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Measuring vocal-tract impedance at the lips: model, hypotheses and limits.

Timothée Maison[1]*, Fabrice Silva[1], Christophe Vergez[1], Nathalie Henrich Bernardoni [2]

[1]Aix-Marseille Univ., CNRS, Centrale Marseille, LMA, Marseille, France
[2]Univ. Grenoble Alpes, CNRS, Grenoble INP, GIPSA-lab, Grenoble, France

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Introduction

Non-invasive techniques (such as the so-called RAVE [1]) were developed to characterize vocal-tract acoustics using a broadband excitation and a microphone positioned closed to the lips. The measured pressure for an open-mouth condition, calibrated by a mouth-closed reference condition, provides estimates of the radiating vocal-tract resonance frequencies. Recently, exponential-sweep-based methods were reported to measure vocal-tract impedance [2, 3]. We propose to explicit the underlying hypotheses of such approaches, and to test their validity domain.

Methods

The measurement principle is based on the coupling between vocal tract and excitation tube, that can be assimilated as two waveguides. The pressure ratio given by the microphone at the lips can be expanded into

$$H = \frac{p^{measure}}{p^{reference}} = \frac{Z^{measure}}{Z^{reference}} \times \frac{U^{measure}}{U^{reference}} \ . (1)$$

The underlying assumptions of the method are: (i) the pressure at the lips for closed-mouth condition is supposed to be the same as the pressure of the capillary output, (ii) the acoustic current source for vocal-tract loading is ideal ($U^{measure} = U^{reference}$). Under the first assumption, the radiation coupling theory [4] leads to the impedance ratio:

$$\frac{Z^{measure}}{Z^{reference}} = \frac{Z^{VT}}{Z^{VT}+Z^{R}} \ . (2)$$

The first hypothesis is validated on a cylinder (L = 15 cm, d = 21 mm) by comparing measured impedances (with sensor [5]) of the left side of Eq. (2) to analytical computing of the right side of Eq. (2) (results not shown here). The second hypothesis (ii) is evaluated with a measurement at the lips (pressure ratio in Eq. (1)) — excitation tube and microphone on the same point at the cylinder inlet. The testbed is equivalent to RAVE [1] but using sweep excitation to characterize an open-closed cylinder as pseudo vocal-tract.

Finally, the robustness of the measure at the lips is explored by moving away horizontally excitation tube and microphone from the inlet, and computing frequency and quality factor ratio errors for the first three resonances.

Results

Figure 1 shows the comparison between a measurement at the lips (pressure ratio) and the numerical computation of Eq. (2). The relative errors on resonance frequencies are less than 1%, those on quality factors around 20%.

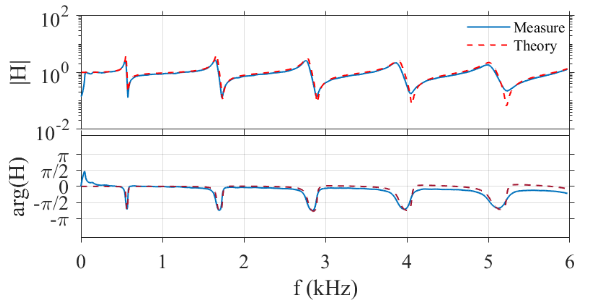

Figure 1: Comparison between experimental approach and numeric computing derived from the hypothesis for a cylinder.

Figure 2 highlights that the relative errors on first three resonance frequencies estimates are lesser than 1% as long as the distance between exciter/microphone and lips remains below 2 cm. Quality factors relative errors continuously increase with distance, reaching 80% at 2cm.

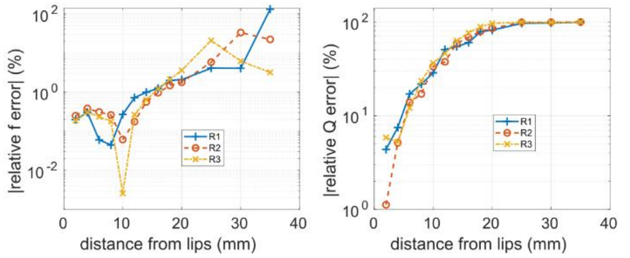

Figure 2: Relative error made on resonance frequencies and quality-factor measurements with cylinder inlet distance.

Discussion

This study focuses on a case with no additional voice source. The impedance ratio obtained with a measurement at the lips displays the resonances of the radiating vocal tract. The good correlation between measurements and numeric computation justifies the hypotheses: uniform pressure on lips plan and ideal source. If this method gives a robust access to resonance frequencies, with a possible distance gap to the lips, the quality-factor estimate suffers from the proximity between maxima and minima. Errors may also come from a long-range inefficient acoustic coupling. Further investigations are needed to improve quality-factor measurement, and to explore the case with voice source.

References

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*maison@lma.cnrs-mrs.fr