Non-invasive vocal-folds monitoring using electrical imaging methods

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Abstract: Many methods have been considered for human larynx imaging and especially vocal-folds monitoring. A widely-used non-invasive technology for vocal-folds monitoring is electroglottography (EGG), a technology based on impedance measurement of the larynx. Electrical impedance tomography (EIT) is another non-invasive electrical measurement method which attempts to reconstruct the conductivity map inside an object. It has been used in several human monitoring applications, and a theoretical study of EIT for vocal-folds monitoring has given promising results [8] but, to our knowledge, no device has been built. In our project, we aim at developing an innovative measurement system for vocal-folds monitoring using both EGG and EIT technologies. Two devices are currently under development. In this paper, we present a brief review of EGG and EIT technologies (section 1), the principles of the two new devices (section 2) and the perspectives they offer for both medical and research fields (section 3).

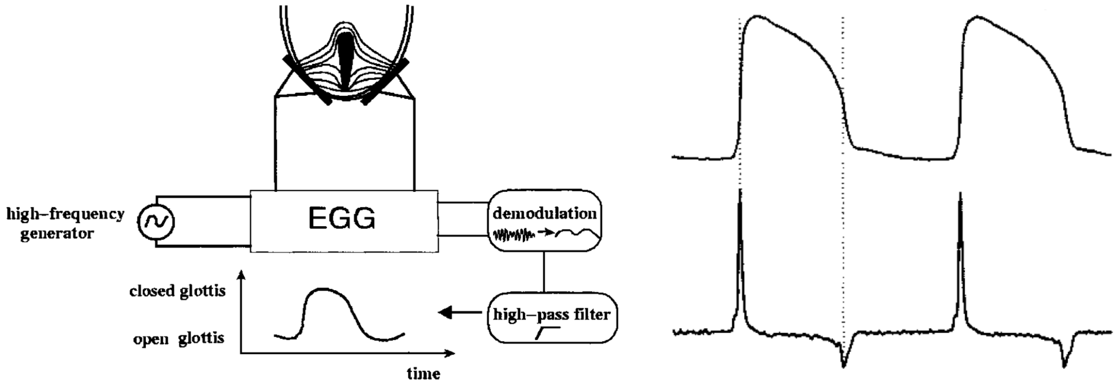
1 EGG and EIT in the context of vocal-folds monitoring

1.1 ElectroGlottoGraphy

The first electroglottograph was developed by Philippe Fabre, professor of biological physics at the University of Lille, in 1957 [1]. This technology is based on impedance analysis of the larynx; two electrodes are placed on each side of the throat, a low-intensity high-frequency modulated current (commonly around $2\ MHz$) is generated and applied to the laryngeal level, and the impedance between the two electodes is measured. This impedance is approximately proportionnal to the vocal-folds contact area. Unlike many imaging technologies (MRI, X-ray, echography) EGG has a frequency range sufficiently large for vocal-folds monitoring: from $0.2\ Hz$ (for deglutition) to F_{max} where F_{max} is between $4\ kHz$ (telephone bandwidth) and $20\ kHz$ (audible bandwidth). However, the output of this measurement system is a time-domain one-dimensionnal signal, which does not reflect the spatial characteristics of vocal-folds vibratory movement.

EGG is used in both medical and research fields. It is commonly used to extract features of the vocal-folds vibration, such as the fundamental frequency, the glottal closure or opening instant, the glottal closed or open quotient [2] or to identify the laryngeal mechanism used by the speaker or singer [3]. The principle of an EGG device and the corresponding signals is schematically presented in Fig. 1.

As we said, the electroglottogram is a one-dimensionnal image of the complex laryngeal activity. Therefore, increasing the number of channels –electrodes– is an interesting way of improving



(a) (b)

Figure 1: (a) Schematic description of an EGG device. (b) EGG signal (top) and its derivative (bottom). Glottal opening and closing instants are marked with vertical lines. From [2].

this non-invasive voice-measurement device. A two-channel EGG was introduced by M. Rothenberg in 1992 [4]. This device monitors the larynx height. It gives simultaneous access to the classic EGG signal, to an EGG signal ponderated by laryngeal movements, and to the larynx-height tracking signal. In 2009, M. Kob & al. proposed an EGG with $6{+}6{=}12$ electrodes –$6^2{=}36$ channels– that would give simultaneous access to EGG signals and two-dimension larynx tracking signal [5].

1.2 Electrical Impedance Tomography

Electrical impedance tomography (EIT) is a recent electrical imaging technology with a wide range of application, from medical monitoring to sismic activity recording. It has firstly been described by D.C. Barber and B.H. Brown in 1984 [6], and it has raised much research interest since then. EIT consists in injecting a high-frequency current inside a body with two electrodes and measuring the resulting potential distribution (with other electrodes) at the bodys surface. The conductivity map inside the body is recovered using reconstruction algorithms. One can read [7] for a complete review of theory, hardware and applications of EIT.

The relevance of EIT for vocal-folds monitoring was recently studied [8]. According to their preliminary results, EIT is sensitive to the vibration of vocal-folds. To our knowledge, no device using EIT for vocal-folds monitoring has been already built.

2 An innovative project of vocal-folds monitoring system

We started a project to conceive a non-invasive vocal-folds monitoring device based on EGG and EIT technologies. The aim of the project is to build a system able to measure precisely the shape and movement of vocal-folds during phonation. In the following, two new devices are described.

2.1 Frequency-division multiplexed multi-channel EGG

An improved version of [5] is currently under development, with an aim to improve both the spatial and temporal resolution. Unlike M. Kob's device, which uses time-division multiplexing, our device is based on frequency-division multiplexing in order to be able to improve the temporal resolution without decreasing the spatial resolution. Thin electrode grids are used to improve the spatial resolution.

Fig. 2-(a) describes the general architecture of the system. Each transmitter $\mathcal{T}_k$ generates a current at the frequency f_k and measures the corresponding voltage. Each transmitter is connected

to several electrodes through an analog router. On the other side, each receiver $\mathcal{R}_n$ connects several electrodes to the ground through another analog router and measures the current for each receiving channel.

With such a system, the neck is equivalent to the complete impedances network presented in Fig. 2-(b). The value of each impedance can be computed from the measurement of the current at each receiver and the voltage at each transmitter for every frequencies when $N \leq K$. The glottal activity should then be detected precisely, on the basis of a parametric model of the conductivity distribution inside the neck which has yet to be defined.

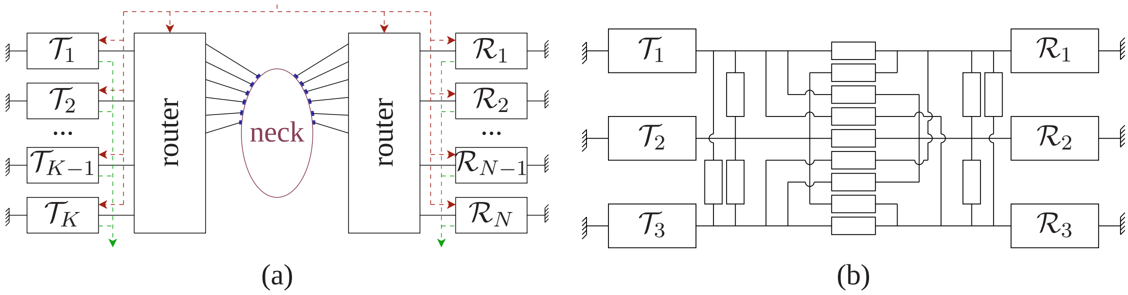


Figure 2: (a) General schematic view of the multichannel EGG device (configuration and command signals in dotted red, measurement signals in dotted green, electrical components and wires in black, electrodes in blue). (b) Equivalent impedances network for $K = N = 3$.

2.2 Orthogonal codes multiplexed multi-channel EIT

The second device is more inspired by the EIT technology. The general schematic is the same, presented in Fig. 2-(a). In this device, each transmitter $\mathcal{T}_k$ generates a current at the unique carrier frequency f_c, modulates this current by a command signal $g_k^t(t)$ (a sum of orthogonal codes) and measures the corresponding voltage. Each receiver $\mathcal{R}_n$ generates a voltage at the carrier frequency f_c, modulates this voltage by a command signal $g_n^r(t)$ (a sum of orthogonal codes) and measures the corresponding current. Moreover, potential measurements (high input impedance) modules are added and can be connected to electrodes through another analog router.

With this system, one code (orthogonal to the others) can be affected to each path (one path corresponds to one impedance in Fig. 2-(b)). The contribution of each path to the potential distribution is then measured simultaneously. Moreover, this system can be used as well as a classic EIT system ($g_{k_0}^t(t) = 1$, $\{\mathcal{T}_k\}_{k \neq k_0}$ disconnected, $g_{n_0}^r(t) = 0$, $\{\mathcal{R}_n\}_{n \neq n_0}$ disconnected), as an orthogonal codes multiplexed multichannel EGG ($\{g_n^r(t) = 0\}_{n \in [1,N]}$) or as a device in between. Therefore this system will be a very interesting tool for research, this prototype and the relevancy of such a system will soon be tested.

This device is part of a mechatronic project conducted with students from Mines ParisTech. The project includes also robotic larynx with driven vocal-folds built with conductive materials. These larynx will be used to validate the devices before testing it on humans.

3 Further work and perspectives

These two devices aim at increasing both temporal and spatial resolution compared to existing larynx and vocal-folds monitoring systems. The ultimate goal of such a device would be to be able to reconstruct precisely vocal-folds shape with a sufficient temporal resolution (audible bandwidth). These devices raise technical challenges that need careful studies. At first, proper parametric conductivity map model will be needed. Next step is the reconstruction algorithms which has not been studied yet.

It was mentioned that we plan to use grids instead of independant electrodes. This gives us the opportunity to impose constraints on the electrodes' relative position and to use many electrodes on a small surface (several tens of electrodes on a few square centimeters), in other words, consider electrodes as pixels on the skin. Note that, for a given temporal resolution, the spatial resolution depends on the number of transmitters and receivers and not on the number of electrodes. Nevertheless, another advantage of our devices is that time-division multiplexing is also possible thanks to the analog routers.

Such a device will have many possible applications in various field, including medical diagnosis, research about voice production and even vocal training.

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