BREATHE: A Digital twin-based Respiratory System Simulator for Mechanical Ventilator Testing and Training

BREATHE General Objective

By means of the digital twin, the goal is to create a realistic and dynamic simulation environment that allows not only practical **training** in ventilator use but also the possibility to **test and validate** respiratory care strategies on customizable virtual patients. This project aims to overcome existing limitations by offering an innovative solution that can be used for both medical training and clinical research.

Abstract

Medical simulation has become a crucial element in training and furthering clinical skills, particularly in mechanical ventilation. Integration between respiratory simulators and virtual mechanical ventilators is still a significant challenge.
This research aims to develop an innovative solution, based on the use of **digital twins**, to overcome these limitations by designing a system that allows the interconnection between a respiratory simulator and a virtual mechanical ventilator, intended for **testing ventilators under development**.
A graphical user interface is implemented, to ensure **effective training** in the use of the devices.
The approach is based on the digital twin concept, creating a virtual representation of the patient that includes his or her clinical condition and pathology, allowing the evolution of vital parameters to be simulated in response to specific events.

SAFEST - truSt Assurance of digital twins For mEdical cyber-phySical sysTems

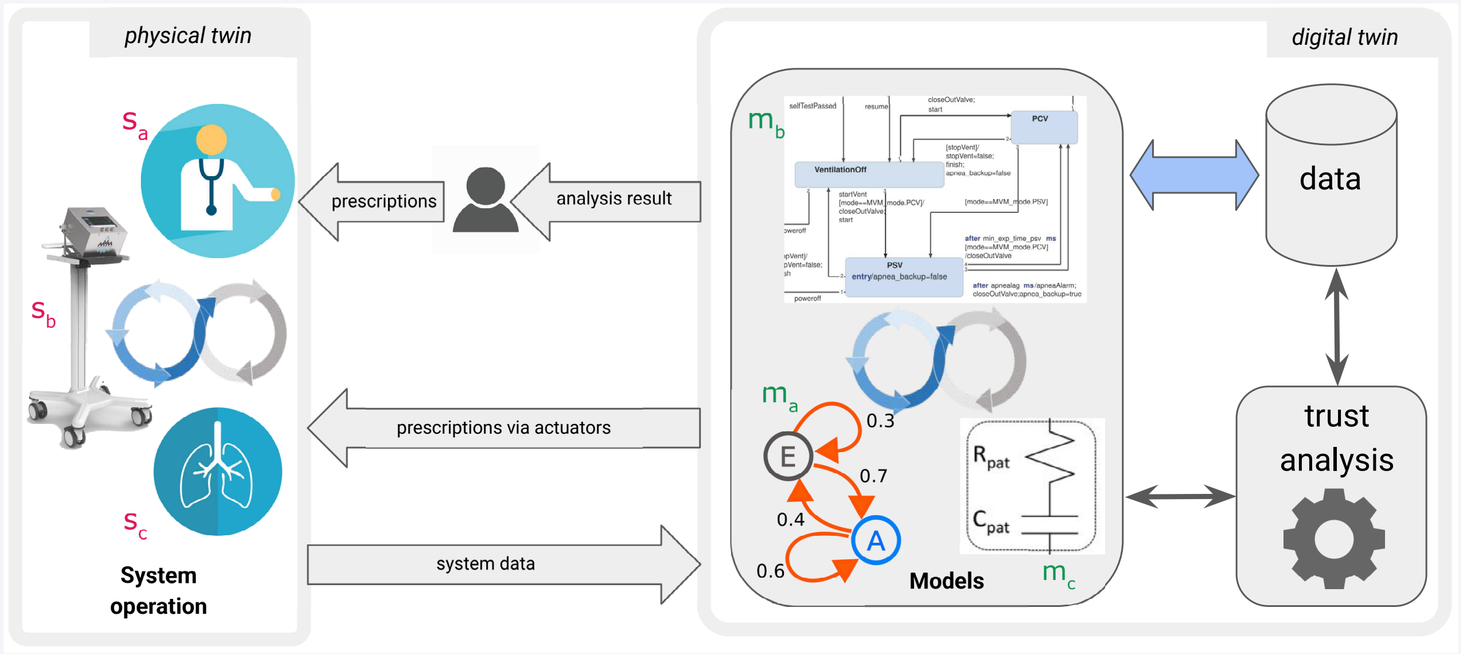
The **SAFEST** project aims to improve DT methodologies and tools in Medical Cyber-Physical Systems (MCPSs). It focuses on two main goals:

- taming the complexity caused by the heterogeneity of the DT components that must be built, operated, coordinated, and evolved together with their physical and human counterparts;
- increasing the level of trust in the results and indications coming from a DT, despite modeling approximations and uncertainties caused by incomplete or imprecise data collected in the field.

To achieve these goals, SAFEST has two objectives:

- developing modeling notations for evolving heterogeneous systems with uncertainty
- providing trust assurances in terms of behavioral conformance, safety, dependability, security, and performance.

The project's methods and tools will be evaluated through a medical domain case study.



BREATHE requirements

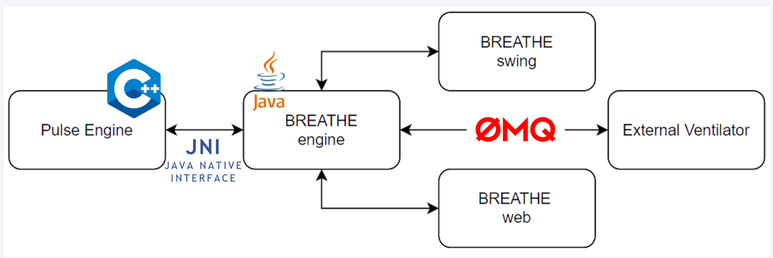
Functional and non-functional requirements for BREATHE have been identified. Here only functional requirements are reported.

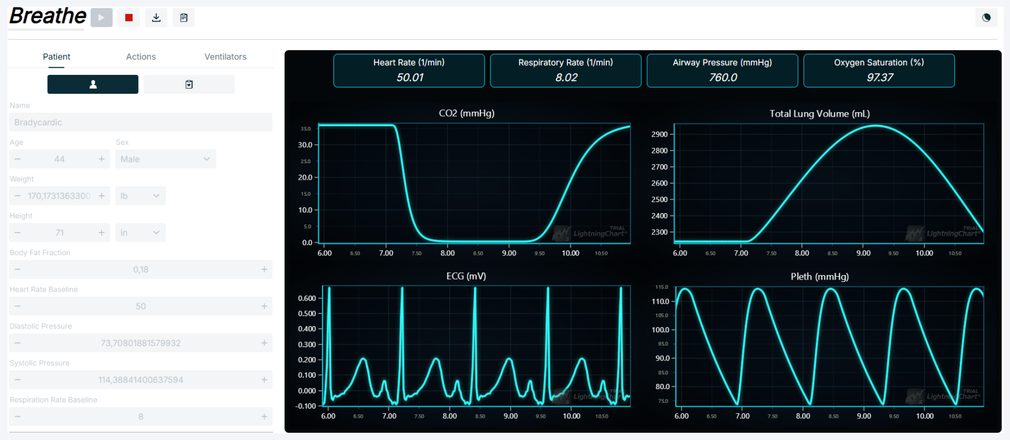
- **Patient Data Entry:** before the simulation, users must be able to enter patient information, including physiological variables and pre-existing conditions.
- **Data Import/Export:** export/import the patient profile and the current simulation state allowing the simulation to resume from the exported state.
- **Action Application:** during the simulation, users must be able to introduce actions representing abnormal conditions, such as respiratory difficulties.
- **Scenario Creation and Loading:** users must be able to create/upload a scenario by specifying the reference patient (in a certain state) and a series of actions to be applied at different moments during the simulation.
- **Ventilator Management:** users must be able to connect an integrated/external mechanical ventilator to the patient to test its functionality.
- **Data Visualization and Monitoring:** patient's vital parameters, applied conditions, and ventilator settings, if present, must be viewable by the user through graphical elements during the simulation.

BREATHE implementation

BREATHE has four main components:

- **BREATHE web**: remotely accessible application to practice using mechanical ventilators
- **BREATHE swing**: extends web application functionalities with ventilator testing





- **Pulse Engine** is an open-source physiological simulation engine based on mathematical models designed to replicate interactions between systems in the human body. It enables the simulation of clinical respiratory conditions and the management of mechanical ventilators by constantly monitoring these parameters and responding in real time to user input.
- The **BREATHE engine** module directly integrates the Pulse libraries and acts as a central component, receiving input (from the web interface or Swing) and providing output with simulation results, to be displayed in the respective interfaces.

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