Generalized Additive Modelling (GAM) to Describe and Visualize Heart-Lung Interactions

Project Overview

This project focuses on building a user-friendly and interactive Shiny application to visualize and analyze heart-lung interactions in mechanically ventilated patients. Rather than developing new mathematical models, the work has concentrated on implementing already developed generalized additive models (GAMs)[1] and making them accessible through an intuitive interface. The aim is to provide clinicians and researchers with a flexible tool to explore complex physiological data without requiring programming skills. The tool supports hypothesis generation, advances understanding of heart-lung dynamics during interventions such as fluid infusion, and contributes to more accurate assessment of cardiac function.

Data and Physiological Background

The interaction between the heart and lungs is critical to both circulation and respiration. Changes in chest pressure during ventilation can affect cardiac filling and blood flow. Key physiological signals are arterial blood pressure (ABP), central venous pressure (CVP), and electrocardiogram (ECG) which are essential for understanding these dynamics (Figures 1–3)[2].

Figure 1: ABP

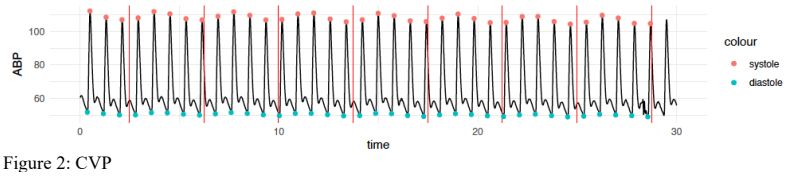
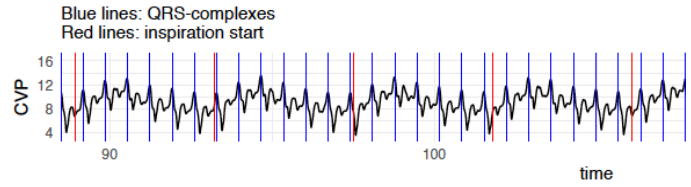


Figure 2: CVP



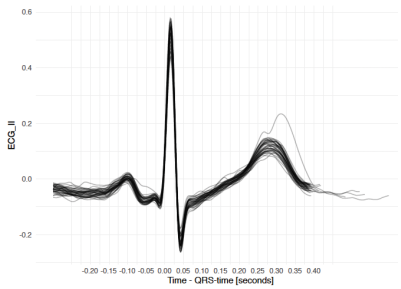


Figure 3: ECG

These signals are collected using clinical monitoring devices and form the core dataset for the application. To ensure flexibility, the tool is compatible with multiple data formats, including .RDS, .EDF, and VitalDB. Recordings are sampled at 125 Hz for ABP and CVP, and 500 Hz for ECG, providing high-resolution data suitable for detailed analysis. Some datasets also include annotations marking clinical interventions, such as fluid infusion (Figure 4)[3], which are crucial for studying physiological responses.

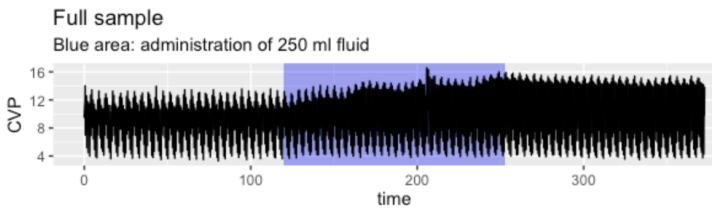


Figure 4: CVP with specified intervention time

[1] Publikation GAM: https://link.springer.com/article/10.1007/s10877-022-00873-7
[2] Publikation GAM (Github): https://github.com/JohannesNE/gam-medical-signals-supplementary/tree/v1.0-submitted
[3] Publikation GAM (Github): https://github.com/JohannesNE/gam-medical-signals-supplementary/tree/v1.0-submitted

The physiological measurements are recorded as follows:

- **Arterial Blood Pressure (ABP)** is measured via an arterial catheter placed in the wrist.
- **Central Venous Pressure (CVP)** is measured through a venous catheter inserted under the collarbone, leading to the heart.
- **Electrocardiogram (ECG)** is measured using 10 electrodes attached to the skin: one on each arm and leg, and six on the chest.

Use Cases Demonstrating Relevance

Use Case 1 - Accurate Pulse Pressure Variation (PPV) Measurement Using GAM

Based on existing GAM models, the tool accurately measures pulse pressure variation (PPV) by modeling PP as a smooth function of respiration cycle phase and time. This approach is especially effective in patients with high respiratory rates, where traditional methods tend to underestimate PPV. By capturing subtle heart-lung interactions through these partitioned effects, the GAM provides a more reliable assessment of cardiac function.

Use Case 2 - Exploratory Modeling of Heart-Lung Dynamics Over Time

Based on existing GAM models, the tool uses a tensor product smooth to model the combined effects of cardiac position, respiration, and time on CVP or ABP. This exploratory approach captures complex heart-lung dynamics and offers promising potential for uncovering new physiological insights and guiding future research.

Application

In building the application, development focused on integrating established statistical models into a robust, responsive application that handles patient-specific variability such as extrasystoles and outliers (figure 5)[4] ensuring accurate and reliable visualization of physiological signals.

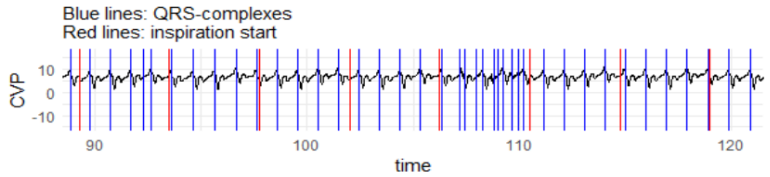


Figure 5: Extrasystoles in CVP (Too frequent QRS complexes corresponding to the blue horizontal lines)

The final product is a practical, ready-to-use tool bridging advanced heart-lung interaction modeling with clinical and research applications.

[4] Publikation GAM (Github): https://github.com/JohannesNE/gam-medical-signals-supplementary/tree/v1.0-submitted