Design of Fuzzy Controller for Supplying Oxygen in Sub-acute Respiratory Illnesses

Prof.Dr. MOHAMED IBRAHIM EL ADAWY, Dr .AHMED MOHAMED EL-GARHY, FADY. O. SAWAFTA
Biomedical department ,Faculty of engineering ,Helwan University
Cairo, Egypt

Abstract
The knowledge in this paper describe methods and systems for supplying supplemental oxygen to patients for use in sub-acute respiratory illnesses which maintains healthy blood oxygen content in the patients by controlled dosing of oxygen with a measured response to the patient's actual blood oxygen content are disclosed. The dosing can be provided by simple ON/OFF control over the delivery of oxygen or the amount of oxygen delivered to the patient with each inhalation can be varied in response to the patient's need as determined by a more sophisticated control scheme, such as PID (proportional–integral–derivative) controller and Fuzzy logic control (FLC) that utilizes the difference between the patient's actual blood oxygen content and a target blood oxygen content and/or trends in the blood oxygen content. The systems and methods are particularly directed at patients receiving supplemental oxygen therapy in a sub-acute care environment. The result of the two controllers is good and best one is the fuzzy logic algorithm.

Keywords: FLC, PID, ***Design of Experiments by using Matlab.***

1. Introduction

Ventilated adult with low level oxygen may require elevated levels of inspired oxygen to maintain adequate tissue oxygenation .The process of administering air/oxygen gas mixtures is known as oxygen therapy and this paper is about its automation as applied to a software model of the adult. During the oxygen therapy, elevated levels of blood oxygenation, hypoxemia, must be avoided or the risk of chronic lung disease or retinal damage increased low levels of blood oxygenation, hypoxemia, may lead to permanent brain tissue damage and, in some cases, mortality. Hypoxemia (or hypoxia) is an abnormal deficiency in the concentration of oxygen in arterial blood. Hypoxemia -A decreased PaO_2 in the blood, Hypoxia -An inadequate O_2 supply to the tissues resulting in the inability to keep up with the metabolic demand of the tissues such that the end organs demonstrate evidence of organ dysfunction and Hypercapnia–An increased $PaCO_2$ in the blood. It is possible to have a low oxygen content (e.g. due to anemia) but a high PaO_2 (pressure of oxygen) in arterial blood so incorrect use can lead to confusion. The parameter causes this is defect abnormal PH (hydrogen's ions concentration (= H^+)) (7.35—7.45), CO_2 (Carbon dioxide) (35--45) and temp (36--42). In this case it leads to defect in the respiratory system called (respiratory system illnesses) so it is required to elevate level of oxygen in tissue. This oxygen is called Oxygen therapy [1-5].

There are many benefits of oxygen therapy. Oxygen therapy can assist the growth and development of children with chronic lung conditions. Adults with chronic lung disease, many studies have shown that long-term oxygen therapy has improved quality and length of life. Oxygen can decrease shortness of breathing during hard work (such as during practicing sports) and to give the ability to do more [6].

Previously many researchers was making and using many methods to solve this problem .They using manual and automatic method .The firstly method was used, manual method by controlling the dosing of oxygen therapy when the respiratory system illnesses this method called simple on/off method [7,and 8].

The second method was used from the authors automatic method in this method, can protect and deliver the oxygen supplement to patients when the respiratory system illnesses by controlling the dose of oxygen therapy automatically [8-10]. One the authors were used the PID (proportional integral – derivative) control and fuzzy logic control (FLC) by dosing the quantity of oxygen therapy delivering to the neonates, He worked his study by using commercial software was used to implement the model for a personal computer, he implement the respiratory system model, cardiovascular model, cylinder model and pulse oximeter model. Attempts to keep the neonatal models at target but more emphasis is often placed by clinical staff on keeping the patient within normoxemia [4].But in our study different from the EDMUND [7] study by controlling the amount of oxygen delivering to adult and using different cardiovascular system model was used previously from [11] . Commercial software was used to implement the model for a personal computer. A four compartment adult respiratory model which accommodated bi-directional gas flow used previously from EDMUND [7] was use in this study. The adult cardiovascular system model was used in this study. These two models were linked together to produce an adult model of the oxygen transport system and output value for oxygen saturation (SaO_2) in the alveoli were validated. In our study using the same cylinder was used previously from EDMUND [7]. A model of the air / oxygen blender (cylinder) was produced. The pulse oximeter model was representing the sensor in the matlab program.

To implement the both automatic control PID and fuzzy logic we should make the design by using Simluink toolbox in matlab software based on the human Nature (adult model).

This study explains use two controllers to delivering supplemental oxygen therapy for adult. This study applying the PID and Fuzzy logic controller on the adult model, both controllers PID and fuzzy logic are good for delivering supplemental oxygen therapy and to protect the patient.

The aim of this research develops and improves the quality for delivering and keeping the oxygen concentration at the target. In future can improve this study by using other control to protect the percent oxygen saturation at the target by using other control these control called neuro fuzzy logic control.

2. Literature Review

Abnormal temp, PH, HCT and PaO_2, causes the abnormal in oxygen saturation in the blood .In this case required to solve this problem, need implement the study should using model to delivering the oxygen therapy was used before from some authors [7].To implement this model is complex task. The inspired gas from mouth to trachea, alveoli, arterial tissue and then to circulation system.
They using three subsystem model (respiratory system, cardiovascular system and cylinder). The pulse oximeter represent by sensor in smuilink program. This study describes how to design the respiratory, cardiovascular system and cylinder then collect the two systems cardiovascular and respiratory to represent the adult model. After this explain the method control for supplying oxygen therapy and the PID, Fuzzy logic control to supplying oxygen therapy. This study used the model of the respiratory system, cardiovascular system and cylinder model, ability to predict the dynamic response of oxygen, carbon dioxide tensions, and PH in blood, tissues to abrupt changes in ventilation is important in the mathematical modeling of the respiratory system. SIMULINK is an icon model building software package and provide some component [12].Model of respiratory system and cylinder was obtained from EDMUND [7]. Model of cardiovascular system was obtained from website [11].

2.1 Modeling.

2.1.1 Respiratory system

The respiratory is primarily dedicated to the function of oxygen and carbon dioxide exchange. These gases enter and exit at each end. Gas pressure, flow and volume are parameters which describe characteristics of respiratory system. The instantaneous respiratory system pressure can be modeled with simplified equation (1):

$$P_{(t)} = P_0 + (1/C)\,V_{(t)} + (R)F_{(t)} \qquad (1)$$

Where
$P_{(t)}$: Pressure difference between atmosphere and patient airway (mmHg).
$V_{(t)}$: Lung volume above residual capacity (ml).
$F_{(t)}$: Gas flow (ml/sec).
P_0: Respiratory system offset pressure (mmHg).
C: Respiratory system compliance (cm^4*s²/gm).
R: Respiratory system resistance (cmH2O*s/L) or (dyne*s/ml).
Compliance measures how easy the respiratory system expands. If we plot the pressures versus volume for single breathe will get a circular shaped curve shown in Fig. (1).

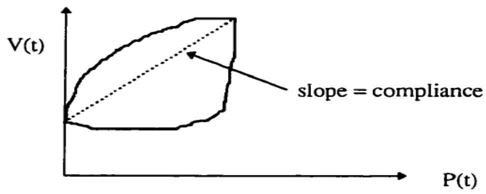

Fig.(1) pressure- volume plots (the plot is for a single breathe starting in lower left hand corner and moving counter clockwise along the curve).

Dynamic compliance is the slope of the curve. The compliance can be calculated using equation (2). A common method of estimating the average compliance is to calculate the slope of straight line from beginning to end inspiration as shown by doted in fig.(1) [13].

$$C_{(t)} = V_{(t)}/P_{(t)} \qquad (2)$$

The variation of lung volume (V) depends on the compliance (C) of the respiratory system and the variation of pressure (P) to which the system is subjected.
The following equation (3) is used to calculate the resistance which is known as the function of pressure, flow and dynamics.

$$R_{(t)} = P_{(t)}/F_{(t)} \qquad (3)$$

If we plot a pressure flow loop, an estimate of the average resistance can be calculated from the slope of straight line between the start and the end of inspiration. It is a procedure similar to calculating the average system compliance.
An analogy between an electrical circuit and pulmonary mechanics is shown in table 1[14, 15].

Table 1 Analogy between Pulmonary Mechanics and Electrical

Respiratory System	Electrical Analogue
Flow (F)	current (I)
Pressure (P)	voltage (V)
Resistance (R)	Resistance (R)
Volume (Q)	charge (Q)

Fig. (2) Represents the respiratory system compartment as modeled in RC circuit.

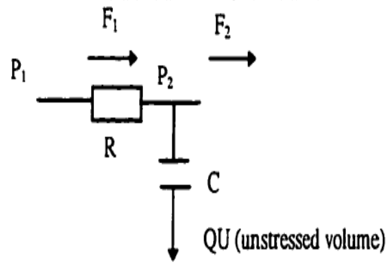

Fig. (2)Respiratory RC networks.

The electrical analogy can be used to define the respiratory values as follow:

$$F_{1(t)} = P_{1(t)} - P_{2(t)} \qquad (4)$$

$$dQ_{(t)}/dt = F_{1(t)} - F_{2(t)} \qquad (5)$$

$$P_{2(t)} = (Q_{(t)} - QU/c \quad (6)$$

Using$P_{1(t)}$, from fig. (2) And $F_{2(t)}$from the equation (5), the instantaneous pressure, flow and volume $P_{2(t)}$, $F_{1(t)}$ and $Q_{(t)}$ respectively can be calculated. Many researchers have used the model of the respiratory system to use its applications in coping with respiratory diseases [13, 16, and 17]. We have used a good model in our study to represent the respiratory system for adult [18]. This model like RC network analogy at varying level details. An appropriate modified respiratory model was given in [18] and illustrated in fig. (3).

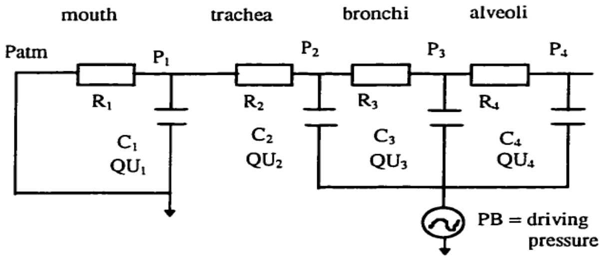

Fig. (3) Respiratory system model as modified by V.Rideout[18].

In this model for an adult there are four chambers -mouth, trachea, bronchi and alveoli, each consisting of resistance and compliance network.

The model shown in fig.(3) Like [18], assumes that resistance and compliance are constants. A more detailed model would include non-linear $R_{(t)}$ and $C_{(t)}$ but would be difficult to be implement. It is assumed that the respiratory compartments contain unstressed volume (QU1, QU2…), defined as compartment volume at zero pressure. The other assumption is that the deriving pressure of the system (i.e breathing apparatus) is sinusoidal in nature and drives negative pressure in the diaphragm. The nursery, ventilator is positive pressure device and in most cases, not sinusoidal, the researcher suggests that the SaO_2 waveform produced from the model and ventilator will produce little difference since the SaO_2 waveform is heavily filtered by the cardiovascular system mixing chambers.

Only about two thirds of each tidal volume reaches the alveoli for gas exchange. One portion not involved with gas exchange is called the anatomical dead space volume and it includes the mouth, trachea, bronchi, and compartments. The model accounts for anatomical dead space by not allowing gas exchange from these compartments with blood; alveolar dead space is a function of the pulmonary blood [18].The respiratory system model was implemented using the MATLAB/SUMILINK. The model shown in the following block diagram fig. (4) Deals with flow of air and assumes that the total flow out of the alveoli (into the blood) is very small and these models represent only station for oxygen transport in adult.

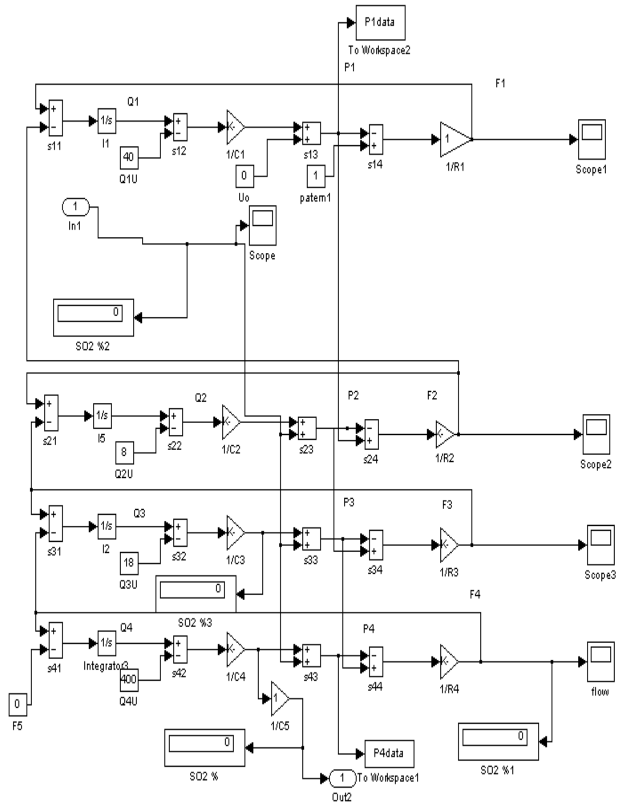

Fig. (4) Respiratory system models in MATLAB/SUMILINK This model represent equation (4), (5), (6).

In respiratory system model the flow, pressure and volume values of oxygen Increases the percentage of oxygen in air and the direction of flow – inspiration or expiration. Thus, the model for air transport is used to produce a total flow for each compartment and from this, the flow and volume of oxygen derived. This model must also deal with the flow of air (and oxygen) in both directions. This is complicated by the fact that oxygen flows out of the model at the alveoli faster during inspiration than at expiration. To account for this, switching function was produced which derives the compartments pressure as a function of the direction of total gas flow. During inspiration the oxygen partial pressure difference between the alveoli (PaO_2) and the pulmonary capillary blood (PcO_2) is high because the lungs are filling with fresh air and deoxygenated blood is flowing through the lungs. On the pulmonary venous side of the lungs, the partial pressure of oxygen is approximately equal to that in the alveoli. In small notes during inspiration oxygen flows out of the lungs and into blood regulated by the circulatory system blood flow. During expiration, oxygen is no longer flowing into the lungs but it is still depleted by the pulmonary capillary blood flow resulting in a lowering of the partial pressure of the oxygen in the alveoli [18].

2.1.2 Cardiovascular system

The cardiovascular system consists of pulmonary capillaries, pulmonary veins, heart, systemic arteries and systemic capillaries. Oxygen bounded to hemoglobin and dissolved through this loop (circulatory loop). Many cardiovascular models were used in [19-22].

A set of Matlab–Simulink modules was developed based of well known and commonly used modeling methods. To use a module, the developer 'drags' a module from the library into a document and can connect it to other modules. A Heart module, for example can be connected to a heart rate generator, a vein on one side and an artery on its other side. Parameters regarding its operation can be set as well. Each module comes with a detailed 'help' document. Thus, building a model is reduced to a 'drag and drop' procedure and setting of parameters. The Cardiovascular modules are partitioned into libraries:

Heart —Include Ventricles Modules, Atrials Modules and Valve Module.
Vessels—Include Vessel Module and Unidirectional/ Bi-directional shunts.
Oxygen Transport—Include Hemoglobin Dissociation Curve module and Oxygen Transfers modules.
Measurements—Blood Flow and Pressure measurements modules.
Miscellaneous—Include different modules used in the toolbox development:

Windkessel Model, Non-Linear Compliance and Resistance etc. The Cardiovascular Blockset uses the Power System Blockset and other standard Simulink Blocksets—creating two types of signals: Power System Blockset signals to simulate pressure and flow (analogous to voltage and current) and standard Simulink signals for other uses. The two types of signals cannot connect to each other, unless using the dedicated I/F in the Power System Blockset. In Cardiovascular Simulink Blockset any signal (block's input or output) without name is a Power System Blockset signal and can be connected only to another signal/port from the same type.

2.1.2.1 Heart Chambers

Cardiac contraction follows the functional ''varying elastance'' model [23]. The varying elastance model predicts ventricular pressure as a function of the elastance function and instantaneous volume.
Volume is affected by preload and after load conditions. When this model is coupled to a model of the circulation, one can simulate the heart response to various filling pressure, end diastolic volume and aortic pressures. The toolbox uses different equations to model the systolic and diastolic stages of the mechanical activity of the chamber. During systolic activity, pressure generated in the chamber follows the well known varying elastance formulation shown in equation 7 [24]:

$$P = E_{max} E_N(t/t_{max}).V(t) - V_0) \qquad (7)$$

Where P the chambers pressure, E_{max} is the maximal chamber pressure–volume relation, $V(t)$ is instantaneous chamber volume and V_0 is a constant. t_{max} Is the time when the elastance function assumes its maximum value—normally close to end systole and may be, adjusted to correct for changes in systolic duration at different heart rates. Left ventricular $E_N(t_n)$ $(t_n = t/t_{max})$ function is described in Equation. (8) While Equation (9) describes the RV, RA and LA E_N function [25]. Note, only the positive values are used.

$$En(t_n) = -1.841\, t_n^3 + 2.685\, t_n^2 + 0.158\, t_n \qquad (8)$$

$$En(t_n) = -3.374\, t_n^3 + 6.568\, t_n^2 + 1.934\, t_n \qquad (9)$$

The diastolic passive stage is related to the blood filling stage of the chamber is characterized by its pressure–volume relation shown in equation (10) [25]:

$$P(t) = e^{(K.V(t))} - 1 \qquad (10)$$

Chambers' in low and outflow are calculated based on the pressure gradients and the properties of the conduits. Through which blood flows depending on the model that is constructed. The graphic representation of the left ventricle is shown in Fig. (5). Inputs are on the left side of the block and outputs are on the rights side. Inputs include the oxygen saturation level of previous segment, HR (Heart rate) from a controlled generator and the unmarked input is the blood pressure/flow—this is the electrical flow signal as in the Power Block set. The outputs include oxygen saturation (in present model—unchanged from input level),V_{MON} (volume monitoring) output and the blood pressure/flow output.

Fig.(5) Graphic representation of the heart module

2.1.2.2 Blood Vessels

The vessel-segment model is based on a reduced Navier-Stokes equation (11) following several assumptions [26].

$$\Delta P = L.\frac{\partial F(t)}{\partial t} + KR.F(t) \qquad (11)$$

Where K is equal to 1 for parabolic velocity profile and can be set to higher values to account for flat velocity profiles as in entrance effects, especially in the proximal aorta [27]; P is pressure, F is flow, R is resistance and L is effective inertance.
The equation (12), where l is segment length, r is the vessel radius η is the Blood Viscosity and ρ - Blood Mass Density. The vessel property that is not included in the Navier- Stokes equation but affects continuity, is the vessel compliance represented by a nonlinear capacitor C in the electrical analog where R is a resistor and the intertance is an inductor Fig. (6).

$$R = \frac{8\eta l}{\pi r^4} \qquad L = \frac{\rho . l}{\pi r^2} \qquad (12)$$

The Vessel Non-Linear Compliance is expressed by the following equation (13):

$$P(t) = p_2 V(t)^2 + p_1 V(t) + p_0 \qquad (13)$$

Where $P(t)$ is the instantaneous pressure, $V(t)$ is the instantaneous volume and P_0, P_1, P_2, are the constants. The blood volume in a segment is represented by the charge in the capacitor. This variable is used to recalculate the vessel radius at each time step and update the value of R and L.

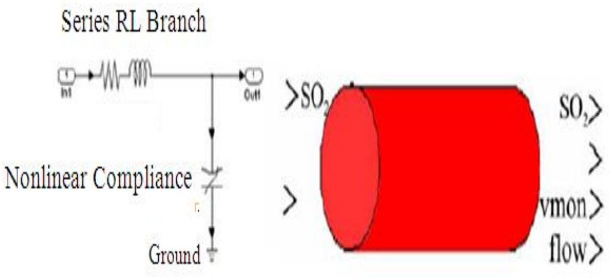

Fig. (6) Vessel analog model and its simulink graphical representation

The graphic representation of the vessel segment includes inputs on the left and outputs on the right. Inputs include SaO_2 and blood flow signal. Outputs include SaO_2, blood flow signal, monitoring of segment's blood volume and flow output (flow meter is included in segment).

2.1.2.3 Heart Valves

The valve model is based on the following electrical analog circuit: The model includes two diodes—one for the forward flow and the second for simulating regurgitation. The parallel RC branch simulates the viscoelastic properties of the leaflets. In the model, each diode has two parameters: R_{on} is the diode forward resistance and V_f is the diode forward voltage that simulates the opening pressure of the valve. The graphic representation of the valve segment includes inputs on the left and outputs on the right. Inputs and outputs include SaO_2 and blood flow signal Fig. (7).

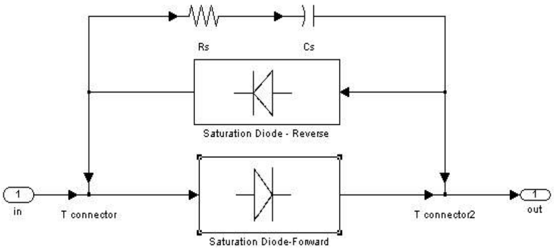

Fig. (7) Valve analog model and its simulink graphical representation.

2.1.2.4 Oxygen Exchange

Gas exchange mostly takes place at the alveoli-pulmonary capillary interface and at the systemic capillary tissue interface [28]. The model assumes gas exchange depends on the gradient of O_2 partial pressure. This assumption is reasonable for healthy human with heart rate less than 180 bpm [28]. The model simulates two physiological phenomena. The first is the active oxygen carrying capability during passage through the lungs while dissolved oxygen is neglected and is based on the dissociation curve and the second is oxygen delivery to the tissue. The dissociation curve is shifted with changes in temperature, 2, 3-DPG,PCO_2, or PH. This simulation the dissociation curve is calculated using the following equations (14, 15) [29]:

$$SO_2 = \frac{a_1 PO_2 + a_2 PO_2^2 + a_3 PO_2^3 + a_4 PO_2^4}{a_4 + a_5 PO_2^5 + a_6 PO_2^6 + a_7 PO_2^7 + PO_2^8} \qquad (14)$$

$$PO_2 = PO_2 . 10^{0.024(37-T)} + 0.4(PH - 7.4) + 0.06.(\log_{10}(40) - \log_{10}(PCO_2)) \qquad (15)$$

Where SaO_2blood's oxygen saturation [%],PaO_2 is blood's oxygen partial pressure [mmHg], PCO_2 is bloods CO_2 Partial pressure [mmHg], T is temperature [Celsius] and a_i are constant coefficients. Oxygen transfer is based on gradients and conservation of mass as described in (Equation 16) for the lungs and Equation (17) for the intracellular interface [30]:

$$D_{pa}O_2 + Vo_2^{\bullet} = D_{pv}O_2 \qquad (16)$$

$$D_{A0}O_2 + Vo_2^{\bullet} = D_{sv}O_2 \qquad (17)$$

Where, $Vo_2^{\bullet}$ is body O_2 consumption, which at equilibrium, equal to O_2 uptake at the lungs, $D_{pa}O_2$ is pulmonary artery O_2 flow rate, $D_{pv}O_2$ is pulmonary vein O_2 flow rate, $D_{A0}O_2$ is aorta O_2 flow rate, $D_{sv}O_2$ is systemic vein O_2 flow rate. The relation between O_2 delivery and oxygen content (CO_2) and flow described in (Equation. 18):

$$DO_2 = Co_2 F \qquad (18)$$

Where F ,is blood flow. Hemoglobin's Oxygen-carrying capacity is 1.36ml O_2 per gram. Each ml of Hematocrit contains 1/3.15 g Hemoglobin [31]. $CO_2 - O_2$ Conversion is done base on (Equation 19):

$$Co_2 \left[\frac{mlO_2}{mlBlood}\right] = 1.34 * Hgb \left[\frac{g}{mlBlood}\right] * \frac{So_2[\%]}{100} = 1.34 * \frac{HCT[\%]}{315} * \frac{So_2[\%]}{100} \qquad (19)$$

2.1.2.5 Blood Flow and Pressure Measurements

Blood flow meter is simulated using Electrical Amper-Meter Module. It is connected in series to any of the modules. The blood pressure meter is—simulated using Electrical Voltage-Meter. It is connected in parallel to the measuring point and the reference point shown in Fig. (8).

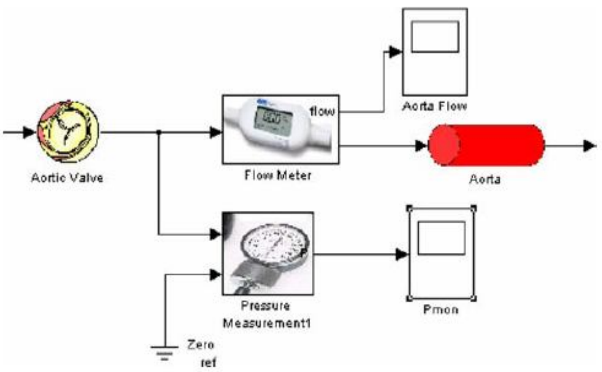

Fig.(8) Example of Measurements tools usage.

Examples

Left Ventricle and a Three-element,Windkessel Model, the simulation includes the following component as shown in the electrical analog model Fig.(9) from left to right:

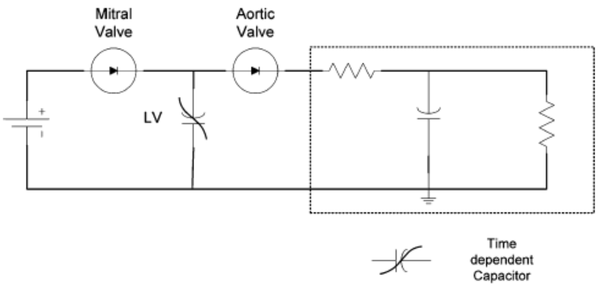

Fig. (9) Windkessel ''Three- Elements'' Model.

1) a voltage source simulating venous pressure for ventricular filling, mitral valve as a simple diode (degenerated valve model), time varying elastance model, aortic valve and a windkessel load (also available as a single component).

The Simulink model including monitoring component is shown in Fig. (10).

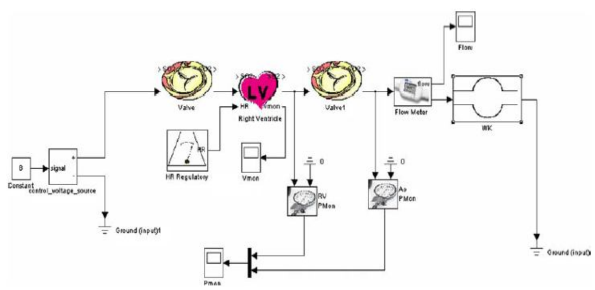

Fig. (3.10) A Simulink model of a single ventricle connected to a windkessel load and monitoring devices.

Collecting the parts of this model will produce the cardiovascular model and test this model has been tested in this program by using matlab program sumlink. The following model fig.(11) was used in our research.

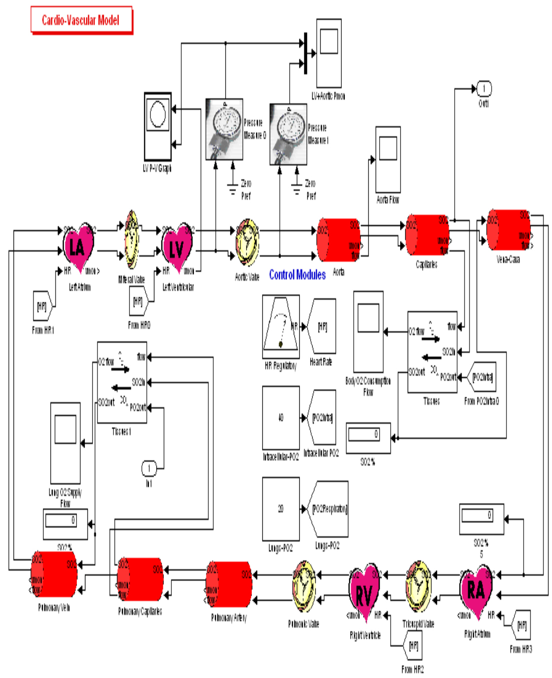

Fig. (11) Cardiovascular system model implement by using sumilink tools. [11].

2.1.3 Oxygen blender model

Other model which used in this study Relates to models of cylinder to deliver supplemental oxygen to the patient. This model was implemented by using simulink program. The model receives the signal from controller and the O/P of this model goes to the patient. Fig.(18) explains how this model used, was acquired from [7].

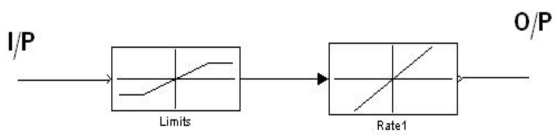

Fig.(12) Represent Cylinder models [18].

2.2 MANUAL CONTROL

Experienced nursing staff can provide stable and accurate oxygen therapy for the patient. They have the ability to filter (ignore) erroneous pulse oximeter signals that are the result of sensor noise. Another skill they possess is the ability to accommodate the non-linearity of the oxygen transport system, small $\mathbf{FiO_2}$ adjustment for desaturation and large adjustment for saturation.The most important ability of nursing staff is associated with the knowledge they gain while working with a patient for a few days. They can pick up trends; accommodate changes due to drug therapy. All these skills have been observed in patient care.

The above paragraph seems to contradict previous statements, about the automation of oxygen therapy leading to an improvement. This contradiction is related to the fact that, in real nursery environments, staff cannot dedicate their time to continuous oxygen therapy. Nursery staff may attend to more than one patient and also must provide time for other tasks such as feeding, changing, suctioning and parental consultation.

A common method of applying O_2 therapy in the nursery is to find a FiO_2 setting which provides the patient with an SpO_2 of about 95%. Then alarm levels are set at about 90% and 98%. When an alarm occurs, the attendant checks for motion artifact by observing the patient and then compares the pulse oximeter's heart rate reading with that from an independent heart rate monitor. If the independent source is stable but the pulse oximeters heart rate value is low or high, the staff concludes that the alarms are the result of sensor and no FiO_2 adjustment is made. If however the heart rates from the two instruments are about the same, saturation or desaturation has occurred. In this case, nursery may wait 10 to 15 seconds to see if patient returns to normoxemia. During this period another check is made of the patient's condition – skin tone is often an indicator of tissue oxygenation. At the discretion of the nurse, an FiO_2 adjustment is made if further episodes occur or SpO_2 levels appear poor.

The above paragraph is a general description of a method for providing oxygen therapy requiring several inputs - SpO_2 pulse oximeter heart rate, skin tone, independent heart rate, patient motion, pervious occurrences. The essence of this type of control is to maintain normoxemia (90% to 98%) rather than a specific set point.

Should the test scripts have a requirement for more manual adjustment, perhaps, but the end result, in manual mode would be the same. In response to the programmed manual adjustments, the patient model would spend most of its time in normoxemia. The automatic controllers would react to SpO_2 changes outside normoxemia in a similar fashion to SpO_2 changes.

Some Studies have dealt with this subject explaining ways to use the nasal canal to deliver the oxygen therapy [32].The set point is blood oxygen saturation (SaO_2) of 90% [8,33].But here in this study the set point of blood oxygen saturation (SaO_2) is 95%.

But this method is too much costly and needs more time for the physician who is supervising many cases at the same time. fig(13) shows this manual control. Here should improve the new method to control delivering oxygen therapy. The said method can be improved by improving automatic control.

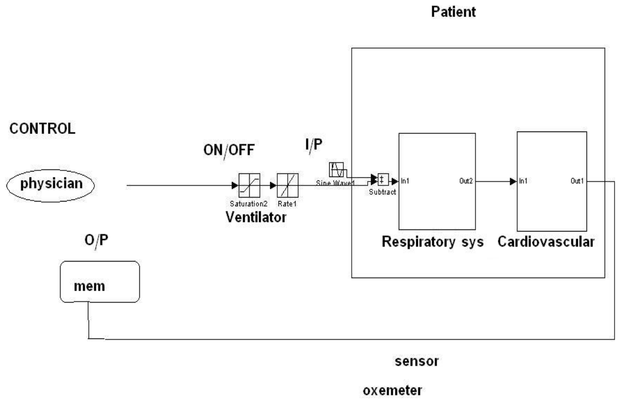

Fig. (13) Block diagram represent manual control.

2. 3 PID CONTROL

The PID algorithm consists of three basic modes: The Proportional, Integral and Derivative mode. When utilizing this algorithm it is necessary to decide which mode is to be used (P, I or D?) and then specify the parameters (or settings) for each mode used, three basic algorithms are used P, PI or PID Dr M.J. Willis [34].

Classic feedback control methodology can be applied to SaO_2 control as was done by [35]. His controller is based on a first order model of the system which consists of a non-ventilated patient in an air/oxygen filled incubator. This resulted in a simple system with, understandably, a large lag. Taube's work is based on the fact that most non-ventilated patients tend to be quite stable. In other words, his controller was applied to a relatively stable system where the patient's oxygen transport system acted in a linear fashion (their SpO_2 set points were far from "knee" of the oxygen dissociation curve). This paper is focused on ventilated low patient who tends to be unstable with target SpO_2 values close to the "knee" of dissociation curve.

The patient model developed in figs.(4,11) is non-linear as illustrated in fig (16). Equation 20 defines the feedback value, $u(t)$ as a function of the error, e, its integral and derivative. When K_P increases, the response speed of the system increases and the overshoot of the closed-loop system increases consequently the steady-state error decreases. However when K_P large enough, the closed-loop system becomes unstable. We can observe the block diagram of the PID controller design in the following fig (14) [36]. Where u(t) is the input signal to the plant model, the error signal $e(t)$ is defined as $e(t) = r(t) - y(t)$, and $r(t)$ is the reference input signal.

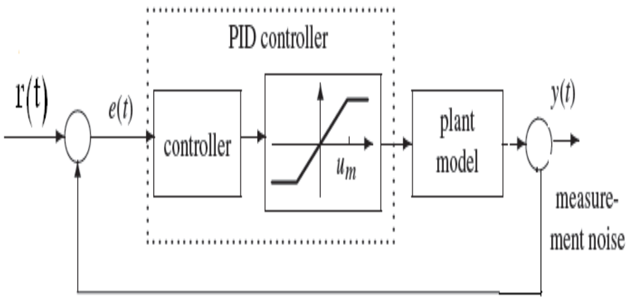

Fig (14) a typical PID control structure. The mathematical representation in equation (20):

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(\tau)d\tau + T_d \frac{de(t)}{dt} \right] \quad (20)$$

Where:

$$Ki = Kp/Ti \quad (21)$$

$$Kd = Kp * Ti \quad (22)$$

Franklin [37] suggests a simple method where the general slope and system lag illustrated by a step response can be used to set the PID gains. Fig (15) is a simplified diagram of a generic system open loop step response. The PID gains can be calculated as follows:

$$Kp = 1.2 * R * L \quad (23)$$

$$Ki = Kp/2L \quad (24)$$

$$Kd = 0.5 * L * Kp \quad (25)$$

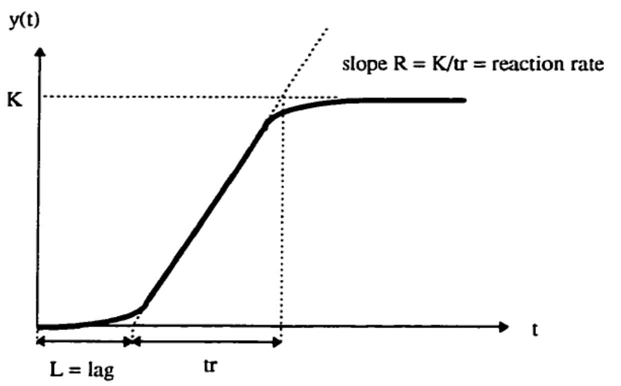

Fig. (15) Generic System Response-modified from Franklin GF.Feedback Control of Dynamic Systems .Addison-Wesley, Don Mills, Ontario, 1986.

The following table 2 suggests that average gains of (1.00, 0.100 and 2.5) for (Kp, Ki and Kd) would provide adequate control. This controller, however, would be slow to respond to SaO_2 drops within the 90% to 95% range since table 2 suggests gains larger for this region. Since the region in question is normoxemia , the proposed average values are acceptable.

Table 2

Kp	Ki	Kd
1.00	0.100	2.5

PID design includes some of the methods of Zichlor and Laplace transform. In our study we have chosen the random mode and we select some of values and trying to run PID at least one month to get the best value for this controller. A PID controller was designed using empirical gains ($Kp = 10, Ki = 0.100, Kd = 2.5$).
We have collected all the part model which relate to the patient and the cylinder to implement our study. We have connected the cylinder model with the respiratory system and cardiovascular systems models and the PID Control with the cylinder. The input of the PID is error from the O/P of the system dependent on the error coming to the controller. The O/P of system compared with target and gets the difference. This difference is the error. The PID dependent on the error, input to increase or decrease the output going to system. The following block diagram Fig (16) represents the PID controlling of the Oxygen. The first block represents the PID control, the second represents the cylinder model and third represents the respiratory model and the last block is the cardiovascular model. Ventilators strategy called high frequency ventilation (HFV) is one of the new ventilator techniques. Ventilator frequency is increased during HFV. Frequency rate is in range 10-25 Hz. This increase of the ventilator frequency allows a significant decrease in pressure amplitude and delivered tidal volume [38].

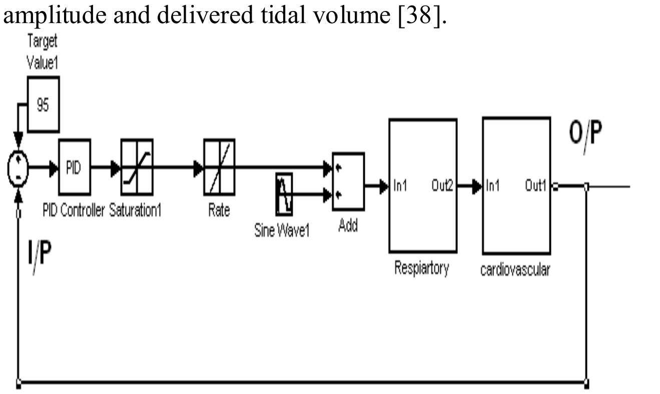

Fig. (16) Block diagram represent modeling using PID control.

Many of the parameters affect in this model used in this research but a high PaO_2 in arterial blood so incorrect use can lead to confusion. The other causes for abnormal PH (6.35—6.45), CO_2 (35--45), temp (36--42) and HCT (21--28), this case required elevated level of oxygen in tissue. This oxygen called Oxygen therapy [39].
Here giving the shortness and some of value used to design PID control in the following figs.(14, 15 and 16). We can observe this value in the following table, also the setting time, rise time and over shoot.

Table *3*

P	I	D	PH	Over shoot	Setting time	Rise time
20	3	10	6.5	4%	47.235	42.5115

Table 4

P	I	D	PH	Overshoot	Setting time	Rise time
30	14	0.3	6.5	5%	82.6613	74.395 1

Table 5

P	I	D	PH	Overshoot	Setting time	Rise time
10	1	14	6.5	0	7.7765	6.9988 5

Finally the good value used to design the PID control in this study, (10, 1, and 14), was getting good result for this value.

2.4 Fuzzy logic control

Fuzzy logic has become common in machine control. Buzzword Fuzzy Logic has emerged as a simple tool for controlling of complex processes. The fuzzy controller is based on fuzzy logic. First introduced fuzzy logic in 1965 [40].
The fuzzy logic Controller is preferred for very complex processes, when there is no simple mathematical model, also for highly nonlinear processes if the processing of (linguistically formulated) expert knowledge is to be performed. The FLC is simplified & reduced development cycle in design and ease of implementation. Addition, FLC can provide more "user-friendly" and efficient performance. FLC is preferred in many applications such as control process (robotics, automation, tracking, consumer electronics), and decision support (sensor fusion). This section explains the principles of fuzzy logic control describing the controller algorithm and main components with different alternatives.
Fuzzy Logic Controller (FLC) Principles: The digital signal is divided into two signals high and low, while the fuzzy logic divides a signal into multi level between high and low called fuzzy set. The controller design depends only on the experience, which provides the relation between the controller input and output.
The FLC describes and deals with the signals like a human description for such signal. For example, it is possible to divide the error signal into negative big, negative, zero, positive, and positive big which is called "fuzzy set" forming the error membership function.
To emulate the controller behavior with the human one, the controller must have an algorithm, which does the following:

1- Translates the crisp input signal into a fuzzy set with a degree of truth (μ) via membership function, which is called fuzzification,

2- Applies the controller base rules (inference engine) to the fuzzification output producing the output fuzzy set.

3- Converts the output fuzzy set into crisp output via output membership function, which is called defuzzification.

To construct a universal controller for different scales, another two steps will be added to deal with as per unit values. The first step is to normalize the input, while the second step is denormalization, which will be carried out to produce crisp output from the corresponding per unit value. The following fig (17) showing the structure of fuzzy logic.

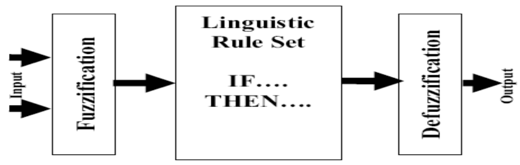

Fig. (17) Structure of Fuzzy Logic [41]

Fuzzification: That means the assigning of the linguistic value; define by relative small number, of the membership function to variable.
Rule: This study, logic operation are applied. So IF THEN rule in this table coming, describe the rule use in our control.
Defuzzification: The method computes the center of composite area represent the output fuzzy term.
A common method of implementing a fuzzy controller is to use the error and error rate as inputs (Driankov,1996) which are used to implement a proportional –derivative (PD) controller .Error inputs have memberships associated with fuzzy sets: positive big (PB); positive medium(PM);positive small (PS);zero (ZO);negative small (NS);negative medium (NM); negative big (NB).On first trial, the error rate input had memberships with three fuzzy sets –"positive", "zero" and "negative" .The output is an FiO_2 increment/decrement which is integrated over time to produce the control .seven fuzzy sets make up the universe to which " FiO_2_increment" can have membership and include positive big (PB); positive medium(PM);positive small (PS);zero (ZO);negative small (NS);negative medium (NM); negative big (NB).a single rule has the form : "if (error is PB) and (error rate is very positive) then (FiO_2_increment is NB)" Table 6 is a summary of 49 rules which make up the control law. The first row and column represent the "error " fuzzy sets respectively ; and "error rate" ,the remaining table entries represent the resultant O/P (FiO_2_increment) sets.

Table (6) represent the Rule base was used [41]

de_k \ e_k	NB	NM	NS	ZO	PS	PM	PB
PB	ZO	PS	PM	PB	PB	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB

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PS	NM	NS	ZO	PS	PM	PB	PB
ZO	NB	NM	NS	ZO	PS	PM	PB
NS	NB	NB	NM	NS	ZO	PS	PM
NM	NB	NB	NB	NM	NS	ZO	PS
NB	NB	NB	NB	NB	NM	NS	ZO

The membership functions for the fuzzy sets associated with the inputs are illustrated in figs. (18 and 19).Triangular error functions have been used in an effort to reduce computational time .The "error " values greater +20% are all PB and less than -20%are NB. Since the physiologically significant SaO_2 values are within this range, by setting these saturation points, de-emphasizes large errors by setting a constant gain. This is one method of ignoring artifact which tends to be outside this region. In other words, error values outside ±20% SpO_2 are suspected as artifact.

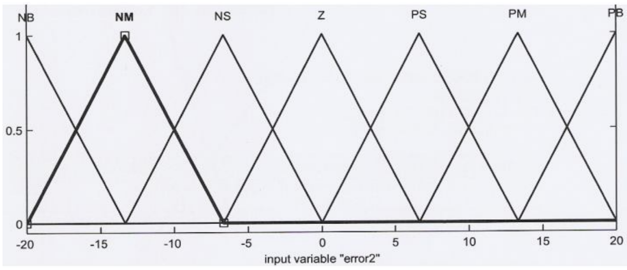

Figure 18 Error Member ship function

The "error rate "fig (19) input is sensitized near zero by placing the "positive "and "negative" membership functions within ±13%..

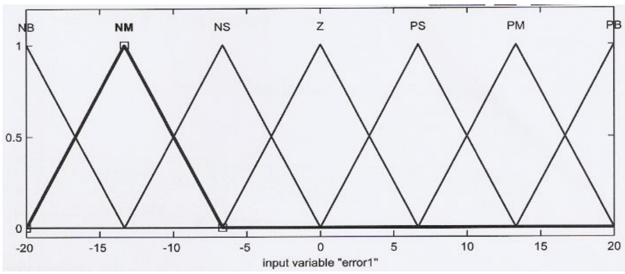

Fig 19 Change of error Member ship function

The range of the O/P linguistic variable "FiO_2_increment", as shown in fig (20), has been normalized so that the overall gain can be set external to the fuzzy controller –a convenient means of tuning it . Also, note positive membership functions cover half the range as those of the negative . This method of implementing the non-linearity of the oxygen transport system .The slope of the oxygen dissociation curve tends to very small above normoxemia but large below implying that negative increments, due to hyperoxemia should be large to effect a small SaO_2 decrease. Conversely, positive increment to counter –act hypoxia should not have to be as large since ,due to the steep portion of the curve, small FiO_2 increments will realize large SaO_2 increments.

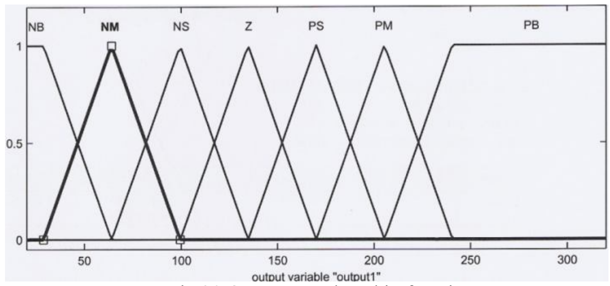

Fig 20 Output Member ship function

Collecting the block of fuzzy logic controller with cylinder model, respiratory system model and cardiovascular system will produce fuzzy control amount of oxygen therapy in the following fig (21). These blocks explain the fuzzy logic control for delivering the oxygen therapy for patients with the respiratory system illnesses. If there is any abnormality in the parameter, the controller sets the system till the target reaches its set.

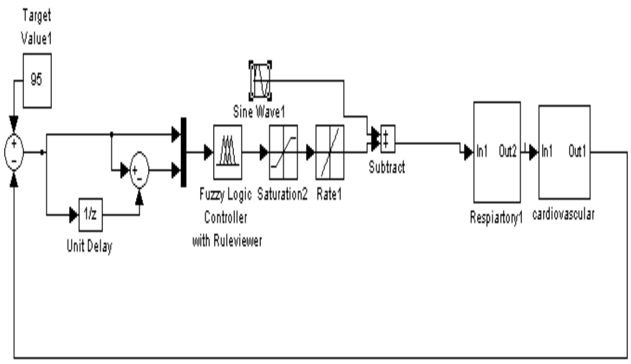

Fig (21) Block diagram using fuzzy logic control.

3. Results

3.1 PID

The automatic controllers provided an improved target performance over manual mode with the FL controller providing the best. Note that the PID controller, on average, did improve normoxemia performance over manual mode but with regards to target performance it did. This implies that the PID controllers success response to caused it push the model to the normoxemia and, quickly back to target.

We have applied the PID control for adult model and put the target 95% for oxygen saturation. If there is any change happens in the parameters, the percentage of oxygen will be oppositely affected. This control increasing / decreasing the oxygen provided to the patient and protects value to the target chosen by medical staff or physician. The model used in this research was two parameters affected in saturation. Incorrect usage of high PaO_2 in arterial blood can lead to confusion. If there is abnormal indices for PH (6.35—6.45), CO_2 (35--45), temp (36--42) and HCT (21--28), in such a case there will be a need to elevate the level of oxygenation for the tissues. This oxygen called oxygen therapy. In the following, some figs. (22a, 22b, 23, 24a, 24b, 25) with different PH and temp, in which we can observe how the controller elevate or decrease the oxygen therapy when the PH and temp increase or decrease.

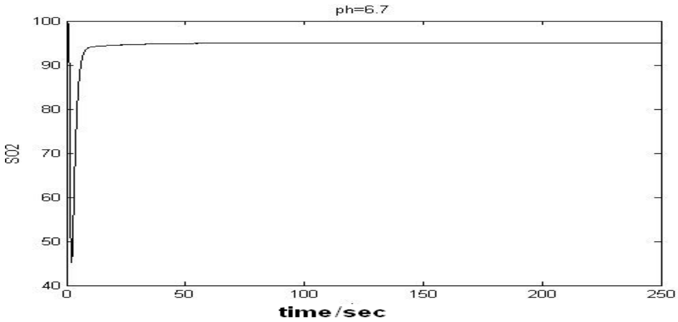

Fig. (22a) with PH=6.7

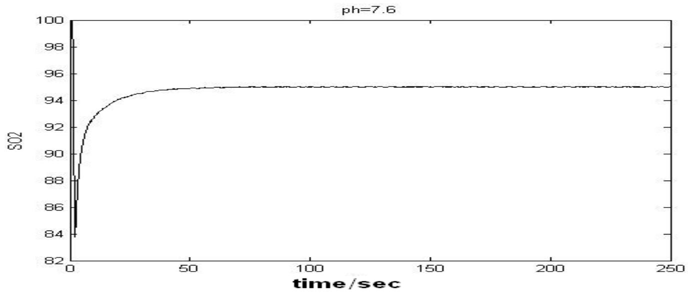

Fig. (22b) with PH=7.6

This result with different value for PH when the system dynamic we can see in the fig. (23).

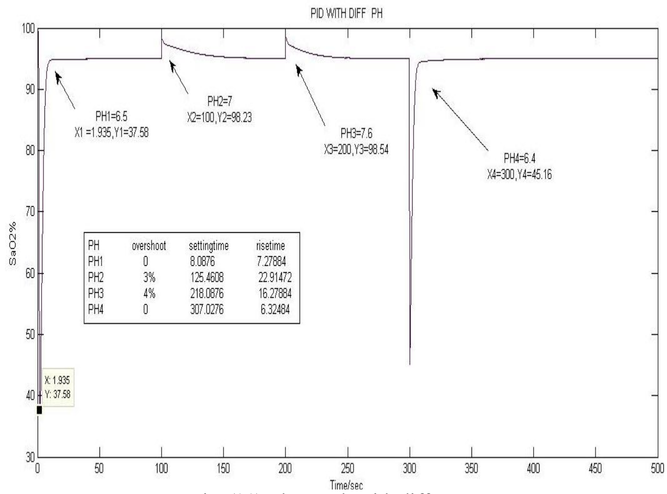

Fig. (23) The result with diff PH

The Temp = 35.5, 42 respectively this the value for Temp out of normal range, and this is the SaO_2 result when the controller controlling for the system by using PID control in the following two figs.(24a,24b) explained that.

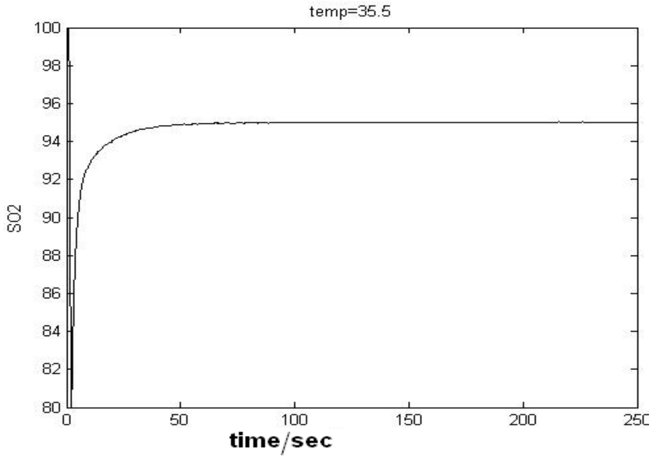

Fig.(24a) with temp= 35.5

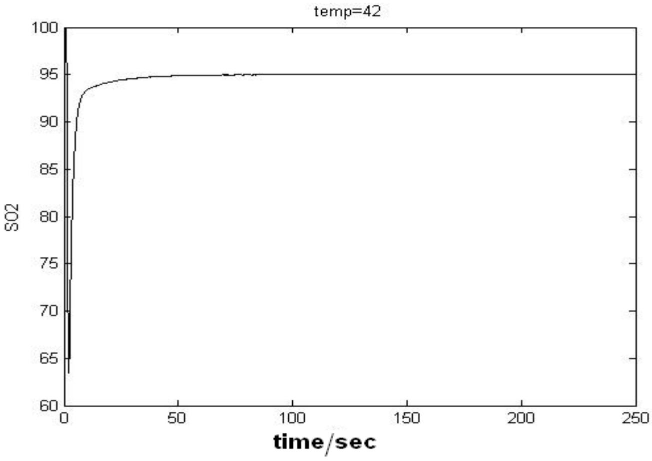

Fig.(24b) with temp 42

This result with different value for temperature when the system dynamic we can see in the fig. (25).

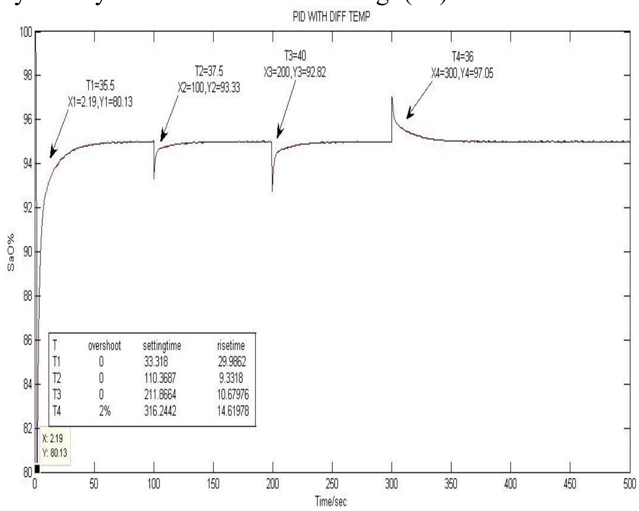

Fig.(25) the result with different temp.

3.2 FUZZY LOGIC

The fuzzy logic controller provided, on average better target and normoxemic performance than PID controller and was good as manual mode. Overall, the fuzzy logic control provided the best target and normoxemic.

The other results for fuzzy with different PH and the value for setting time, rise time and over shoot Figs. (26 a, 26 b). Tables 8 explain these values.

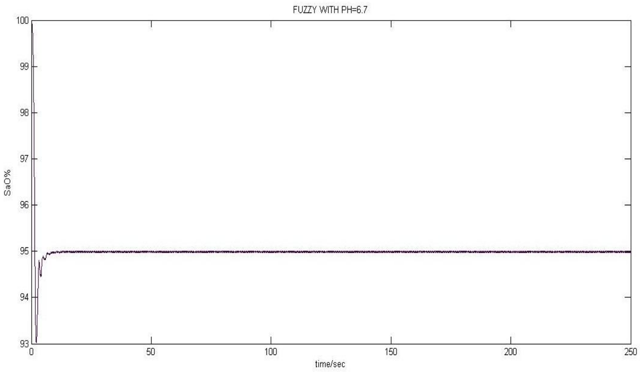

Fig.(26a) with PH=6.7

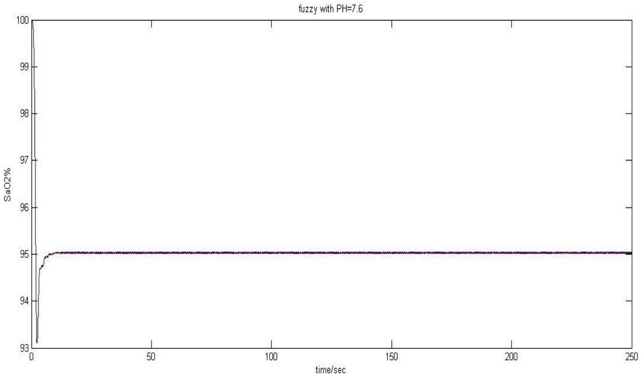

Fig. (26b) with PH=7.6

This result with different value for PH when the system dynamic and the change as the same time changing apply to PID control fig.(27) explain that.

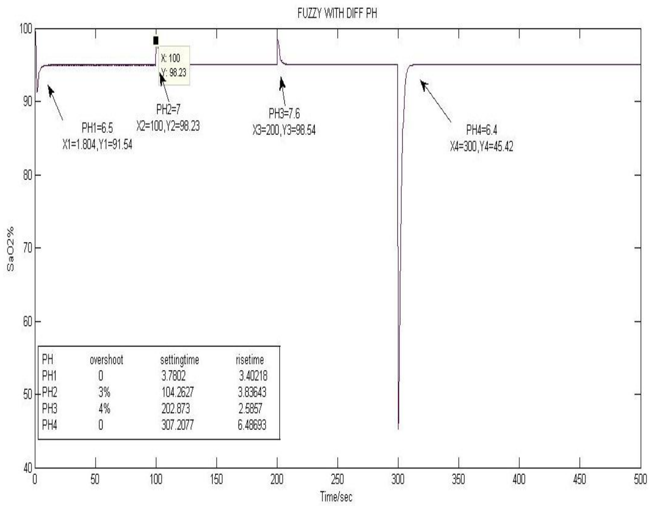

Fig. (27) With different PH.

The Temp = 35.5, 42 respectively this the value for Temp out of normal range, and this is the SaO_2 result when the controller controlling for th system by using fuzzy logic control we can showing that in figs.(28a,28b) .

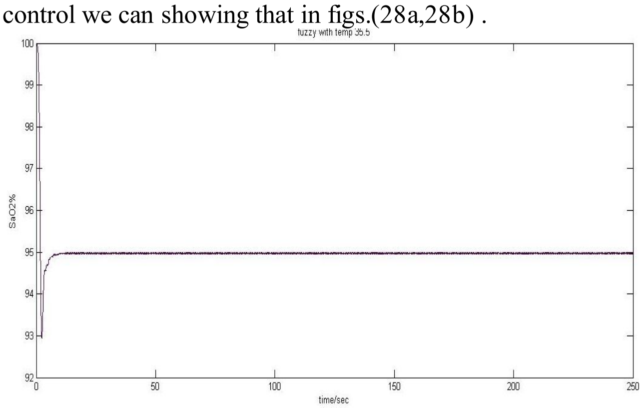

Fig. (28a) with temp =35.5

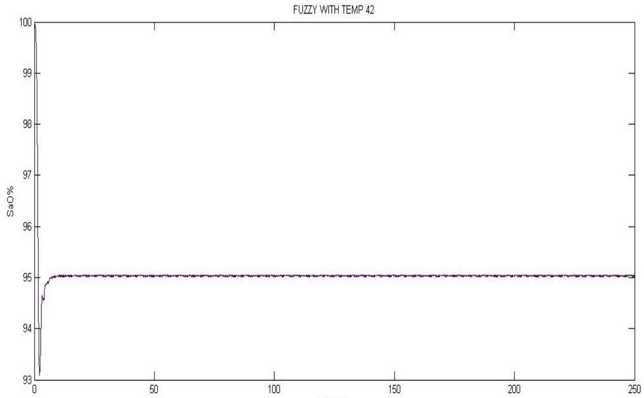

Fig. (28b) with temp=42

This result with different value of temperature when the system dynamic and the change as the same time changing apply to PID control fig.(29) explain that.

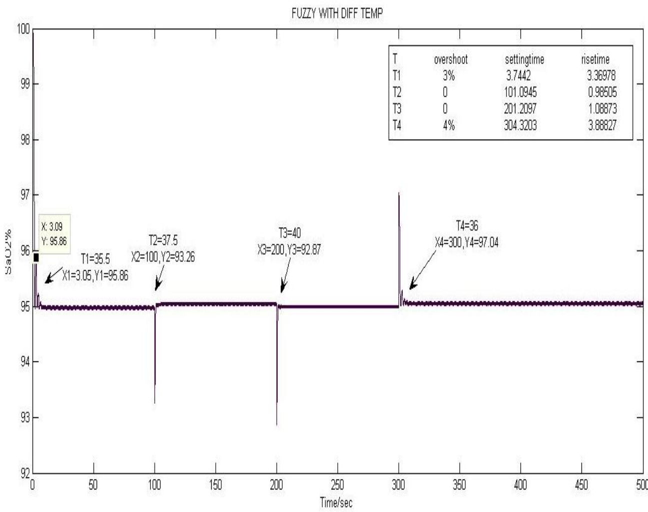

Fig. (29) With different temp

In this study we observe the result for two controllers. The fastest and the better control we can talk from this two table .PID table and FUZZY LOGIC table.
This is the result for PID control with different value of the PH .When the system dynamic. Table (7) explains that's result.

PH	overshoot	Setting time	Rise time
PH1	0	8.0876	7.27884
PH2	3%	125.4608	22.91472
PH3	4%	218.0876	16.27884
PH4	0	307.0276	6.32484

Table (7) Result of PID control with different PH.

The other table (8) for the FUZZY control with different PH.

PH	overshoot	Setting time	Rise time
PH1	0	3.7802	3.40218
PH2	3%	104.2627	3.83643
PH3	4%	202.873	2.5857
PH4	0	307.2077	6.48693

Table (8) Result of fuzzy control with different PH.

This is the result for PID control with different value of the temperature; explain in the following table (9).

T	overshoot	Setting time	Rise time
T1	0	33.318	29.9862
T2	0	110.3687	9.3318
T3	0	211.8664	10.67976
T4	2%	316.2442	14.61978

Table (9) Result of PID control with different temp.

This is the result for FUZZY control with different value of the temperature .we can see in the following table (10).

T	overshoot	Setting time	Rise time
T1	3%	3.7442	3.36978
T2	0	101.0945	0.98505
T3	0	201.2097	1.08873
T4	4%	304.3203	3.88827

Table (10) Result of fuzzy control with different temp.

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4. Conclusion

Patients with respiratory system illnesses require the administration of elevated levels of oxygen through mechanical ventilation. This process is known as oxygen therapy and clinical staff often use the output signal from a pulse oximeter, SpO_2 , as an indirect indicator of tissue oxygenation. A mechanical air/oxygen gas blender is used to administer a percentage of fractional inspired oxygen, FiO_2. Hypoxemia may result when SpO_2 levels indicate low tissue oxygenation and may lead to permanent brain damage if frequent and prolonged. High levels of blood oxygen saturation, as indicated by high SpO_2 may lead to bronchopulmonary dysplasia (chronic lung disease) and/or retinopathy of prematurity (retinal damage). Normoxemia is a safe range of SpO_2 and may be defined as 90% to 98% saturation.

As oxygen moves from the mouth to the lungs its partial pressure drops. At the alveoli it diffuses across the lung walls into the pulmonary capillary blood where a small portion is dissolved. The majority of the oxygen is bounded to hemoglobin, related to the partial pressure of O_2in the blood by the oxygen dissociation curve. The SaO_2or blood oxygen saturation, is a measure that indicates the percentage of total hemoglobin bonded with oxygen. A computer model of this oxygen transport system was used and contains a 4 compartment respiratory system linked to a compartments cardiovascular circuit.

Three controllers were developed –manual, PID and fuzzy logic. Manual mode was used to represent actual clinical oxygen therapy where the emphasis is on keeping the adult with normoxiemia rather than at a specific target .The PID controller gains were set from empirical values that were also confirmed by the literature. A non-linear fuzzy logic controller was developed around 49 rules. It uses two inputs, "error" and "error rate" to formulate a single output," FiO_2 _increment" which is integrated to produce a FiO_2setting for the blender.

Each control algorithm was applied to each of the adult model and the resulting data showed that the fuzzy logic controller provided the best performance .The PID controller produced better target performance manual control and the fuzzy logic controller was better than both.
Normoxemia performance is measured by the percent of experiment duration which the model stays within normoxiemia (90% to 98%SpO_2). The PID controller on average provided a good normoxemic performance than manual control. Fuzzy logic control had as good a normoxemic performance as manual mode and PID control, FL controller was better than both. In summary, the fuzzy logic controller provided the best target and normoxemic performance on model.

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40.L.A, Zadeh ,FUZZY SETS, Department Of Electrical Engineering And Electronic Research Laboratory ,UNIVERSITY OF CALFORINIA ,BERKELEY ,California

41.Awang N.I. Wardana*,PID-Fuzzy Controller for Grate Cooler in Cement Plant, Control Department Indonesia Cement and Concrete Institute Jalan Raya Ciangsana, Bogor, 16969, Indonesia.
Phone: +62-21-82403650 Fax: +62-21-82403654 e-mail: awang.wardana@telkom.net

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