Monitoring phrenic nerve stimulation-induced breathing via tracheal sounds

Xinyue LU[1, 2], David GUIRAUD[1], Serge RENAUX[2], Thomas SIMILOWSKI[3, 4], Christine AZEVEDO[1]

[1]*INRIA, University of Montpellier, Montpellier, France*
[2]*NeuroResp, Les Aires, France*
[3]*INSERM, University of Sorbonne, UMRS1158, Paris, France*
[4]*APHP, Paris, France*

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Introduction

Central respiratory paralysis induces a dependence on artificial ventilation If patient's phrenic nerves and diaphragm remain functional, **diaphragm pacing (DP)** through **electrical stimulation** can provide a more natural respiration instead of **mechanical ventilation** [1]. However, commercialized systems do not embed any **respiratory monitoring** function and cannot adapt to patients' electro-ventilation needs. To increase the performance and safety of these systems, in this study, a **real-time acoustic respiratory monitoring method** based on a **microphone** is investigated. This method is tested on recordings from an individual equipped with a commercial **intrathoracic phrenic nerve stimulation (PNS)** system: **AtroStim®**, Atrotech (Fig.1).

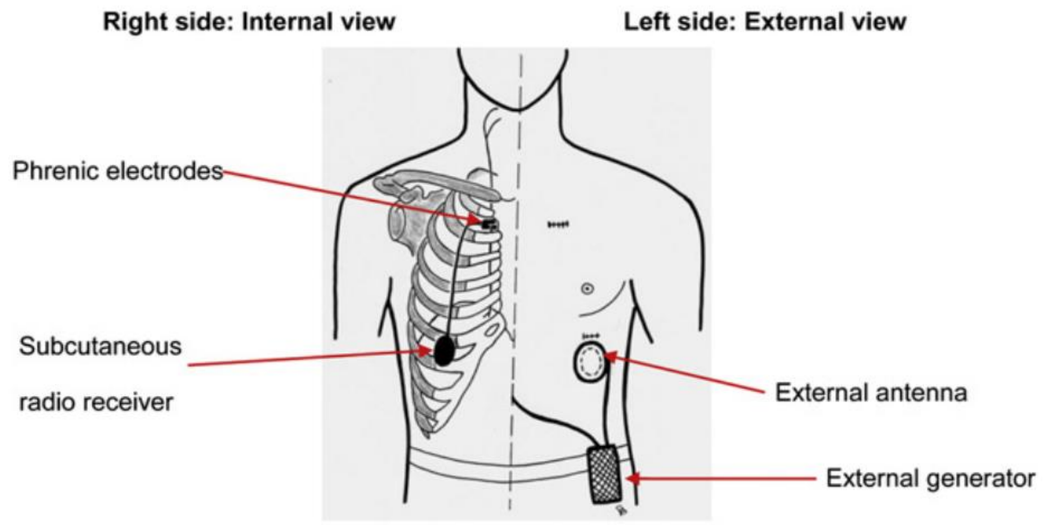

Figure 1 – Structure of AtroStim® PNS system [2]

Results

The detection result of this 30 seconds recording is illustrated in Fig.6:

- **All** 9 induced **inspirations** and **8 expirations** are **detected**;
- **Noises** at 2s, 6s, 17s and 21s (in Fig.3) **are eliminated**;
- All pre-inspirations are not taken into account.

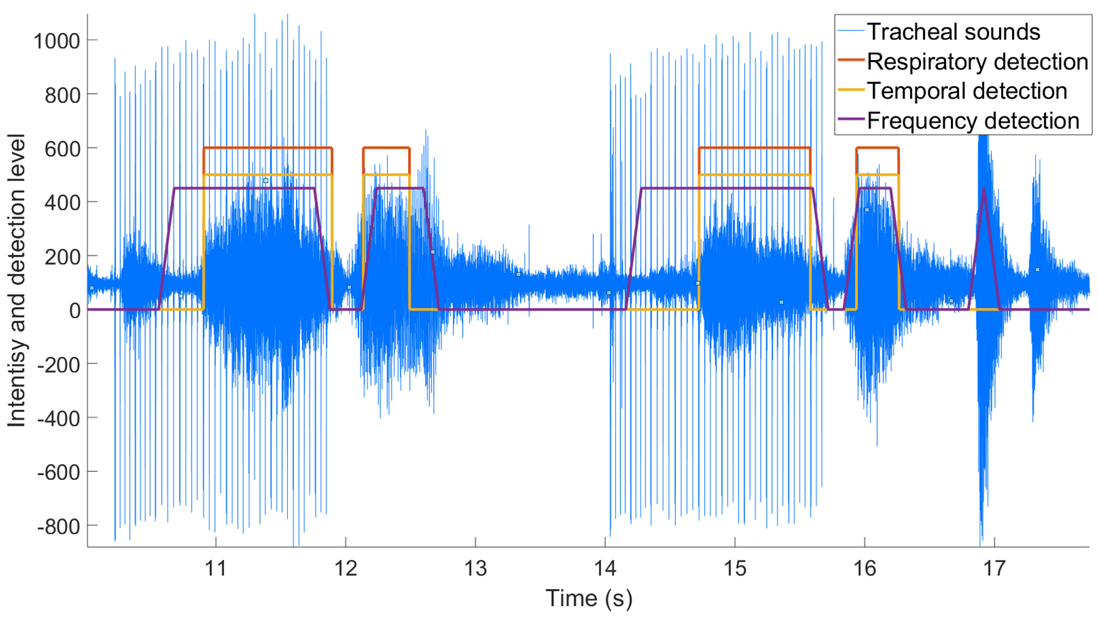

Figure 6 – Detection result

Discussion:

- Proposed respiratory detection method for DP monitoring allows **detecting breathing events and electrical stimulation**;
- **Short noises** can **be eliminated** by **temporal detection**, while **long noises** similar to respiration can **be eliminated** by **frequency detection**;
- Synchronization of the respiration detection with captured stimulation image can **indicate** a **bad/lost electrodes' contact, obstructive apnea**, …

References:

1. *F. Le Pimpec-Barthes et al., "Diaphragm pacing: The state of the art," J. Thorac. Dis., vol. 8, no. Suppl 4, pp. S376–S386, 2016.The first obtained result is very promising;*
2. *F. Le Pimpec-Barthes et al., "Intrathoracic phrenic pacing: A 10-year experience in France," J. Thorac. Cardiovasc. Surg., vol. 142, no. 2, pp. 378–383, 2011.*

Contact : xinyue.lu@inria.fr

Methods

Materials:

- An **omni-directional** microphone was inserted into a 3D-printed support, which was positioned above patient's tracheotomy (Fig.2.)
- Tracheal sounds were first filtered (**100Hz - 1200Hz**) and amplified (230 times), then sampled at **8500Hz**.

Figure 2 – Position of microphone

Signals analysis:

One patient with high spinal cord injury and under stimulation participated in this observational study. One recording of **30 seconds** was shown in Fig.3, and one enlarged cycle is shown in Fig.4:

- **Noises** are circled in **green**;
- Induced **inspiration**, **expiration** and captured **stimulation image** are indicated in **orange**;
- Some **pre-inspirations** are circled in **red**, one enlarged example is presented in Fig.4.b, in which two inspirations were induced during one cycle of stimulation.

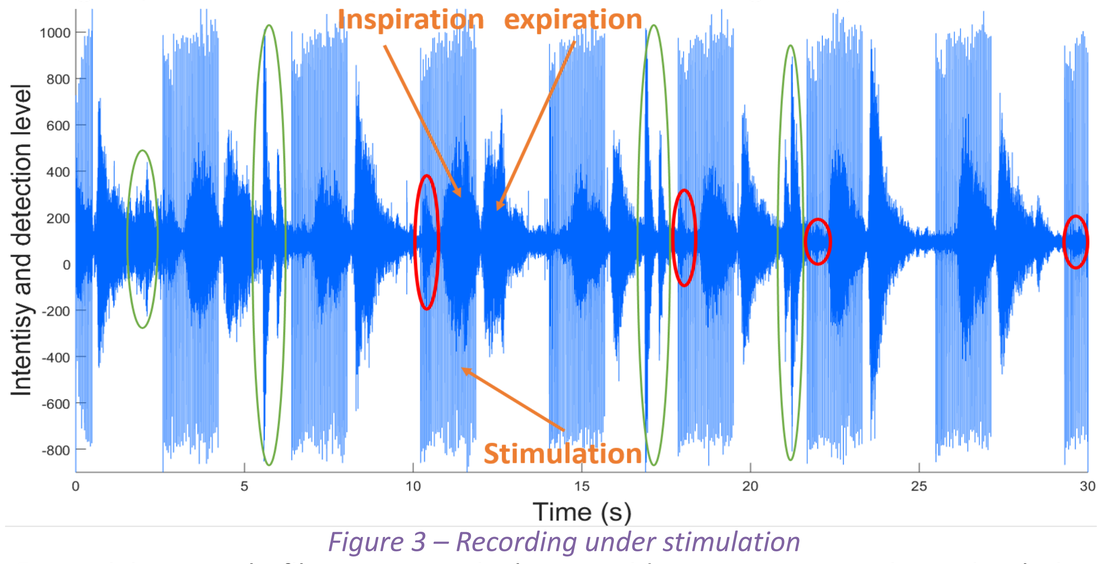

Figure 3 – Recording under stimulation

For activing muscle fibers progressively to avoid a strong contraction, stimulation intensity increases from $I_{threshold}$ to $I_{TidalVolume}$, and then the induced inspiration begins (Fig.4.a). A pre-inspiration appears during increasing phase (Fig.4.b) may because a too high $I_{thresould}$ had been set.

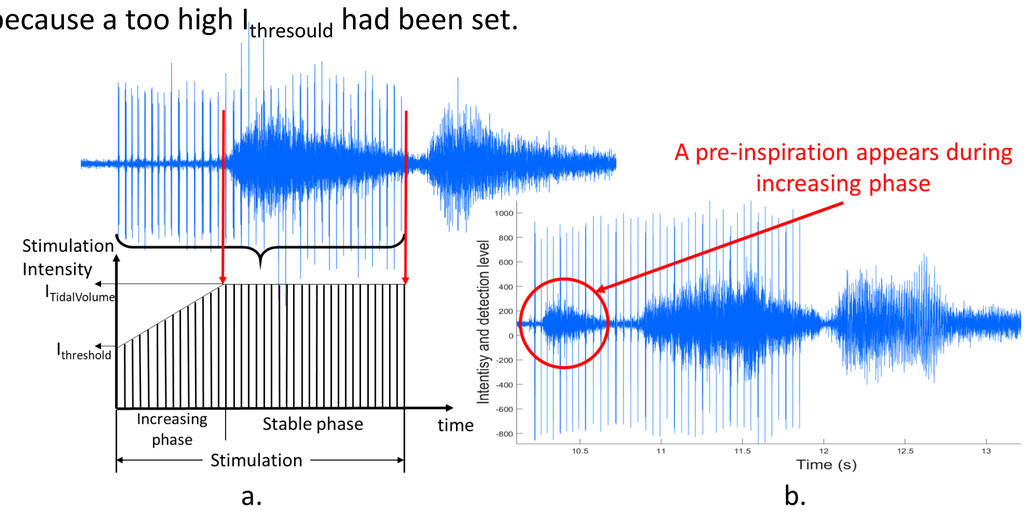

Figure 4 – One enlarged cycle of recording under stimulation

Detection algorithm:

Tracheal sounds recordings are processed in **real-time** with a **delay of 0.22s**, corresponds to a moving segment of 3×1024 samples. As shown in the detection flow diagram (Fig.5), the segment of recording is first **high-pass filtered at 300 Hz** to **remove cardiac noises**, then processed both in **temporal** and **frequency** domains. At the end, the detection results of theses two domains are **combined** to get the **final result**.

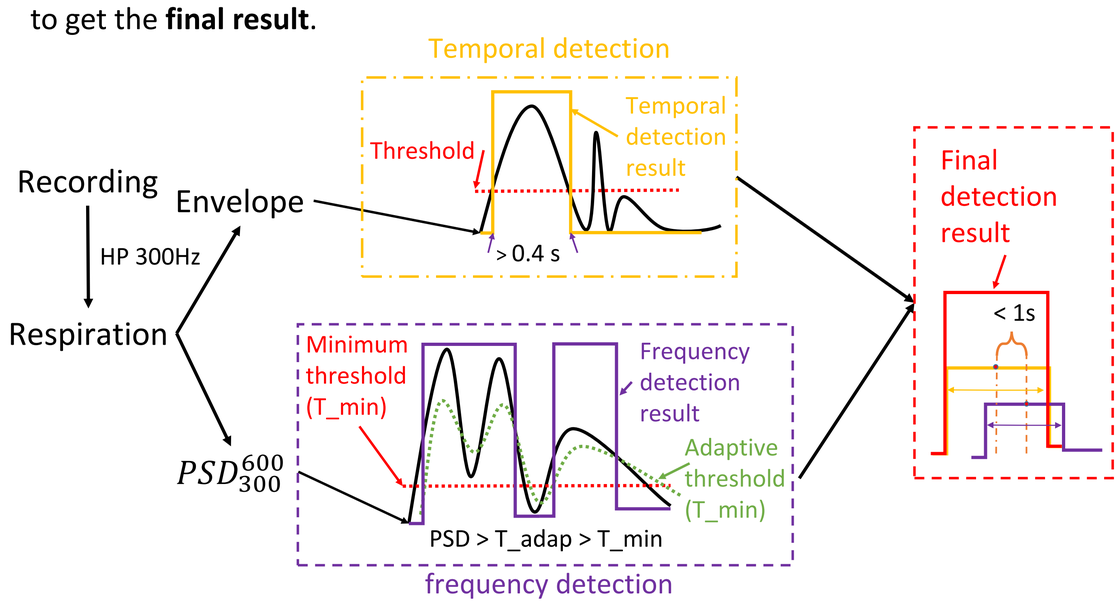

Figure 5 – Detection flow diagram