State feedback control for human inspiratory system

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ABSTRACT

The mathematical modeling of human respiratory system is an essentially part in saving precision information of diagnostic about the disease of cardiovascular respiratory system. The physics of respiratory system and cardiovascular are completely interconnected with each other. In this paper, we will study the state feedback control for the inspiratory system during study the characteristics of the response output with the stability. The model of system is nonlinear and linearized it by Tayler method to be simple to matching with the control theory. We convert the system from differential equation to state equation to find the optimal control that helps to drive the respiratory system. Simulations are managed to indicate the proposed method effectiveness. The results of simulations are validated by using a real information form the health center.

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1. INTRODUCTION

The diseases in the world health organization (WHO) of non-communicable like diseases of respiratory are causing of deaths in the hospitals. The diseases of respiratory and cardiovascular can be predicted with real tools and diagnostic information. The mathematical model of respiratory system will assist in supplying more information of diagnostic. It permits to make the complex interaction be accuracy between several systems, and estimate the certain diseases which change the function of normal system as shown in Figure 1. This paper will improve the stability.

Jabłoński and Mroczka [1] have presented a model reduction for respiratory system focused on electrical educed circuit. The chief technique depends on a numerical procedure for parametric and structural analysis that applied to equivalent of forward linear which designed for interrupter experiment conditions. The results were reliable in the frequency and time domain for response of dynamic behavior. Amini *et al.* [2] have developed a model of the central pattern for respiratory system to mimic the medullary neurons salient characteristics. The model has designed and dived by neuron of pacemaking from complex of pre-Botzinge. The results of this model have been focused on data of voltage clamp. Ionescu *et al.* [3] have provided the parameters of respiratory airway mechanical to make the correlation the pathologic changes is easy with fractional-order models. This technique involves of tube length, wall thickness and inner radius for level of airway to collect them into equations for modeling the wall elasticity, flow air velocity, and pressure drop. The parameters of mechanical have derived offer the capability to evaluate the impedance of input by varying the parameters morphology to the disease of pulmonary.

Chbat *et al.* [4] have developed a model of comprehensive cardiopulmonary to take into account the relationship between the respiratory and the cardiovascular systems. This model involves the gas exchange, lung mechanics, heart, control of cardio-ventilatory and equations of transport. The results have showed good acceptable with date of published patients in case of the simulation of hyperoxic and normoxic. Ionescu *et al.* [5] have developed a model to demonstrate the relation between the fractional-order model appearance and the respiratory tree recurrence. This model is enable of simulating the lungs mechanical properties and did compare this model with measurement of vivo for the respiratory input impedance in 20 healthy patients. They have provided an additional of the fractal for consequence appearance and human lungs in impedance of the total respiratory system.

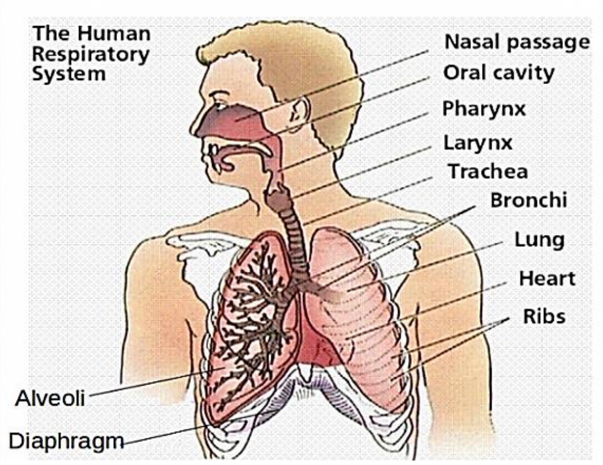

Figure 1. The human respiratory system

Ionescu *et al.* [6] has designed a model for sponeous breath and pressure of respiratory muscle. The pressure of respiratory muscle for autonomous respiration is utilized in the construction of the model. They have got a good result with the tool and flow of respiratory. Quiroz-Ju´arez *et al.* [7] have presented a model with heterogeneous oscillator of cardiac system for electrocardiogram (ECG) waveform. The model has consisted the pacemarkes of main natural that has represented by equations of Van Der Pol and ventricular and atrial muscles. They have included an artificial RR-tachogram with the statistics of frequency domain and heart rate by waves of respiratory and Mayer. The standard 12 ECG has computed by the signals of ventricle and atria and this model has been fitted for real patients by clinical ECG.

Hsieh *et al.* [8] have presented a radar signal of ultra-wideband impulse radio utilized to the features of human respiratory system. They have modified raised a waveform of cosine respiration model that could obtain extra features of inspiratory system such as speed of expiation and inspiration, ratio of respiration holding and respiration intensity. This model has suggested the signal of measured respiration that compared with the model of modified raised cosine waveform (MRCW) and reduced the complexity of computation. The results have showed that system can detect the respiration rates of human at 0.1 to 1 Hz in the real time analyzing. Revow *et al.* [9] have provided a framework for automatic neonatal respiratory control has been designed to help the control of respiratory during the period of newborn. A model with perturbation analysis has determined the response of dynamic ventilator was the sensitive to affect the loop of peripheral chemo reflex. The results have showed that the model provides valuable during the period of neonatal and provides a method to examine the human infants in clinic units.

Chen *et al.* [10] have developed a model and corrected motion of respiratory for free breathing imaging of MR. The respiration was modeled and estimated from sensor of Marmot and belts of Pneumatic, focused on images of real-time and method of regression. The accuracy of sensor was validated by comparing errors of motion the kidney. The results were compatible for sensors with environment of magnetic resonance (MR) and the errors of motion of modeling and estimation with sensors were compatible. Lee *et al.* [11] have proposed a technique to estimate the correct respiratory rate in intensive care unit in the services of home care and hospitals. The concentration of carbon dioxide can be monitored by using a capnography or gases of partial pressure of respiratory to supply accurate measurements of respiratory rate. It has been supplied to the sector of medical processing while the techniques of various machine learning including deep learning. The proposed technique displays a more accurate predict of the respiration rate. Qi *et al.* [12] have proposed a technique of motion corrected reconstruction for heart free breathing coronary magnetic resonance angiography motion. This technique requires estimation of accurate and efficient for fields of motion from images of under sampled at positions of different respiratory. This technique has realized similar motion image of coronary magnetic resonance angiography to the method of conventional registration regarding coronary sharpness and length.

Brugarolas *et al.* [13] have proposed a technique to improve detection system to match the efficiency of tracking, interfering odors, and mobility by detector dogs. The dogs reliability as detectors of olfactory that does not depend on the performance but also on skill of the handler in interpreting the dog behavior. The electronic stethoscope and electrodiagram are combining by wireless wearable system for monitoring te events of cardiopulmonary in dogs towards interfaces of cybernetic dog machine. These combining for real time to detect the monitoring system to supply decision support for handlers in the field to interface of future computer dog. Rosenzweig *et al.* [14] have introduced a method for data base for technique that reduction time analysis for cardic magnetic resonance imaging. In this theory, they helped the patients increase the efficiency and burden and robustness of cardiac. They used numerical simulation to prove the basic functionality of time series analysis and apply it to signal of cardiac radial measurements. They used the signals for image of high dimension by using parallel imaging with regulation of temporal total variation and in plane wavelet.

Lu *et al.* [15] have designed a model for time lag between exposure of short term to fine particular matter (PM22) and to determine this length by artificial recurrent neural network with long short term memory used in the field of deep learning. They managed to achieve it to obtain the length of time lag in the relationship of exposure response. The relationship between response and exposure is assumed as nonlinear and linear and this model is performed under these two assumptions. The results detect and prove the lag effect of PM22 on diseases of respiratory.

Abid *et al.* [16] have designed a model of a single-alveolar-compartment to depict the carbon dioxide partial pressure in breathing. Parameters of respiratory are predicted by this model and then applied to the patients in the clinic with obstructive the disease of lung. This model permits prediction the parameters of underlying respiratory from the capnogram and may be used to obstructive lung disease by diagnosis and monitoring of chronic. Yu *et al.* [17] have proposed a recurrent neural network (RNN) to estimate network model the tracking of respiratory motion. The stat of patients respiratory may alter in the process of the precision of estimation. The estimation network of the actual position of the tumor got by imaging by X-ray will be necessary. The RNN network has update with a long time, and it can’t finish the estimation modeling the cycle of X-ray. They have reduced the average time of updating of RNN model. Jarchi *et al.* [18] have proposed a model for monitoring of respiratory rate by using of accelerometers that is necessary in post intensive care patients or inside unit of intensive care. The model of respiratory can be predicted by depending on signals of photoplethysmography and accelerometer for patients according to discharge of intensive care unit. They have described algorithm to check the error of maximum absolute between accelerometer and photoplethysmography.

Karlen *et al.* [19] have presented algorithms to estimate the respiratory rate by using videos acquired by putting finger on lens of camera of mobile phone. The algorithms focused on Empirical mode decomposition and smart fusion to discover advantages and variations of respiratory in signals of photo plethysmographic to predict the rate of respiratory for 29 patients adults with range of respiratory between 6 to 32. The results showed the estimated respiratory by placing a finger on a mobile camera was feasible. Birrenkott *et al.* [20] have proposed a method to predict the respiratory rate focused on electrocardiogram and photoplethymogram for the patient physiology in the clinic. This work has described a prediction of respiratory rate algorithm by respiratory quality that determines the absence and presence the modulation of electrocardiogram and the photoplethymogram. The results have tested on sets of two data and found that the errors very low with estimation date.

Shahhaidar *et al.* [21] presented results of human testing of a weight 30 g with energy sensor of respiratory effort. The output voltage of harvester, metabolic burden, and power are tested on 20 patients in conditions of exercise and resting each lasting 5 minutes. The model system involves movements of abdominal and electromagnetic generators harvesting sensing thoracic. The results were good to get respiratory range is acceptable. Tseng *et al.* [22] have designed a model of radar system for features of human respiratory. The model radar includes three parts: a receiver, a transmitter, and a digital to time convertor. The receiver includes a sampling for high linearity and it is essentially for signal to noise ratio with register A/D converter for quantization of the signal. The transmitter includes of digital pulse generator. The digital to time converter provides a time resolution for sensing process. The model system was validated by neural network based on fuzzy interface system to the clinical results and the model confirmed the effectiveness of the proposed model in testing diseases of respiratory.

2. MODELING THE RESPIRATORY SYSYEM

The model of respiratory system in [23]-[25], the differential equations as (1), (2):

$$V_A \frac{dp_a}{dt} = 863\ F_i(\ C_v - C_a) \tag{1}$$

$$R = \frac{\Delta P_a}{Q} \tag{2}$$

$$V \frac{dc_v}{dt} = MR + \ F_i \tag{3}$$

$$C_a \frac{dp_a}{dt} = Q - \ F_i \tag{4}$$

$$C_v \frac{dp_a}{dt} = F_i - Q \tag{5}$$

$$Gp = \frac{\Delta P_A}{\Delta P_I} \frac{\Delta P_a}{\Delta P_A} \tag{6}$$

$$Gp = \frac{(\ 1 - x_d\ )\ \dot{V}_I}{8.63\ (1 - y_s) Q\ \ \beta_c\ \dot{V}_I} \tag{7}$$

$$\tau = \frac{V_A}{8.63\ (1 - y_s) \dot{Q}_P\ \ \beta_c\ \dot{V}_I} \tag{8}$$

$$\tau = \frac{V_A}{\dot{V}_A + 8.63\ \dot{Q}_P\ \ \beta_c} \tag{9}$$

The changing of oxygen saturation SpO_2 to inspiration fraction Fio_2 is

$$\tau\ \Delta SpO_2\ s + \ \Delta SpO_2 = \ G_{pc}\ \Delta Fio_2 \tag{10}$$

The transfer function of output SpO_2 to Fio_2 is

$$\frac{V_A}{\dot{V}_A + 8.63\ \dot{Q}_P}\ \Delta SpO_2 s + \ \Delta SpO_2 = \ \frac{(1 - x_d)\dot{V}_I}{(8.63(1 - y_s) Q \beta_a \dot{V}_I\ )} \Delta FiO_2 \tag{11}$$

The response of oxygen saturation of $SpO_2$for the a mature human will be started form 90-95% while The response of oxygen saturation of $SpO_2$for the infants will be started form 85-90% when applied FiO_2 from 20-40% as shown in Figure 2.

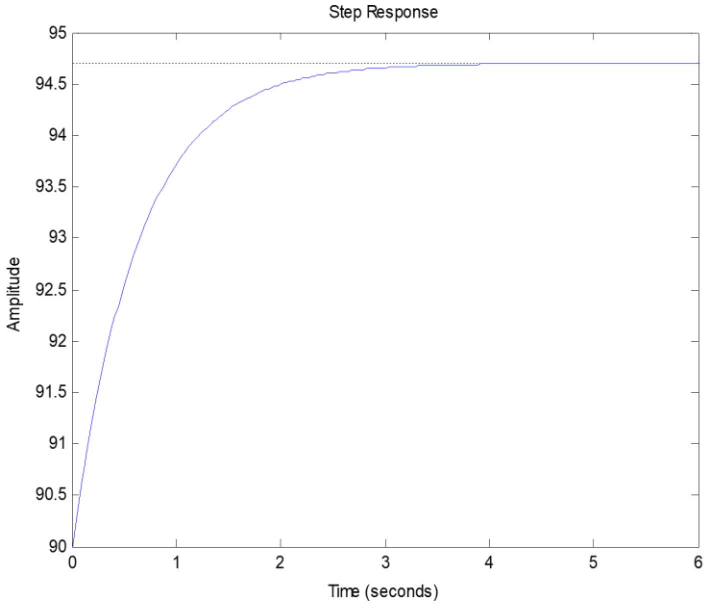

Figure 2. Output SpO_2 for human respiratory when FiO_2 input

3. STATE FEEDBACK CONTROL SYSTEM

The dynamical system state is an accumulate of variables that allows estimation the response of future system. The designing the system to be controlled is depicted by a linear state model for the human respiratory and has single input. The control of feedback will be developed by the positioning the eigenvalues of closed loop in required locations. The typical control system by using state feedback as shown in Figure 3. The full system includes the dynamic of process, which is linear, the elements of controller K_r and K, the disturbances of process d and the reference input r. The objective the controller of feedback is to control the system output y that follows the reference input in the disturbances presence.

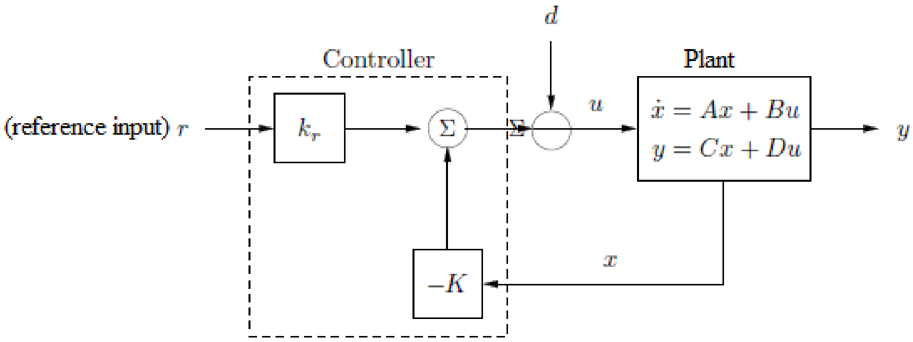

Figure 3. A state feedback controller

The significant of the design the controller is performance specification to be stability. We would like the equilibrium point of the system to be stable by absence of the disturbances. The linear differential equation describes by (12),

$$\dot{x} = Ax + Bu$$
$$y = Cx \quad (12)$$

when we take $D = 0$ to be simple and rejected the signal of disturbance d for test. Our significant is to drive the response of output y to a set point r.

The control law of time invariant is a function of the set point and the state since the state at time t includes all information essential to estimate the behavior of the future system, it can be described by (13),

$$u = k_r r - K_x \quad (13)$$

where, r is the value of set point. The control law is relating to block diagram shown in Figure 3. The close loop system got when the feedback is applied to the system (13) is given by (14),

$$\dot{x} = Bk_r r + (A - BK)x \quad (14)$$

The problem of control is named the problem of eigenvalue assignment. The value of k_r does effect on the solution of steady state but does not affect on the system stability. The output of steady state and equilibrium point for the closed loop system are written as (15),

$$x = -(A - BK)^{-1}Bk_r r,\ y = Cx \quad (15)$$

Consequently, k_r should be selected such that, $y = r$.

$$k_r = \frac{-1}{(C(A-BK)^{-1}B)} \quad (16)$$

The value of k_r is the zero frequency gain inverse of the closed loop system. By utilizing the gains k_r and K, we will design the controller of the closed loop system to meet our aim. By modeling the state feedback control, we can get the values of $A, B,$ and C. The values of K is 10 and k_r is 1. By simulation the human respiratory system and with state feedback controller, we can get the response of output as shown in Figure 4.

Now we can use another controller is like proportional integral derivative PID to compare with response of the output and display what is the best. The transfer function of PID is (17),

$$U(s) = \left(\frac{k_d s^2 + k_p s + k_i}{s}\right) e(s) \tag{17}$$

where, k_p, k_i, and k_d are factors of PID and by tuning the values of these factors, we can get the best response. In this case we chose many values of PID factors and got the best response at values k_p, k_i, and k_d pi as shown in Figures 5-7.

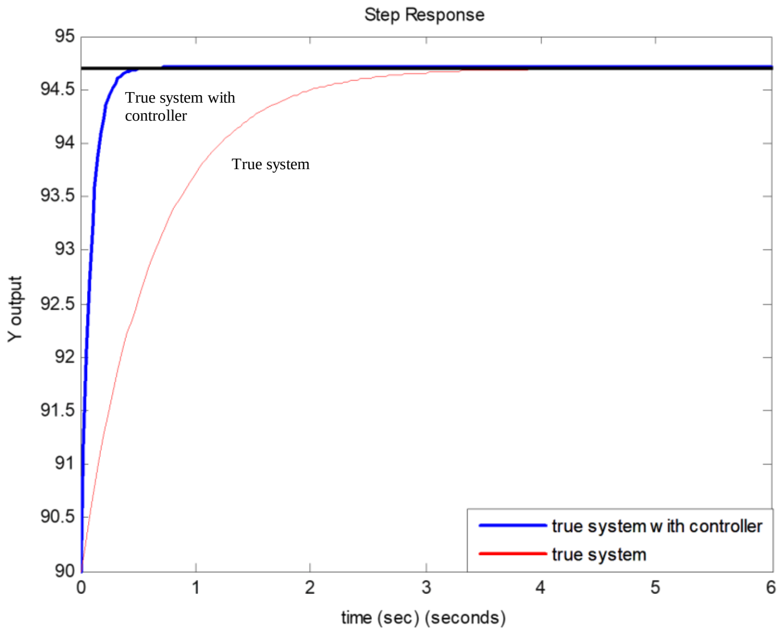

Figure 4. The output with state feedback controller

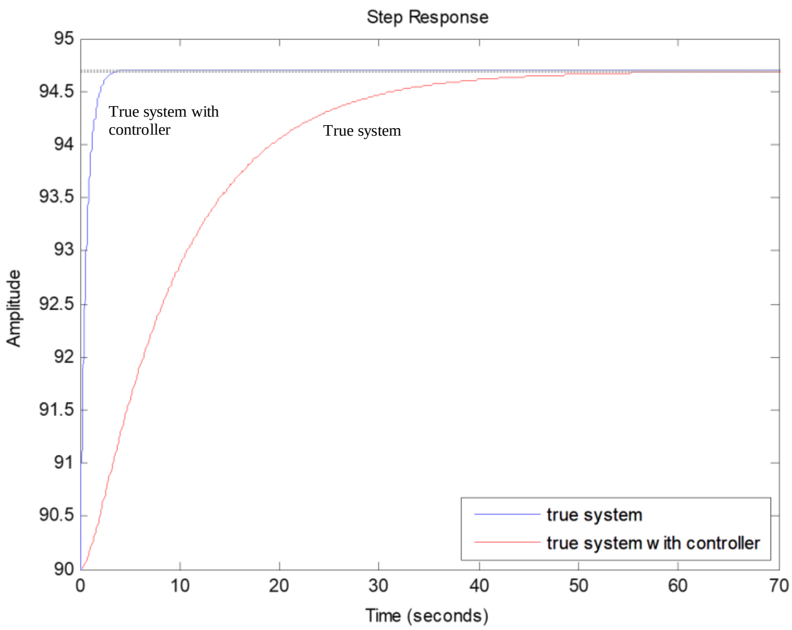

Figure 5. The output with PID ($Kp = 2.1$, $Ki = 2.1$, $kd = 0.0005$)

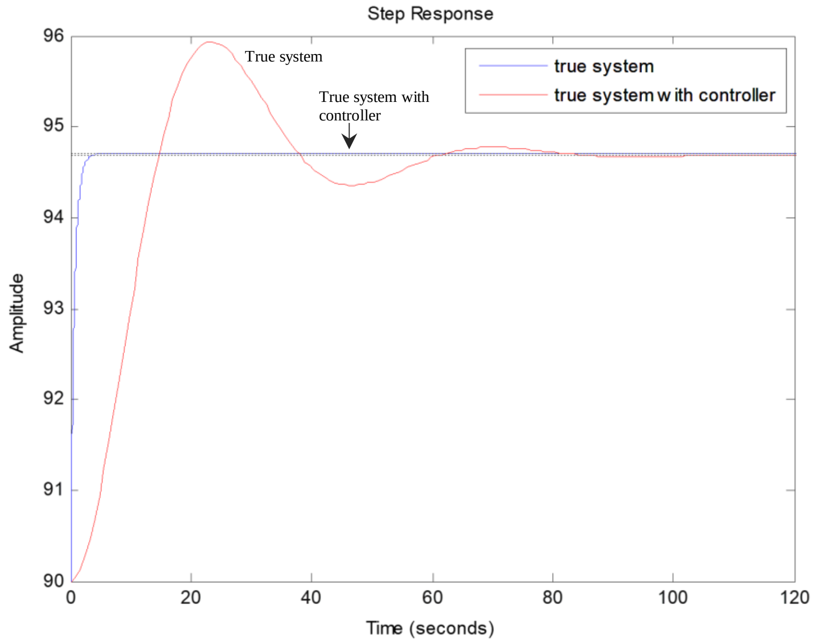

Figure 6. The output with PID ($Kp = 10, Ki = 1, Kd = 0.0005$)

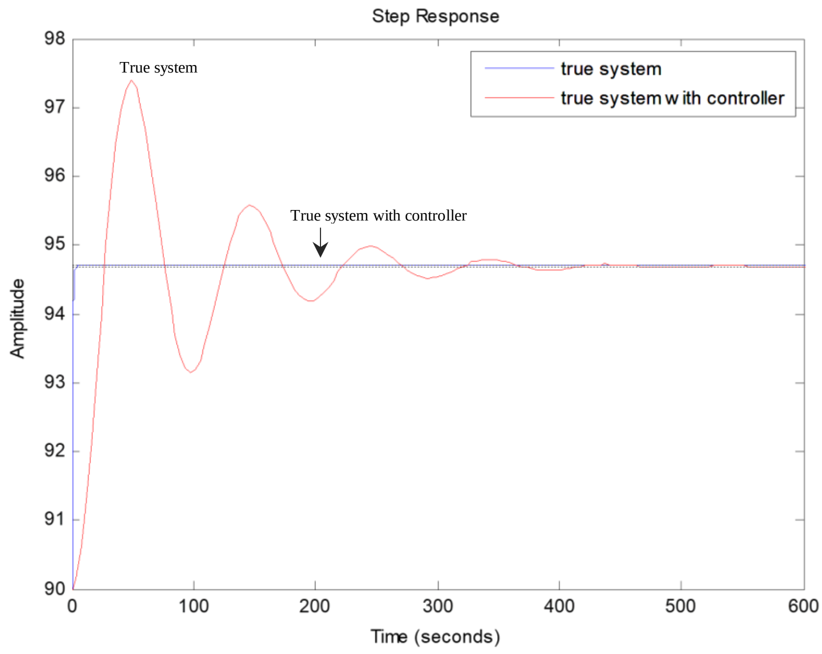

Figure 7. The output with PID ($Kp = 50, Ki = 1, Kd = 0.0005$)

4. CONCLUSION

Modeling of human respiratory system is the main important to study the factors that effects on the lungs, heart, and alveoli. When supply FiO_2 inspiratory input between 20-40% and get the SpO_2 saturation output between 90-95%. To control the SpO_2 between ranges 90-95% with stability response and minimum settling time and zero steady state error, we chose two controllers to compare which one is the best for controller. State feedback controller is more suitable than PID controller. The SpO_2 output can get after 50 sec without peak overshoot and zero steady state error when we use state feedback controller but the SpO_2 output can get after 550 sec and without peak overshoot and zero steady state error.

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