Application of impedance measurements for the diagnosis of articulatory dysfunction

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Introduction

In clinical everyday life, there is no instrument for characterising a specific articulation disorder objectively. Most of the communication disorders are due to morphological alterations of the vocal tract (VT), different coordination processes of articulation or a combination of these.

In our study we try solve this problem from an acoustical point of view: we investigate the resonance properties of the VT in healthy subjects and in patients with morphological changes (pre- and post-surgery) in order to characterise the degree of disorder, and to provide a practical tool for therapeutical treatment of articulation problems which is independent of the speech signal.

During speech, the articulatory organs such as tongue, lips, velum and pharynx, determine the filter properties of the VT that can be characterised by the VT transfer function (VTTF) or the vocal tract resonances. However, it is difficult to measure the VTTF directly without substantial inconveniences for the patient (e.g. by transnasal application of a microphone at the glottis). As a non-invasive method, an indirect way is chosen: acoustic resonances of the vocal tract can be identified as formants in the speech signal which can be measured by, for example, linear predictive coding analysis (LPC). However, this indirect method has some inaccuracies, and requires a rather stationary voice source and careful choice of the number of LPC coefficients. Our method excites the VT externally, independent from the subject's phonation, with a broad band sweep tone. A similar method has been applied to speech training (cf. [1]).

Our first setup [2] suffered from the problem that the impedance measurements were distorted by the voice signal during phonation. Instead a new setup without the velocity sensor was chosen. The resonance measurements were validated by simultaneous formant measurements with LPC, and also by VTTF measurements of an externally excited vocal tract model.

Theory and Setup

The vocal tract impedance measurement setup (VTMI) as presented previously in [2] consists of a loudspeaker connected to an inverted horn with a microphone and a velocity sensor at the end. The end of the inverted horn has a diameter of 1 cm. This small opening is positioned at the lips and a sweep is generated in order to measure the impedance of the vocal tract. The acoustical input impedance of the vocal tract is the pressure-velocity ratio at the mouth opening.

A way of verifying the impedance curves measured with

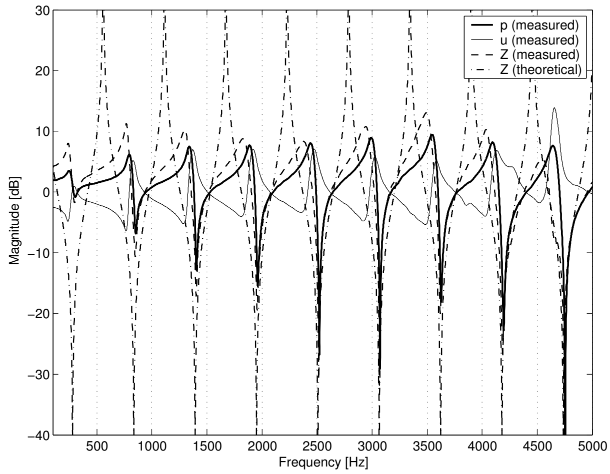

Figure 1: Comparison between the measured and theoretical impedance of a 30 cm long steel tube.

the VTMI setup is to measure an object with a known impedance. This could be a tube of a certain length with a smooth inner surface and closed at one end, resembling a simplified vocal tract. The acoustic impedance of a lossless tube of length L closed at one end is:

$$\frac{Z_A}{\rho_0 c S} = -j \cot kL \tag{1}$$

c is the speed of sound, S is the surface of the opening, ρ_0 is the density of air, k is the wavenumber.

The impedance versus frequency calculated from (1) is shown in Fig. 1. The resonance frequencies are identified as minima in the impedance spectrum. In (1) a term for the radiation impedance is left out because the distance between the end of the inverted horn and the tube (mouth) is so small that accounting for a conventional radiation impedance of a tube is just as erroneous as not taking it into account.

A comparison between the measured impedance of a tube of 30 cm, using the VTMI set-up and the theoretical impedance according to (1), is shown in Fig. 1. From the pressure (thick solid line) and the velocity (thin solid line) the impedance is calculated. This curve should correspond to the dashdot line on the graph. It shows good agreement at the minima (resonances). The maxima of the measured impedance, however, deviate considerably.

Looking at Fig.1 it can be seen that the contribution of the pressure and impedance curves overlap for most of the region around the resonances and that the velocity curve contributes little to the valid part of the impedance. Therefore an evaluation of the pressure only was chosen.

Measurements

Corpus

Specific phonemes were chosen to allow a comparison of the results with previous work in this field [5], [6], [7].

Due to the choice of the excitation signal length and sequential signal processing, we are able to analyse sustained sounds only. Therefore, the long vowels /a/,/i/,/o/,/u/ for the representation of the whole vocal range, /ä/ to have a nearly neutral position of the tongue, the denti-alveolar sound /l/ and the velar sound /x/ have been chosen.

Analysing these sounds should show significant differences in patients with morphological alterations of the VT, e.g. with oropharyngeal-, tongue- and mouth floor carcinoma, supraglottal stenosis, chordectomia etc. compared to a group of normal subjects. A wave file of each sound is recorded for further analysis.

Measurement Sequence

A fixed position of the horn is achieved by adapting the end of the horn to the test subject's lower lip. The following measurement sequence was carried out: Subjects starts phonation → Start of measurement → LPC analysis → Impedance analysis 1 → Stop phonation, keep articulated position → Impedance analysis 2 → save data.

Evaluation

The VTMI software that evaluates the output from the VTMI setup simultaneously displays the curves of the LPC and the two impedance measurements of an utterance. Criteria of evaluation concerning the LPC curves are bandwidth, relative amplitude and frequency of the formants. Concerning the VTMI curves, bandwidth (only taking the left slope into account) and the frequency of the impedances will be part of the evaluation.

Further statistical analysis will be undertaken to define the correlation between LPC and VTMI values and to obtain average values for each sound measured by VTMI. Age, sex, weight, height and common surgeries in the oral and pharyngeal cavity like adenoidectomy or tonsillectomy of the subject are taken into account.

Results

A typical impedance measurement of the vocal tract for the vowel /a:/ is shown in Fig. 2. As mentioned earlier, the set-up uses only a microphone which allows higher output levels and therefore a stronger excitation of the vocal tract. The high output has a particular advantage for the measurement during phonation because the speech signal has to be extracted from the measurement signal. At high loudspeaker levels the speech signal can simply be cut out by carefully choosing the window length, such that the window does not alter the course of the impedance curve significantly.

Windowing is preferred to more complicated filtering algorithms because of its short computation time which is necessary for a real-time evaluation. In Fig. 2 the symmetric hanning window of length 30 ms produces very

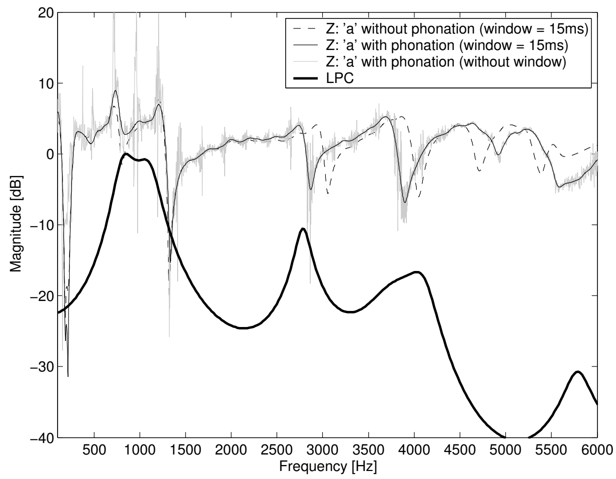

Figure 2: Comparison between an impedance measurement of the vowel /a:/, with and without phonation, and the corresponding LPC measurement.

similar impedance curves for the vowel /a:/ with and without phonation.

The simultaneously measured LPC curve is also shown in Fig. 2. A visual evaluation surely shows that the LPC formants correspond to the VTMI resonances. The extend of the correlation between the two methods will be further investigated in the near future.

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