Subglottal impedance-based inverse filtering for the ambulatory monitoring of vocal function: Initial results

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Contrasting traditional clinical evaluations, the ambulatory assessment of vocal function adds the capability to better characterizing vocal behaviors when individuals engage in their typical daily activities. However, the clinical potential of ambulatory methods has not been fully developed, in part, due to limitations of the analysis algorithms. In this study, we applied a recently developed inverse filtering technique for an accurate, non-invasive estimation of the source of voiced sounds at the glottis in the context of wearable monitoring of voice. The scheme, known as subglottal impedance-based inverse filtering (IBIF) [Zañartu (2010). PhD dissertation, Purdue University], takes as input the signal from a lightweight accelerometer placed on the skin over the extrathoracic trachea and yields estimates of glottal airflow, offering important advantages over traditional supraglottal inverse filtering methods. The method is based on mechano-acoustic impedance representations from a physiologically-based transmission line model and a lumped skin surface representation. A subject-specific calibration protocol is used to account for individual adjustments of subglottal impedance parameters and mechanical properties of the skin.

Using the IBIF scheme, glottal airflow measures are computed from a neck surface acceleration signal (ACC) that is recorded in a smartphone. The device is set with a 13.5 dB gain, a sampling frequency of 11025 Hz, and a high-pass filter with a cutoff frequency of 0.1 Hz. This latter setup removes undesired low-frequency artifacts in the ACC due to bulk body movements, without introducing phase distortion. The IBIF results are contrasted with oral-based estimates recorded using a circumferentially-vented mask (model MA-1L, Glottal Enterprises) and a traditional DAQ system (6259 M series, National Instruments). The oral-based glottal airflow is obtained using closed-phase inverse filtering [Alku *et al.*, (2009). J. Acoust. Soc. Am., 125(5), 3289-3305] with the aid of an EGG signal to identify instants of glottal closure. Although this latter method is considered the current criterion standard for aerodynamic assessment of vocal function, it is not suitable for an ambulatory evaluation.

We demonstrate that the ambulatory system can provide quantitative estimates of the following glottal measures: Simple spectral tilt, harmonic richness factor, maximum flow declination rate, amplitude of the unsteady flow, speed quotient, and open quotient. Note that robust automatic detection of these parameters has not been achieved before in an ambulatory voice monitoring system. Preliminary results for sustained vowels show that the subglottal IBIF scheme yields comparable estimates with respect to the current aerodynamics-based standard of clinical vocal assessment. A mean absolute error of less than 10% is observed for the non-harmonic measures, which makes the system capable of detecting vocal hyperfunction. The proposed method further advances signal analysis methods for ambulatory assessment of vocal function, which has been previously limited to the estimation of loudness and pitch. Thus, long-term variability of vocal function can be investigated using more targeted measures and high temporal resolution in ambulatory systems. Detecting vocal hyperfunction may indeed enhance the overall potential of wearable monitoring of voice. New methods for dynamically detecting hyperfunction will be explored in this time-varying context, and a complete set of normal and pathological recordings are underway to allow for further refinements. As the subglottal IBIF scheme is also suitable for real-time biofeedback, it may also contribute to the clinical management of commonly-occurring voice disorders.

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