Modeling and Analysis of a New Technique for Protecting Human Lungs during Heart Surgery Using LabVIEW

We chose NI CompactDAQ to centralize and synchronize the acquisition of multiple physiological parameters.

"Ease of use in programming and seamless hardware/software integration helped us get up and running faster with our modeling experiments, and the NI platform brought high reliability to our results."
- Youssef Abdelmoumen, Hôpital du Haut-Lévèque, CHU de Bordeaux

The Challenge:
Developing a set of acquisition, processing, and modeling tools for a state-of-the-art lung protection method used in heart-lung machine support during heart surgery.

The Solution:
Using multiple NI software and hardware products to simulate and analyze the physiological processes of lung injury during cardiac surgery with machine support.

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Heart surgery often requires the temporary exclusion of the heart and lungs from the bloodstream. An extracorporeal blood pump and oxygenator (cardiopulmonary bypass machine) artificially maintain the circulatory and respiratory functions during the surgery.

The respiratory side effects after such a process remain a major challenge, leading to potential postoperative respiratory failure. Medical researchers have theorized that organ deterioration after surgery is likely due to local reduction of functional blood input and energy impoverishment of the lung tissue, which occur during the cardiopulmonary bypass.

Hypothermic Ventilation

Therapeutic hypothermia is a medical treatment that lowers a patient's body temperature to help reduce the risk of the ischemic injury to tissue following a period of insufficient bloodflow. To slow down the metabolism of jeopardized organs, surgeons often induce therapeutic hypothermia during cardiopulmonary bypass; however, the respiratory benefit of induced hypothermia is still controversial.

Evidence suggests that the circulatory exclusion via diversion of the coolant blood of the lung during bypass surgery reactivates the intermediate vascular sections. This triggers a diversion of the feeding arterial flow toward the functional component, accounting for the energy shortage of the lung tissue. The results demonstrate the inefficiency of general hypothermia for lung protection.

Since 2008, the laboratory research unit of Haut-Lévèque Hospital in Bordeaux-Pessac, France, has used a pioneering technique for lung protection during the cardiopulmonary bypass called hypothermic ventilation. Hypothermic ventilation is achieved through cooling gas. The thermal insulation status induced by the cardiopulmonary bypass supports the benefits of this approach. Our goal is to study the lung lesion-causing process as well as the protective role of hypothermic ventilation therapy.

Acquisition of Physiological Data

For our investigation into hypothermic ventilation, our first goal was to develop a powerful tool suited to gather and synchronize the complete acquisition of various physiological data within an experimental research environment.

Using LabVIEW graphical system design software, we built an application that consists of a customized user interface, a display interface for the follow-up, and a recording. The data we had to acquire includes a variety of parameters:

- An electrocardiogram
- Three blood and venous pressure measurements
- Several thermocouples through the bronchial tree
- Multiple blood-flow measurements, including heart, cardiopulmonary bypass, and bronchial artery blood flows
- Oxygenation parameters

NI CompactDAQ allows the application to easily handle multiple inputs as well as interface with various medical devices, which correspond to each measurement. The NI CompactDAQ system includes an NI cDAQ-9172 chassis with three NI 9221 analog input modules and NI 9219 universal analog input modules. Running in LabVIEW, the application is supported by an NI PPC-2015 panel PC (PPC).

Using NI vision tools, we developed a complementary application for lung tissue that involves optical microscopy image acquisition. The application operates via a digital 3-CCD KY-F75U camera connected by an IEEE 1394 wire to the PPC. This addition allows for a quantitative and automated analysis of inflammatory reaction and tissue disorders, including alveolar surface, tissue oedema, and inflammatory cell count.

Biostatistical Data Analysis

NI DIAdem data management software provides a well-suited and scalable tool for event-oriented sequencing and biostatistical data analysis. This application consists of a graphical display as well as single and partial correlation tests. It allows for averaging, diversion, and manipulation of data according to the experimental investigation needs.

Modeling and Simulation

We developed a model of lesion-caused processes using the LabVIEW Simulation Interface Toolkit. The toolkit integrates various steps of the artificial heart-lung machine implementation and weaning.

The model mimics the “semifractal” structure of the bronchial tree, including convection-diffusion and bidirectional ventilation dynamics (inspiration and expiration), as well as air scattering along the bronchial structure. We chose a thermal behavioral model developed from the bond graph method with a fractal network structure of RC elements.

Conclusion

Using a variety of NI software and hardware tools greatly facilitated the experimental process. Ease of use in programming and seamless hardware/software integration helped us get up and running faster with our modeling experiments, and the NI platform brought high reliability to our results. We plan to continue using LabVIEW and the NI platform for additional medical research projects in the future.

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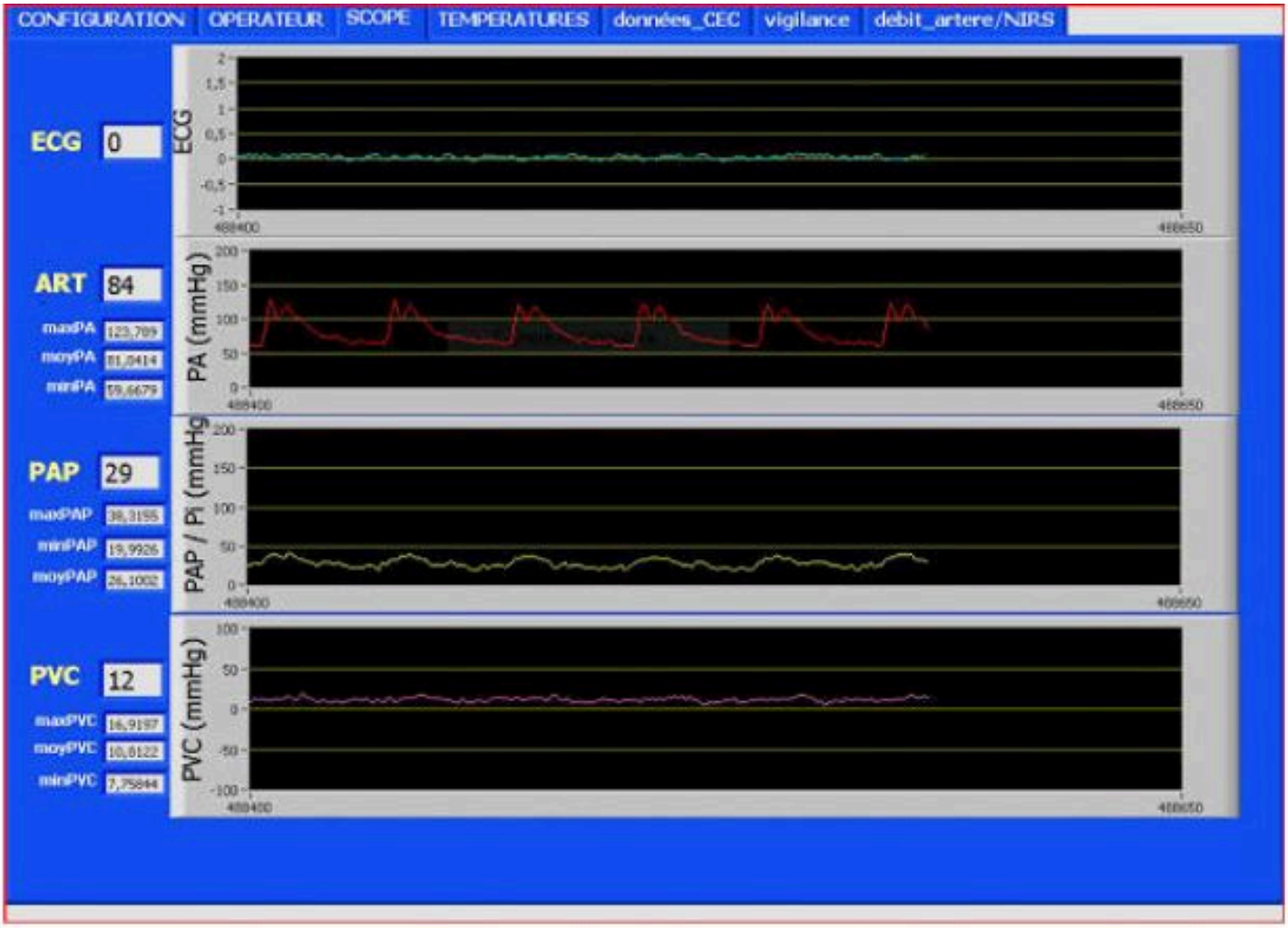

Front panel displaying the evolution of the physiological parameters.
