BIOSIGNALS 2013

6th International Conference on
Bio-inspired Systems and Signal Processing

Proceedings

Barcelona, Spain
11 - 14 February, 2013

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Selected Papers Book

A number of selected papers presented at BIOSIGNALS 2013 will be published by Springer-Verlag in a CCIS Series book. This selection will be done by the Conference Co-chairs and Program Chair, among the papers actually presented at the conference, based on a rigorous review by the BIOSTEC 2013 Program Committee members.

FOREWORD

This book contains the proceedings of the International Conference on Bio-inspired Systems and Signal Processing (BIOSIGNALS 2013). In collaboration with the University of Vic, this conference is sponsored by the Institute for Systems and Technologies of Information, Control and Communication (INSTICC) in cooperation with the Association for the Advancement of Artificial Intelligence (AAAI) and technically co-sponsored by the Biomedical Engineering Society (BMES) and European Society for Engineering and Medicine (ESEM).

The purpose of the International Conference on Bio-inspired Systems and Signal Processing is to bring together researchers and practitioners from multiple areas of knowledge, including biology, medicine, engineering and other physical sciences, interested in studying and using models and techniques inspired from or applied to biological systems. A diversity of signal types can be found in this area, including image, audio and other biological sources of information. The analysis and use of these signals is a multidisciplinary area including signal processing, pattern recognition and computational intelligence techniques, amongst others.

BIOSIGNALS is integrated in BIOSTEC (International Joint Conference on Biomedical Engineering Systems and Technologies) a conference composed by four complementary and co-located conferences, namely: BIODEVICES (International Conference on Biomedical Electronics and Devices), BIOINFORMATICS (International Conference on Bioinformatics Models, Methods and Algorithms), HEALTHINF (International Conference on Health Informatics) and BIOSIGNALS.

The BIOSIGNALS technical program includes a special session on Multivariable Processing for Biometric Systems (MPBS).

The joint conference, BIOSTEC, received 392 paper submissions from 57 countries in all continents. To evaluate each submission, a double blind paper review was performed by the Program Committee. After a stringent selection process, 56 papers were published and presented as full papers, i.e. completed work (10 pages/30' oral presentation), 100 papers reflecting work-in-progress or position papers were accepted for short presentation, and another 88 contributions were accepted for poster presentation. These numbers, leading to a "full-paper" acceptance ratio of about 14% and a total oral paper presentations acceptance ratio close to 40%, show the intention of preserving a high quality forum for the next editions of this conference.

BIOSTEC's program includes panels and six invited talks delivered by internationally distinguished speakers, namely: Pedro Gómez Vilda (Universidad Politécnica de Madrid, Spain), Christian Jutten (GIPSA-lab, France), Adam Kampff (Champalimaud Foundation, Portugal), Richard Reilly (Trinity College Dublin, Ireland), Vladimir Devyatkov (Bauman Moscow State Technical University, Russian Federation) and Pietro Liò (University of Cambridge, United Kingdom).

As in previous editions of the Conference, based on the reviewers' evaluations and on the quality of presentations, a short list of authors will be selected and invited to submit extended revised versions of their papers for a book that will be published by Springer with the best papers of BIOSTEC 2013.

We would like to express our thanks to all participants. First of all, to the authors, whose quality work is the essence of this conference. Next, we thank all the members of the program committee and the auxiliary reviewers for their diligence and expert reviewing. We would also like to deeply thank the invited speakers for their excellent contribution in sharing their knowledge and vision. Fourthly, we thank the BIOSIGNALS program chair, Sergio Alvarez, whose collaboration was much appreciated. Finally, special thanks to all the members of the INSTICC team whose collaboration was fundamental for the success of this conference.

We wish you all an inspiring conference and an unforgettable stay in Barcelona, Catalonia, Spain and we hope to meet you again next year for BIOSIGNALS 2014, details of which will soon be available at http://www.biosignals.biostec.org.

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INVITED SPEAKERS

KEYNOTE SPEAKERS

Voice as a Vehicular Tool to Organic and Neurological Disease Tracking
How Far we May Go?

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Keywords: Parkinson's Disease, Phonation Biomechanics, Voice Production, Phonation Tremor.

Abstract: Neurological diseases (ND) are a growing concern nowadays in developed societies due to the growth of life expectancy. The tasks of diagnosing, treating, monitoring and assisting patients with ND is demanding more resources in a world with difficult economic and social challenges. It is known since long time ago that voice and speech are vehicular conveyors of psychological and neurological disease, and as such they have been used in subjective evaluation of ND. The present paper aim is two-fold: in one hand it reviews voice and speech correlates which may be used by automatic machine learning applications in producing objective evaluation of ND to comply with the main tasks demanded; on the other hand a new methodology based on phonation biomechanical correlates is presented to offer a description of Parkinson's Disease (PD) voice correlates which may be used in grading and monitoring patients. The paper presents the main characteristics of the methodology and provides results from a set of PD and control study cases. The first important result is that all cases studied present tremor in voice, which is very low in amplitude in control cases, but significantly large in PD cases. Cases labelled subjectively as tremor-free would coincide with tremor frequencies over 8-10 Hz. In all PD cases tremor relative amplitude and vocal-fold stiffness statistical dispersion were well above average estimates for the control population. Results include many other indicators which could be used to implement applications for objective evaluation and monitoring of PD and other related diseases.

1 INTRODUCTION

Neurological diseases (ND) are a very serious concern nowadays due to the progressive increase of life expectancy. Special attention must be put in health-caring these problems as more people is expected to need some medical and social assistance regarding them in developed countries in the near future. In a society which is suffering from enormous economical and growth problems ND may pose an unbearable burden. Any help in improving assistance and reducing attention costs may seem an important goal to achieve. The relation between voice and speech production and neurological deterioration is a well known fact since long (Ramig et al. 1988). Therefore voice could be a simple, easy, clean, fast and inexpensive means to monitor ND progression. This fact was early foreseen by several researchers, as King et al. (1994) and Gamboa et al. (1997), proposing evaluation methodologies to monitor phonation changes and drug dosage using acoustic analysis of voice. Recently several interesting works have been published in this sense (Ramig et al. 2008, Little et al. 2009, Tsanas et al. 2009, Sapir et al. 2010). An essential reference in this field is the PhD thesis of A. Tsanas (2012). The reflection which follows is how systematize voice and speech analysis for ND detection, grading, classification and monitoring. This task must be afforded from different description levels due to its multidisciplinar nature. At least the following levels should be considered:

- Neurological and physiological description of voice and speech production, covering from neuromotor speech centers in neocortex to midbrain and brainstem neuropathways, muscle,

bone and cartilage biomechanical structures responsible for voice and speech production (larynx, pharynx, tongue, mandible, facial, lungs, diaphragm, etc.). Each of these subsystems has to be described both in terms of neuromotor and biomechanical activation.

- Direct biophysical description explaining the build-up of elastic and inertial forces in bones, muscles and cartilages forcing airflows and related pressures, and sound transmission and propagation both in tissues and biological structures as well as in air.
- Inverse signal processing algorithms to reconstruct sound propagation pathways, estimating precise timing phenomena in voice and speech (open and close phases in glottal signals, vowel onsets and decays, articulation and organ coordination, naso- and velo-pharyngeal switches, etc.) and producing time-frequency domain descriptions of speech and voicing at acoustic and phonetic levels.
- Phenomenological description of speech and voice disorders related to neurological diseases.
- Neurological description of speech and voice disorders in clinical and rehabilitation terms.
- Relation with other neurological disease monitoring methodologies studying gait, limb biomechanics, writing, etc.

It is clear that the task to accomplish is too wide and ambitious to be afforded from a single field or by a single team, requiring the collaborative work of neurologists, speech therapists, laryngologists, engineers, phoneticians, statisticians, etc. The purpose of the present work is to give a simple view on how the study of larynx biomechanics may help in establishing phonation correlates which may be used in Parkinson's Disease (PD) detection, and possibly grading, proposing a new way which may take to further studies to combine phonation observables with neuromotor activity monitoring in cortex and midbrain (Papadelis et al., 2009). The proposed methodology derives from previous studies to estimate biomechanical phonation correlates in organic disease detection and grading (Gómez et al. 2005, 2009). Previous work demonstrated the possibility of extending these studies to neurological disease description (Gómez et al. 2011) basing further research on the following assumptions:

- Main Hypothesis: meaningful correlates of PD disorder in voice may be derived from vocal fold biomechanics, namely from body and cover stiffness, either as over-tenseness or as tremor.
- Secondary Hypothesis:, Vocal fold stiffness must be affected differently by organic larynx pathologies than by ND in order to distinguish PD disorders from organic pathology ones.

The first idea already explored was to use tremor as an indicator of PD disorder, but there are several considerations to have in mind to proceed in this way: tremor is not a pattern of voicing exclusive of PD. It may be intentional (as in singing vibrato), essential (present in certain subjects since an early age and not progressing), emotional (induced by stress, anger, sadness, etc.) or due to other neurological diseases (spasmodic dysphonia, multiple schlerosis, Huntington's chorea, etc.). Besides tremor, PD could produce rigidity, bradykinetic, and hypokinetic behavior in limbs, and these motor signs could be present in many muscles of the body affected by the same lateralization, including larynx muscles, and thus affect phonation (see Ramig et al. 2008). Therefore the problem should be divided into several sub-problems, as detecting stiffness in vocal folds, estimating cyclical changes in this parameter, and designing classification methods to disregard intentional, essential and emotional factors, and discriminate stiffness patterns produced by other neurological pathologies to sustain a possible PD differential diagnosis and monitoring methodology. Through the present paper both the main and secondary hypotheses are tested and using a database of equally balanced normophonic subjects as well a set of 8 study cases: 4 control and 4 PD subjects of both genders. The structure of the paper is as follows: Section 2 is devoted to describe the neuro-biomechanical model of the vocal folds used in the study. Section 3 presents the dynamic characterization of vocal fold stiffness in terms of hypo- and hyper-tonic deviations from the standard expected values for a normophonic control set to detect pathological patterns, and in terms of cyclical oscillations to characterize tremor. Section 4 presents the materials used in the experiments. Section 5 is devoted to present and discuss the results, and in section 6 conclusions are drawn and future work is envisioned.

2 VOCAL FOLD BIOMECHANICS

The vibration of the Vocal Folds is driven by transglottal pressure and modulated by mechanical interaction with the resulting glottal flow (deVries et

al., 2002). In a phonation cycle the neuromotor stimulus of the transversal and oblique cricoarytenoidal muscles brings both Vocal Folds together producing a closure of the larynx. Pressure build-up forces the Vocal Folds to come apart against viscoelastic muscular forces. The interaction between the glottal flow and the vocal folds is a fluid-structure problem, which requires solutions in 3D and time domain. Nevertheless for the purpose of obtaining first-order estimates simpler models may be used reducing the computational complexity of the problem. In this sense the vocal folds may be modelled as biomechanical second-order multiple-mass systems as far as small signal vibration is concerned (Berry, 2001), see Figure 1. The behavior of such a system may be studied using electromechanical equivalents as the one in 0 where inductors emulate dynamic masses, capacitors represent inverse stiffness parameters, and resistors explain viscous loss factors. In such a system external driving forces f_b and f_c due to transglottal pressures acting on the body and cover lumped masses are related to resulting mass speeds v_b and v_c by trans-admittance transfer functions, which show resonance peaks resulting from body-cover mass-spring interactions ($R_{bl,r}$, $M_{bl,r}$, $K_{bl,r}$, $R_{cl,r}$, $M_{cl,r}$, $K_{cl,r}$, b: body, c: cover, l: left, r: right) and in-between troughs induced by inter-elasticity $K_{bcl,r}$.

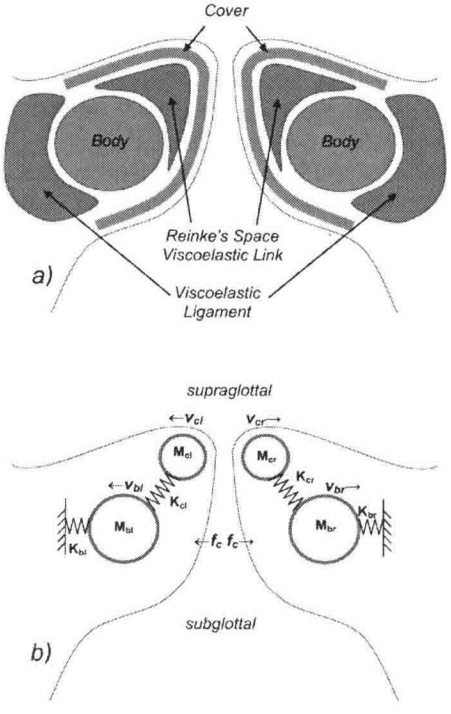

Figure 1: Vocal fold 2-mass biomechanical model considered. a) Stuctural description of vocal folds. b) Model equivalent in masses and viscoelastic springs.

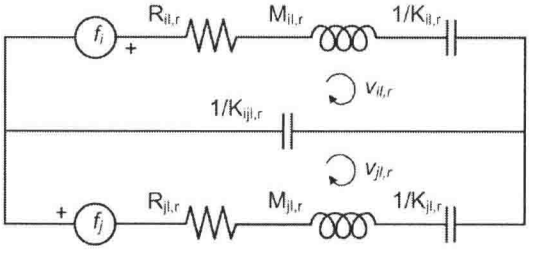

Figure 2: Electromechanical equivalent of the small signal two-mass vocal fold model (body and cover).

The estimation of the electromechanical equivalents requires the solution of an inverse problem given the power spectral density of the glottal source. Removing the first vocal fold vibration mode from the glottal source and matching the power spectral density of this signal to the trans-admittance of the equivalent system in 0 between f_b and v_c, estimates of the electromechanical parameters may be obtained. These can be used as estimates of the biomechanical system as well. A detailed description on the estimation procedure may be found in Rodellar et al. (2013).

3 MODELLING STIFFNESS

The main hypothesis in the present work is that neurological disease may leave correlates in different biomechanical parameters, but specifically in the stiffness ξ_c on the vocal folds, both as a bias, and as a cyclic pattern. 0 summarizes the estimation procedures. The glottal source $s_g(n)$ is derived from voiced speech $s_v(n)$. The power spectral density $S_r(\omega)$ of the residual after removing the first vibration mode from the glottal source (see Gómez et al, 2009) is matched against the trans-admittance functions from the biomechanical model in 0 to obtain the vocal fold body stiffness ξ_{cm} at each phonation cycle m. Values of this parameter over some hundred millisecond intervals may be used to estimate the cyclic parameters $\{c_{km}\}$ as will be described in what follows. A possible approach is to use AR modelling by adaptive lattice inverse filtering (Deller et al, 1993) as shown in 0. Under AR modelling the stiffness estimate ξ_{cm} at phonation cycle m could be described as

$$\xi_m = \sum_{i=1}^{K} a_i \xi_{m-i} + \varepsilon_m \qquad (1)$$

where $\mathbf{a}=\{a_i\}$ are the AR model parameters. Either the lattice filter pivoting coefficients $\mathbf{c}_{Km}$ or those of the equivalent transversal model $\mathbf{a}_{Km}$ may be used as

cyclicality descriptors. Both sets of coefficients are related by the Levinson-Durbin iteration

$$\mathbf{a}_{km} = \mathbf{a}_{k-1m} - c_{km}\tilde{\mathbf{a}}_{k-1m} \tag{2}$$

where $\tilde{\mathbf{a}}$ is the order-reversal operation on vector $\mathbf{a}$. In the present study pivoting coefficients will be preferred, as they are pre-normalized to (-1, 1), which allows easier result contrasting. In the present case the three lowest-order pivoting coefficients $\{c_{1m}, c_{2m}, c_{3m}\}$ will be used as descriptors of the stiffness cyclicality pattern. Examples of the estimation of these parameters from 0.2 s of vowel /e/ are given in 0 to 0.

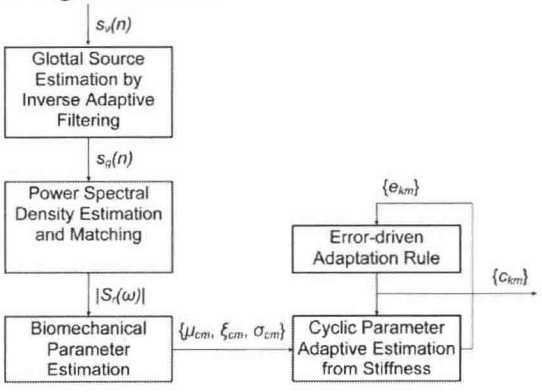

Figure 3: Biomechanical parameter estimation chain.

Once the AR model parameters are known the associate inverse model transfer function in the z domain may be described as

$$H(z) = \frac{1}{1 - \sum_{1}^{K} a_i z^{-i}} = \prod_{i=1}^{K} \frac{z}{z - z_i}; \qquad z_i = r_i e^{j\varphi_i} \tag{3}$$

where $\mathbf{z}=\{z_i\}$ is the set of poles of the transfer function $H(z)$, with modulus given by r_i and angular phase φ_i. The phase of each pair of complex conjugate poles may be used to estimate the tremor frequency as

$$f_{ti} = \frac{\varphi_i}{2\pi} f_0; \tag{4}$$

where f_0 is the phonation fundamental frequency. The relevance of the pole will be given by the inverse of its distance to the unity circle

$$\rho_{ti} = \frac{1}{1 - r_i}; \tag{5}$$

Another relevant parameter is the relative root mean square amplitude of tremor, given by

$$\eta_t = \frac{\frac{1}{N_k} \sum_{n \in W_k} \left[\xi_{Kn} - \bar{\xi}_K\right]^2}{\bar{\xi}_K^2} \tag{6}$$

where N_k is the number of samples in the estimation window W_k. The simplest AR model describing tremor would be a third order system with a real pole and two complex conjugate poles, for which the following relations among model parameters and cyclicality coefficients hold

$$c_1 = \frac{a_1 - a_2 a_3}{1 + a_2 - a_1 a_3 - a_3^2}; \qquad c_2 = \frac{a_2 - a_1 a_3}{1 - a_3^2}; \qquad c_3 = a_3 \tag{7}$$

This model has important semantic properties. For instance, it may be shown that the more relevant the complex poles are ($r_i \rightarrow 1$), the closer will be c_1 to -1. Therefore c_1 could be a phonation tremor mark.

4 MATERIALS AND METHODS

4.1 Control Database Description

The character of the present study is exploratory. Therefore a possible way of approach before a large database of PD voice is evaluated under the biomechanical premises proposed in the present work is to refer any contrastive methodology against a control database integrated by subjects presumably normophonic, having been inspected to discard any organic or neurologic pathology. A reference baseline could be defined on a database of recordings from 50 normal males and 50 normal females. The records consisted in sustained utterances of vowel /a/ 2 s long at least. Glottal Source correlates were obtained from the voice segments, and body and cover biomechanical mass and stiffness parameters were evaluated for each speaker. Estimate distributions are given in 0 (vocal fold body) and 0 (vocal fold cover) and summarized in 0.

Body and cover masses as dynamic factors, are a fraction of inertial masses, as only the inner rims of the vocal folds participate fully in vibration. Body stiffness is related to the lateral tension exerted on the *musculus vocalis*. Cover stiffness affects mainly Reinke's space. Body mass female distribution is relatively compact with a median at 0.012 g, whereas the male distribution is more spread with a

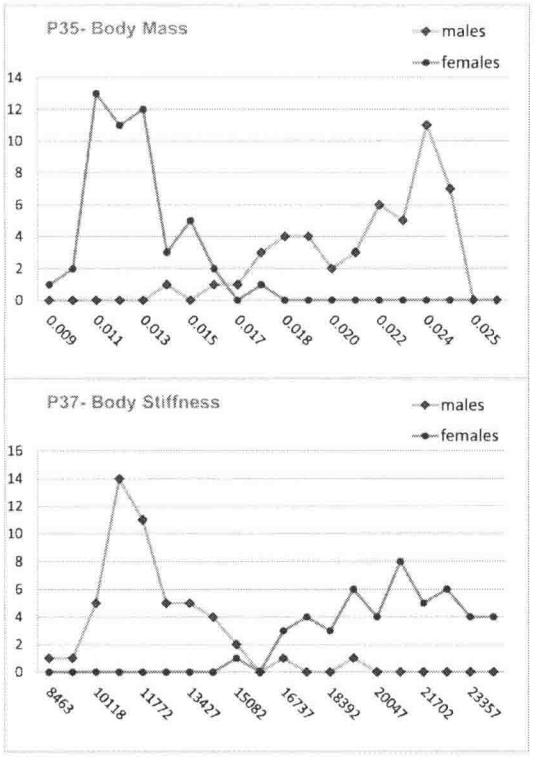

Figure 4: Vocal fold body parameter distributions for normophonic subjects of both genders.

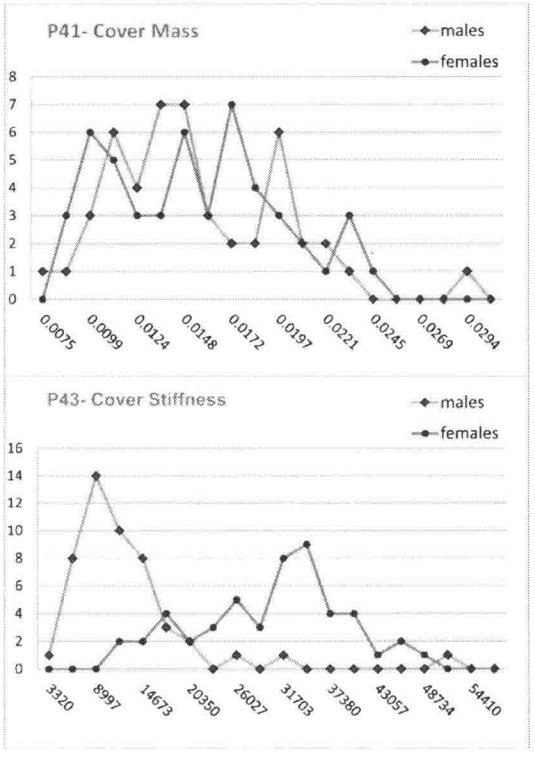

Figure 5: Vocal fold cover parameter distributions for normophonic subjects of both genders.

Table 1: Male and female biomechanical parameter distribution quartiles (MQ_{1-3} and FQ_{1-3}). The second and third columns give body mass and stiffness quartiles. The fourth and fifth give cover mass and stiffness quartiles.

Parameter	μ_b (g)	ξ_b (N/m)	μ_c (g)	ξ_c (N/m)
Males, MQ_1	0.019	10.43	0.012	6.80
Males, MQ_2	0.022	11.07	0.014	9.22
Males, MQ_3	0.023	12.67	0.019	12.60
Females, FQ_1	0.011	18.61	0.011	22.37
Females, FQ_2	0.012	20.39	0.015	30.80
Females, FQ_3	0.013	22.20	0.017	33.83

median estimate almost twice larger (0.022 g). Body stiffness distribution behaves the reverse, with male and female medians of 11.07 and 20.39 N/m, showing less dispersion in males than in females. Cover mass distributions are very widespread in both genders with large overlap and close medians (0.014 and 0.015 g), whereas stiffness distributions are clearly gender differentiated being highly peaked for males and more widespread for females and medians at 9.22 and 30.8 N/m respectively. Body stiffness is used to estimate the tremor frequency f_t and relative root mean square value η_t as well as the cyclic coefficients c_1, c_2 and c_3 as given in ,2, (6) and (7) as will be further explained in Section 5.

4.2 Description of Study Cases

To exemplify the capabilities of the methodology proposed to characterize PD affected patients several phenomenological study cases are presented. These correspond to a set of subjects, equally distributed by gender, half of them being diagnosed PD, and half of them being evaluated as normophonic speakers (no organic, no neurologic affections). A key point was to evaluate if tremor had a conclusive role to play in characterizing PD, knowing beforehand that many PD patients do not show a clear perceived tremor pattern perceived (subjective estimation). For such reason subjects with and without perceived tremor were included both in the normal as well as in the PD affected sets, resulting a total of 8 cases which are listed in 0. Estimates of their vocal fold stiffness for phonations 200 ms long are given in templates presented in 0 to 0 (see explanations in the figure captions). The contents in Table 2 give a description of each speaker in the study, ordered by gender (M vs F), then by normal (NP) or PD condition (PD), and finally by presenting perceived (YT) or not perceived tremor (NT). It may be seen that the age of the normophonic speakers