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Identifying a stochastic process related to the stiffness in a voice production mechanical model

E. Cataldo[a], C. Soize[b]

[a] *Universidade Federal Fluminense, Applied Mathematics Departament and Graduate program in Telecommunications Engineering, Rua Mrio Santos Braga, S/N, Centro, Niteroi, RJ, CEP: 24020-140, Brazil*

[b] *Université Paris-Est, Laboratoire Modelisation et Simulation Multi-Echelle, MSME UMR 8208 CNRS, 5 Bd Descartes, 77454 Marne-la-Vallée, France*

Abstract

The quasi-periodic oscillation of the vocal folds causes perturbations in the length of the glottal cycles that are known as jitter. The observation of the glottal cycles variations suggests that jitter is a random phenomenon described by random deviations of the glottal cycle lengths in relation to a corresponding mean value and, in general, its values are expressed as a percentage of the duration of the glottal pulse. The jitter has been the subject for researchers due to its important applications such as the identification of pathological voices (nodules in the vocal folds, paralysis of the vocal folds, or even, the vocal aging, among others). Large values for jitter variations can indicate a pathological characteristic of the voice. In this paper the construction a stochastic model for jitter using an one-mass mechanical model of the vocal folds is proposed. The corresponding stiffness of each vocal fold is considered as a stochastic process and its modeling is proposed. The probability density functions of the fundamental frequency related to the voice signals produced are constructed and compared for different levels of jitter. Some samples of synthesized voices in these cases are obtained. Then, two experimental voice signals are obtained and, for each experimental voice, the corresponding stochastic process modelled is identified. New voices are synthesized using the stochastic processes identified and compared with the original experimental voices.

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1. Introduction

In voiced speech production, the production of the voice signal is due to the oscillation of the vocal folds, which modifies the airflow coming from the lungs into pulses of air (the so-called glottal signal), which will be further filtered and amplified by the vocal tract and, finally, radiated by the mouth. The oscillations of the vocal folds are not exactly periodic and, consequently, the pulses of air which compose the glottal signal have not the same time duration.

* Corresponding author. Tel.: +55-21-99631-8344 ; fax: +55-21-2629-5515.
E-mail address: ecataldo@im.uff.br

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The small random fluctuation in each glottal cycle length is called jitter and it is a way to characterize voice signals even those with pathological characteristics. Typical values of jitter are between 0.1% and 1% of the fundamental period, for the so-called normal voices; that is, without presence of pathologies. The jitter value can be seen as a measure of the irregularity of a quasi-periodic signal and it can be a good indicator of the presence of pathologies such as vocal fold nodules or a vocal fold polyp [1,2]. In general, the authors who work with models of jitter (or the variations of the fundamental frequency) do not introduce mathematical models for the voice production and only a few authors consider stochastic models [3–7]. Some motivations for developing models of jitter include the discussion about the mechanisms that may cause the movements of the vocal folds to be aperiodic, which can be modeled as a random phenomenon. The objective of this paper is to use the stochastic model of jitter proposed by Cataldo and Soize [5], which is based on the use of the voice production deterministic model introduced by Flanagan and Landgraf [8], including the modifications carried over from the Ishizaka and Flanagan model [9] and those introduced by the authors. This model proposes a stochastic model for the stiffness that is a stochastic process. In this paper, the objective is to identify some parameters of this stochastic model solving a statistical inverse problem.

2. Deterministic model used

The underlying deterministic model used is the nonlinear one-mass model proposed by Flanagan and Landgraf to generate voice. The complete model is composed by two subsystems: the subsystem of the vocal folds (*source*) and the subsystem of the vocal tract (*filter*). The two subsystems are coupled by the glottal flow. During the phonation, the filter is excited by the sequence of pulses of the glottal signal. Each vocal fold is represented by a mass-stiffness-damper system and a symmetric system is composed of two vocal folds. The vocal tract is represented by a standard configuration of concatenated tubes. The complete model considered here presents some modifications in relation to the original Flanagan and Landgraf model. Some of them have been introduced by Ishizaka and Flanagan, and others by Cataldo et al. [3]. The system of differential equations to be solved can be divided in three parts (see Fig. 1 that illustrates a sketch of the model)

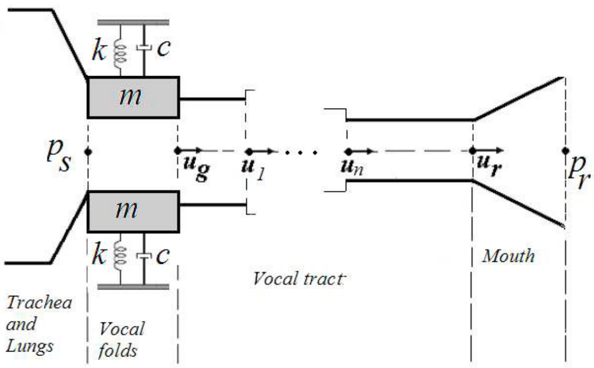

Fig. 1. Sketch of the Flanagan and Landgraf model (1968).

All the equations related to this model can be seen in details in [5].

3. Stochastic modeling of jitter

All the procedure to be followed to generate jitter is the same that the one used in [5]. Summarizing, $\{K(t), t \in \mathbb{R}\}$ is a stochastic process indexed by the real line $\mathbb{R}$, with values in $\mathbb{R}^+$, which models stiffness k. The vocal folds dynamic equation in $x(t)$, the position of the vocal focal, depending on $u_g(t)$, the glottal flow, becomes a nonlinear stochastic differential equation for the stochastic process $X(t)$ coupled with the stochastic process U_g, such that

$$m \frac{d^2X(t)}{dt^2} + \{c + c^*(X(t))\} \frac{dX(t)}{dt} + K(t)\, X(t) + a_1\, p_B(X(t), U_g(t)) = a_2\, p_s(t)\,, \tag{1}$$