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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).

![Image of respiratory system](image1.png)

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

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.

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.

![Image of microphone placement](image2.png)

**Figure 2 – Position of microphone**

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.

![Image of detection result](image3.png)

**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, ...

![Image of detection flow diagram](image4.png)

**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 these two domains are combined to get the final result.

![Image of detection flow diagram](image5.png)

**Figure 5 – Detection flow diagram**

References:

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