American-Eurasian Journal of Scientific Research 11 (4): 298-304, 2016
ISSN 1818-6785

DOI: 10.5829/idosi.aejsr.2016.11.4.22936

Design of the Hybrid Fuzzy PI Controller for Auto Regulation of PO_2 in Perfusion System for CPB Surgery Conditions

M. Dhinakaran and S. Abraham Lincon

Department of Electronics & Instrumentation Engineering, Annamalai University, Tamil Nadu, India

Abstract: Cardiopulmonary Bypass (CPB) is a cardiac surgical procedure performed in a motionless, bloodless surgical field. CPB has an extracorporeal circuit called Heart Lung Machine (HLM) setup to provide physiological support to the patients.HLM artificially takes over the functions of heart and lungs and it is operated and maintained manually by trained perfusionist along with anesthesiologists and cardiac surgeons. This is a HLM is a higly complicated process which may lead to fatal error by improper settings. So this problem can be rectified by introducing an automatic control in HLM setup. In this work a Hybrid Fuzzy PI Controller is designed for an automatic PO_2 regulation for oxygenation process in the perfusion system and it is tested in MATLAB Simulink for CPB surgery conditions.

Key words: Cardio Pulmonary Bypass (CPB) · Blood Gas Analyzer (BGA) · Partial pressure of Oxygen (PO_2) · Partial pressure of Carbon dioxide pressure (PCO_2)

INTRODUCTION

To perform an open Heart surgery in a Blood fewer zones by making the heart not to beat is called Cardio Pulmonary Bypass (CPB). CPB supports the circulation of the blood with the help of Heart Lung Machine (HLM) setup. The Heart Lung machine, or perfusion pump, is composed of a venous reservoir that receives all the Deoxygenated blood from the body, then the blood is pumped through an Oxygenator. This Oxygenator removes the Carbon dioxide and adds Oxygen to the blood, which is the typical function of the lungs. Then the oxygenated blood continuously pumped back to the body. Some additional pumps also present like Cardioplegia pump which supplies the cardioplegia solution to arrest the heart function. The vent pump is connected to the left ventricle to evacuate air from the cardiac chambers, to improve surgical exposure and to create a dry surgical field. Two suction pumps are present to suck the fluids and blood in aortic root and outer parts of heart to the receiving venous reservoir. a series of tubes that are connected to the patient and HLM. The HLM is operated and maintained by the trained perfusionist during the time of CPB surgery condition [1].

Blood Gas Analyzer: Blood Gas Analysis (BGA) are performed to measure Partial pressure of Hydrogen (pH), Partial pressure of Carbon dioxide(PCO_2), Partial pressure of Oxygen (PO_2), concentrate of many ions (sodium, potassium, chloride, bicarbonate) and metabolites (calcium, magnesium, glucose and lactate) in whole Blood specimen [2, 7]. They are also used to determine abnormal metabolite and electrolyte levels in Blood and the acid-base balance in the human body.

BGA report evaluates how well the persons Lungs and Kidneys are working and how well the body is using the energies. BGA report also used to check the performance of the HLM perfusion system how it delivers Oxygen to the Blood and how efficiently it eliminates Carbon dioxide from the Blood, during the time of the CPB surgery Condition.

Polynomial Function: CPB surgery patients' real time Blood Gas Analyzer reports measured during HLM support are collected from various hospitals. These BGA reports are completely analyzed and by taking the suggestion from perfusionists the oxygenation process values are separated into four conditions Mild, Moderate, Deep and Profound depending on its temperature level.

Corresponding Author: M. Dhinakaran, Department of Electronics & Instrumentation Engineering, Annamalai University, Tamil Nadu, India.

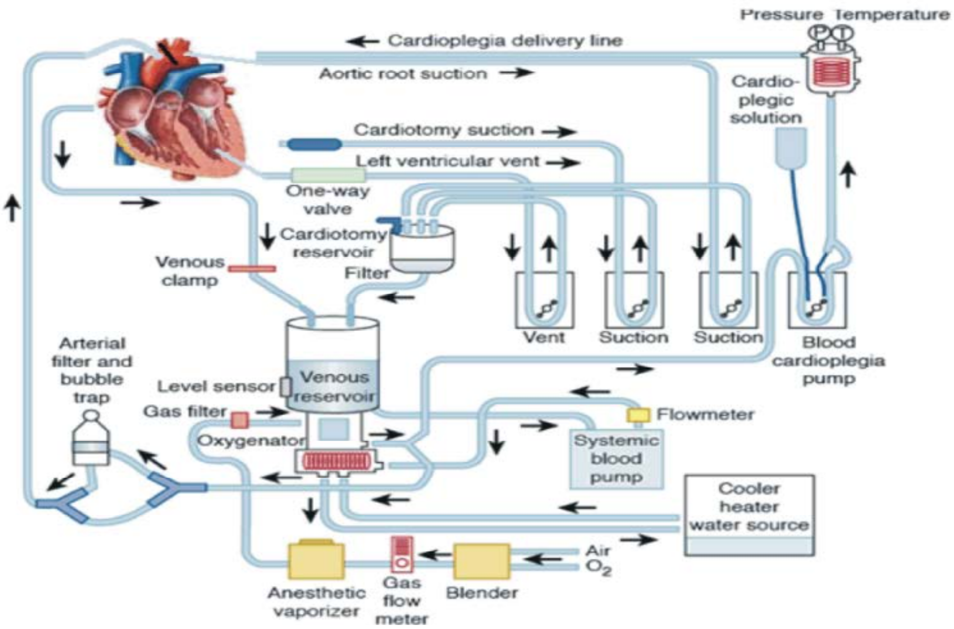

Fig. 1: Block Diagram of HLM Setup

Fig. 2: Blood Gas Analyzer (Model Rapid Lab-348)

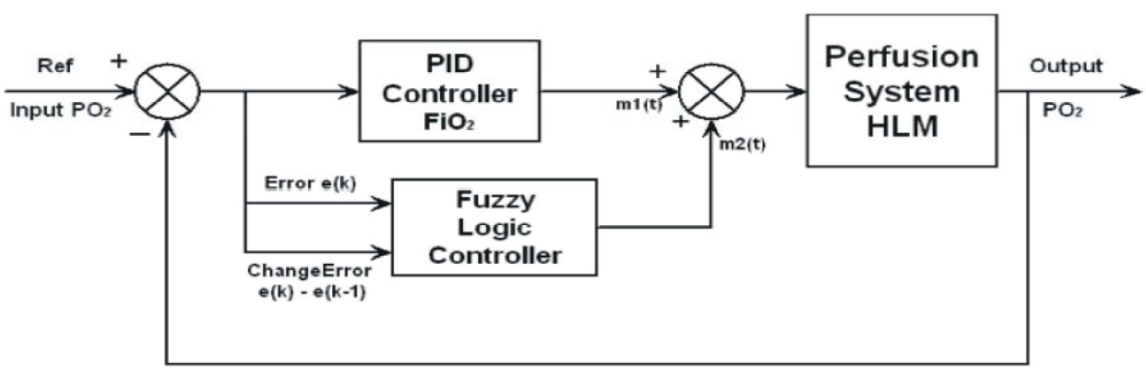

Fig. 3: Perfusion System with Hybrid Fuzzy PI Controller

For Auto regulation of PO_2 the input value is FiO_2 (%) and output value is PO_2 (mmHg) [1, 2]. For this Oxygenation processes values the Polynomial function for these four temperature condition are identified using curve fitting toolbox in MATLAB environment.

Design of Hybrid Fuzzy PI Controller: The hybrid fuzzy PI controller combines the advantages of a fuzzy logic controller and a conventional PI controller. The fuzzy ‘P’ term plays an important role in handling the overshoot and the rise time response. The conventional integral ‘I’ term reduces a steady state error. The Hybrid fuzzy PI controller keeps the simple structure of the PI controller [8]. The stability of a system does not change after the conventional PI controller is replaced by the hybrid fuzzy PI controller without modifying any PI type controller parameters. Fig. 3 shows the block diagram of hybrid fuzzy PID controller.

The number of necessary fuzzy sets and their ranges were designed based upon the experience gained on the process. The standard fuzzy set consists of three stages: Fuzzification, Decision MakingLogic and Defuzzification

Fuzzification: Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable into a linguistic variable is called fuzzification [8-14]. In the present work the error and change in error are taken as inputs and a part of FiO_2 that is m_2 (t) is taken as output. The error and change in error is converted into seven linguistic values namely NB, NM, NS, ZO, PS, PM and PB Similarly controller output is converted into seven linguistic values namely NB, NM, NS, ZO, PS, PM and PB. Triangular membership function is selected and the elements of each of the term sets are mapped on to the domain of corresponding linguistic variables.

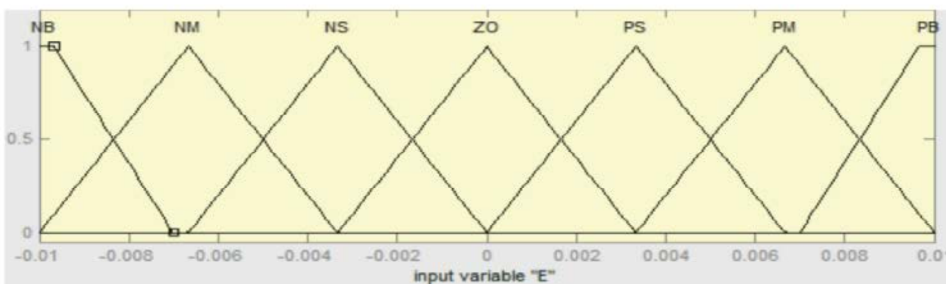

Fig. 4: Membership function for the Error

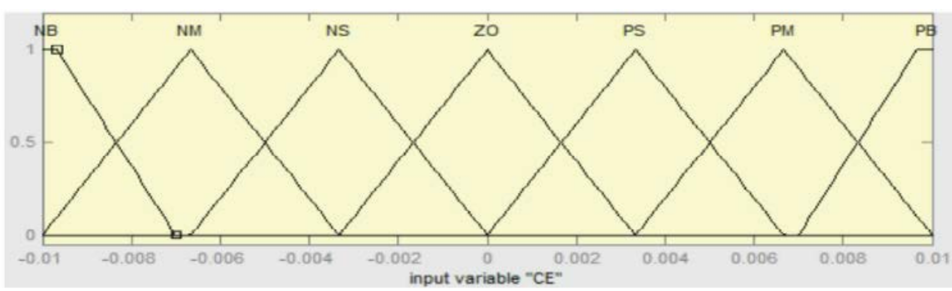

Fig. 5: Membership function for the Change in Error

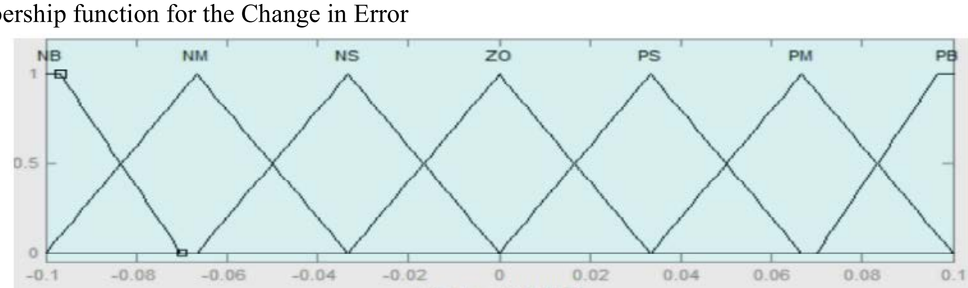

Fig. 6: Membership function for the Controller output

Table 2: Hybrid Fuzzy PI Decision Making Logic.

	CE	NB	NM	NS	ZO	PS	PM	PB
E	CO							
NB		NB	NB	NB	NM	NM	NS	ZO
NM		NB	NB	NM	NM	NS	ZO	PS
NS		NB	NM	NS	NS	ZO	PS	PS
ZO		NM	NS	NS	ZO	PS	PS	PM
PS		NS	NS	ZO	PS	PS	PM	PB
PM		NS	ZO	PS	PM	PM	PB	PB
PB		ZO	PS	PM	PM	PB	PB	PB

E – Error CE – Change in Error CO – Controller Output

Decision Making Stage: This stage consists of fuzzy control rules which decide how the fuzzy logic control works. This stage is the core of the fuzzy control and is constructed from expert knowledge and experience. Based on the knowledge gained by analyzing the feedback control system decision making logic is given in Table 2 where 49 rules are used. The fuzzy logic control rule will be of the following type:

IF (Condition) and (Condition) THEN (Action): The rules can be interpreted as follows and then similarly other rules can be interpreted in the same way. IF error is NB AND change in error is NB THEN Control action is NB. IF error is NB AND change in error is NM THEN Control action is NB.

Defuzzification Stage: It converts fuzzy value into crisp value. In this study centre of area (COA) method is used. The triangular shaped membership function with seven linguistic values is used and it is shown in Fig. 6 the range of error, change in error and the controller output are made on the basis of practical experience.

RESULTS

The Simulation results of the Hybrid Fuzzy PI controller of the perfusion system for the four temperature conditions Mild, Moderate, Deep, Profound are given below.

Mild Temperature Condition

The given Setpoint PO_2 is 150 (mmHg)
Controller Output FiO_2 is 44.126 (%)
The PerfusionSystem Output PO_2 is 149.98 (mmHg)

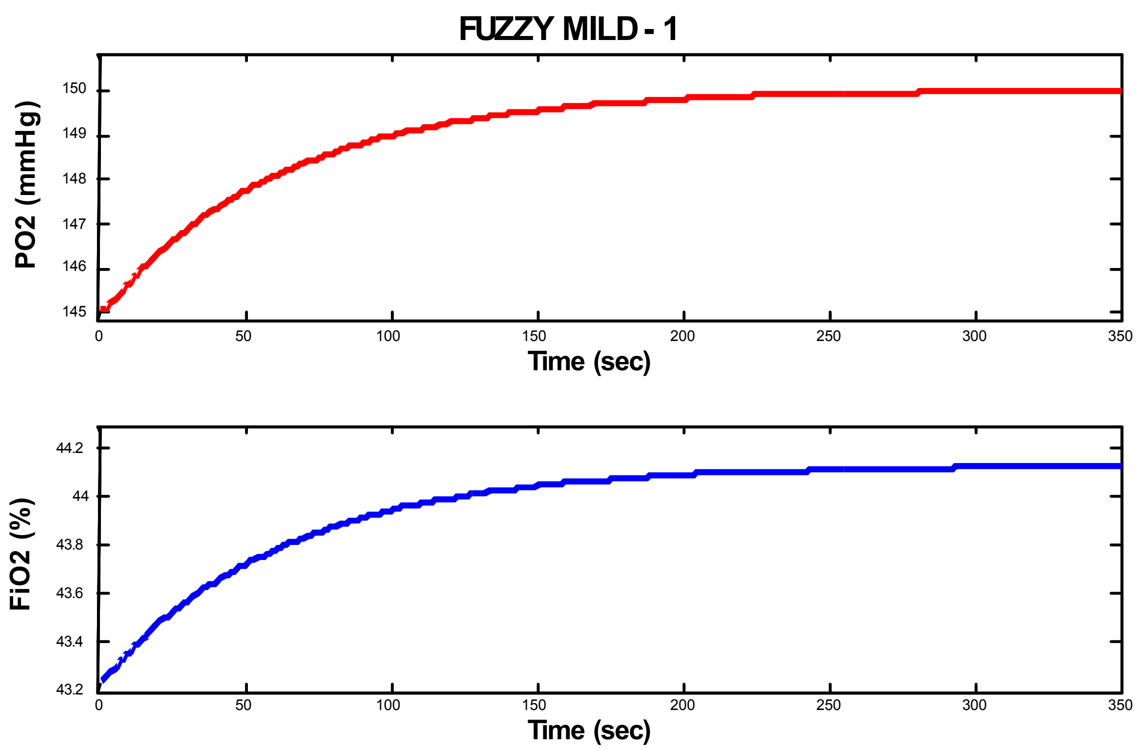

Fig. 7: Perfusion system and Controller Output(Mild)

Moderate Temperature Condition

The given Setpoint PO_2 is 190 (mmHg)
Controller Output FiO_2 is 44.501 (%)
The PerfusionSystem Output PO_2 is 189.91 (mmHg)

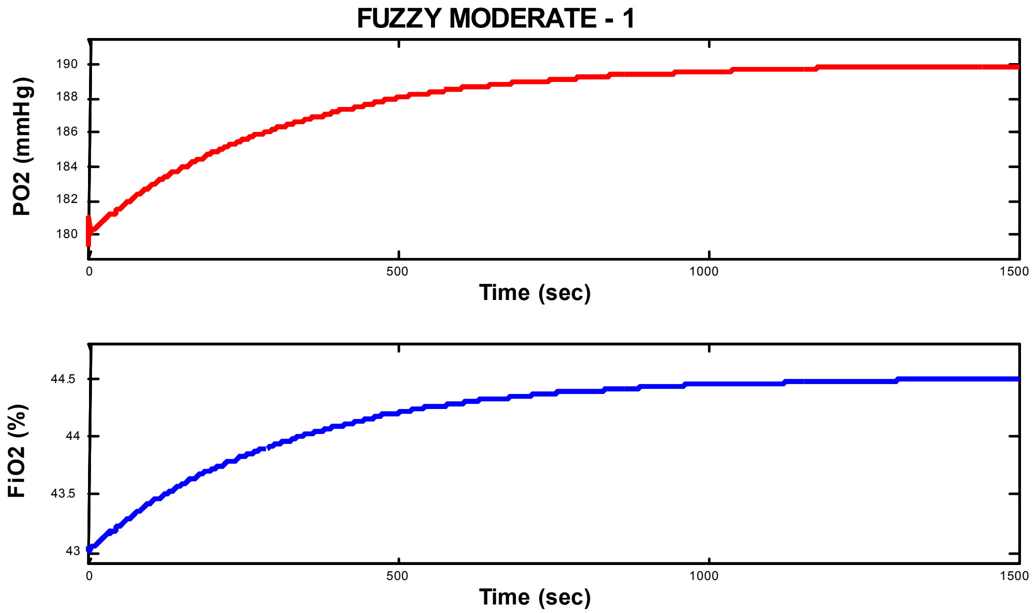

Fig. 8: Perfusion system and Controller Output(Moderate)

Deep Temperature Condition

The given Setpoint PO_2 is 215 (mmHg)
Controller Output FiO_2 is 44.205 (%)
The PerfusionSystem Output PO_2 is 214.98 (mmHg)

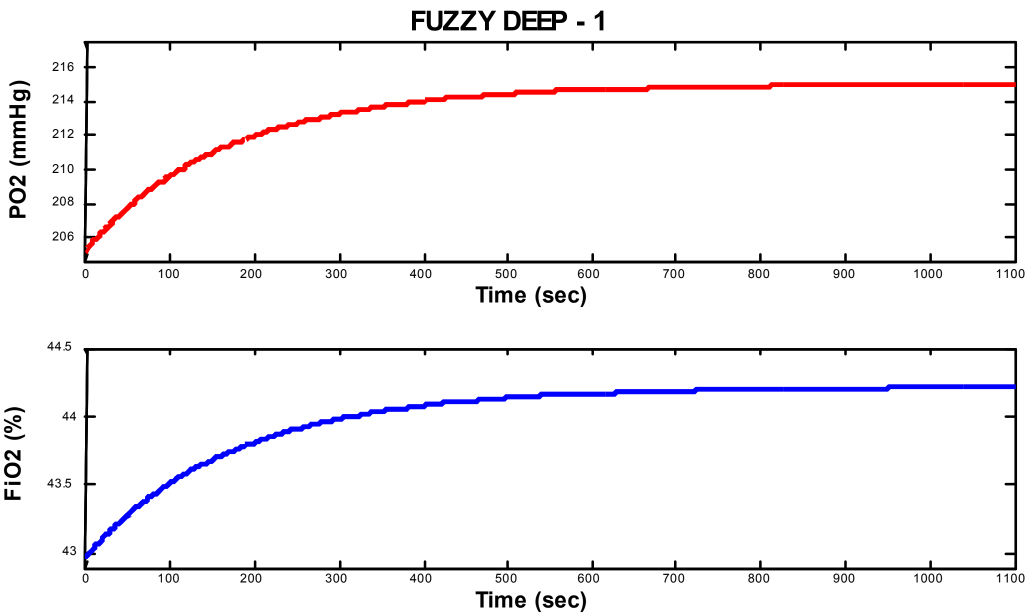

Fig. 9: Perfusion system and Controller Output (Deep)

Profound Temperature Condition

The given Setpoint PO_2 is 310 (mmHg)
Controller Output FiO_2 is 43.945 (%)
The PerfusionSystem Output PO_2 is 309.91 (mmHg)

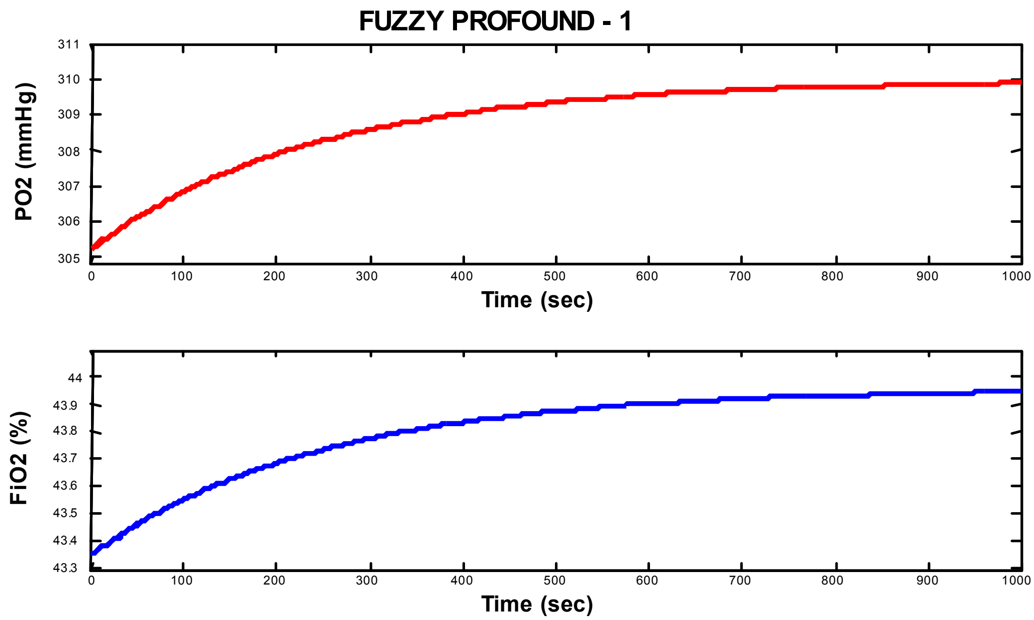

Fig. 10: Perfusion system and Controller Output(Profound)

Table 2: Performance and Evaluation of the Controller

Temperature Condition	ISE	IAE
Mild	$7.065x10^6$	$9.931x10^4$
Moderate	$2.707x10^7$	$1.055x10^6$
Deep	$2.404x10^7$	$7.72x10^5$
Profound	$4.698x10^6$	$2.181x10^5$

DISCUSSION

In this work, the Hybrid fuzzy PI controller is designed for the oxygenation process of the perfusion system in MATLAB simulink enivornment. The superiority of the controller clearly shows the potential advantages of using it. The evaluation of Integrated Absolute Error (IAE) and Integrated Square error (ISE) of the controller reveals that it has a smoother controller output. The control algorithm of the Hybrid Fuzzy PI controller has a good set point tracking and better error rejection.

CONCLUSION

Real time Blood Gas Analyzer reports of CPB surgery patients measured during HLM support are collected and completely analyzed. For perfusion system oxygenation process input value FiO_2 (%) and output value PO_2 (mmHg) are only considered for control process and it is grouped into four conditions Mild, Moderate, Deep and Profound depending on its temperature level. The Polynomial function of the Oxygenation processes values for these four temperature condition are identified using curve fitting toolbox in MATLAB environment. A Hybrid fuzzy PI Controller is designed for Oxygenation process of the perfusion system. The evaluation of the controller clearly shows the potential advantages of using this controller. The Hybrid fuzzy PI Controller is superior to minimize the error and gives good disturbance rejection which improves the performance of the process. This controller characteristics can be used in future developments of Automatic control of HLM perfusion system for CPB Surgery conditions.

REFERENCES

1. Allen, J., A.C. Fisher, J.D. Gaylor and A.R. Razieh, 1992. Developmentof a digital adaptive control system for PO_2 regulation in a membrane oxygenator, Journal of Biomedical Engineering, pp: 404-411.
2. Marlow, S., P.H. Gaylor, R.H. Wildevuur and I.C.M. Taylor, 1981 A PO_2 Regulation system for membrane oxygenators, ASAIO Truns, 27: 299-303.

3. Misgeld, B., J. Werner and M. Hexamer, 2005. Robust and self-tuning blood flow control during ExtraCorporeal Circulation in the presence of system parameter uncertainties", Medical and Biological Engineering and Computing, 43(5): 589-598.
4. Dhinakaran, M. and S. Abraham Lincon, 2014. A Study and Development of Auto Tuning Control in a Perfusion System for Extracorporeal Membrane Oxygenator, International Journal of Computer Applications, 106(16): 21-26.
5. Dhinakaran, M. and S. Abraham Lincon, 2014. Perfusion System Controller Strategies during an ECMO support, International Journal on Soft Computing (IJSC), 5(3): 13-22.
6. Zhinong Wang, 2013. The blossom of the rose of surgery The birth of heart-lung machine, Journal of Medical Colleges of PLA, 28: 11-19.
7. Manimala Rao S. and V. Nagendranath, 2002. Arterial Blood Gas Monitoring, Indian Journal of Anaesthesia, pp: 289-297.
8. Bauernschmitt, R., J. Hoerer, E. Schirmbeck, H. Keil, G. Schrott, A. Knoll and R. Lange, 2003. Fuzzy-logic based automatic control of hemodynamics, Computers in Cardiology, 30: 773-776.
9. Ziegler, J.G. and N.B. Nichols, 1993. Optimum Settings for Automatic Controllers, Journal of Dynamic Systems, Measurement and Control, 115(2): 220-222.
10. Mendel, J.M., 1995. Fuzzy Logic Systems for Engineering A Tutorial, IEEE Conference, pp: 345-377.
11. Buckley, J.J. and H. Ying, 1989. Fuzzy controller theory: Limit theorems for linear fuzzy control rules, Automatica, 25(3): 469-472.
12. Korari, M. and E. Zafriou, 1989. Robust Process Control, Prentice-Hall International, Englewood Cliffs, New Jersy.
13. Ross Timothy J., 2004. Fuzzy Logic with Engineering Applications, John Wiley & Sons.
14. Yager, R.R and P. Dimitar Filev, 2002. Essentials of Fuzzy Modeling and Control, John Wiley & Sons.
15. Driankov, D., H. Hellendoorn and M. Reinfrank, 1993. An Introduction to FuzzyControl, Springer-Verlag, New York,
16. Mamdani, E.H. and B.R. Gaines, 1981. Fuzzy Reasoning and Its Applications, Academic Press.