Sensitivity Analysis of Respiratory Model

150684U
W.A.D.N. Wickramarachchi

1. Introduction about the model

The forced oscillation technique (FOT) is a non-invasive method used to analyze impedance of the respiratory system by applying external signals to the respiratory system. It does not require active cooperation of the subject, hence well suited for lung function analyzing in new born.

Often Respiratory System is analyzed through computer simulation and results of these analysis are used to detect 'Obstructive Pulmonary Diseases', growth and development of lung etc. Therefore depending on the purpose of the analysis, different linear lung mechanics models are used.

In this analysis, 'One Compartment(RLC)' model is used and circuit system given below represents the Electrical Analogy of lung mechanics model. In here R represents the flow resistance of airways and the viscous properties of the lung tissues. C describes the elastic properties of the lungs and chest walls. L describes the inertance of air and tissues. P_{ao} is the randomly generated pressure perturbations and Q is the air flow rate.

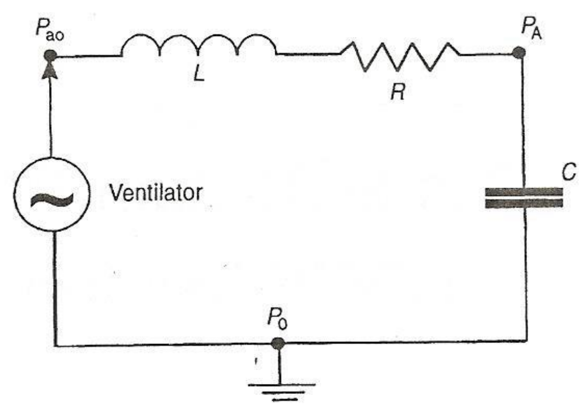
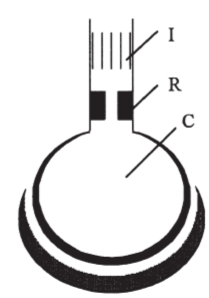


Figure 4.1 Electrical analog of lung mechanics model.



One compartment RLC model

2. Deriving the Transfer Function

The differential equation in time domain,

$$P_{ao} - P_o = L\frac{dQ_t}{dt} + RQ_t + \frac{1}{C}\int Q_t dt$$

Assume that $P_{ao} = P_{atm} = 0$

Then,

$$P_{ao} = L\frac{dQ_t}{dt} + RQ_t + \frac{1}{C}\int Q_t dt$$

By Transforming into Laplace Domain

$$P_{ao}(s) = L\{sQ(s) - Q_t(0)\} + RQ_t(s) + \frac{1}{sC}Q_t(s)$$

Assume that $Q_t(0) = 0$

Then,

$$P_{ao}(s) = sLQ(S) + RQ(s) + \frac{1}{sC}Q(s)$$

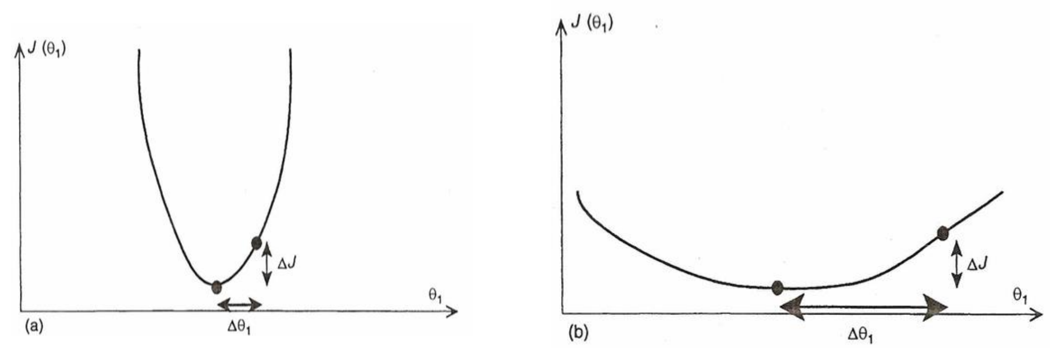
Therefore transfer function is given by,

$$\mathbf{H(s)} = \frac{\mathbf{Q(s)}}{\mathbf{P_{ao}(s)}} = \frac{\mathbf{sC}}{\mathbf{s^2LC+sRC+1}}$$

3. Sensitivity Analysis

In linear lung mechanics model we use predefined values for ‘R’, ‘C’ and ‘L’ to represent subjects with normal functioning lungs. This ignores the fact that there is a variation of ‘R’, ‘C’ and ‘L’ values from one subject to another and also the variations due to presence of noise. This may lead to structurally unidentifiable. Therefore when a model is developed is should be evaluated to see whether parameters that needs to be estimated are still applicable against small variations. This process sis carried out by sensitivity analysis.

Sensitivity analysis is carried out by criterion function which involves with finding properties of multidimensional J-Surface. Figure below shows 2 possible occurrences of J surfaces with estimating parameters.



In (a) we can observe the variation of J due to variation in θ (with respect to minimum point in the graph) is higher compared to that of graph (b). In such case we can assume that effect of noise on J is lower in (b).

Similarly, by plotting centurion function with estimated value of one parameter while keeping others constant we can analyze the effect of variation in lung mechanics model in finding respiratory impedances. It is important to adjust considered estimated value of the parameter to minimum point to make error symmetric. When analyzing one parameter others should be kept at constant.

Modifications in the code

```
global t u

%Assigning values to Parameters
R = params(1);
L = params(2);
C = params(3);

%Creating the Laplce Equation
num=[C 0];  %sC
den=[L*C  R*C  1];  %(s^2)LC + sRC + 1
Hs=tf(num,den);
ypred=lsim(Hs,u,t);
```

In fn_rlc den (values in denominator) and num (values in numerator) are adjusted to suite the derived transfer function

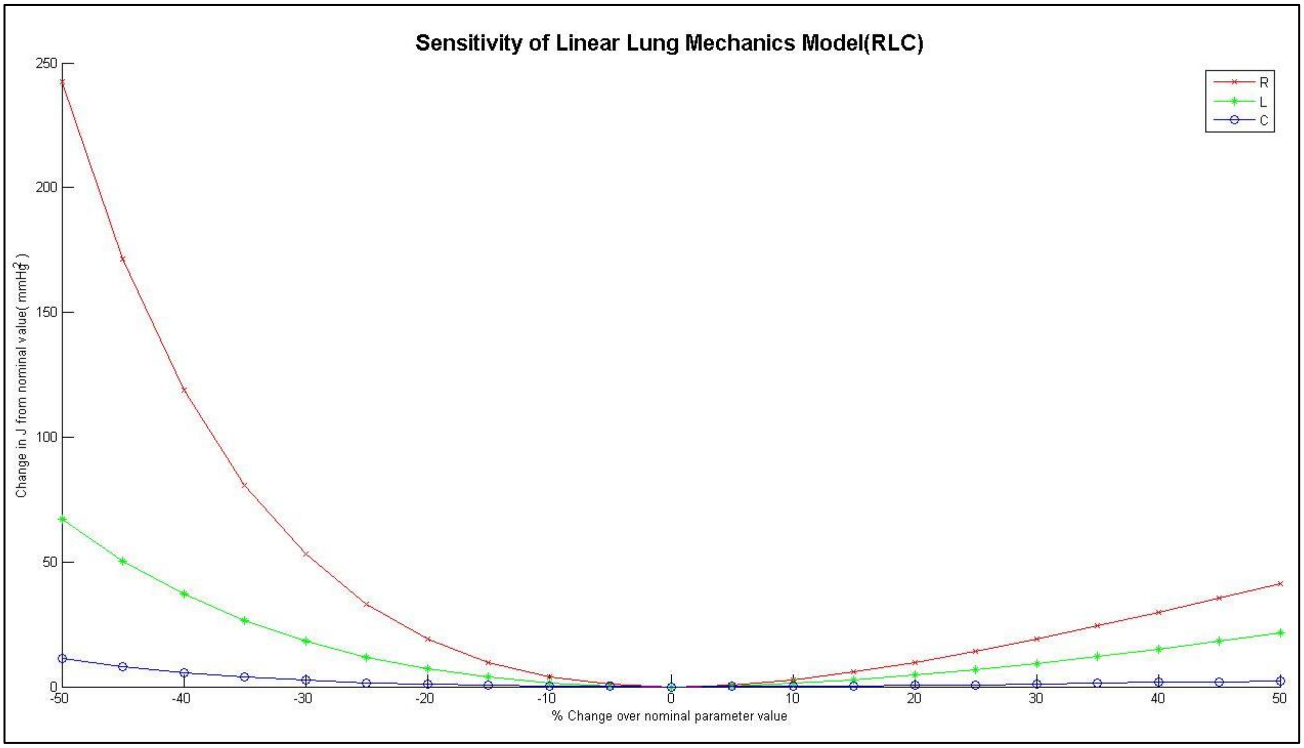
```
global t u
%Teim Vector and Input Signal
t = 0:0.01:25;
u = randn(numel(t),1);

%Entering the parameter values
pararef = [1.5, 0.01, 0.1]; %R =
Np = numel(pararef);
```

In Sensanl.m input time vector is given as $t = 0{:}\,0.01{:}\,25$ and input pressure signal as $randn(numel(t), 1)$

Finally R, L, C nominal values are given to pararef

4. Interpretation of results



According to the graph when 'C' and 'L' kept constant we can observe that 'R' shows higher value for change in J from nominal value as variation from estimated value (R=1.5 cmH_2O s L^{-1}) increases. Similarly, 'L' represents a significant variation in J from nominal values as percentage of variation increases. That is 'R' and 'L' has higher sensitivity towards noise.

When 'C' considered, variation in J from nominal value is very small compared to 'L' and 'R'. That is it has a lower sensitivity towards noise. Therefore presence of noise like factors will have minimum effect on 'C', while it 'R' and 'L' have significant sensitivity towards variations due to noise.

When applying the given estimated values for 'R' and 'L' in this model we should take necessary steps to minimize variations such noise.

5. References

- Physiological Control Systems: Analysis, Simulation, and Estimation Book byMichael C. K. Khoo
- Lecture Slides : Respiratory Mechanics and Mechniacl Ventilation by Dr. Nuwan Dayananda
- Medical Engineering & Physics 20 (1998) 220–228
  Computer simulation of the measured respiratory impedance in newborn infants and the effect of the measurement equipment by M. Schmidta, B. Foitzika, O. Hochmuthb, G. Schmalisch a,*