

Universal respiratory controller for novel insight into respiratory failure and mechanical ventilation

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Introduction

Mechanical ventilation is often an essential intervention for the successful treatment of respiratory failure. However, there are risks associated with mechanical ventilation: ventilator induced lung injury Ref. [1], infection, as well as issues relating to atrophy of the diaphragm. Personalised approaches for the treatment of respiratory failure, improve patient outcomes [2]. Better insight into the safe bounds for mechanical ventilation for a variety of observed pathologies could improve treatment. To test disease specific structures a testing device was developed.

Method

The Universal Respiratory Controller (URC) was developed to enable a wide array of different possible testing methodologies: forced ventilation, natural respiration, and any combination of the two. By using proportional integral derivative (PID) control combined with volumetric flow sensors, and pressure sensors both pressure-controlled and volume-controlled ventilation is possible. The addition of negative pneumatics enables the control of a 'pleural cavity' for the modelling of spontaneous breathing responses.

A diagram of the URCs pneumatics is shown in Figure 1, both the pump inlet and outlet respectively are connected to a 3 ported solenoid in-line with a 2 ported proportional solenoid, the control of these two solenoids is carried out by the driver circuitry shown in Figure 2, the circuit employs an integrated pulse width modulation driver to control each of the solenoids.

In initial testing hydrogels and silicones were used to fabricate model lung volumes. The model lung structures were inflated through a variety of breaths per minute at varying applied volumes similarly to the methods from Ref. [3]. Digital Image Correlation (DIC) was used as a non-contact, optical, method of recording deformation in the surfaces of the model lung volumes.

Results & Discussion

Readings from pressure and volumetric flow sensors were used to tune the PID control variables. Pressure-volume (PV) curves out match with desired input waveforms. The real time strain values, recorded using DIC, combined with PV measures were used to compare the mechanics of the model lung volumes to lung tissue. Inflation of model volumes was carried out using both the URC and a commercial ventilator system, results were compared and found to be insignificantly different.

Conclusion

The URC is capable of a variety of different loadings for experiments and can accurately reproduce loading conditions produced by alternative systems. Initial hydrogel and silicone model lung volumes require fine adjustment to better represent lung tissues. Further work should include the development and testing of disease specific structures for insight into ventilator-induced lung injury, and testing of the URC through a wider variety of experimental regimes.

References

1. Kumar et al. Ventilator induced lung injury. PMID: 33085391. 2022.
2. Pelosi et al. J Critical Care. 25(250). 2021
3. Nelson et al. J Physiol Rep. 10(19): e15466. 2022.

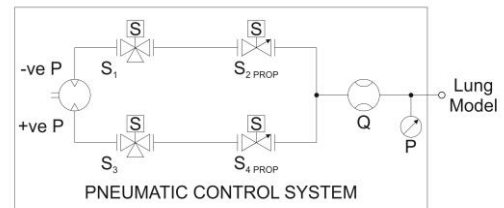


Figure 1. Universal Respiratory Controller – Pneumatics. Shows diaphragm pump with positive (+ve P) and negative (-ve P) relative pneumatic outlets, 3 ported solenoids S_1 & S_3 , 2 ported proportional solenoids S_2 & S_4 , volumetric flow meter Q, and pressure sensor P.

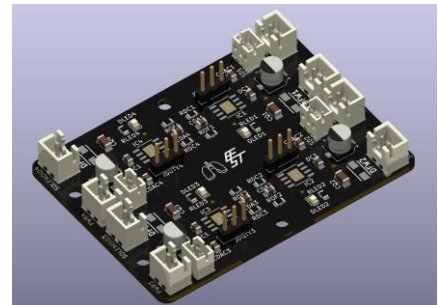


Figure 2. Universal Respiratory Controller – Driver Circuitry.