Breathe at ease

Neural impulse measurement makes artificial respiration more comfortable

Normally, when we want to breathe in, we just do it. But with artificial ventilation, how does the machine know how much air the patient needs, and when? Mechanical intervention can be stressful for the patient, and to minimize the discomfort, the machine must respond to the patient's breath initiation as early as possible.

How We Breathe

The act of breathing depends on rhythmic discharge from the respiratory center of the brain. This discharge travels along the phrenic nerve and excites the diaphragm muscle cells, so that the muscles contract and the diaphragm is lowered. As a result, the pressure in the airways drops, causing an inflow of air into the lungs.

Conventional Artificial Ventilation

Conventional mechanical ventilators sense a patient respiratory effort by either a drop in airway pressure or a reversal in flow. In other words, the last and most slow-reacting step in the chain of respiratory events is used to sense the patient's effort. The patient has to act before the ventilator joins in.
This is hard work, especially for weak patients. And because a conventional ventilator intervenes relatively late, a slight asynchrony can occur between human and machine. This may lead to patient discomfort and agitation. But using a ventilator that takes over the breathing activity completely should be avoided as long as possible to maintain the patient's breathing abilities and to promote spontaneous breathing.

NAVA (Neurally Adjusted Ventilatory Assist)

To improve artificial ventilation and to make the situation more comfortable for the patient, we at Maquet developed a new way of detecting patient breath initiation. Instead of measuring the airway pressure, we use an electrode array to capture the electrical activity of the diaphragm (figure 1). The raw electrical signal measured on the single electrodes is called EMG (**e**lectro**m**yo**g**raphy). Signal processing is performed on the EMG to obtain what we call the Edi signal, which contains only the signal related to the diaphragm.
The Edi signal is transmitted to the ventilator and used to assist the patient's breathing. That way, the machine can react to the patient's wishes faster. As the ventilator and the diaphragm work with the same signal, their mechanical coupling is practically instantaneous.
The activation signal of the diaphragm is the earliest possible detectable signal we can use with today's technology (figure 2).

Testing NAVA

The key technology of NAVA is the signal processing performed on the EMG. To test the EMG algorithm and

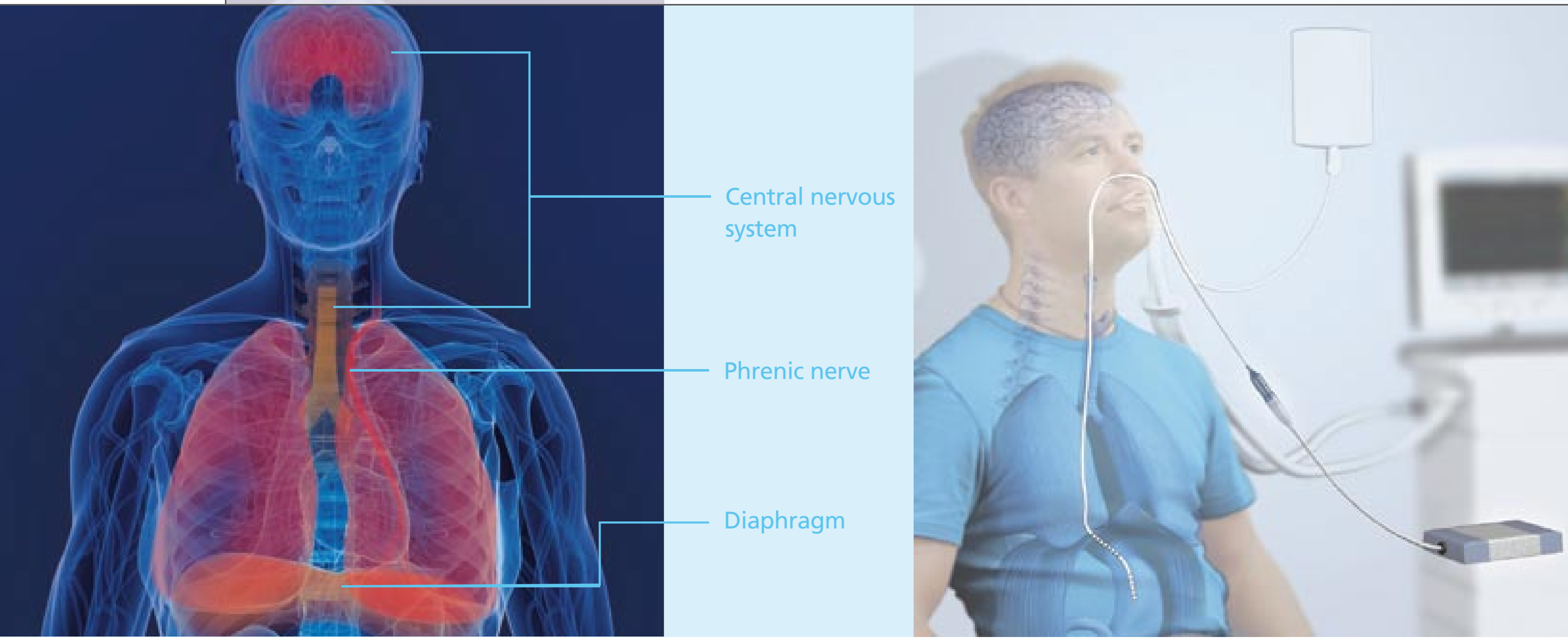


Figure 1: Attachment of the NAVA to the patient.

its interaction with the SERVO-i ventilator, we used a laboratory setup (figure 3) consisting of:

- A catheter that provides measured EMG signals, or a simulator that simulates the EMG signals as breathing impulses
- A dSPACE DS1005 PPC Board for processing the EMG signals
- The SERVO-i ventilator for controlling artificial respiration

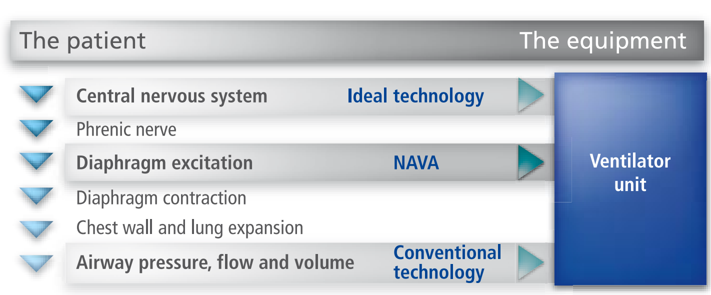
> "With the dSPACE system, we easily set up a prototype to accelerate the development process."
>
> *Fredrik Jalde, Maquet Critical Care AB*

To stimulate the system, we can use four different inputs:

1. Real input from a patient or a volunteer: This is obtained by inserting a catheter in the esophagus to pick up the EMG signal from the diaphragm. As an alternative to inserting the catheter in a patient, we have a system with a water tube with two wires connected to an iPod. The iPod generates two stereo signals to the water tube to provide EMG and ECG signals.
2. Simulated input from a hardware simulator: A signal generator provides a sinus signal at about 200 Hz.
3. Simulated input from a software model: This was implemented as a Simulink model and can be controlled with dSPACE ControlDesk.
4. Files containing patient recordings: The files are read from the PC and transferred to the dSPACE hardware in real time via C-Lib functions. The files are selected in ControlDesk.

All the different input signals have in common that they contain information about the breathing – inhalation or exhalation – and the desired inhalation strength. The modular hardware from dSPACE, a DS2002 A/D-board, receives these signals. The DS1005 PPC Board is used for signal processing with the EGM algorithm to obtain the Edi signal. The SERVO-i receives the analog Edi signal from the DS2102 D/A board, and the signal is used as a trigger signal but also to support the patient by providing oxygen and air pressure in proportion to the amplitude of the Edi signal.

We used the dSPACE test and experiment software ControlDesk to create a graphical interface for our development and tests. This gave us an easy way to manage and manipulate the controller model, for example, to select the breathing mode and define the settings for it, and to choose between simulated and measured EMG signals.



(Source: Sinderby C. et al. Nat Med 1999;5(12):1433-1436)

Figure 2: By using the electrical activity of the diaphragm, NAVA technology senses the earliest respiratory signal that can be detected.

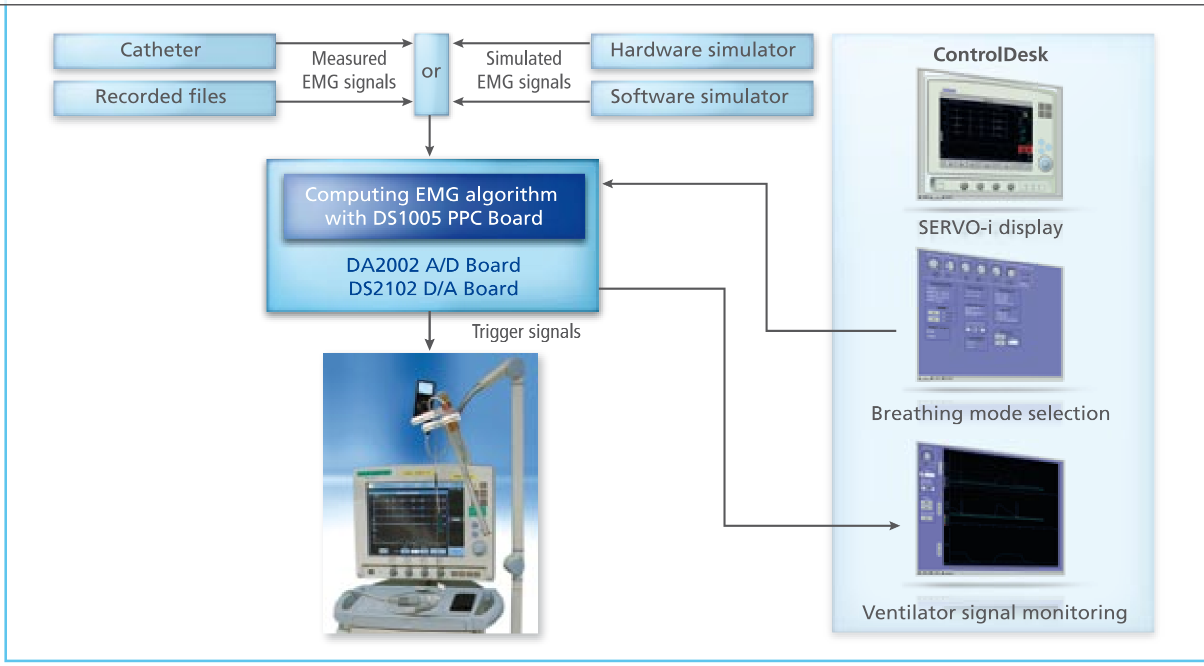


Figure 3: Schematic of the laboratory set-up for the NAVA development system.

We were also able to monitor the measured ventilator signals.

The most important use of the dSPACE system has been our work on the algorithms for signal processing for the EMG signal and setting up a prototype for testing without having to adapt the SERVO-i ventilator.

NAVA in Everyday Use

The NAVA technology, together with the Edi module and Edi catheter, is an addition to our SERVO-i ventilator. The user does not have to buy a complete new ventilator system. Moreover, and far more importantly, there are several benefits for the patients that have been experienced in daily work so far:

- Improved synchrony: In NAVA, the ventilator is cycled-on as soon as neural inspiration starts. Moreover, the level of assistance provided during inspiration is determined by the demand from the patient's own respiratory center. The same applies to the cycling-off phase: The ventilator cycles off inspiration the instant it is alerted to the onset of neural expiration. By utilizing the Edi signal, the maintenance of synchrony between the patient and the ventilator is improved.
- Lung protection: With NAVA, the patient's own respiratory demands determine the level of assistance. NAVA provides the ability to avoid over- and under-assisting the patient.
- Patient comfort: With NAVA, the respiratory muscles and the ventilator are driven by the same signal. The delivered assistance is matched to neural demands. This synchrony between patient and ventilator helps minimize patient discomfort and agitation, promoting spontaneous breathing.
- Decision support for unloading and extubation: The Edi signal can be used as an indicator to set the level of support given by the ventilator, and to optimize weaning. As the patient's condition improves, the Edi amplitude decreases, resulting in a reduction of ventilator-delivered pressure. This pressure drop is an indicator for deciding whether to wean the patient off artificial ventilation and extubate.

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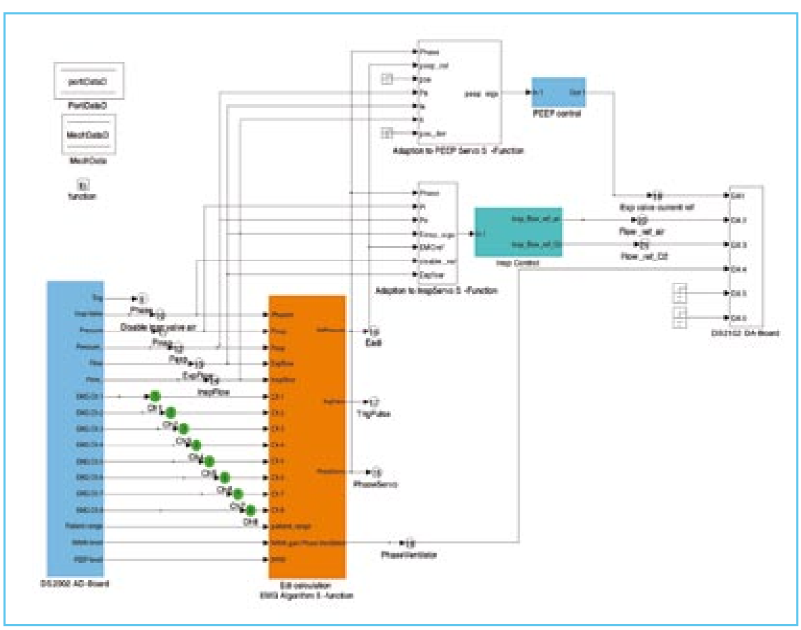

Figure 4: Simulink® model for EMG control of SERVO-i.