Team 18 Background Report

A summary for *Modelling and simulation of pressure controlled mechanical ventilation system*

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Project Summary

Conventionally, ventilators require precise input and constant monitoring from clinicians to achieve desired patient conditions.

Introduction of Paper

The paper that we would like to present is : **Modelling and simulation of pressure controlled mechanical ventilation system.** It was published in the ***Journal of Biomedical Science and Engineering*** in 2015.

Connection with the current Project

We selected this paper as our background reading because of several reasons listed below. First, it lays the foundation for our project. As we have suggested in our plan proposals, we needed a mathematical model which could simulate and produce the results of a lung under ventilation. This produces data related to the lung's reactions when different inputs are feeded into the ventilator. Analyzing the patterns and changes of the datasets is a crucial step in understanding the relations between the inputs(Peak Inspiratory Pressure(PIP), PEEP(Positive End Expiratory Pressure), I/E(IE ratio) and Respiratory Rate(RR)) and the outputs(Pressure(P), Flow Rate(Q) and Volume(V)). This in turn, allows us to determine the boundaries of the input parameters which is crucial for creating warning states for the Markov Decision

Process(MDP) and the rewards that should be given to the RL agent. Secondly, it also provides us a fallback or alternative option for the MIMIC III dataset. Given that it is data based on real-world medical data, the processing time and the approval required could hinder our progress. If that should occur, the dataset generated by the model would serve as another source for training data. Above all, in all the papers we viewed, this paper was the most detailed one and could be recreated given the figures, structures and the raw equations given. The results could also be compared with the given graphs to confirm the reliability of our recreation.

Assessment of Paper Reliability

As mentioned above, this paper was used as a basis for our studies and in order to ensure that the basis which we are building upon is reliable, we also checked the publication's journal and also verified with Hopkins Professors from the School of Medicine the simulated graphs and results. The results were positive and gave us confidence to apply and recreate it.

Paper Summary

The Paper proposes a set of mathematical models which can simulate the PCV signals including the respiratory activities. In addition, an important parameter during ventilator support, PEEP, was included as well.
The newly proposed model is able to output the signals as continuous waveforms.

Related Works

According to the description of the authors of the paper itself, previous studies have shown that the lung can be simulated using a multi-compartment model consisting of electrical resistors and capacitors.

Modeling of PCV signals has also been done considering the system as a pure pneumatic system. However, those models could not model the PCV signals and its dynamic characteristics.

Detailed Description

The paper proposed a method using Simulink in Matlab. The design of the multi-component mathematical model is divided into multiple parts:the model which simulates the PCV signal, the model which outputs the airflow and simulates lung reaction, the model which derives and outputs volume and pressure and the model which represents each cycle and the PV-Loop.

Modeling PCV Signals

The first component, the model for PCV signals, is designed based on 3 equations(listed below) that involve all inputs. The boundaries for each equation is determined by the time, whether it is in the inspiratory, expiratory or at the beginning. The PEEP is directly used along with the PIP value as Paw(airway pressure) in order to determine the output value while RR and IEratio was used to produce the cycle and inspiratory/expiratory periods.

$$P(t) = \begin{cases} P_{aw} \cdot \frac{t}{\tau} + \text{PEEP}, & 0 \le t \le \tau \\ P_{aw} + \text{PEEP}, & \tau \le t \le T_{in} \\ \text{PEEP}, & T_{in} \le t \le T_{ex} \end{cases}$$

For this step of calculations and simulation, boundaries have also been set for the input values. The IE ratio, which determines the inspiratory and expiratory time(T_{in} and T_{ex}) is often kept at 1:2 or 1:3 while RR, which determines the total time of a cycle, is set to a value between 10 and 20. PEEP is set between 5 to 10 and IP is set between 15-20 in order to achieve a tidal volume of 5 to 6 ml/kg.

Lung Model

The lung model is an implementation proposed by Michael C. in another paper.(Michael C. 2001) The model is based on the following equation as an electric model. The equation represents the airflow(I) as an equation of applied pressure produced by the ventilator(V). The other parameters listed are constants representing the conditions of a normal lung.

$$\frac{I(s)}{P(s)} = \left(\frac{s^2 + \left(\frac{s}{R_P \times C_T} \right)}{R_C \times s^2 + \left(\frac{1}{C_S} + \frac{R_C}{R_P \times C_T} \right) s + \left(\frac{1}{R_P \times C_S} \right) \left(\frac{1}{C_L} + \frac{1}{C_W} \right)} \right) \tag{9}$$

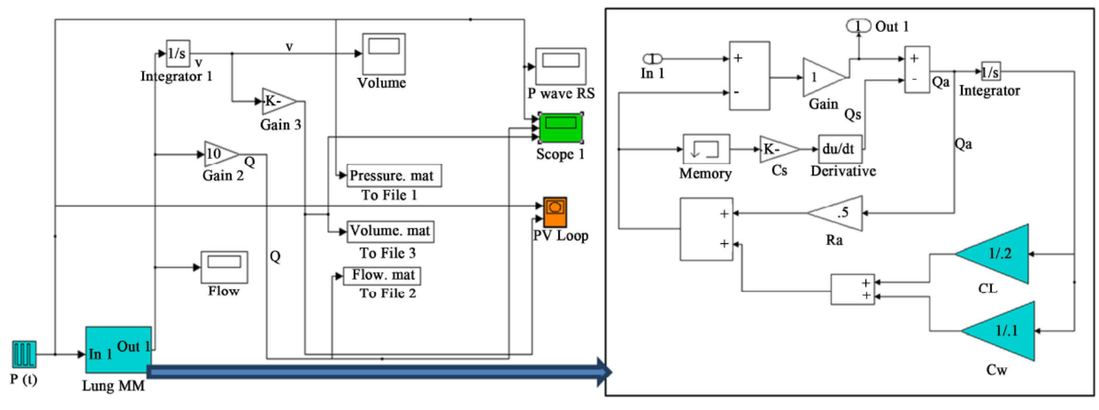
Deriving Outputs

Aside from the outputs for Flow Rate, Pressure and Volume, the model is also able to display the dynamic compliance of the lung through the PV-Loop derived by calculating the ratio of the change in applied pressure to the change in Volume.

Results

Model Construction

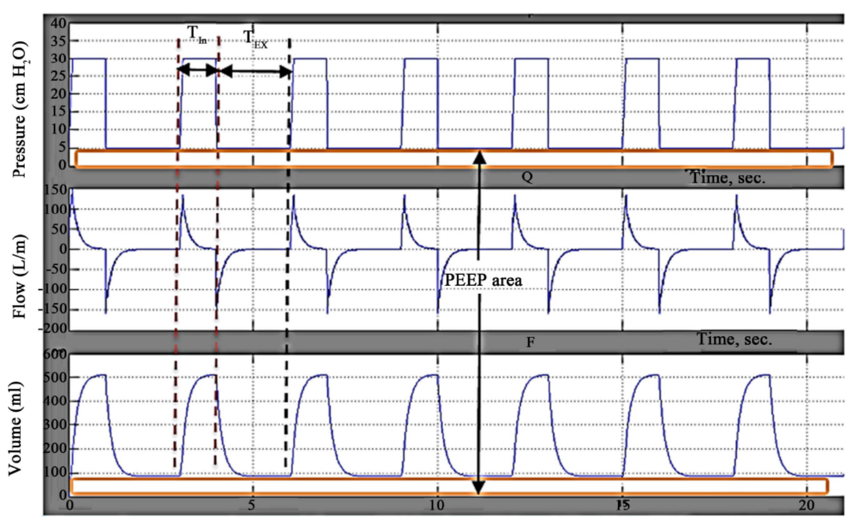
The Constructed Model as whole can be represented in the following simulink image.



Outputs for Pressure, Volume and Flow Rate

Parameters	IP	PEEP	Rise Rate	Inspiratory Time	Respiratory Rate
Normal	25	5	1:2	1	20
Abnormal	27	8	1:2	1	20

Using the above two sets of inputs, the following results were achieved.



From the periods represented by the T_{in} and T_{ex} and also the boundaries of pressure created by the input of PEEP and IP, it can be concluded that the proposed models could model the reactions of the lung under certain respiratory cycles and ventilation inputs.

Results of PV-Loop

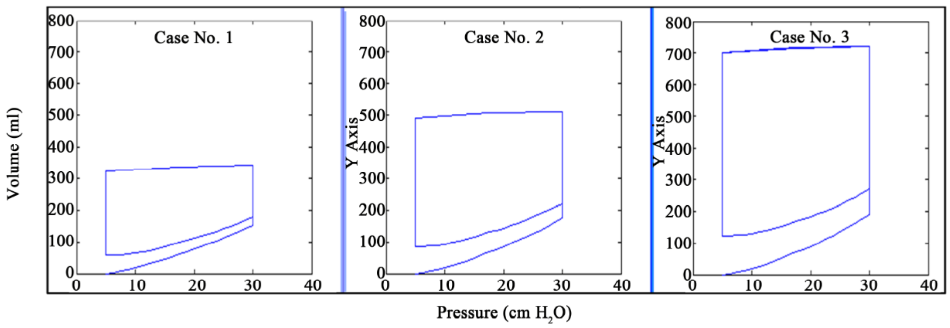


Figure 9. PV loop of PCV at different C_T.

Table 2. The parameters values changed in Lung simulator.

Parameters of PCV signal	Case number	C_T, ml/cm H_2O	C_T^{-1}, ml/cm H_2O	C_L, ml/cm H_2O	C_w, ml/cm H_2O	V_T, ml
IP = 25 cm H_2O,	1	15	0.07	0.2	0.1	320
PEEP = 5 cm H_2O,	2	10	0.1	0.2	0.2	500
T_{in} = 1 sec., τ = 0.1,	3	7	0.14	0.2	0.5	700

The above set of figures display how parameters affected the PV Loop. The difference in Volume along the Y axis is a representation of the tidal volume which varies based on the inputs.

Review of the Paper

We would like to assess this in terms of Pros and Cons both in itself and how it could help in our research.

The Pros are as followings:

1. The paper proposes a comprehensive model which includes the entire system including the PCV and also the patients' lungs. The data and graphs will allow us to understand how the inputs and outputs are correlated.
2. The model is implemented in Simulink, Matlab and the overall graph including the base equations used were all included. This allows us to have a clear reconstruction which we can compare and adjust.

However, there are also places where it could improve.

1. Since it is based on a software like Matlab which is updated very constantly(about two new versions, a and b, are released every year), newly introduced or adjusted functionalities could affect how the model runs. This is why it would be preferable for the version information and settings could also be listed.
2. The results were concluded as reliable while no comparisons of real-time data was given. It would have been better if the waveforms of a ventilator in real-life could be presented. In the case that medical data could not be given, it would be preferable to list some more compelling evidence to prove the correctness of the results.

Conclusion

This paper proposed a model which can simulate the PCV signals and the lungs' responses. Patterns in the graphs were verified through our meetings with professionals. It is a reliable source of crucial data and waveforms for us to understand the relations and mechanics in respiratory systems.

References:

1. Al Naggar, Noman. (2015). Modelling and Simulation of Pressure Controlled Mechanical Ventilation System. *Journal of Biomedical Science and Engineering*. 8. 707 - 716. 10.4236/jbise.2015.810068.
2. Khoo, M.C.K. (2001) Physiological Control Systems: Analysis, Simulation, and Estimation. *IEEE Press Series on Biomedical Engineering*, New York, 1-319.