Pressure Prediction System in Lung Circuit using Deep Learning and Machine Learning

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Abstract - *A massive number of patients infected with SARS-CoV2 and Delta variant of COVID-19 have generated acute respiratory distress syndrome (ARDS) which needs intensive care, which includes mechanical ventilation. But due to the huge no of patients, the workload and stress on healthcare infrastructure and related personnel have grown exponentially. This has resulted in huge demand for innovation in the field of automated healthcare which can help reduce the stress on the current healthcare infrastructure. This work gives a solution for the issue of Pressure prediction in mechanical ventilation. The algorithm suggested by the researchers tries to predict the pressure in the respiratory circuit for various lung conditions. Prediction of pressure in the lungs is a type of sequence prediction problem. LSTM (Long Short-Term Memory) is the most efficient solution to the sequence prediction problem. Due to its ability to selectively remember patterns over the long term, LSTM has an edge over normal RNN. RNN is good for short-term patterns but for sequence prediction problems LSTM is preferred.*

Key Words: Machine Learning, RNN, LSTM, Pytorch, COVID-19 Pandemic

1. INTRODUCTION

Many diseases, such as pneumonia, heart failure, COVID-19, etc., lead to lung failure for many different reasons. A person who cannot breathe on his own or has difficulty breathing needs to be given some external support to help with breathing. This help is provided to the patient with the help of a mechanical ventilator, and once the patient is stable, they are weaned off the ventilator. A mechanical ventilator is a machine that helps pump oxygen into a person's body through a tube that goes in the mouth and down to the windpipe. According to the patient's condition and needs, the doctor programs the ventilator to push air when the patient needs help.

Mechanical ventilators use a PID (proportional-integral-derivative) control algorithm to automatically adjust the oxygen concentration in the patient according to the patient's requirements. These controllers use several physiological data points of the patient, such as the breathing frequency, oxygen level, etc., to help the patient get stable and provide an appropriate amount of oxygen. The input to the system includes the carbon dioxide level, oxygen level, and air resistance. These ventilators help adjust the breathing frequency in a clinically appropriate manner in response to the changes in the patient's breathing frequency. Mechanical ventilators are clinically controlled and operated by doctors and nurses who are trained to handle them.

However, PID controllers have certain limitations. When it comes to a process that is integrated and has a large time delay, performance is poor. Small changes or deviations are not reflected easily. The purpose of the given system is to eliminate these limitations. Using the concepts of deep learning, these limitations can be almost eliminated and the system can work with greater efficiency. Given technology is budget-friendly for hospitals. The amount of manpower required to ventilate a single patient will be reduced, which can be an enormous benefit, especially in pandemic situations.

According to the resource Virus Centre of Johns Hopkins Medicine, 2.2% out of total worldwide COVID-19 affected people are died due to the acute respiratory syndrome analyzed since November 2019. Ground Glass Opacity (GGO) has been observed that the COVID-19 variants especially delta one cause pneumonia in both the lungs. A large number of people infected with Delta and other variants have acute respiratory distress syndrome (ARDS) and they need high-level medical facilities like invasive mechanical ventilation. The effect of COVID-19 variants on the immune system, ground-glass opacity, and the different neoplastic changes in the lungs due to SARS-CoV2 and other variants attacks is the key focused area.

2. LITERATURE SURVEY

In this paper [1] author tries to suggest that it is convenient to use HMMs algorithm to predict the pressure of ventilators in sedated patients and to results that the given threshold value of asynchrony events has such a probability. Unlike other studies based on very limited observation periods in patients with specific conditions, authors analyzed the whole period of mechanical ventilation in a different wide range of the population of ICU patients with a different variety of critical illnesses.

In this paper [2], different settings of mechanical ventilation of ventilators are analysed depending on the particular patient's lungs condition, and the determination of these parameters depends on the observed patient's past medical history and the experience of the clinicians involved in their practice. In the research, they have used Graded Particle

Swarm Optimizer (GPSO) for the analysis of patients' medical data. The main limitation of the current study is, all the data of patients were recorded manually, and these readings of ventilator parameters were taken at random intervals of time that are not continuous readings.

In this paper [3] author suggests a retrospective multicentre study of all patients with COVID-19 patients, who were presented to the ER clinician at Beaumont Health, which is the largest health care system in Michigan. The author has developed two separate decision-tree-based, which is an ensemble to ML algorithm. This study has two objectives, one is a prediction of mechanical ventilation and the second one is Mortality.

In this paper [4] author designed the end-to-end pipeline for learning a PID controller, also the improvement is done upon PID controllers for tracking ventilator pressure waveforms. All the improvements measures are considered concerning the ISO standards for better performance of ventilator support parameters.

3. PROPOSED SYSTEM

Feature engineering means the process of using domain knowledge for the purpose to extract the data and convert the most relevant variables from raw data while building a predictive model using supervised learning, deep learning or statistical modeling. The main need of the feature engineering phase is to enhance the performance of machine learning (ML) and deep learning (DL) algorithms.

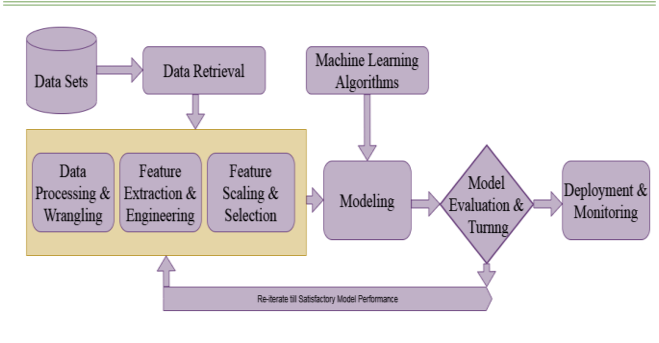


Figure 1: Feature engineering framework

4. METHODOLOGY

4.1 Recurrent Neural Networks

RNN is a progression on the feedforward type of neural networks where the output from the last computation is supplied as input for the next computation and this is where the word recurrent comes from. In RNNs the output from the last computation is copied and stored as a hidden state. For the next computation, the input for that step and the value in the hidden state is taken into consideration. With us dataset contains data in the form of a sequence, and RNN is found to be one of the better models for dealing with such sequential data.

4.2Long Short-Term Memory Network

LSTM network is a modern version of recurrent neural networks, which has a memory so it makes it easier for it to compute a large sequence of data. The problem of insufficient memory or storage to remember previously stored data in hidden states for a long term in RNN is solved here. The LSTM operates a bit similar to the logic circuit and it has three gates that help it in its decision-making process.

4.3MLP Multilayer Perceptron

Understanding the multilayer perceptron network helps us to get information about the underlying reasons in the high-level models of deep learning. Simple regression problems can be easily solved with the help of MLP. A multilayer perceptron tries to remember patterns in sequential data, because of this to process a multidimensional dataset we require a large number of parameters in the dataset.

4.4 K-Fold technique

K-Fold is a validation technique in which the data are divided into k subsets and the holdout method is applied k times. In the process, every set of subsets is used as a test set and the other remaining subsets are used for the training purpose. Then the mean value error is calculated from all these k outcomes, which is more reliable as compared to the standard handout method. Group K-Fold is an advanced version of the k-fold technique which validates that the same sample group data is not represented in both the test set and train set.

4.4.1 Cross-validation

It is not a good practice to swat the parameters of training data and test it on the same. A model which is trained and built by just repeating the labels of the samples of data that it has just seen would give perfect results but with the unseen data, it may fail to predict anything useful. Such kind of problem is known as over fitting.To overcome this over fitting, it is suggested to divide available test dataset data into two parts such as X-test and Y-test while performing a supervised learning experiment. Now comes the most important part which is training the model and experimenting on it, because the experiment phase is an integral part of model development. Even commercially machine learning usually starts experimentally.

4.5 DATASET DESCRIPTION

These are the data parameters we have used in our model:

- Breath_id: unique id for each breath

- R: lung attribute indicating how restricted the airway is
- C: lung attribute indicating how compliant the lung is
- Time_step : Time stamp
- U_in: control input for inspiratory valve. Range 0-100 percentage
- U_out: control input for expiratory valve Range 0-1 closed or open
- Pressure: pressure in the respiratory circuit

	id	breath_id	R	C	time_step	u_in	u_out	pressure
0	1	1	20	50	0.000000	0.083334	0	5.837492
1	2	1	20	50	0.033652	18.383041	0	5.907794
2	3	1	20	50	0.067514	22.509278	0	7.876254
3	4	1	20	50	0.101542	22.808822	0	11.742872
4	5	1	20	50	0.135756	25.355850	0	12.234987

Figure 2: Dataset components

4.6 OUTCOME

The predicted pressure as a output for a unique id of Patient:

	A	B
1	id	pressure
2	1	6.249185
3	2	5.960309
4	3	7.022456
5	4	7.727304
6	5	9.06085
7	6	10.19921
8	7	11.39467
9	8	12.52998
10	9	13.71457
11	10	14.79273
12	11	15.87531
13	12	16.60973
14	13	17.4365
15	14	18.05306
16	15	18.6604
17	16	19.3957
18	17	20.05368
19	18	20.73082

5. ALGORITHM

Step 1: Start

Step 2: Login activity validates the user data.

Step 3: Enter patients Lung attribute Parametres (R &C)

Step 4: enter the Time stamp and u_in, u_out Parmeters

Step 5: Raw data send to server application, and input data to trained Model

Step 6: Output data (predicted pressure) sent from server displayed on the screen

Step 7: Plot graph for u_in u_out and predicted pressure

Step 8: Exit

6. IMPLEMENTATION

What do doctors do when a patient has trouble breathing? They use a ventilator to pump oxygen into a sedated patient's lungs via a tube in the windpipe. Our project aims for mechanical ventilation control by Machine Learning. We believe that neural networks and deep learning can better generalize across lungs with varying characteristics than the current industry standard of PID controllers.

Typically workflow of machine learning projects is expressed by following figure.

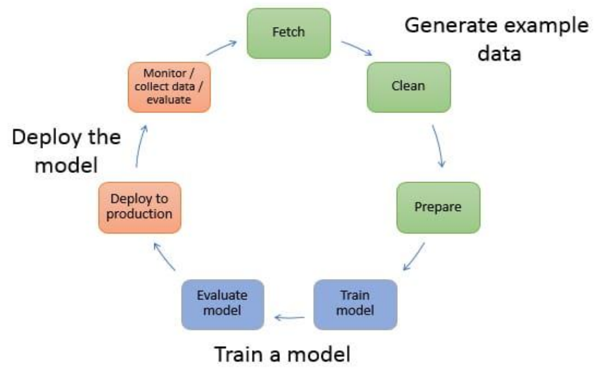
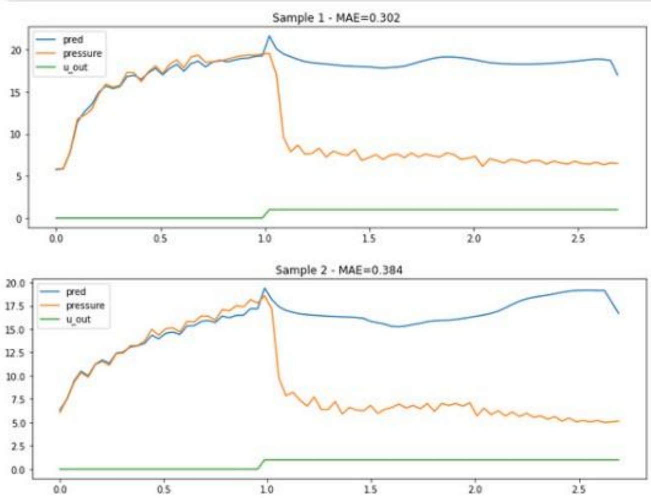


Figure 3: Workflow of ML Model

Matplotlib in python is a powerful tool used for the graphical representation of data with the help of other libraries like pandas and NumPy. It is like performing MATLAB functions and methods in python. It is used for generating statistical interferences and plotting 2D graphs of arrays and sometimes 3D also. Matplotlib was used to create the graph. The graph describes the u_in, u_out, and pressure variance of a particular patient over different time steps. Figure 5 depicts a graph plotting example using Matplotlib.



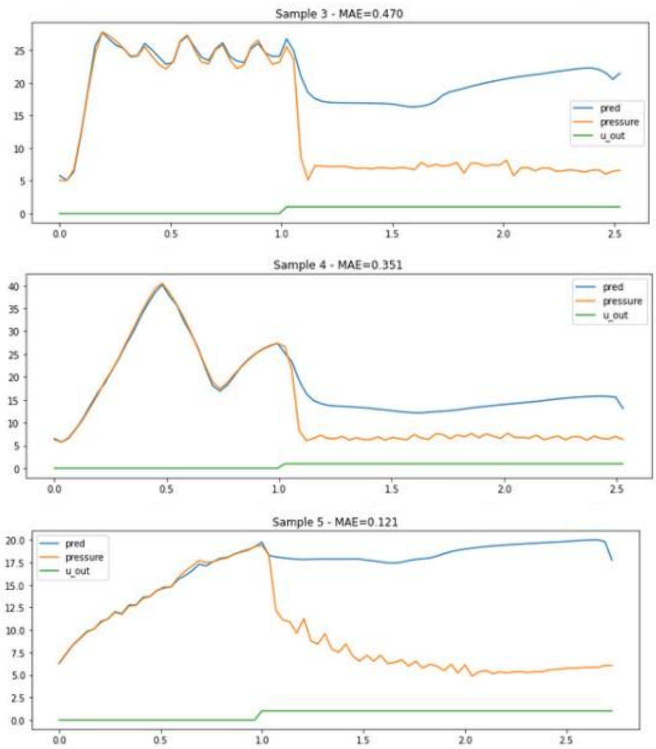


Figure 3: Change in u_in, u_out and pressure for particular patient over different time stamp

MAE(Mean Absolute Error):

Mean Absolute Error, also known as MAE, is one of the many metrics for summarizing and assessing the quality of a machine learning model.

$$mae = \frac{\sum_{i=1}^{n} abs\left(y_i - \lambda(x_i)\right)}{n}$$

7. OBJECTIVES

- To predict the Ventilator pressure using machine learning model with the help of LSTM algorithm.
- To predict the pressure in respiratory circuit for different lung conditions
- To implement the project using web development.

8. CONCLUSIONS

This study will help us develop an algorithm and machine learning that will help clinicians in predicting pressure levels in the lungs of patients with varying different body conditions while putting them on mechanical ventilation. This will reduce the workload from the healthcare workers, which is present like conditions like pandemics are increasing. The predictions for mechanical ventilation get easier with parameters such as age, resistance in the respiratory tract, and compliancy of lungs this helps the clinician in their decision-making process.

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