UNIVERSIDAD DISTRITAL
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Pressure Prediction in Mechanical Ventilators Using Neural Networks

Workshop 1 - Team 13

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Overview

To reduce the costs associated with the development and research of mechanical ventilation systems, Google Brain, in partnership with Princeton University, is working to design neural networks and deep learning systems capable of simulating patients' lungs. Unlike traditional PID control systems, which provide only static simulations, this approach aims to create dynamic models that can adapt to the varying characteristics of individual lungs, thereby enhancing the accuracy and effectiveness of mechanical ventilation simulations.

Core Challenge

While there are some simulators that provides a mechanical solution to the ventilator pressure, these simulations are made on the configuration of a particular lung, so you must manually change the attributes of the patient lung, with this the challenge is to develop a neural network and deep learning tool to analyze and predict the pressure of the ventilator based on the attributes of the patient.

Systemic Analysis

This system consists of two main components connected to each other. One is the mechanical ventilator, which is used to simulate the patient's lungs, while the other is an artificial test lung. These two components are connected via a respiratory circuit, this, now the following directed acyclic graph can summarize Ventilator Pressure system:

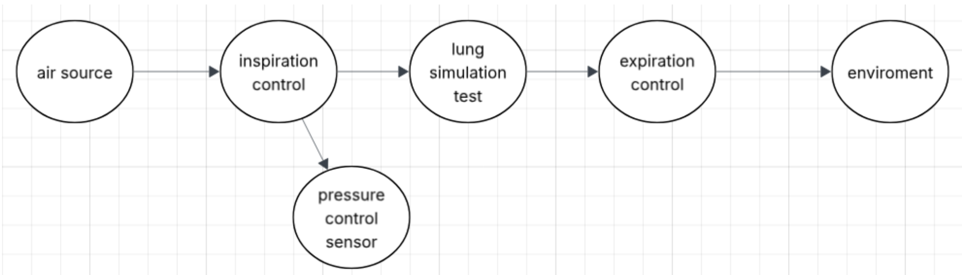

Figura 1: Diagrama del sistema de presión del ventilador

Then, an extended version and each element interaction can be explained on the original block diagram:

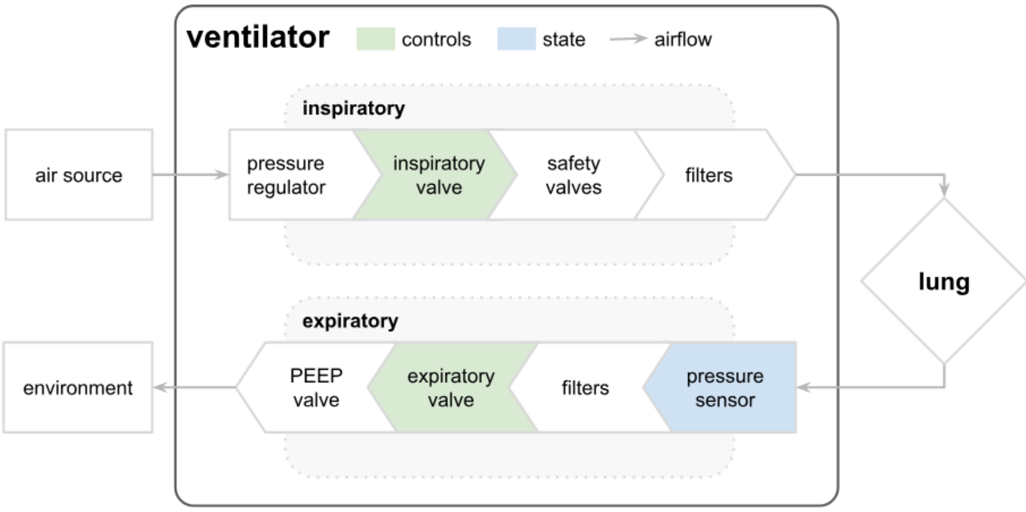

Figura 2: Diagrama extendido del sistema

The system works with an air flow input the system, the first element it encounters is a pressure regulator that is being the feedback it receives from a later part of the system, it starts in the default configuration, then goes into the inspiratory valve which have a number between 0 and 100 that represents the amount of pressure the system does, after that goes to the safety valves that helps to solve some emergences that may occur in the process, after that filter the particles of the air so the lung receives clean and pure air, the sensor learn and interpret the behavior of the patient lung and gets information and feedback, using cybernetic processing it auto-control himself with the valves and auto-regulate the pressure with the information it gets from the lung behavior, the air goes out through another filter, and encounter the expiratory valve, that has an 0 or an 1 that let the valve being closed or open, and to prevent some emergences the peep valve let some air into to manage the patient health, goes to the environment and give the feedback to the next iteration of pressure, going in a loop that helps the new air coming in getting in a better manner.

Dataset Structure

The data structure consists of the following items:

- **Air:** this input has a very high sensibility to the system, as if it comes in in a bad way can cause the death of the patient.
- **Particles:** Another input that may merge with the air that goes into the lung
- **Manual operation by the doctor:** An input that varies depending on the person manipulating the system.
- **Patient allergies:** Sometimes some allergies can affect the function of some medical treatments, and this can affect the development of the system.

- **Patient respiratory illnesses:** The main reason this project is being made is that not all lungs are the same, and by that, not all the pressure needed is the same, so this is an input that is very relevant to the system.
- **Patient physical attributes:** Another key input is the physical attributes the patient has in relation to the lungs; the thickness may be a variable that indicates the pressure.
- **Pressure:** An element of the system, it is the core of the system as the purpose of the ventilator is to predict his pressure.
- **Inspiratory valve:** this element is key to manage the pressure, since it is the value of air coming into the lung.
- **Safety valve:** it consists of a mechanism that allows the system to know when the air coming into the patient is reaching its limit and let it go out to the environment.
- **Filters:** A group of elements that helps the system to clean the air from the particles that merge with the air.
- **Pressure sensor:** This element is the objective to make a tool that predicts the pressure, after the air is being processed by the lung's patient, the sensor learns from the interaction between the input and the system and gives the optimal pressure.
- **Expiratory valve:** A valve that indicates if it opens or not, letting the air come out or not.
- **PEEP valve:** A tool that prevents some emergences of the patient by letting some air get in after the exhale process.
- **Air getting out:** this is the output of the system, that gives the information of the pressure needed.
- **Difficulty of the patient in the process of exhalation:** An item that helps to measure the possible flaws of the system that doesn't help the patient.
- **Reaction of the patient to some configurations:** to help the adaptation of the system, it is important to measure the output of the patient reaction to the system.

Sensitivity and Complexity

The sensitivity is a key element to analyze since it gives the relevance to the inputs of the system, following are the structure and sensitivity of the inputs:

Input	**Type**	**Sensitivity**
Air	Range of integers	0.9
Particles	List	0.6
Manual operation	List	0.6
Patient allergies	List	0.8
Patient illnesses	List	0.8
Patient attributes	List	0.9

We can see that the air is the more sensible input since if it comes in a bad manner, it can cause the direct death of the patient, while the particles can be cleaned by the filters, the manual operation can cause some troubles to the patient but the objective is that the main function operates from the deep learning tool, so it isn't that sensible, and the patient allergies can cause some trouble and emergences that may not studied before and may cause difficulties to the patient health, same as that comes the patient illnesses as if the patient has a specific illness that impossibilities his capacity to breath then the configuration of the ventilator has to be very specifical according to his illness, and ending with the inputs, the Patient physical attributes are very important since it's the main reason of the development of this project, since is the main element that causes the variation of pressure between patients.

Complexity

The systems have a medium – high complexity, while it doesn't interact with many elements of the environment, the interaction with the environment and the feedback is fundamental to the function of the system, such as the type of air and his pureness, or the types of particles that mixes with the air and causes the differences between the pressure and the diagnosis about the attributes of the specific lung.

Some items of complexity can be:

- Quality of air
- Type and attributes of the lung
- Illnesses of the patient
- Malfunctioning of the manual manipulation
- Types of reaction of the patient

Chaos and Randomness

Pressure and volume in the lungs do not follow a linear pattern, but rather exhibit complex behaviors such as hysteresis, where the curve during inspiration differs from that of expiration. This non-linear pattern is accentuated near physiological limits, where small changes in airflow (u_in) can generate disproportionate variations in pressure. The competition model attempts to capture this with the R and C parameters, but in reality there exist viscoelastic properties and regional heterogeneities that introduce greater unmodeled complexity.

The system shows high dependence on initial conditions, a typical characteristic of chaotic systems. Small differences in the first moments of the respiratory cycle can lead to completely divergent pressure trajectories. Furthermore, transitions between inspiration and expiration represent critical points where system behavior changes abruptly, generating discontinuities that are challenging for prediction models and can originate phenomena such as unwanted oscillations.

The simplification of pulmonary mechanics using only two parameters (R and C) is a major limitation, since in practice factors such as tissue resistance, chest wall compliance, and frequency-dependent behaviors intervene. This simplification creates a gap between simulation and reality, which translates into structural unpredictability. Additionally, the lack of feedback in control (open-loop system) conceals dynamic interactions that in a real ventilator can be a source of chaotic behaviors.

Conclusion

The system presents a well-founded physical basis that allows understanding of key concepts in mechanical ventilation. The R and C parameters have clear clinical meaning and the evaluation metric (MSE) aligns directly with the medical need for pressure precision.

The controlled environment of the competition eliminates external variables, facilitating focus on central modeling without additional noise, which is ideal for educational purposes and initial model development.

The main limitation is the scarce data diversity, with only 75 simulated patients, which do not capture the real variability of conditions such as COPD or ARDS. Furthermore, the simplified physiology omits important phenomena such as the patient's spontaneous effort or the heterogeneity of pulmonary ventilation. The use of an open-loop system also differs greatly from clinical practice, where real-time feedback is crucial for patient safety.

This competition serves as an excellent case study for analyzing cyber-physical systems, where digital and physical components are integrated. It allows us to understand the need for robust models that handle non-linearities, parametric uncertainty, and critical transitions. However, it also shows that good performance in simulation does not guarantee clinical applicability, highlighting the importance of validation in real environments before implementation.