Neuro-PID Adaptive Control Scheme for Blood Pressure Regulation

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Control of physiological states such as mean arterial pressure (MAP) has been successfully achieved using single drug by different control algorithms. Multi-drug delivery demonstrates a significantly challenging task as compared to control with a single-drug. Also the patient's sensitivity to the drugs varies from patient to patient. Therefore, the implementation of adaptive controller is very essential to improve the patient care in order to reduce the workload of healthcare staff and costs. This paper presents the design and implementation of a Proportional Integral Derivative controller (PID) using neural network based parameter tuning mechanism to regulate mean arterial pressure and cardiac output (CO) by administering vasoactive and inotropic drugs that are sodium nitroprusside (SNP) and dopamine (DPM) respectively. The parameters of PID controller were optimised offline using Simulink Response Optimization tool. The proposed Neuro-PID controller has been implemented, tested and verified to demonstrate its merits and capabilities as compared to the existing approaches to cover wide range of patients.

Keywords **- Mean Arterial Pressure (MAP), Cardiac Output (CO), Proportional-Integral-Derivative (PID) controller, Sodium Nitroprusside (SNP), Dopamine (DPM), Simulink Response Optimisation and Neural Network.**

I. INTRODUCTION

The automatic control of physiological parameters has been considered as important point for several decades. One of the particular problems that have been subjected is the control of homodynamic variables such as mean arterial pressure (MAP) and cardiac output (CO). The implementation of automatic control system is very essential to improve the patient care in order to minimise the workload of the physicians and reduce the costs. The Cardiovascular system has been used to designs control systems for blood pressure control. E. Furutani et al. [1] have developed and implemented a state-predictive servo controller for continuous feedback control of MAP and inference fuzzy rules to avoid the risk and make the patients in safe side during surgical operation [2].

Over the past several years, different approaches have been investigated. Many have focused on the single-input single-output (SISO) control systems to lower the patients' blood pressure and maintain it at desired level using single drug particularly sodium nitroprusside (SNP) [3, 4, 5, 6, 7, 8] and [13]. Fuzzy controller-based Multiple-model adaptive control (MMAC) has been reported by H. Zheng and K. Zhu in [3]. The patient model and its response to one drug have been developed and a nonlinear proportional-integral-derivative PID digital controller has been implemented with a minicomputer system to control the MAP by infusion SNP [4]. Adaptive proportional-integral (PI) controller have been implemented for blood pressure regulation using SNP [5]. An integrating self-tuning control strategy has been involved in single drug infusion control system to maintain the MAP using SNP [6]. The Internal model control (IMC) has been implemented on the patient response model to one kind of vasoactive drugs that is SNP [7, 8].

Controlling of homodynamic variables commonly used more than one drugs. A nonlinear electrical analog model with a baroreflex feedback, and the MAP was used as the input of a baroreflex to control circulatory variables using a computer model [9] and the indirect adaptive controller based on recursive identification and linear quadratic regulation has been used to control the infusion rates of two drugs [10]. The control advance moving average controller (CAMAC) is one kind of adaptive algorithms has been implemented to control MAP and CO using two drugs [11]. Multiple model adaptive predictive controllers has been designed and implemented to regulate MAP and CO by adjusting the infusion rates of SNP and DPM [12]. The problem of controlling the cardiovascular parameters of a patient using multiple drug administration represents a difficult control problem. Blood pressure control by vasoactive drugs is essentially a single-input single-output problem and has been successfully solved by Sheppard et al [13], using a PID controller. A continuous optimal controller and an ARMA discrete controller have been used by Koivo [14, 15, 16], also, Stern has used a self-tuning regulator [17], and a model reference adaptive controller implemented by Kaufman [18, 19].

The adaptive controller based on the Generalized Fuzzy Neural Network (GFNN) has been applied to control MAP using SNP by Er and Gao [20]. Kashihara has represented the implementation of a multiple adaptive predictive control based on neural networks to maintain the unanticipated responses to therapeutic agents of C0 and MAP [21]. The PID controller based on neural network has been used to control time-delay systems, the structure of the controller has introduced by Shu and Pi [22].

This paper presents an investigation into the design and development of a Neuro-PID control scheme for blood pressure control. A multi-inputs, multi-outputs system (MIMO) PID controller using neural network is designed with

a patient model represented by first-order transfer function of 2x2 matrixes with time delay [19]. The controller parameters have been adapted using four inputs and three outputs as patients' sensitivities and controller parameters respectively. Matlab Simulink Toolbox utilized to design and develops the proposed model. The proposed scheme has been implemented, tested and verified to demonstrate its merits and capabilities as compared to existing approaches through a set experiment.

II. Plant Characteristics

The patient model represented by two inputs and two outputs system as first order model is shown in fig. 1. The objective of the system is to decrease a patient's mean arterial pressure to desired value tracking the reference signal and increase the cardiac output to desired value tracking the reference signal. The patient response model is defined by a linear small-signal first-order transfer function matrix equation 1, as represented in [18]. The drugs which have been used to maintain the homodynamic variables CO, and MAP are dopamine (DPM) and sodium nitroprusside (SNP). The effect of DPM increases both CO and MAP while SNP increases CO and decreases MAP.

$$\begin{bmatrix} CO \\ MAP \end{bmatrix} = \begin{bmatrix} \frac{K_{11}e^{-T_{11}s}}{\tau_{11}s+1} & \frac{K_{12}e^{-T_{12}s}}{\tau_{12}s+1} \\ \frac{K_{21}e^{-T_{21}s}}{\tau_{21}s+1} & \frac{K_{22}e^{-T_{22}s}}{\tau_{22}s+1} \end{bmatrix} \begin{bmatrix} DPM \\ SNP \end{bmatrix} \quad (1)$$

K_{ij} - Plant gain.
T_{ij} - Time delay between the input and the system response.
τ_{ij} - Time constant.

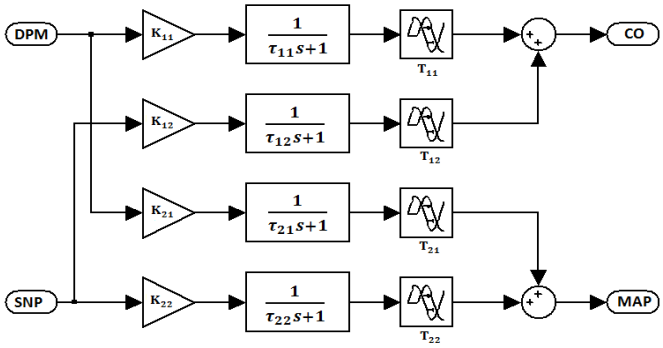

Fig. 1 Simulink Block Diagram Of The Plant Model.

The parameters of the patient model have been represented as nominal and ranges values are given in table 1.

TABLE 1
NOMINAL AND RANGES VALUES OF THE PATIENT MODEL PARAMETERS.

parameters	*Nominal*	*Ranges*	*Unit*
K_{11}	5	1 to 12	ml/µg
τ_{11}	300	70 to 600	Sec
T_{11}	60	15 to 60	Sec
K_{12}	12	-15 to 13	ml/µg
τ_{12}	150	70 to 600	Sec
T_{12}	50	15 to 60	Sec
K_{21}	3	0 to 9	$mmHg/[\mu g/min.kg]$
τ_{21}	40	30 to 60	Sec
T_{21}	60	15 to 60	Sec
K_{22}	-15	-13 to -50	$mmHg/[\mu g/min.kg]$
τ_{22}	40	30 to 60	Sec
T_{22}	50	15 to 60	Sec

III. Neuo-PID Adaptive Control

The patient's model with three-term controller, proportional, integral and derivative (PID), shown in Figure 2, has been widely used in the field of process control because of its simplicity and robustness. In conventional PID control, once the well tuned PID gains are obtained, the controller usually exhibits good performance. However, when the dynamic characteristics of the system are time dependent or the operating conditions of the system vary, it is necessary to retune the PID parameters again. The manual tuning of PID controllers, which requires optimization of the parameters, is a time-consuming task. To deal with this difficulty, much effort has been invested in developing systematic tuning methods. Many of these methods depend on knowledge of the plant model. Some of these tuning methods are described in [23, 24]. In this paper we used Simulink Response Optimization to obtain the optimal values of the controller parameters and the Neural Network has utilized to tune the PID controller online.

Most authors will be able to prepare images in one of the allowed formats listed above. This section provides additional information on preparing PS, EPS, and TIFF files. No matter how you convert your images, it is a good idea to print the files to make sure nothing was lost in the process.

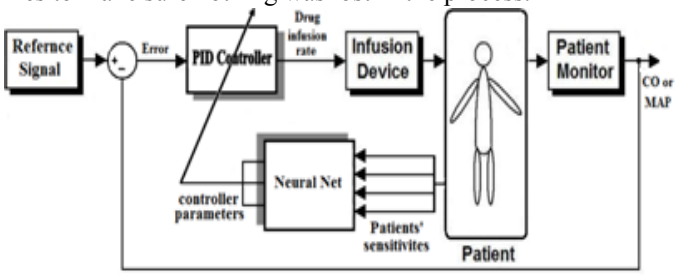

Fig. 2 General Form of the Patient's Model with Neural PID Controller.

As the system has two inputs and two outputs we have designed two controllers, the first controller function aims to control the infusion rate of the first drug that Dopamine (DPM), its parameters updates by neural network (1) and the second controller function is to control the infusion rate of the second drug that Sodium nitroprusside (SNP) its parameters updates by neural network (2). Fig. 3 illustrates the Simulink block diagram of the system.

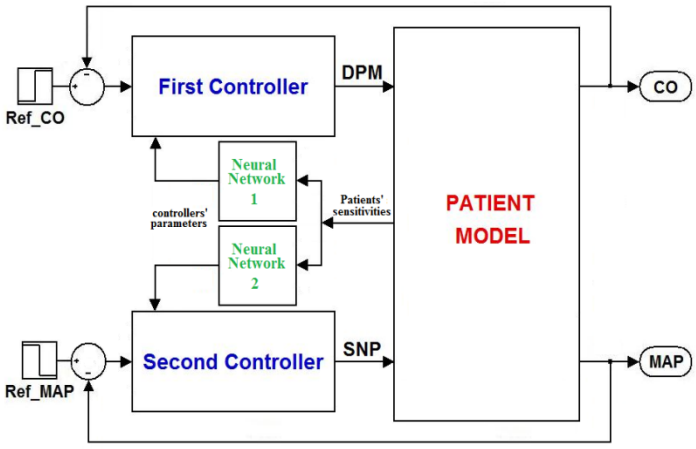

Fig. 3 Simulink Block Diagram Of The Patient Model With The PID Controllers And Neural Networks.

The Neural Network is widely used in fitting functions because of its ability to generalise, to respond to unexpected inputs and to learn how to do tasks based on the data given for training. We have designed and utilised the neural network to make the controller be able to work online and cover the wide range of patients. The components of this neural network are four inputs and three outputs with two layers. The patients' sensitivities to drugs (DPM and SNP) have been considered as inputs which are represented respectively by K_{11}- K_{21} and K_{12} - K_{22}. The PID controller parameters, which are represented by proportional gain (k_p), integral gain (k_i) and derivative gain (k_d), have been considered as outputs.

IV. Simulation Results

The Matlab Simulink has been implemented to simulate the patients' model which has been presented in fig.3 and the PID controllers' parameters named k_{p1}, k_{i1}, k_{d1}, k_{p2}, k_{i2} and k_{d2} have been adaptive using Neural Network.

Table 1 presents the ranges values of the patient's sensitivity to drugs, in order to take into account the different type of patients and the patient's sensitivity to drug varies from patient to patient. Due to that the drug infusion controller should be designed to be work well in a real-time environment for a wide range of patients. In the simulation, automatic multiple drug delivery system simulates the MAP and CO using DPM and SNP with different sensitivity. The PID based on neural network has been implemented to control the infusion rate of the drugs. The controller has adapted using the neural network with patients' sensitivities as inputs and controllers' parameters as the outputs to make the controller will be suitable for a wide range of patients. The system has been tested using different patient's sensitivity, the parameters value of the patient's model has included different types of patients as sensitive, nominal and insensitive. The patients' sensitivities to DPM have represented by K_{11} and K_{21} and K_{12} and K_{22} have represented the patients' sensitivities to SNP.

Table 2, 3 and 4 shows the simulation results of multi-drug infusion control using PID controller based on neural network. From these results we observed that the proposed controller was satisfied to control simultaneously MAP and CO using two drugs. That results have depicted the controller performances in simulation results are suitable to cover wide range of patient.

TABLE 2
INSENSITIVE PATIENT RESPONSE TO DPM AND SNP.

Patients' sensitivities				DPM	SNP	CO	MAP
K_{11}	K_{12}	K_{21}	K_{22}				
1	-15	0	-50	26	0.4	20	-20
2	-15	1	-50	15.3	0.7059	20	-20
3	-15	2	-50	10.84	0.8334	20	-20
4	-15	3	-50	8.389	0.9033	20	-20
5	-15	3.5	-50	6.582	0.8608	20	-20
6	-15	4	-50	5.417	0.8334	20	-20
7	-15	5	-50	4.727	0.8727	20	-20
8	-15	6	-50	4.194	0.9033	20	-20
9	-15	6.5	-50	3.689	0.8795	20	-20
10	-15	7	-50	3.291	0.8608	20	-20
11	-15	8	-50	3.023	0.8837	20	-20
12	-15	9	-50	2.796	0.9032	20	-20

TABLE 3
NOMINAL PATIENT RESPONSE TO DPM AND SNP.

Patients' sensitivities				DPM	SNP	CO	MAP
K_{11}	K_{12}	K_{21}	K_{22}				
1	4	0	-25	16.8	0.4	20	-20
2	4	1	-25	7.778	1.111	20	-20
3	4	2	-25	5.059	1.205	20	-20
4	4	3	-25	3.75	1.25	20	-20
5	4	3.5	-25	3.022	1.223	20	-20
6	4	4	-25	2.53	1.205	20	-20
7	4	5	-25	2.154	1.231	20	-20
8	4	6	-25	1.875	1.25	20	-20
9	4	6.5	-25	1.673	1.235	20	-20
10	4	7	-25	1.511	1.223	20	-20
11	4	8	-25	1.368	1.238	20	-20
12	4	9	-25	1.25	1.25	20	-20

TABLE 4
SENSITIVE PATIENT RESPONSE TO DPM AND SNP.

Patients' sensitivities				DPM	SNP	CO	MAP
K_{11}	K_{12}	K_{21}	K_{22}				
1	10	0	-12	3.324	1.667	20	-20
2	10	1	-12	1.177	1.765	20	-20
3	10	2	-12	0.7148	1.786	20	-20
4	10	3	-12	0.5126	1.795	20	-20
5	10	3.5	-12	0.4208	1.789	20	-20
6	10	4	-12	0.3572	1.786	20	-20
7	10	5	-12	0.2986	1.791	20	-20
8	10	6	-12	0.2564	1.795	20	-20
9	10	6.5	-12	0.2312	1.792	20	-20
10	10	7	-12	0.2105	1.789	20	-20
11	10	8	-12	0.1887	1.792	20	-20
12	10	9	-12	0.1708	1.795	20	-20

Figures 4, 5 and 6 have shown the simulation results of the patient responses to drugs, and from that we observed the PID based on neural network gives satisfactory results.

Figures 4, 5 and 6 illustrate the response of the patient to DPM and SNP when increase CO of (20 ml/min.kg) and decrease MAP of (20 mmHg). Figures 4, 5 and 6 have depicted that insensitive, nominal and sensitive patient response to DPM and SNP respectively.

The results of simulation demonstrated that the PID controller based on neural network has able to cover different types of patients in real-time.

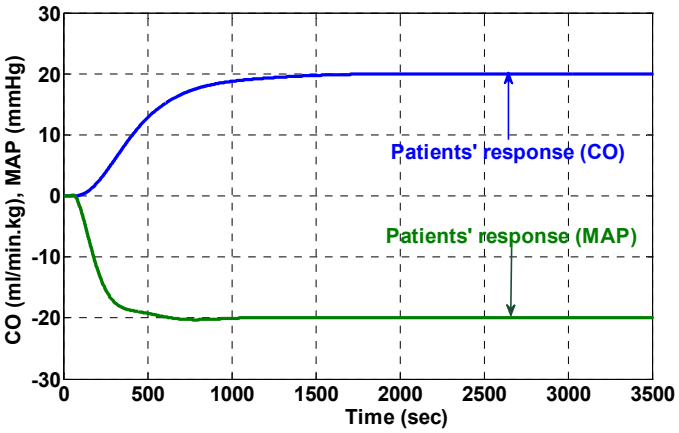

Fig. 4 Insensitive Patient Response, when K_{11} = 1, K_{12} = -15, K_{21} = 0 and K_{22} = -50

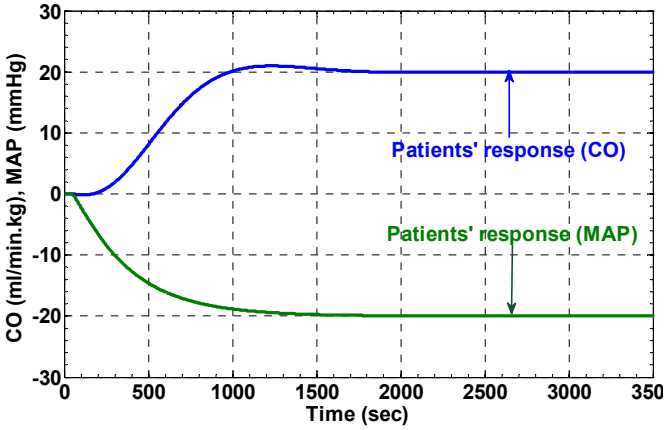

Fig. 5 Nominal Patient Response, when $K_{11} = 6$, $K_{12} = 4$, $K_{21} = 4$ and $K_{22} = -25$

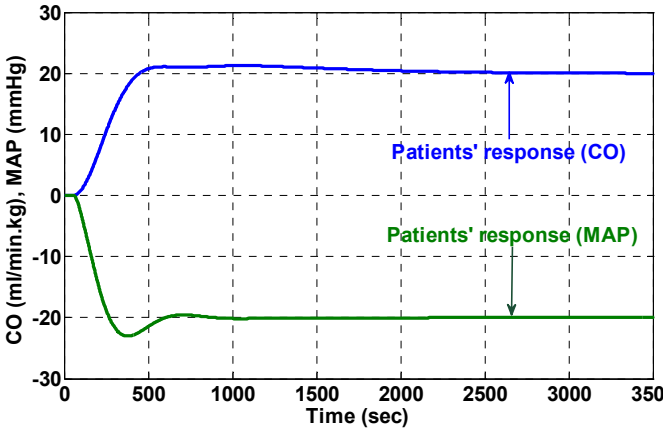

Fig. 5 Nominal Patient Response, when $K_{11} = 12$, $K_{12} = 10$, $K_{21} = 9$ and $K_{22} = -12$

V. Conclusions

The paper has presented an adaptive multi-drug Neuro-PID control scheme for blood pressure control. The proposed scheme was designed and evaluated in simulation study to maintain the nonlinear responses of CO and MAP using two drugs, namely DPM and SNP for the patients of various sensitivities. The simulation results have confirmed that PID controller based on neural network is potentially useful for regulating the MAP and CO by computing the DPM and SNP infusion rate. The proposed approach offered much better performance as compared to existing approaches, particularly to cover wide range of patients. As future work, the proposed controller will be improved further for its adaptability for a wide range of patients using more than two drugs. Finally, the model will be implemented in real-time to verify through clinical test.

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