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„Regulating Mean Arterial Blood Pressure using Fuzzy Gain Scheduling of PID Controller“

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Regulating Mean Arterial Blood Pressure using Fuzzy Gain Scheduling of PID Controller

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INTRODUCTION

This article presents a method of controlling mean arterial pressure (MAP) at a substantial low level during anesthesia by sodium nitroprusside (SNP) infusion using an online fuzzy gain scheduling for a PID controller. An "early detecting method" is used to estimate the dead time L and slope R of the MAP curve when it has been decreased around 10 mmHg from initial value. These are used to modify the fuzzy sets of the gain scheduler. Moreover, during operation, the controller is also adapted stronger to handle body reaction by a supervising algorithm. A new model was developed based on Slate's model and Furutani's ideas for designing and testing the control system. Simulations and clinical experiments on pigs in deep hypotensive control (MAP = 40mmHg) indicated the safety and stability of the designed controller.

MATERIALS AND METHODS

A. *Modeling of blood pressure response to SNP*

Using Furutani's ideas in changing the transport delay [Furutani1995], [Furutani2004], the model from Slate is modified as follows [Slate1980]:

$$\frac{\Delta MAP(s)}{SNP(s)} = K\left(\frac{e^{-Ts}}{1+\tau s} + \frac{\beta e^{-T_3 s}}{1+\tau_3 s}\right) \qquad (1)$$

$$T = \begin{cases} T_1 & decreasing\ MAP \\ T_2 & increasing\ MAP \end{cases}, \quad \tau = \begin{cases} \tau_1 & decreasing\ MAP \\ \tau_2 & increasing\ MAP \end{cases}$$

where *ΔMAP(s)* and *SNP(s)* are the change of MAP and drug infusion rate, respectively. *K* presents the patient sensitive to the drug. The transport delay *T* is set to T_1 when blood pressure has been decreased, and set to T_2 when it has been increased (Fig. 1). The response time constant τ also changes similarly. A negative value of β illustrates a factor of body reaction other than the recirculation fraction of drug α ($\alpha \geq 0$) in Slate's model. T_3 and τ_3 denote the transport delay and the response time constant of the body reaction, respectively.

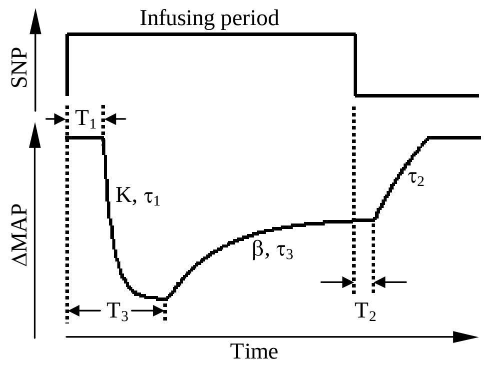

Fig. 1: Model parameters for identification

All individual parameters of our model in (1) are listed in Table 1 obtained by statistics on the measured MAP from 25 clinical experiments on 7 pigs.

Tab. 1: Parameters of Pigs (n=7)

Para.	Ave.	Min.	Max.	Unit
K	-0.7	-0.1	-2.3	mmHg/ml/hr
β	-0.4	-0.05	-0.9	-
τ_1	40	30	75	sec
τ_2	290	225	390	sec
τ_3	375	300	425	sec
T_1	60	20	175	sec
T_2	15	1	30	sec
T_3	400	300	820	sec

B. *PID gain scheduling with Fuzzy logic*

It is assumed that the PID gains (K_p, K_d and K_i) are in prescribed ranges [$K_{p,min}$, $K_{p,max}$], [$K_{d,min}$, $K_{d,max}$], and [$K_{i,min}$, $K_{i,max}$], respectively [Zhao1993]. This appropriate ranges are determined experimentally and will be given in equation 2 (K_p, K_d and $K_i < 0$).
Based on the error between setpoint and process output and the change of error, the fuzzy gain scheduler (with 35 rules) adjusts for the suitable values of K_p, K_d and K_i. Selecting these ranges requires determining the dead

time L and slope R of the MAP response curve. In our system, we only calculate the 'early' slope R when the MAP has decreased around 10 mmHg for reducing identification time [Kähler2004].

Tab. 2: Calculating T_d* and T_i* due to the dead time L

L(sec)	**[20 - 30]**	**(30 - 60]**	**(60 - 90]**	**(90 - 175]**
T_d*	0.75L	0.35L	0.2L	0.1L
T_i*	3.5T_d*	3.5T_d*	4T_d*	4T_d*

Tab. 3: Calculating Kp* due to the early slope R

-R	[min-.05]	(.05 - .4]	(.4 - 1]	(1-max]
K_p*	2/RL	6/RL	8/RL	12/RL

Note: (*) presents that K_p*, T_d* and T_i* are only initial values.

$$K_p \in [1.75K_p^*,\ 0.75K_p^*]$$
$$K_d \in [1.25K_d^*,\ 0.25K_d^*] \qquad (2)$$
$$K_i \in [2.25K_i^*,\ 0.75K_i^*]$$

After estimating R and L, the initial K_p*, K_d* and K_i* are calculated as shown in Table 2 and Table 3 (K_d*=K_p*T_d* and K_i*=K_p*/T_i*) and used to modify the ranges in (2).
In addition, during operations, a supervising algorithm based on [Isaka1993], observes the MAP response to update the output fuzzy sets of the gain scheduler (2). This method allows the PID controller to act stronger or weaker against the body reaction or the overshoot response, respectively.

RESULTS

A selected result from clinical experiments on pigs is illustrated in Fig. 2. The MAP reaches the target within 340s without overshoot. Clinical results indicated that the controller is effective, safe and stable. However, there exists a problem on increasing MAP every time of changing a new syringe.

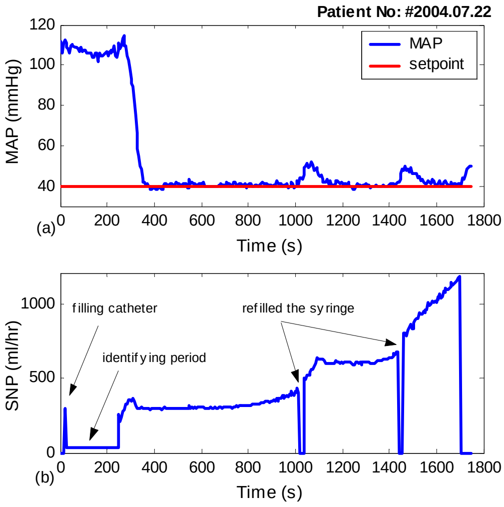

Fig. 2: A clinical result on a pig (realized on July 22, 2004)

DISCUSSION

There are two advantages of using two infusion pumps. First one is to avoid the behavior at the time of changing the syringe (Fig. 2). When the first pump is empty, the last one could be switched on automatically. Second one is to prevent increasing of MAP when the infusion rate reaches the saturation (in Fig. 2a, after the time of 30 min., the MAP was increased because of saturated infusion rate in Fig. 2b). The second pump will be started when the first one is saturated. However, an overdose of SNP is dangerous, so another drug may be used.

CONCLUSION

In order to control MAP by SNP infusion, we developed the PID control system using online fuzzy gain scheduler. The new model based on Slate's model and Furutani's ideas was modified for designing and testing the control system. The early estimation of dead time L and slope R was effective in reducing the identification period. Isaka's supervising algorithm for online setting the fuzzy logic illustrated a good way to handle the body reaction during surgeries. Although animal trials indicate the safety and stability of the controller, there exist some problems presented in the discussion that we need to solve in future.

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