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Technical note

Videokymographic image processing: Objective parameters and user-friendly interface

Claudia Manfredi[a,*], Leonardo Bocchi[a], Giovanna Cantarella[b], Giorgio Peretti[c]

[a] Department of Electronics and Telecommunications, Università degli Studi di Firenze, Via S. Marta 3, 50139 Firenze, Italy
[b] Otolaryngology Department, Ospedale Maggiore Policlinico Mangiagalli e Regina Elena, Fondazione IRCCS, Milano, Italy
[c] Otolaryngology Clinic, Spedali Civili di Brescia, Brescia, Italy

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ABSTRACT

Videolaryngostroboscopy (VLS) is undoubtedly a first choice examination technique in the diagnosis of several laryngeal pathologies. However, in case of low intensity or strong a-periodicity of the vocal sound, the VLS mechanism becomes ineffective in describing subsequent phases of the vocal cycle. To overcome such limitations, a new technique, called videokymography (VKG), was developed. VKG delivers images and displays the vibratory pattern from a single line selected from the whole VLS image, at the speed of approximately 8000 line-images/s. Despite its usefulness, parameter evaluation has been mostly based on visual inspection and no quantitative analysis of videokymographic images is commercially available at this time.

This article presents the VKG-Analyser, a new tool for measuring and tracking quantitative parameters from VKG images. Specifically, the left-to-right period, amplitude and phase ratios and phase symmetry index were evaluated. The case of incomplete glottis closure, the minimum distance between folds was implemented.

A digital image processing algorithm was developed and optimised for the analysis of VKG recordings that require intensity adjustment, noise removal and robust techniques for edge detection to avoid fluctuations of the grey levels in regions far from the vocal folds. The VKG-Analyser relies on a user-friendly interface that allows for the storage and retrieval of patients' data and optimises the image analysis, according to a set of parameters that can be manually adjusted by the user.

It was successfully tested on a set of synthetic images and applied to real VKG images, both in the case of complete and incomplete glottis closure.

The new software tool aims to provide fast, reliable and reproducible measures. When applied to a large set of data, it can define reference values for normal and pathological cases, providing a valid support for diagnosis and evaluation of surgical effectiveness.

1. Introduction

Along with the refinement of diagnostic and therapeutic techniques in phoniatrics and phonosurgery, the need for objective methods for vocal fold cycle evaluation, and its pathological or post-treatment changes, has gained increasing relevance.

Videolaryngoscopy (VLS), which is currently considered a first-choice test for the diagnosis of most laryngeal pathologies, bears some intrinsic limitations that restrict its clinical application. In fact, the stroboscopic image of the vocal fold vibration is basically an optical illusion made by the human eye, arising from the virtual reconstruction of adjacent phases of different vocal cycles, as given by the stroboscopic flashes in subsequent time instants. Hence, in the case of strong intensity deficiency or a-periodicity of the vocal fold vibrations, the stroboscopic technique, at the phonatory frequency, is ineffective in representing subsequent phases of the vocal-fold vibration cycle [20,4,27]. To overcome these limitations, research has developed in two main directions: digital high-speed videoendoscopy, and videokymography (VKG). Digital high-speed videoendoscopy (HSV) systems contain a large amount of physiological and dynamic information in a single examination [43,5,3,6]. Although the technology for HSV capture is improving, the clinical application of these systems is limited, because the device is very expensive. Digital kymography (DKG) is defined as kymography extracted from HSV. With DKG the measurement position can be selected from any part of the vocal folds after the recording is performed [10,12,17,42,18,24,9]. With the latest DKG systems, the line resolution and the image rate are about the same as with the

* Corresponding author. Tel.: +39 055 4796410; fax: +39 055 494569.
E-mail addresses: claudia.manfredi@unifi.it, manfredi@det.unifi.it (C. Manfredi).

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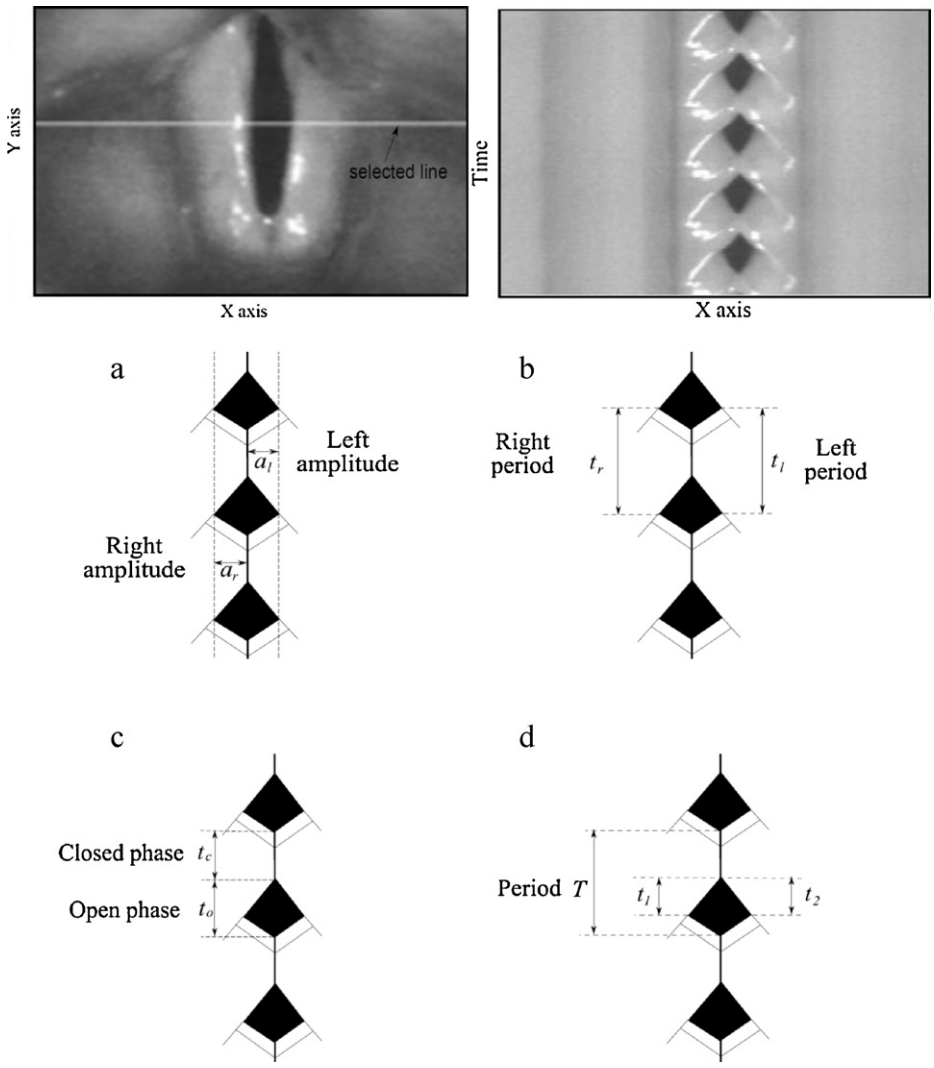

Fig. 1. Upper figure: standard videolaryngostroboscopy (left) and high-speed videokymography (right) for the selected line. Lower figure: schematic view of the parameters R_{amp} (a), R_{per} (b), R_{oc} (c) and PSI (d) extracted from VKG images.

VKG method. Finally, some authors have combined VLS and VKG in a new technique, called videostrobokymography (VSK) [13,34]. In VSK, the individual line-images are taken from the digitised successive stroboscopic video images. The advantage of the method is that it does not require a special high-speed video camera. The disadvantage is that it suffers from stroboscopic limitations and does not allow reliable viewing of irregular vibrations.

Hence, these approaches will not be analysed here, our focussing will be on videokymography (VKG), and its high-resolution and low-cost characteristics. Photokymography, which could be considered as a first approach to VKG, was introduced in 1984 [8]. It developed into VKG and has been improved in subsequent years, with many applications [11,31,32,35–38,14,40]. Though not curently common in daily clinical use, the new generation of VKG devices has appealing characteristics, and its extensive application in laryngological diagnosis is foreseen.

VKG can overcome the VLS limitations because it is capable of delivering images from a single line selected from the whole image, at a speed of approximately 8000 line-images/s, independent of the vocal sound characteristics. The selected line is marked in white on the screen, and the user can position it by moving the endoscope. The VKG recording is divided into video frames, i.e., segments of approximately 15/18 ms in duration. Images are not in colour, and continuous high-intensity light is needed [31,35–38,14,40,16].

In the first generation of VKG devices, such as the KayElemetrics VKG Camera, Model 8900 considered also in our first study [16,22], the line selection is fixed to the first line of the VLS image. Before activating the VKG mode using a footswitch, the user had to position the desired line at the upper edge of the VLS image. With this device, the two working modes (VLS and VKG) are mutually exclusive, preventing the operator from seeing the scan position while using the kymographic mode. This restriction has been removed with the new device considered here, as described in Section 2.

The selected portion of the vocal fold is registered for all medial–lateral movements during several vocal cycles. Movements of the selected glottal line are displayed on the monitor (time is on the vertical axis). A picture is shown in Fig. 1 (upper plots).

Images are digitally stored for further examination in slow-motion or for printing, which allows for visual comparison between different patients or different laryngoscopical pictures from the same subject corresponding to different stages of her/his clinical history (e.g., pre–post surgical/pharmacological treatment).

As a drawback, the positioning and orientation of the device with respect to the glottis are critical in VKG, making the fulfilment of the examination more involved than with VLS, because greater co-operation is needed from the patient [28]. Recently, a new VKG system was developed, whose features can overcome some of these drawbacks [29]. Although developed under the old