Static Aortic Pressure Model for a Moving-Actuator type Total Artificial Heart

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Abstract

It is needless to say that the hemodynamic variables estimation is a very important study for the artificial heart. Even though its importance there have not been satisfactory results which can be applied to the real-world situations. In this paper, we propose a practical afterload model (AoP, PAP) which can be applied to the real-world situation.

- Glossary -

MA-TAH: Moving-Actuator type Total Artificial Heart
LAP: Left Atrial Pressure
RAP: Right Atrial Pressure
PAP: Pulmonary Artery Pressure
AoP: Aortic Pressure
CO: Cardiac Output
IVP: Interventricular Pressure
Vel: Velocity
SL: Stroke Length

I. Introduction

As stated in the previous Abstract, it is needless to say that the hemodynamic variables estimation is a very important study for the artificial heart, and even though its importance there have not been satisfactory results which can be applied to the real-world situations. Well-known pneumatic artificial heart has a subsidiary compliance chamber for preventing suction problem. But our developing moving-actuator type total artificial heart (MA-TAH) does not need compliance chamber, and the air located in the interventricular volume plays its role [1][2]. Nevertheless, when much higher load is applied, there is possibility that the suction will occur. Not only the suction problem the other hemodynamic variables, e.g., Left Atrial Pressure (LAP), Right Atrial Pressure (RAP), Pulmonary Artery Pressure (PAP), Aortic Pressure (AoP), Cardiac Output (CO), estimation is a very important for the physiological control. Especially, the temporary state of a high LAP is related with the sudden death, so the real time supervision of the LAP is required.

Our MA-TAH has the potentials of the possibility of estimation of all pressure variables and CO. In this paper, we propose a practical afterload estimation model (AoP, PAP) which can be applied to the real-world situation.

This paper is organized as follows. After this part of Introduction, the proposed model was explained in section II. In section III, the experimental results were stated. Finally, in section IV, conclusions are stated.

II. Static Afterload Model

We can categorize the modeling technique like Table I. The general approach is the dynamic state and mathematical mode [3][4][5].

Table I. Categorization of Modeling Technique.

State Approach	Dynamic (If the system uses previous state, it is called a dynamic system.)	Static (If the system does not use previous state, it is called a static system.)
Mathematical Model	Electric Component Modeling [4][5]	Approach of this study
Input-Output Data	ARMA modeling Kalman Filtering Fuzzy Reasoning [9] Neural Network	Interpolation Fuzzy Reasoning Neural Network [6][7][8]

But in practical point of view, it fails to satisfy the real-world situation and it is hard to implement in the microcontroller (e.g., 80C196 of Intel) which is the CPU of the MA-TAH's controller. So, popular approach is the input/output data approach based model in nowadays. The desire of adaptation to the real-world situation and implementation in the microcontroller can be achieved by the static state and input/output data approach based model [6][7][8]. And our team tried the static state and input/output data approach based model and succeeded in the estimation of full hemodynamic variables. But shortcoming of this method is that there is' t a physical meaning. This motivated our and we tried the static state and mathematical model which can be applied in the real-world and implemented in the microcontroller. Namely, the target of this study is to present the simple and practical model - especially the afterload (AoP, PAP).

Power from a motor point of view is

$$\text{Power} = \text{I} \times \text{V} \tag{1}$$

(V=Constant, 36[V] DC Brushless Motor)

Power from a hemodynamics point of view

$$\begin{aligned}\text{Power} &= (\text{Flow Rate}) \times (\text{Pressure}) \\ &= \frac{(\text{Effective Stroke Length})}{(\text{Time})} \times (\text{Effective Pressure}) \\ &= \begin{cases} \dfrac{(\text{Left SL} + \text{Right SL})}{(\text{Left Time})} \times (\text{AoP} - \text{RAP}), & \text{for left} \\ \dfrac{(\text{Left SL} + \text{Right SL})}{(\text{Right Time})} \times (\text{PAP} - \text{LAP}). & \text{for right} \end{cases}\end{aligned} \tag{2}$$

From (1) and (2), the work for one stroke

$$\begin{aligned}\text{Work} &= \text{Power} \times \text{Time} \\ &= \text{I} \times \text{V} \times \text{Time} \\ &= (\text{Integral of current}) \times \text{V} \\ &= (\text{Effective Stroke Length}) \times (\text{Effective Pressure})\end{aligned} \tag{3}$$

Where V is constant depending on the motor (e.g. 36[V]). So,

$$(\text{Integral of Current }) \propto \begin{cases} (\text{Left SL} + \text{Right SL}) \times (\text{AoP} - \text{RAP}), & \text{for left stroke} \\ (\text{Left SL} + \text{Right SL}) \times (\text{PAP} - \text{LAP}). & \text{for right stroke} \end{cases} \tag{4}$$

The current data are not continuous but sampled ones, and they depend on the transmission ratio. So, the coefficient K_1 must be considered like Eq. (5)

$$(\text{Left SL} + \text{Right SL}) \times (\text{AoP} - \text{RAP}) = K_1 \sum_{i=1}^{n} I_i \tag{5}$$

But the practical experience shows integral of current increases as the velocity increases (maybe comes from motor and actuator characteristics) and the left stroke length requires more current than the right stroke length for the left stroke (AoP). If we assume that this effects have a linear relationship, we can

$$(K_3\times(\text{Left SL})+(\text{Right SL}))\times(\text{AoP}-\text{RAP}) + K_2\times(\text{Left Velocity}) = K_1\sum_{i=1}^{n} I_i \tag{6}$$

So,

$$\text{AoP} = \frac{K_1\sum_i I_i - K_2\times(\text{Left Velocity})}{(K_3\times(\text{Left SL})+(\text{Right SL}))} + \text{RAP} \tag{7}$$

Similarly,

$$\text{PAP} = \frac{K_1\sum_i I_i - K_2\times(\text{Right Velocity})}{(K_3\times(\text{Right SL})+(\text{Left SL}))} + \text{LAP} \tag{8}$$

We can see that there are only three parameters ($K_1 > 0$, $K_2 > 0$, $K_3 > 0$) which must be determined from experiments.

III. Experimental Results

Table II is the *in vitro* experiments. The parameters K_1, K_2, and K_3 were acquired properly from the experiment and it must be reminded that they are not optimal values. The RAP is about 0~10[mmHg], and the control variables (velocity, left and right stroke length) are the extreme cases, i. e., lowest and highest values in the operation range. And for the simplicity of model, we uses the rectangular model not circular model for the stroke length. So we can predict that the error between the real and estimated value is lower than the Table II in the other operational range. Considering these points we can conclude the estimation ability of our model is quite acceptable and precise except some table values.

Table II. Comparisons between Real AoP and Estimated AoP

(K_1 = 6, K_2 = 200, K_3 = 3)

ΣI	Left Vel	Left SL	Right SL	(Real) AoP-RAP	(Estimated) AoP-RAP
1000	10	30	30	24	33
1000	10	30	60	29	27
2000	10	30	30	90	83
2000	10	60	30	33	48
2000	10	60	60	26	42
2000	31	30	30	30	48
2000	31	30	60	43	39
3000	10	30	30	129	133
3000	10	30	60	115	107
3000	31	30	30	93	98
3000	31	30	60	133	79
4000	10	60	30	98	105
4000	31	30	30	190	148
4000	31	60	60	160	119
4000	31	30	30	38	85
4000	31	60	60	35	74
5000	10	60	60	192	187
5000	10	60	60	98	117
5000	31	30	30	98	113
6000	31	60	60	110	124
7000	10	30	30	166	190
7000	31	30	30	195	170
8000	10	60	60	150	192
8000	31	60	60	160	174

IV. Conclusions

It is needless to say that the hemodynamic variables estimation is a very important study for the artificial heart. Even though its importance there have not been satisfactory results which can be applied to the real-world situations. In this paper, we proposed a practical afterload estimation model (AoP, PAP) which can be applied to the real-world situation and can be implemented in the microcontroller. One of the merits of the proposed model compared with the input/output approach based one is that it can predict the outof range data, namely extrapolation is possible. Further researches are necessary to find the static preload (LAP, RAP) and output (CO, PO) estimation model,

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