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Blood Pressure Control by Deterministic Learning Based Fuzzy Logic Control

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Abstract*: *Automatic control of blood pressure after cardiac operation of patient is wanted in favor of enhanced patient concern; it decreases work of personnel and expenses. Automation of medical drug infusion for controlling of mean arterial pressure (MAP) is extremely advantageous in much clinical function. An assimilating self-tuning control approach for the regulation of mean arterial pressure by infusing sodium nitroprusside is discussed. This paper focuses on omnipresent and verified FUZZY controllers based on reinforcement learning for arterial blood pressure control. The major problem is patient's sensitivity in different condition although is same condition at different time. To extract the patient's parameter reinforcement learning approach is proposed and verified. Complete & convenient model of hypertensive patient is effectively developed and processed; with drug response model depiction. Intend and execution of such control arrangement will be controlled using FUZZY logic controllers and for parameter extraction deterministic learning is used. MATLAB Simulation of the designed system models are done for revelation..

Index Terms*: *Drug Delivery system, Deterministic Learning, Fuzzy Inference System, Mean Arterial Pressure

I. INTRODUCTION

In today's world scenario most people are suffering through immense high blood pressure, whereas in some clinical surgery blood pressure varies drastically. A large number of clinical persons are required to monitor blood pressure and infuse the drug according blood pressure changes. It makes their work tedious and monotonous. The aim of this work is for advancing the value of patient care and set the medical workforce free from monotonous task. The intention is for updating the accessible involuntary drug release system to enhance the control action and decrease unsteadiness. Blood pressure is articulated with 2 dimensions, systolic pressure is maximum pressure and diastolic pressure is minimum pressures in arterial system. When the left ventricle is maximum constricted, the systolic pressure appears; when left ventricle is mainly unperturbed, diastolic pressure occurs earlier to subsequent reduction. The systolic blood pressure of living person exists between the range of 110–140 millimeters mercury (mmHg) whereas diastolic pressure exists between 70–90 mmHg. High BP occurs only if pressure is steadily at or else above 130/90 mmHg mainly for grownups; unlike figures are valid to children. Pre-operative control of the blood pressure will be an imp issue in medical practice. Though control of hypertension earlier than surgery is needed, hypertension at postsurgical condition for heart patients is rather general. It is clear that later than coronary blood vessel bypass graft operation .unattended high BP past a surgical procedure leads to increase of bleeding, stitch line commotion etc. for reducing probabilities of the complication, it's essential to decrease high BP soon. By continuously infusing drugs, such as sodium nitroprusside (SNP) or Nitroglycerin, it speedily lowers BP in the majority of the patients. Dissimilar type of drugs might take unlike time of instruction and have diverse reactions [1]. A title Hypotension is reverse of hypertension, high blood pressure. It is understood as a physiological condition, more than a disease. Extremely low blood pressure causes dizziness and fainting and point towards a serious heart, endocrine or neurological disorders. Enormously low blood pressure can divest the brain and other imp organs of oxygen and nutrients, leads to a critical condition called shock.[2].The fast-acting drug SNP is frequently adjusted to decrease blood pressure in hospitalized patients [3]. Drug Manufacturer also recommends closed loop feedback control; i.e. the based on measurement of mean arterial pressure (MAP) drug infusion rate can be controlled [4]. The clinical personnel has to face severe pressure due be manual control because this process is time-consuming, inappropriate and sometimes of poor performance. In most patients nonlinear PID system satisfactorily controls the MAP. Still, clinical person's experiences showed that system performance requires major development for patients like sensitive or insensitive to the particular drug, and patients having large fluctuations in blood pressure. A model showing mathematical relationship and simulation of necessary features of the patient showing the response of sodium nitroprusside is designed for system design and analysis [5,6]. The model was used for analysis and simulation of the nonlinear PID system, the examination of patient's blood pressure and nonlinear adaptive controller design [6]. System performance can be improved by model-based adaptive controller techniques. Still certain issues can be experienced in clinical applications which may necessitate administrator cooperation. The study of physiology and pharmacology for high blood pressure in post-operative patients can be done by PC-based feedback system. Presently research is focused on developing an economic compact control system. This system can be helpful in operative room during and post-operative open-heart surgery for blood pressure regulation [7]. Since few years the automatic control has been receiving considerable attention [8] this area also includes blood pressure control [9],

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[10], depth of anaesthesia [11], and type-I diabetes patient [12]. There are many researches already going on in the field of multidrug method. The control advance moving average controller was designed by Serna et al. [20]. The SNP and dopamine were used for control of CO and MAP with a model reference adaptive controller, the control advance moving average controller (CAMAC) was implemented. The CAMAC is a self-tuning controller is used to control nonminimum phase system having unknown or varying dead time, has been effectively implemented to regulate MAP with SNP in anesthetized animals [20]. For the implementation of discrete adaptive controller past inputs, outputs and an on-line estimation of patient's response which regulates the suitable drug infusion rate to achieve the desired MAP and CO. CAMAC decides the input value of drug at every control interval to reduce the difference between the set point blood pressure and predicted blood pressure. This control strategy optimizes the rate of drug infusion and provides accurate control of MABP. The advantage of this strategy is that blood pressure can be controlled without making a bias in the controlled pressure [13]. In this paper we have used an integrating self-tuning (IST) control system derived by Tuffs and Clarke [14-15] to attain an optimum SNP infusion rate. The modelling of control strategy that reduces the changes in the amount of infused drug optimizes the SNP infusion rate. To remove output biasing, an algorithm is designed that frequently outcomes from efforts to optimize the input infusion rate. The present control system has two principle preferences over the past techniques. First, it has a theoretical mathematical modelling, and not a heuristic one; hence, MABP can be controlled by using this method under wide range of physiological deviations. Second, the controller tries to enhance the measure of infused drug without making a bias in MABP. This controller is highly recommended where toxic drugs like SNP are used in control of MABP. There is a major problem in the design of this controller that it requires the prior knowledge of system delays. A.V. Sebald et al [16] stated that a requirement of membership functions for a fuzzy logic controller is important matter of engineering. They developed a latest method for the design of the fuzzy controller by standard numerical optimization algo is given. Here inside this case, maximization program's efficiency for the design of a fuzzy controller is presented, also discusses the link between membership functions and controller presentation. The planned technique was executed for blood pressure controlling cases. Highly nonlinear system fractional PID controller is also implemented based on prior knowledge of response [17].Reinforcement learning method is used to extract the patient's parameters [22].

II. PATIENT'S MODEL

For the study of blood pressure control a patient's model should have a drug response model. Characteristics of patients would vary with each other and also vary according to time. Slate et al. (1980) did several experiments about medical studies on patients to obtain a representation to relate with the MAP to different infusing rates of SNP. Depending on gray box study, the investigational results related infusion rate of SNP as a random binary signal, Slate also produced first-order transfer function for patient's drug response model along with time delays. Even though drug response model must have both variable and nonlinear characters, he observed that the SNP's reaction to blood pressure is practically constant over a definite range and thus it will be examined with the assumption of piece-wise linearity [5].

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

Here

ΔPd is diff of MAP (mmHg)

I(s) refer to infusion rate of SNP (ml/H). K (mmHg/(ml/H)) is the sense duty of patient respond for the retort of SNP

α will be the nearly all the drug which is absorbed before circulating againThe advanced fixed amount of K shows high sensitivity, the constraint α denotes the amount of drug which is obtainable to circulate it again past absorbing it initially. The steady state gain is denoted by K (1+α), its value differ from -0.29 and -9.0 mmHg/(ml/H). Patient's with higher sense duty toward SNP have lower amount of α that is the nearly all the drug which is absorbed before circulating again. The three other constraints are: Ti is initial transport delay, Tc recirculation transport delay and the system time constant is τ, cells reactions and other biotransformation causes change in the whole secondary vasculature confrontation [18]. Obviously declared by Slate et al. (1980), that the representation may only be suitable for minor differences in SNP infusion rate and it may not notice the changes caused by drugs other than SNP infusion.

Patient's model used is the model projected through Slate(1980) used for blood pressure control system.Models transfer function is shown in equarion (2)&(3).

$$\frac{Y(s)}{U(s)} = e^{-Ts}\frac{G(t_3 s+1)}{[(t_3 s+1)(t_2 s+1)-\alpha](t_1 s+1)} \quad (2)$$

$$P(s) = P_0 - Y(s) \quad (3)$$

Here P(s), mean arterial pressure, is initial pressure, Y(s) is change in pressure because of drug infusion, and U(s) gives rate of infusion of SNP in patient.

Constraints were chosen as: G is plant gain = 0.25 to 9 mm/Hg/ (ml/h). T is infusion delay = 50s by later edition is the time constant of SNP action is the time constant for flow throughout pulmonary circulation is the time constant for flow throughout complete circulation α gives the portion of SNP recirculates Here patient's model designed in this work has an actual Blood pressure of 140 mmHg.

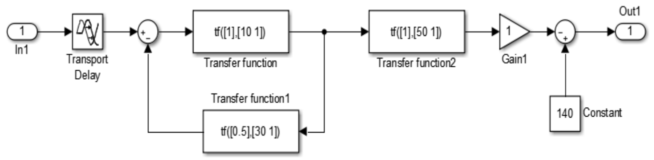

Figure 1: Simulink model of Patients model with actual BP of 140mmHg

III. CONTROL STRATEGY

Blood pressure regulatory structure calculates mean arterial pressure (MAP) with the help of a sensing device and further compares with required MAP. Calculated error b/w considered MAP with required MAP; e is provided as controller input.

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Controller then calculates the quantity of sodium nitroprusside (SNP) drug which is required for infusing in the body to get preferred quantity of pressure change occurred in patient's body. Here u is amount of SNP injected in patient by several infusing instrument. Human body is taken as Plant, and again the MAP will be calculated and the procedure will continue till preferred MAP is attained.   is the cause of the disturbance in MAP [19]. An active patient's model of MAP with the use of SNP was made by J.B.Slate and it is given by-

$$MAP = P_0 - P_\Delta + P_d + n \qquad (4)$$

Here MAP refers to mean arterial pressure, Po indicates primary mean blood pressure, moreover known as the background pressure, PΔ gives the variation in mean BP because of drug infusion SNP, is difference in the mean pressure caused by the reflex action, and it is the patient's reaction to the vasodilator drug, n is the casual disturbance. It is understood that is a constant value.

IV. Blood Pressure Control Using Fuzzy Logic Controller

Fuzzy controller design needs the condition of both membership functions and the decision rules. Membership function and decision rules are based upon the proper info about the process. Even though utilization of expert info in decision making is very beneficial for the fuzzy control design, due to the lack of efficient design techniques, it is a restrictive cause for its failure. Many fuzzy controllers are likewise in their basic construction, designing of a controller requires specification of large no of parameters. Valuation and modification of the controller values are done by trying and finding out errors through simulation and execution. This requires considerable amount of attempt. If a simulation model is obtainable for testing, also numerical optimization is capable tool for the design of membership functions, and fortuning and automatic testing of the controller. In this approach blood pressure error and rate of change of blood pressure are computed and appropriate membership function is evaluated. For identifying all potentially useful control action fuzzy rules are applied. Blood pressure error and rate of change of error are converted into fuzzy sets, whose membership functions are pre-defined.

A. Controller Design

The purpose of design is to find appropriate values for the membership function parameters, so as to properly describe the fuzziness of physical variables. Performance of the controller which is represented by the cost function can be optimized over repeated simulations and give the values of the parameter. Nonlinear and time-varying plant performances can be easily handled, if suitable simulation models are given. Major benefit of using fuzzy logic controller is that knowledge of an experienced person can be used in the designing the solution of the problem. Two inputs used in fuzzy logic are the error and rate of change of error and output is in infused drug rate. Error E(t) and the rate of change of error R(t) are given by,[21]

$$E(t) = MAP_c(t) - MAP(t) \qquad (5)$$
$$R(t) = E(t) - E(t-1) \qquad (6)$$

Mamdani type fuzzy logic controller is designed here. Seven membership functions are selected for input 1 shown in figure 1. E(t) is given by 10 ≤ E(t) ≤ 130mmHg.

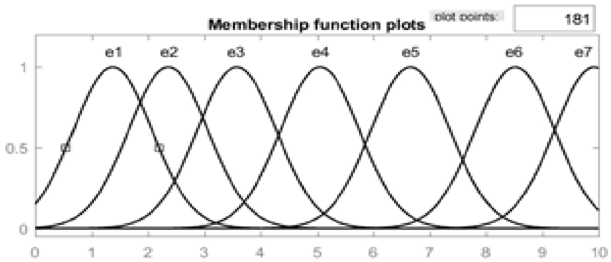

Figure 2: Membership functions for Error Input.

The rate of change of MAP is second input considered. The measure of sensitivity to a particular drug is achieved by rate of change of error. The rate of change of MAP relates patient sensitivity and is separated into five membership functions as shown in figure 3.

$$\Delta MAP(t)| = MAP(t) - MAP(t-1) \vee \le 15mmHg$$

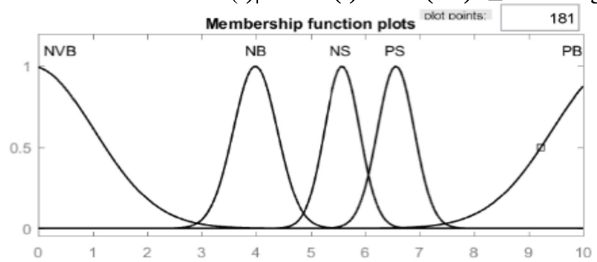

Figure 3: Membership functions for Input 2

Two conditions have been applied here first; the decrease of blood pressure should be more than 10mmHg less than the set point. Since set point given is 130mmHg, standard blood pressure is 120mmHg second; the range of infusion rate of SNP is 0.5 ≤ SNP(t) ≤ 10mcg/kg/min.

As SNP has toxic effect so the maximum dose of injection is generally avoided. Hence for precaution output is constrained and drug infusion rate is limited as, 0.5 ≤ SNP (t) ≤ 7mcg/kg/min. The output is divided into nine membership functions as shown in figure 4

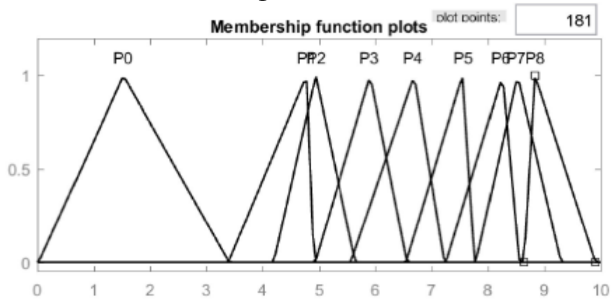

Figure 4: Membership functions for Output

B. Fuzzy Rule Base

The controller here considered has following fuzzy terms. NVB: Negative Very Big NB: Negative Big NS: Negative Small PS: Positive Small PB: Positive Big P: denotes the dosage of SNP drug

Table 1: fuzzy control algorithm

ΔMAP(t) e(t)	PB	PS	NS	NB	NVB
e1	P1	P1	P0	P0	P0
e2	P3	P2	P1	P1	P0
e3	P4	P3	P2	P2	P1
e4	P5	P5	P4	P3	P3
e5	P6	P5	P5	P4	P4
e6	P7	P7	P6	P6	P5

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C. Design of control system using rule based fuzzy controller

Design of Fuzzy controller is completely base on the rules stated. Working and reaction of the system is evaluated with controller. Fuzzy controller is used for regulation of blood pressure of the Plant. Simulation of fuzzy controller is carried out using MATLAB.

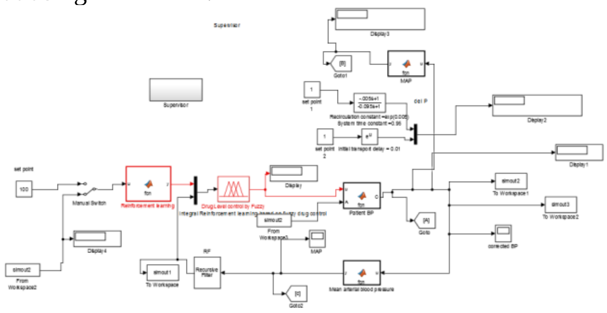


Figure5: Simulink model for BP control using Reinforcement learning based Fuzzy Controller

V. REINFORCEMENT LEARNING

Reinforcement learning methods deal with the solution of optimal control problems based on-line measurements. In this approach an agent is considered who relates with a changing situation. An ideal model is derived from environment, based on the model decision making will be performed. Blood pressure patient's response is non-stationary, the patient's state may not be fully decided, the state and drug infusion spaces are discretized, and the environment may comprise additional decision makers who are not stationary. Learning schemes should be calculated considering robustness to these modeling approximations.

A. Deterministic Q-Learning

In deterministic learning we don't have the knowledge of system behavior but control policy will be structured with learning the model. We begin with a simplified learning calculation that is appropriate for a deterministic Markov Decision Processes (MDP) display to discuss some key ideas. To start with, the agent needs to use some parametric model of the environment. Here the model of a stationary MDP is used; state space and actions space are given from initial response. But, the state transition matrix P = (p(ss; a)) and the instantaneous reward function r = (r(s; a; sr)) possibly not be specified. Further from adopted the observed signal is certainly the state of the dynamic progress, and that the reward signal is the instant reward rt, with mean $r(s_t; a_t)$.

$$S_{t+1} = f(S_t\ a_t) \qquad (7)$$

$$r_t = r(s_t\ a_t) \qquad (8)$$

The discounted return criterion is given as: $V^{\pi}(s) = \sum_{t=0}^{\infty} \gamma^t r(S_t, a_t)$, given $s_0 = s, a_t = \pi(s_t)$

$$V^*(s) = \max V^{\pi}(s) \qquad (9)$$

From the definition of the Q-function, studied to the present deterministic set

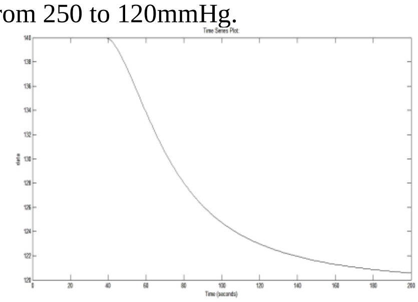
$$Q(s,a) = r(s,a) + \gamma V^* f(s,a) \qquad (10)$$

The optimality relation is the

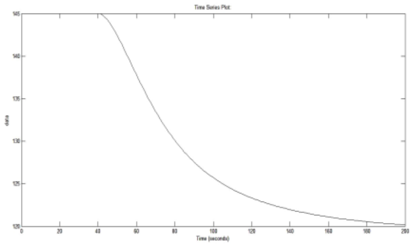
$$Q(s,a) = r(s,a) + \gamma max Q(f(s,a), a' \qquad (12)$$

VI. RESULTS AND DISCUSSIONS

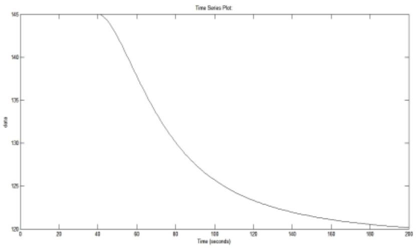
The deterministic reinforced learning model used to give the reward as input to the fuzzy. The deterministic reinforcement learning checks the output from the patient model and provides it as input to the fuzzy, the corresponding amount of SNP would be provided. Similarly on running the program again and again would lead to decrease in the amount of person BP till 120 after which it would be terminated by the supervisor. Inputs given to controller are error and variations of the mean arterial pressure. The output is the drug concentration. All response obtained for different initial pressures of 140,145,200 and 250mmHg is plotted It is found that the MAP reaches within the tolerance limit in 200sec. It is also seen that it has less oscillations and settles faster. In figure 6 (a) Results shows the response when initial blood pressure is 140 mmHg and it is reduced to 120 mmHg when drug is infused. Similarly figure 6(b) shows blood pressure reduced from 145 to 120mmHg, 6(c) shows Blood pressure reduced from 200 to 120mmHg 6(d) shows Blood pressure reduced from 250 to 120mmHg.



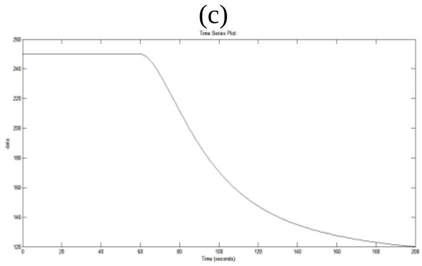
(a)



(b)



(c)



(d)

Figure 6: (a) Blood pressure reduced from 140 to120 mmHg (b) Blood pressure reduced from 145 to 120mmHg (c) Blood pressure reduced from 200 to 120mmHg (d) Initial Blood pressure 250mmHg

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All the results of simulations of blood pressure control by means of Fuzzy controller is presented here. Blood pressure is reduced from given initial value to the desired value of 120mmHg by infusing vasodilator drug sodium nitroprusside. Table 2 shows the steady state pressure and setting time for different initial pressure.

Table 2: comparison of results of different initial pressure using fuzzy controller

Controllers	Fuzzy controller	
Initial blood Pressure(mmHg)	Stead y State pressure (mmHg)	Settlin g Time(sec)
140	120.6	38.5
145	120	40
200	120.5	50
250	120	60

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