Automatic Mechanical Ventilation Control (AMVC)

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Background

1. Ventilators Requires Personnel to operate
2. Pressure Controlled Ventilator:
    a. "Pressure-controlled ventilation is a modality utilized in patients with an indwelling endotracheal tube or tracheostomy tube that affords the practitioner the ability to ventilate a patient with a maximal peak pressure."(Messina, 2021) Therefore, the target is to let the patient reach a certain tidal volume and control the pressure to a certain max value.
    b. Issues:
        i. This requires accurate control inputs from clinicians
        ii. No direct value associated with tidal volume
        iii. Incorrect Max Pressure settings could cause barotrauma

Description

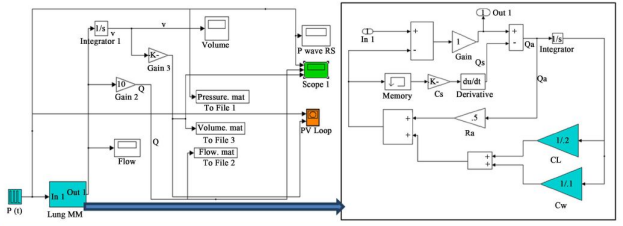
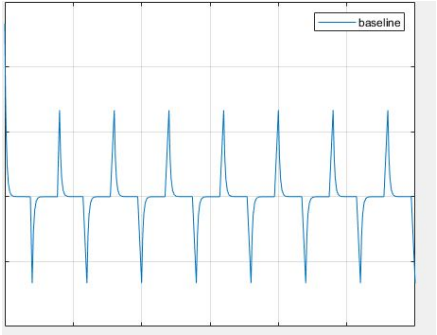
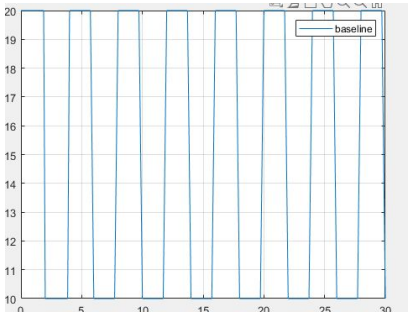
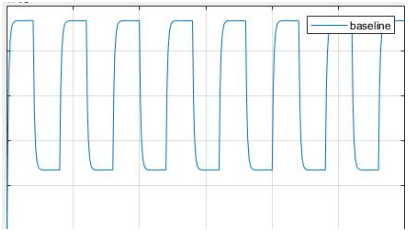


Image from Naggar, 2015

1. Inputs :
    a. IP(Inspiratory Pressure)
    b. IEratio(Inhale and Exhale Ratio)
    c. Respiratory Rate(number of breaths per minute)
    d. PEEP(Positive End Expiratory Pressure)
        i. Pressure to prevent the lung from collapsing
2. Outputs:
    a. Pressure
    b. Volume
    c. Flow
    d. PEEPi(intrinsic PEEP)
    e. P_peak(Peak Pressure)
    f. P_plat(Plateau Pressure)
    g. delta_P(Driving Pressure)
    h. P_L(Transpulmonary pressure)
    i. delta_P_L(Transpulmonary driving preasure)
    j. P_0dot1(Esophageal pressure generated 100 ms after onset of inspiratory effort)
    k. PTP(Pressure-time product per minute)
    l. Energy_L(Mechanical energy)
    m. MPI(Mechanical power and intensity)







Goals

1.Develop an automatic framework for AMVC based on different patients' response and their impact on Mechanical Ventilator 's I/O interactions

2.Build the Markov decision process of PCV controller.

3.Explore RL techniques for this approach (e.g with DQN, MPC)

4.Find metrics to evaluate the actions and the RL agent's final result.

Brief Overview of Technical Approach

1. With mathematical models of lung(multi-componential models), we could have an reliable simulation for lung reaction.
2. Change pressure control ventilator settings(RL action) to adjust the state of lung (Flow, Pressure, Volume, etc : RL agent state)
3. Build MDP in Custom AI-GYM environment
4. Explore RL frameworks and compare results
5. Use MIMIC-III dataset to train and evaluate the cost/reward of RL actions

Deliverables

1. Minimum：

   1.Build a reliable mathematical lung model and a Pressure Control Ventilator model

   2.Train a RL agent that automatically makes decisions to adjust the parameters

2. Expected:

   1.Initial proof of concepts of MDP in ventilator controller

   2.Documented code and performance metrics.

3. Maximum: Improving Based on Feedbacks from Clinicians or Evaluation Metrics

Milestones

Name	Date	Status
Regular PCV model with Lung	2/18/2022	Done
Explore and define legit actions for RL agent(PCV controller)	3/14/2022	In Progress
Build and Evaluate MDP	3/21/2022	Not Started
Build the RL environment	4/6/2022	Not Started
Train a RL agent and find metrics to evaluate its performance	4/14/2022	Not Started
Evaluate and Improve Model	4/28/2022	Not Started

Timeline

https://docs.google.com/spreadsheets/d/10wgqIGFvgbJcVbbN_oGNLb9jwD2ymPH1l61_hUq7l3A/edit?usp=sharing

Dependencies

Name	Method	Alternative	Impact	Status
MIMIC III Dataset	Apply for access	Simulation	Affect Training Results	Waiting for Approval
Computer for Training Datasets	Google Cloud	NA	Unable to finish training	Not Started
Interface between simulink and python	Self Constructed	Rebuild lung model in python	Need a week or two to migrate the code.	Not started

Management

1. Meetings twice a week with Dr Antwan D. Clark Mondays & Fridays 1PM
2. Code and Related Works are on Github
3. Daily Communications with mentor by email.

References

1. Messina, Z. (2021, August 2). Pressure controlled ventilation. StatPearls [Internet]. Retrieved February 22, 2022, from https://www.ncbi.nlm.nih.gov/books/NBK555897/
2. Mohammad Jaber, Lara Hamawy and Mohamad Hajj-Hassan et al. MATLAB/Simulink Mathematical Model for Lung and Ventilator. DOI: 10.1109/ICM50269.2020.9331820
3. H. Y. Al-Hetari, Y. Alginahi, M. N. Kabir, N. Q. Al-Naggar, M. A. Al-Rumaima and M. M. Hasan, "Modeling Lung Functionality in Volume-Controlled Ventilation for Critical Care Patients," 2020 IEEE 2nd International Conference on Artificial Intelligence in Engineering and Technology (IICAIET), 2020, pp. 1-4, doi: 10.1109/IICAIET49801.2020.9257851.
4. Al Naggar, N.Q. (2015). Modelling and Simulation of Pressure Controlled Mechanical Ventilation System. Journal of Biomedical Science and Engineering, 08, 707-716.
5. Yan Shi, Shuai Ren, Maolin Cai, Weiqing Xu, Qiyou Deng, "Pressure Dynamic Characteristics of Pressure Controlled Ventilation System of a Lung Simulator", Computational and Mathematical Methods in Medicine, vol. 2014, Article ID 761712, 10 pages, 2014. https://doi.org/10.1155/2014/761712
6. Talebi, S. (2021, January 8). The wavelet transform. Medium. Retrieved February 28, 2022, from https://towardsdatascience.com/the-wavelet-transform-e9cfa85d7b34

Thank you!