading RC circuits. The Figs 16 to 19 show the responses of MAP to ZN-PI, and IMC controller for the pre/post-operative conditions. The MAP outputs correlate with that of simulated MAP outputs.

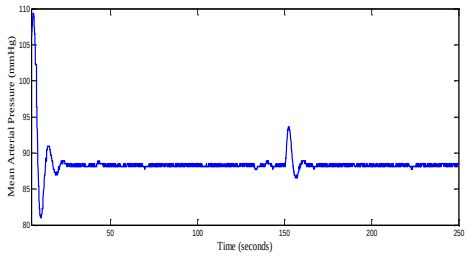

Fig.16. MAP response to ZN based SNP under pre/post-operative condition.

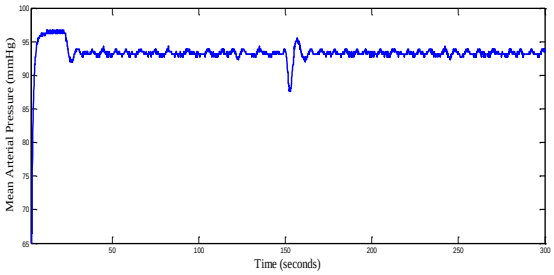

Fig.17. Experimental simulation of MAP response to ZN based DP under pre/post-operative condition.

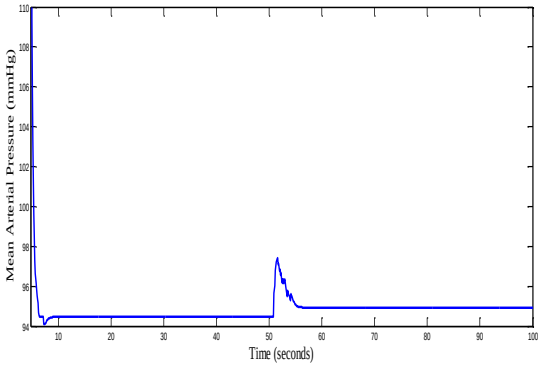

Fig.18. Experimental simulation of MAP response to IMC based SNP under pre/post operative condition.

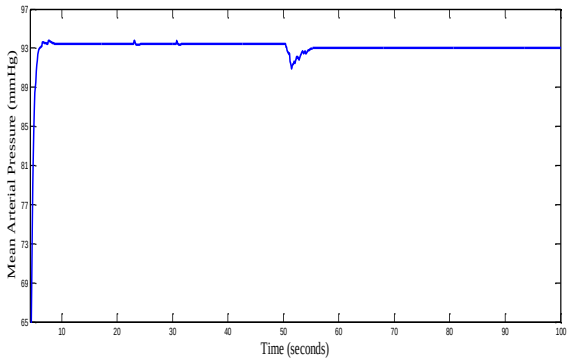

Fig.19. Experimental simulation of MAP response to IMC based SNP under pre/post-operative condition.

Table.3. Real time Performance measure of controllers for pre/post-operative condition

Controller	ISE	% Overshoot	Settling time (seconds)
PI (SNP)	76.79	6.0021	4.6
IMC (SNP)	11160	0	74
PI (DP)	286.20	16	6.7
IMC (DP)	16200	0	56

5.CONCLUSION

An automatic regulation of pre/post-operative period and in anesthesia period can provide tighter control allowing anesthesiologist to focus on more critical issues which will result in less time spent by the patients in the post-operative care unit. It allows a reduction in the amount of drugs used and side-effects and above all a much safer platform for surgery under anesthesia. By combining the CVS drug effect model MAP the patient can be controlled. It can be inferred that from the results IMC has enhanced performance MAP. During surgery the presence of noise and disturbances are inevitable especially when automation attempts to control MAP.

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