Comparative study on the controllers for vasopressors in Mean Arterial Pressure control

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***Abstract* - Control of hemodynamic variables such as Mean Arterial Pressure (MAP) has been approached using single drug Noradrenaline (NAR) by various control algorithms and compared the results with patient model obtained using single drug Dopamine (DPM) in the literature. This paper presents the design and implementation of the controllers such as Proportional Integral (PI), Proportional Integral Derivative (PID), Smith Predictive Controllers for the patient model which is developed by the readings obtained during Cardiovascular surgery. Implementation of these controllers is necessary to improve and automatically maintain the patient safety and minimum recurring time. The controlled Mean Arterial Pressure is compared, and time domain specifications are determined. Simulation results are obtained using MATLAB Software.**

***Keywords:* Dopamine, Mean Arterial Pressure, Noradrenaline, PI, PID, Smith Predictor**

I. INTRODUCTION

Cardiovascular diseases globally contribute a major role in leading cause of death. Improvements in the field of cardiovascular surgical studies are still under development. Modern development of science and technology has contributed significantly to the advances in medical care though cardiovascular diseases are increasing adversely on the other hand [9].

During ccardiovascular surgery, the important hemodynamic parameter for the surgeon to keep track of patient's health is Mean Arterial Pressure [5]. Surgeons of cardiovascular surgery face a great problem while controlling Mean Arterial Pressure because the sensitivity of the patient to the infusing drug varies from patient to patient. The demand for better control of Mean Arterial Pressure remains unsatisfied even though numerous technologies have been developed [6].

In view of controlling Mean Arterial Pressure, many engineering approaches have been proposed such as common conventional P, PI, PID, Smith Predictive Control, fuzzy logic control, Model Predictive Control and so on. The most common drawback of designing a controller is complexity in their designing procedure. To minimise the complexity, conventional linear controllers such as PID are most commonly employed to control Mean Arterial Pressure. The patient model is approximated into the first order plus time delay system. Due to the approximation for the original process, still Mean Arterial Pressure control is tedious process in the medical field [4].

II. PATIENT RESPONSE MODEL

The patient response model represented by single input and single output system as first order model. The first order transfer function with time delay system is mentioned below,

$$G(s) = \frac{K_p}{1+\tau s} * e^{-t_d s} \tag{1}$$

where, K_p is the proportional gain of the system.
τ is the time constant of the system.
t_d is the time delay in the system.

The drugs which are used to maintain the hemodynamic variable such as Mean Arterial Pressure are Noradrenaline under clinical practice and it is compared with Dopamine (from literature [1]), since the nature of both the drugs remain the same.

The patient model is the transfer function which is obtained from Noradrenaline drug dosage and Mean Arterial Pressure data during clinical practice is represented as,

$$G(s) = \frac{15.28}{1+5.1904s} \tag{2}$$

From the literature [1], the patient model is obtained from Dopamine drug dosage and Mean Arterial Pressure data and their respective transfer function is expressed as,

$$G(s) = \frac{15}{1+40s} * e^{-40s} \tag{3}$$

Noradrenaline as well as Dopamine shows similar characteristics in cardiac surgery. Both drugs are used for increasing the Mean Arterial Pressure. Noradrenaline and Dopamine are the drugs used during cardiovascular surgery to increase the Mean Arterial Pressure and hence they are called as Vasopressors.

III. PROPORTIONAL INTEGRAL (PI) CONTROLLER

The aim of implementing controller in the closed loop system is to reduce the error between the process output and the setpoint. Proportional controller can minimize the error, but it cannot be eliminated from the system completely.

If some residual error in the system is accepted for a process, then Proportional controller is the best choice [2]. Meanwhile, the residual error in the system is not tolerable, then additional control mode Integral is added with proportional controller. The function of the Integral mode is to drive the error to zero. The implementation of Proportional Integral controller is quite complicated than Proportional controller though the advantage of no error at steady state is attained in exchange for additional complexity.

Proportional Integral mode is used for correcting the offset that may occur between the setpoint and the process output automatically over time. The mathematical representation of PI controller is,

$$G(s) = K_c * \left[1 + \frac{1}{\tau_I s}\right] \tag{4}$$

where, K_c is the proportional gain of the controller.
τ_I is the integral time.

The advantage of Proportional Integral is hidden by the disadvantage of more oscillatory behavior.

IV. PROPORTIONAL INTEGRAL DERIVATIVE (PID) CONTROLLER

The implementation of Derivative term in the control system is to overcome the drawback of PI controller. Integral mode gives the slow response to the rapid changing error [8]. The purpose of adding Derivative control mode is to act upon the derivative of the error, so that it can able to respond to the changing error very rapidly. In addition to that PID can able to reduce process oscillation. The rise of controlled variable is arrested, and it is returned to original value with little or no oscillation. Despite the various dynamic characteristics of the patient model, PID shows an excellent control performance. The mathematical representation of PID controller is,

$$G(s) = K_c * \left[1 + \frac{1}{\tau_I s} + \tau_D s\right] \tag{5}$$

where, K_c is the proportional gain of the controller.
τ_I is the integral time.
τ_D is the derivative time.

V. TUNING METHOD

The selection of a type of the controller and its parameters such as K_c, τ_I, τ_D depends on the model of the process to be controlled. The adjustment of the control parameters to obtain satisfactory control is called as tuning. The most conventional tuning method such as Ziegler Nichols tuning is used to control the PI and PID controllers for both Noradrenaline versus MAP data and for Dopamine Versus MAP data. K_u value is obtained by tuning the Proportional mode of the controller by trial and error method. While tuning by this method, larger values of K_u shows that the system is already crossed the accurate tuning value of the controller and smaller values shows that system needs more K_u value. The value of K_u is finalized when the sustained oscillation is obtained as shown in the Fig. 1 and Pu is obtained as mentioned in the Fig. 1. The substitution of obtained K_u and P_u values in the formulas mentioned in the Table 1, the parameters of the controllers such as K_c, τ_I, τ_D for PI and PID is obtained.

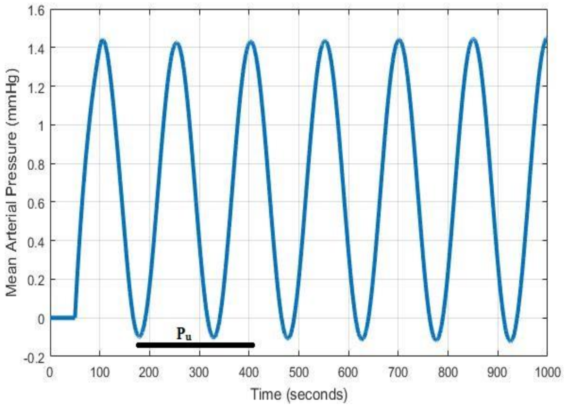

Fig.1 General sustained oscillation diagram

TABLE I
TUNING PARAMETERS

Type of control	**Kc**	τ_I	τ_D
Proportional Integral (PI)	$0.45K_u$	$\frac{Pu}{1.2}$	–
Proportional Integral Derivative (PID)	$0.6K_u$	$\frac{Pu}{2}$	$\frac{Pu}{8}$

VI. SMITH PREDICTIVE CONTROL

In practical, dynamic components of the closed loop control system may exhibit certain time delays in the response [3]. Optimum control of the process with long time delay may be tedious using conventional PI, PID control modes, this paved the path for the discovery of advanced controller such as Smith Predictive control [10].

O.J Smith developed the structure which can compensate the large time delay occurring in the system [7]. This dead-time compensator is also called as Smith predictive control. Patient model with Smith predictive Control is developed based on the Fig.2 mentioned below. The MATLAB software is utilized to get the values of $G_c(z)$, $G_p(z)$, $P(z)$, $P_o(z)$. Dead time compensation response can be further improved by adding integral action to the controller and tuning the controller parameters.

The advantage of Smith predictive control is that the use of higher value of controller gain K_c, decreases the offset and produces low oscillatory response.

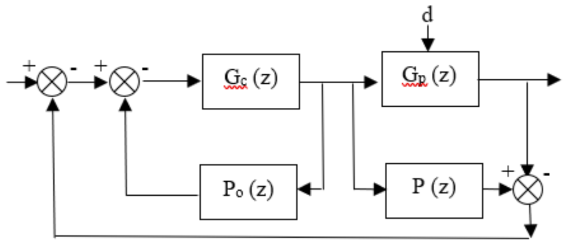

Fig. 2 Smith Predictor block diagram

VII. RESULTS AND DISCUSSION

The simulated results for the Proportional Integral (PI) in the Fig. 3, Proportional Integral Derivative (PID) in the Fig. 4, Smith Predictive Controller in the Fig.5 are similar to the experimental results obtained from the literature [1] for the Proportional Integral (PI) in the Fig. 6, Proportional Integral Derivative (PID) in the Fig. 7, Smith Predictive Controller in the Fig.8. The time domain specifications for clinical practice is listed in the TABLE II and for the literature [1] model is listed in the TABLE III.

TABLE II
TIME DOMAIN SPECIFICATIONS FOR CLINICAL PRACTICE

Time Domain Parameters	**NAR-PI**	**NAR-PID**	**NAR-SMITH**
Overshoot	4.2456	3.7520	42.1022
Rise Time (seconds)	2.1115	3.6558	0.3827
Settling Time (seconds)	9.1335	16.7653	8.2622
Peak Time (seconds)	4.6954	11.8471	1.2000

TABLE III
TIME DOMAIN SPECIFICATIONS FOR THEORETICAL MODEL

Time Domain Parameters	**DPM-PI**	**DPM-PID**	**DPM-SMITH**
Overshoot	4.5444	5.3332	36.8336
Rise Time (seconds)	103.9071	80.4849	17.6924
Settling Time (seconds)	354.9789	371.9579	287.8592
Peak Time (seconds)	257.20	203.60	94.70

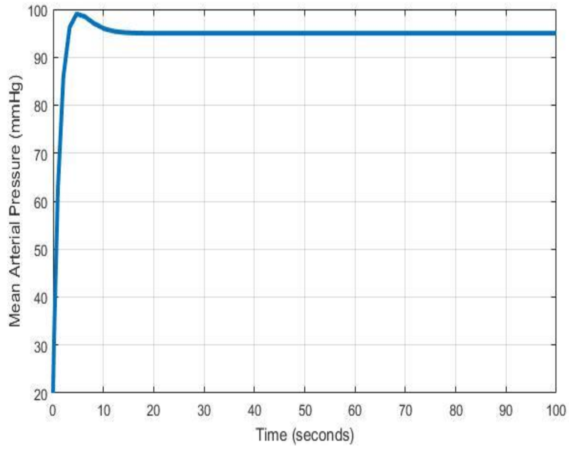

Fig. 3 Plot of Time Vs Mean Arterial Pressure for PI mode of controller for Noradrenaline

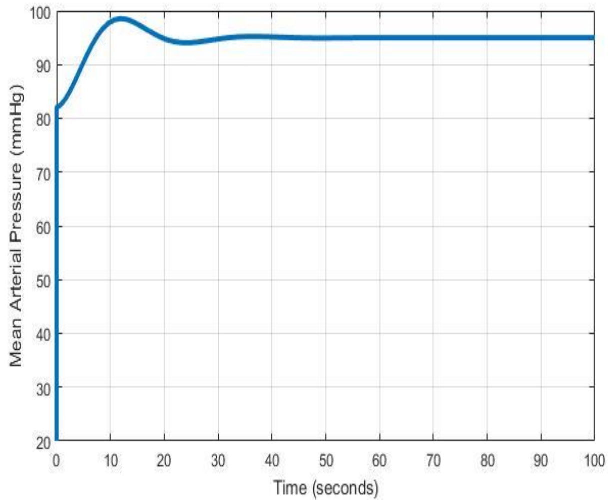

Fig. 4 Plot of Time Vs Mean Arterial Pressure for PID mode of controller for Noradrenaline

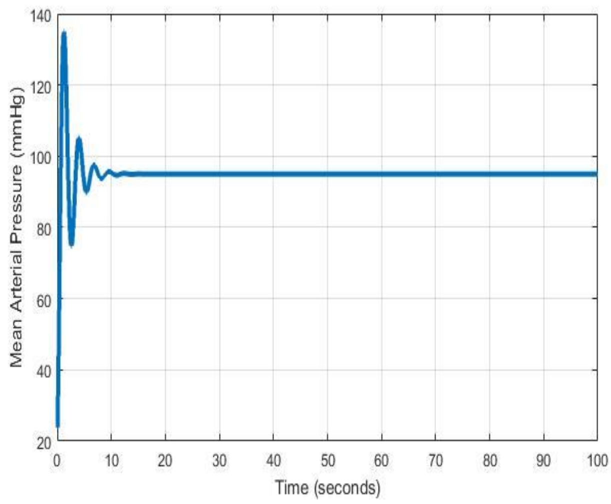

Fig.5 Plot of Time Vs Mean Arterial Pressure for Smith Predictive mode of controller for Noradrenaline

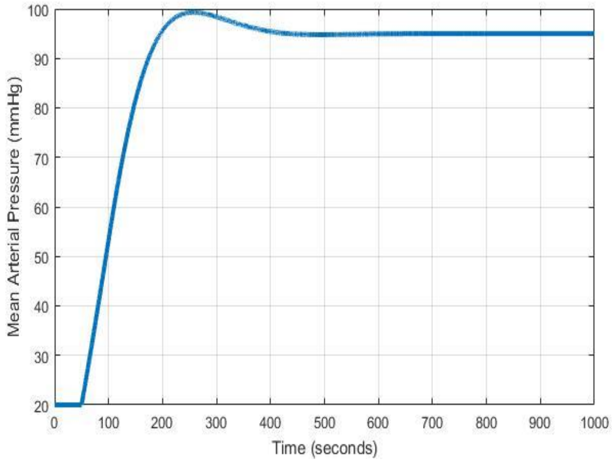

Fig.6 Plot of Time Vs Mean Arterial Pressure for PI mode of controller for Dopamine

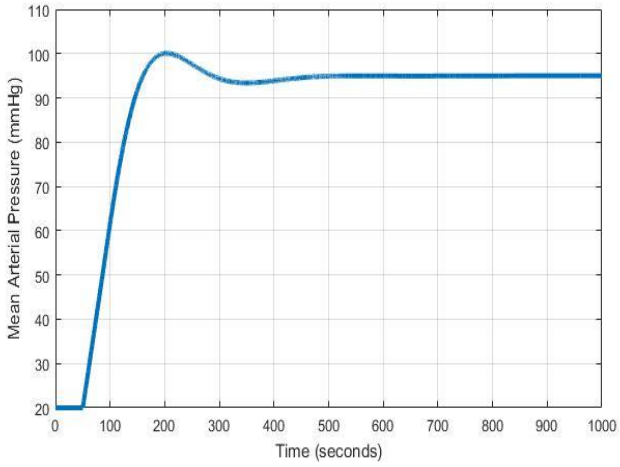

Fig.7 Plot of Time Vs Mean Arterial Pressure for PID mode of controller for Dopamine

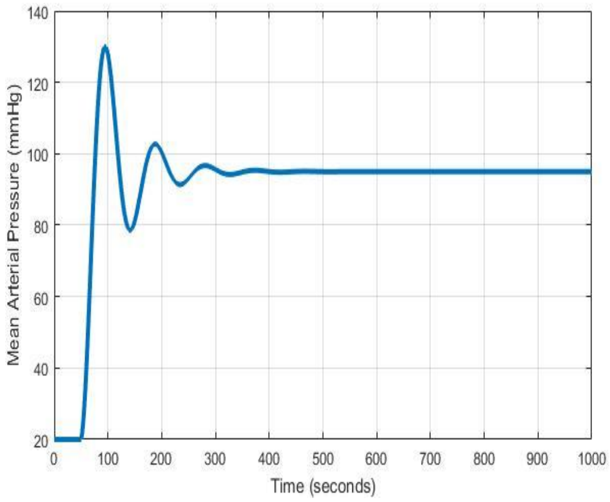

Fig.8 Plot of Time Vs Mean Arterial Pressure for Smith Predictive mode of controller for Dopamine

VIII. CONCLUSION

In this paper, we have implemented two conventional control modes and one advanced control mode such as PI, PID and Smith Predictive controllers respectively for the patient model obtained under clinical practice and for the patient model obtained from the literature [1]. From the simulated results, it is confirmed that Smith Predictive mode of control is the suitable controller for the obtained patient model, but the overshoot of Smith Predictive controller is very high comparing with other controllers. Therefore, the implementation of advanced controllers like Internal model controller and Sliding mode controller will be developed for the obtained patient model.

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