ELECTROGLOTTOGRAPHY AND MICROPHONE SIGNALS ASSESSED BY APPROXIMATE ENTROPY IN NORMAL AND DYSPHONIC SUBJECTS

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Abstract: **Approximate Entropy is a method which provides a model independent nonlinear measure (the index ApEn) of the "regularity" of the process generating a time-series. In recent years, ApEn has been vigorously employed in the study of several biological signals, but only a few applications in the analysis of vocal disorders have been proposed. Here, we investigate the potential usefulness of ApEn in the study of electroglottography and microphone signals in normal and dysphonic subjects. Results show that statistically significant ApEn differences between the two groups can be found, more easily detectable in the microphone signal case.**

Keywords: **Chaos, time-series, signal processing, vocal disorders**

I. INTRODUCTION

Voice is the main vehicle of communication among human beings and its analysis is crucial for the differential diagnosis and follow-up of several pathologies. The sound signal (MIC), which can be picked up in a straightforward fashion by a microphone, brings information on several aspects related to voice generation, from vocal fold biomechanics to aerodynamic variables. In a slightly more sophisticated experimental setting, the so-called laryngograph allows the acquisition of the electroglottogram (EGG) which, by measuring the translarynx electrical impedance variation, permits the investigation of the vibration of the vocal folds.

In order to analyze MIC and EGG signals in both normal and pathological states, several tools have been proposed. In clinical practice, in particular, approaches which can be traced back to linear spectral analysis are most commonly used, with some classical parameters, such as jitter (fundamental frequency variation), and shimmer (amplitude variation), which evaluate perturbation contents. Recently, the use of these perturbation measures has been questioned. In particular, it has been suggested that linear approaches cannot reliably analyze strongly aperiodic signals and that jitter and shimmer are sensitive to several experimental and methodological settings [1]. In fact, spectral analysis does not handle cycles whose timing is inherently irregular, which can be a common situation in voice disorders, and cannot easily detect changes in the pattern of the signal which can characterize some patho-physiological states. As a consequence, the use of nonlinear time series methods, such as correlation dimension and Lyapunov exponents, has been proposed for the study of vocal disorders [1, 2, 3]. Approaches based on the use of entropy measures have been also investigated [4]. These approaches are significantly appealing because they are able to condense the entire history of the signal into a single number, which can be relatively simple to interpret for clinical purposes.

Approximate Entropy is a method developed in the early nineties to provide a model independent measure of the "regularity" of the underlying secretion process by calculating the logarithmic likelihood that patterns in the time-series that are similar remain similar on the next incremental comparison [5]. Notably, such a notion of regularity is quite different from that usually considered in engineering, where, for a signal, regularity is meant as a synonymous of smoothness. The Approximate Entropy algorithm summarizes the time-series into a single nonnegative number, ApEn: the higher is the value of ApEn, the more irregular is the process. Approximate Entropy is not intended to replace more classic techniques such as spectral analysis, but is complementary to them. In fact, Approximate Entropy focuses on the similarity between patterns within the signal, thus relaxing the spectral analysis requirement of a dominant set of frequencies at which some patterns within the time-series are repeated.

In recent years, ApEn has been vigorously employed in the study of several biological signals, e.g. endocrine-metabolic time-series, electroencephalogram, heart rate variability, and found capable of successfully identifying pathological or pre-pathological states characterized by an enhanced signal irregularity. A few ApEn applications in the analysis of vocal disorders have been also proposed [6, 7, 8].

Here, we investigate the potential usefulness of ApEn in the study of MIC and EGG signals in normal and dysphonic subjects. The aim is to determine if statistically significant differences occur between the two groups and also to assess if such differences are more easily detectable in MIC or in EGG.

II. METHODS

Data Base. 60 subjects have been classified in two groups, normal (10 males and 10 females) and dysphonic (19 males and 21 females), according to the independent

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perceptual evaluation of speech and language therapists. In all subjects, synchronous MIC and EGG recordings of the sustained Italian vowel /a/, kept at similar intensity and pitch for at least 4 seconds, were provided. Data recordings were made in a quiet room with the subject comfortably seated. The electroglottography system (Laryngograph Ltd, London, UK) employed a pair of electrodes attached on either side of the thyroid alae and held in place by a collar. The vocal signal was captured by a dynamic directional microphone (Prologue Shure, USA), placed at a constant distance of less than 5 cm from the mouth and at an angle of 45°. The MIC and EGG signals were acquired at 50 kHz, with 16 bits of amplitude resolution, by a commercial software (CSL 4300B, Kay Elemetrics, USA). In each subject, the middle, stationary appearing, segment of 1 s of data (correspondent to 50000 original samples), was considered for ApEn calculation.

The ApEn index. Briefly, let {u(k)} = {u(1), u(2), ..., u(N)} denote the N-size time-series from which we want to calculate the ApEn index. Let r (a real) and m (an integer) be two given positive parameters. In order to compute ApEn, first form the sequence of vectors x(1) through x(N-m+1), where each x(i) is defined by x(i)=[u(i), u(i+1), ..., u(i+m-1)]. Vector x(i) contains m consecutive samples of the time-series {u(k)}, commencing with the i-th point. Having defined the distance d[x(i), x(j)] between vectors x(i) and x(j) as the maximum difference in their respective scalar components, compute, for each i≤N-m+1, the number $C_i^m(r)$={number of x(j) such that d[x(i), x(j)]≤r}/(N-m+1). This values measures, within a tolerance r, the frequency, or regularity, of patterns similar to a given pattern of window of length m. Next, define $\Phi^m(r)$ as the average value of ln $C_i^m(r)$. Finally, define the ApEn index as ApEn= $\Phi^m(r)$- $\Phi^{m+1}(r)$. It is possible to demonstrate that ApEn measures the logarithmic likelihood that runs of patterns that are close (within a tolerance r) for windows of m observations remain close for windows of m+1 observations. The greater the likelihood of remaining close (i.e. the regularity), the lower the value of ApEn.

III. Results

Tuning of ApEn parameters. In order to speed up calculations, signals were downsampled at 10KHz. Starting from the recommendations of the author of the method, who suggested to determine m such that 10^m is of the order of the sampling points and r as a suitable value between 0.1 and 0.25 of the SD of the signal (depending on the signal-to-noise ratio), we have obtained the best values of m and r (m=4, and r=10% and 20% of the signal SD, respectively for MIC and EGG) after retrospective analysis of the results arising from several trial values. Of note is that these parameters should be reassessed, should the original 50KHz sampling be considered.

ApEn outcome. No statistically significant ApEn differences have been found between males and females. Average values (± SD) of ApEn for the MIC signals are 0.2838 (±0.0418) and 0.4196 (±0.1662), for normal and dysphonic subjects, respectively. For the EGG signals, ApEn values are 0.1153 (±0.0525) and 0.3867 (±0.4643). Notably, ApEn in MIC signals is higher than in EGG signals, as it could be expected from the higher complexity of the system generating the sound signal. The MIC signals have ApEn values which, in both the groups, are significantly less dispersed (i.e. lower SD) than the EGG signals. Finally, even if ApEn differences between the two groups are statistically significant in both cases, the error probability using MIC (10^{-4}) is lower than using EGG (10^{-2}).

IV. Discussion

ApEn is a simple, easy-to-implement, technique which, in the literature, was found useful in the nonlinear analysis of several biological signals. As stressed by the author of the method, ApEn is not intended to replace approaches resorting to spectral analysis, but is complementary to them. In fact, ApEn discerns changes in the signal behavior that are not reflected e.g. in changes in frequency and amplitudes of periodic components. Therefore, the application of ApEn to the study of vocal signals can deserve some consideration. Here, we have shown that, consistently with expectations, ApEn on EGG results smaller than ApEn on MIC, according to the fact that the laryngograph recordings are unaffected from the complicated mechanisms introduced by the vocal tract resonance, which converts the effects of fold vibrations into the sound delivered from the mouth. Also, our study shows that both EGG and MIC signals present average ApEn values which, in the dysphonic subjects, are higher than in the normal subjects. The difference is statistically significant with both signals, but seems more pronounced in the MIC case.

V. Conclusion

In this work, ApEn has been assessed of potential usefulness in the study of EGG and MIC signals in normal and dysphonic subjects. In particular, ApEn differences between the two groups are statistically significant and more easily detectable in the MIC case.

Although our analysis is preliminary and further studies are required to draw any conclusion on safe grounds, results suggest that the vocal tract plays a quantitatively important role in the alteration of vocal signals.

Further development of the present work should comprise the possible relationships between the optimal m and the signal sampling frequency (sampling higher than the 10KHz considered here could yield to a larger value of m) and the comparison of ApEn results with those of well consolidated linear approaches based on classic indexes such as jitter and shimmer. In fact, it is worthwhile reminding that ApEn does not replace spectral analysis techniques, but is complementary to them, as widely discussed by the author of the method in several papers e.g. in [9].

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