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Improved Model for Blood Pressure Regulation in Post Cardiac Surgery Patients

Including automatic control of blood pressure in post cardiac surgery patients has obvious benefits such as reduced costs, effort and enhanced level of safety for the patients. The focus of this study is on the model of a hypertensive patient which is improved relative to the detailed and realistic model proposed, successfully developed and implemented by Lee et al. (2005). This study will be used afterwards with the proven and widespread PID controller for the control of the blood pressure.

Keywords*: Blood pressure regulation, patient model*

1. Introduction

Some of the natural control systems of the body are disrupted during a cardiac surgical intervention. So the patients need drug administration in order to keep their mean arterial pressure within safe limits. There are many benefits to including automatic control in the regulation of mean arterial pressure (MAP) in post cardiac surgery patients. In such patients, we have the blood pressure measured and the infusion of the fast-acting vasodilator - sodium nitroprusside (SNP) is adjusted as necessary. One of the above mentioned benefits is that the precision of the amount and of the rate of the administrated vasodilator is significantly increased. As a result, the goals of safety, reducing costs and human effort are met more rapidly and naturally. The paper focuses on the model of patient and its components and proposes a new and improved model for one of these components.

2. Patient Model for Blood Pressure

A realistic model of patient in the context of blood pressure regulation has four components:

2.1 a drug response model,

2.2 models for internal reflexes (the focus of this paper),
2.3 measurement dynamics, random noise due to respiration,
2.4 patient movements etc. (Fig. 1).

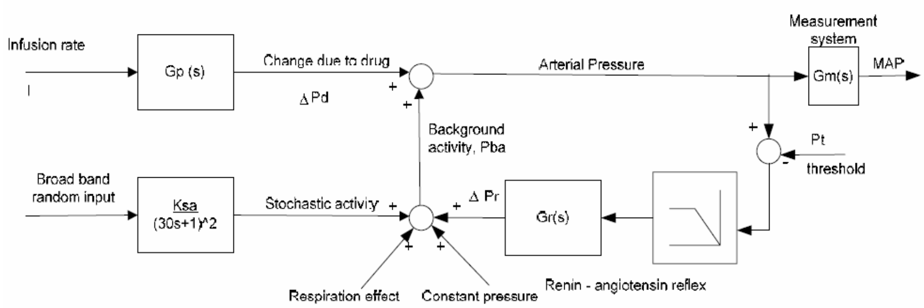

Figure 1. Schematic of blood pressure model showing drug response model (Gp), internal reflexes (RAS) model (Gr) and random disturbances (Slate et al., 1980)

2.1 Drug response model

In this study the drug response model of Slate et al. (1980) is used:

$$\frac{\Delta P_d(s)}{I(s)} = \frac{Ke^{-T_i s}(1+\alpha e^{-T_c s})}{\tau s+1} \tag{1}$$

where

- $\Delta Pd(s)$ is the change in MAP (mmHg)
- $I(s)$ is the infusion rate of SNP (ml h^{-1}),
- K gives the patient's sensitivity (a high value of K->sensitive patient),
- α is a recirculation index,
- τ is a time constant,
- T_i is the initial transport delay and
- T_c is the recirculation time.

2.2 Models for internal reflexes

There are internal reflexes in the human body to regulate blood pressure. Lee (2004) identified that RAS (renin-angiotensin system) and BRS (baroreceptor reflex system) are necessary for a complete model of a patient for good blood pressure control. The former (which is the focus of this paper) "is an internal blood pressure buffering system that is activated when MAP drops below a threshold value.

Through a series of chemical reactions from renin to angiotensin II, RAS can alter the total peripheral resistance of arterioles and hence increase blood pressure." (Lee et al. (2005)).

Lee improved the model of Hahn et al. (2002) as follows:

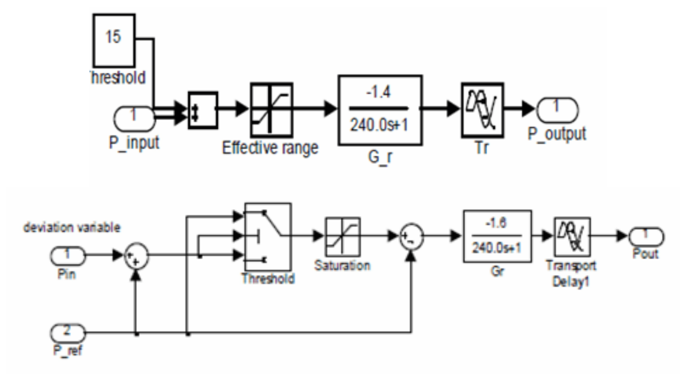

Figure 2. Model of Hahn et al. (2002) on the left and model of Lee et al. (2006) on the right for RAS

The typical range of threshold for activation of RAS is between 70 to 75 mmHg for the general population. Hahn et al. (2002) noted the existence of the threshold and range for RAS, but he did not use them. Lee's model used the threshold value 72 mmHg and the range of 50-110: the "switch" simulates the RAS threshold of 72 mmHg whereas the saturation block represents the range of MAP (50 - 110 mmHg) where RAS remains effective.

We improved the model of Lee et al. (2005) as follows:

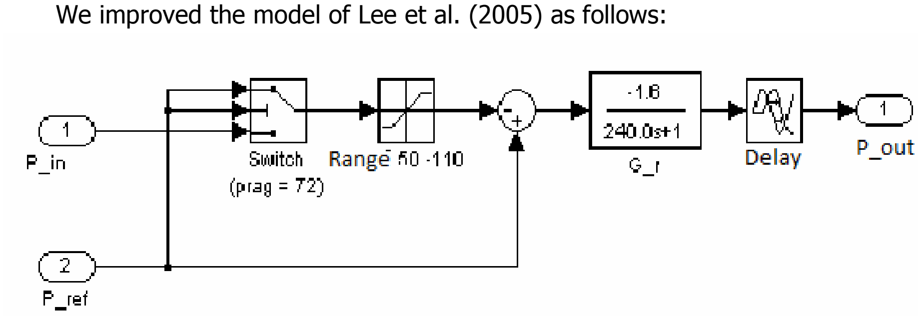

Figure 3. The improved model for RAS

Our model for RAS (we will call it *the improved model*) proves its added value when the reference is changed with more (or less) than 30 mmHg (therefore when the change of reference is different from the value 30mmHg):

We compare the responses of the 3 models for a pressure drop from 130 to 75 mmHg (Fig. 4.a) and from 80 to 60 mmHg (Fig: 4.b).

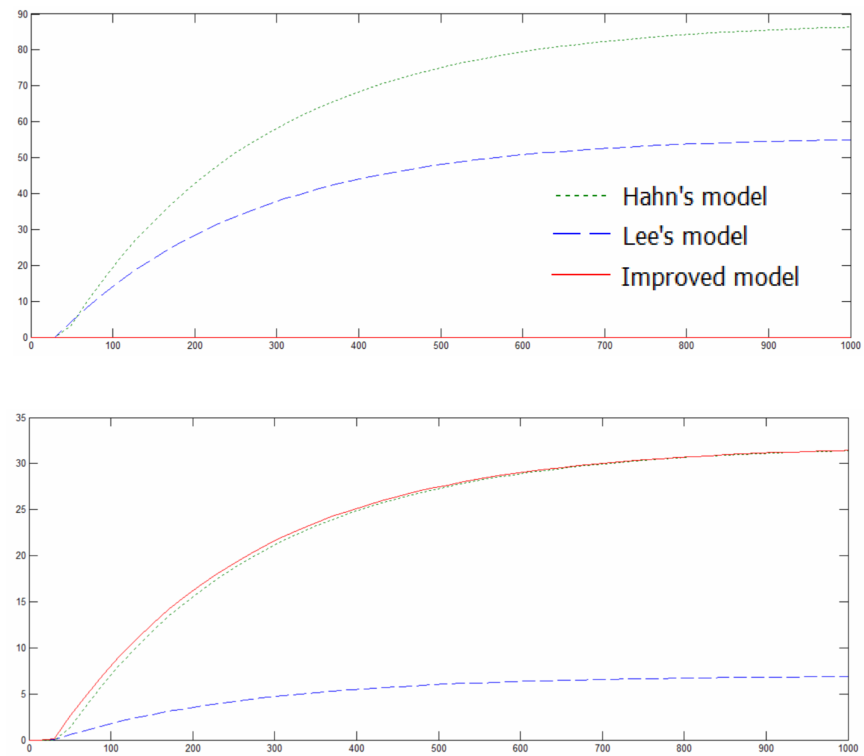

Figure 4. Comparison between the responses (pressure variation in time) of the 3 RAS models : Hahn’s, Lee’s and the improved one for a reference change from 130 to 75 mmHg (top) and from 80 to 60 mmHg (bottom)

In the first situation (left) both Hahn’s and Lee’s models are wrong, for they activate the reflex without reaching the 72 mmHg threshold, while the improved model acts as expected: it does not react to the reference change. When the threshold is reached, all three models are right, sensing the threshold.

This is due to the fact that the control variable of the switch in the case of Lee’s model depends on the reference *and* on the deviation variable. In the improved model, the control variable only depends on the reference.

3. Conclusion

Modeling and control of blood pressure regulation in post cardiac surgery patients are studied. A detailed and realistic model for blood pressure regulation is developed by including the drug response model of Slate et al. (1980) and models for internal reflexes (namely, RAS) of body in addition to the random disturbance. This paper proposes an improved model for RAS. The improvement consists in modifying the existing models such that it covers a wider area of situations as explained in the "Models for internal reflexes" section. The model is to be used with a PID controller – for example – in order to control the mean arterial pressure in post cardiac surgery patients.

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