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TIC2002-2273: Modelado y Clasificación Automática de Patrones de Voz Patológica para su aplicación clínica sobre Internet

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Abstract

Pathologies of the speech apparatus are a great concern in nowadays society, having experienced a large increase due to the persistence of certain social habits. The praecox diagnose of these pathologies may yield spectacular results in the treatment of serious diseases, avoiding more drastic interventions which can not always grant absolute cure. The possibility of *screening* a large number of patients whose speech, electroglotographic or endoscopic records could be sent through Internet to specialized care services from primary attention centres may open an important way for early diagnose and treatment. This project is oriented to develop and complement Diagnose-Aid tools with the possibilities offered by Internet to facilitate this kind of actions. A computer platform to record and store patient data for its transmission from primary attention centres to specialized care services is to be defined. A *screening* procedure based on the use of a Computer-Aided Diagnose System is to be designed, based on estimation of biomechanical parameters. Data gathered following the before mentioned procedures will be used in improving current models of the speech apparatus to optimise the Diagnose-Aid methods. The system is to be experimented in two hospitals of the Area of Madrid.

Keywords: Speech Processing, Voice Pathology Diagnose-Aids, Neural Networks, Biomechanics, e-Health

1. Project Objectives

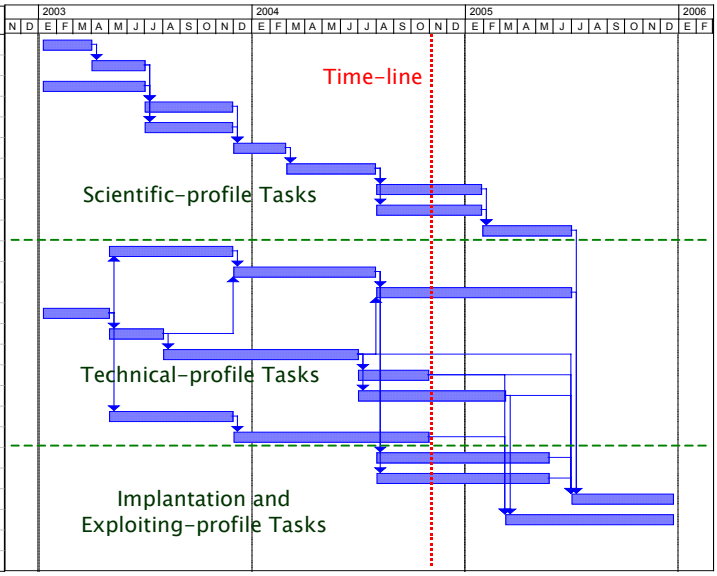
The objectives defined within the project are structured in a Task-Oriented Workplan. The list of Objectives and Tasks is the following:

Objective O.1.: Explore the use of Inverse modeling of the vocal tract from electroglottographic and voice recordings to characterize the glottal source in automated diagnose of vocal fold pathologies.
T.1.1. Determination of the Biomechanical Model of the Vocal Tract best suited for inversion.
T.1.2. Construction of a Numerical Simulator of the Biomechanical Model of the Vocal Tract.
T.1.3. Design of a Procedure for the Reconstruction of the Glottal Source from Voice records.
T.1.4. Design of a Biomechanical Parameter Estimator from Glottal Source using Joint-Process Estimation.
T.1.5. Design of a Biomechanical Parameter Estimator from Glottal Source using Artificial Neural Networks.
T.1.6. Comparison between the accuracy and computational performance of both methods.
Objective O.2.: Study the use of associative algorithms, artificial neural networks and modelling of dynamic non-linear systems to establish automatic classification procedures for vocal fold pathologies.
T.2.1. Determination of the Biomechanical Parameters for Pathology Classification and Automated Diagnose.
T.2.2. Construction of a Pathology Classifier using Artificial Neural Networks.
T.2.3. Design of a User Interface to support the Diagnose Aid System.

T.2.4. Integration of the Classifier, Database and User Interface into a Diagnose Aid System.
Objective O.3.: Environment for data collecting from Primary Assistance Centres for pathology screening.
T.3.1. Design of a Data Capture Platform from the Primary Attention Centres.
T.3.2. Design of a User Interface for the capture of data from a Web Page.
T.3.3. Data recording, evaluation and storage on a specialized Database.
Objective O.4.: Adapting telematic services for the interchange of information between the Primary Assistant Centres and the Specialized Attention Services in Oto-Rhino-Laryngology.
T.4.1. Set up of the central server for the Specialized Assistance Service.
T.4.2. Web and FTP services associated to the Primary Attention Centres and Specialized Assistance Services.
T.4.3. Basic Web application to provide the remote services.
T.4.4. Talk and chat services.
T.4.5. Video/audioconferencing services.
T.4.6. Specification of the activities for local and remote data collection.
T.4.7. Definition and installation of the maintenance procedures for the remote PAC services.
Objective O.5.: Diagnose tool for the automatic evaluation of voice pathology both from the Primary Assistance Centres and the Specialized Attention Services using the algorithms developed in O.1 and O.2.
T.5.1. Validation and Adaptation of Medivoz/Captura.
Objective O.6.: Development of a procedure and protocol to produce voice, electroglottographic and video-endoscopic DataBases to be shared by clinical services and research centres.
T.6.1. Specification of procedures and protocols for the creation and maintenance of the ORL DataBase.
Objective O.7.: System Set Up in the hospitals linked to the network.
T.7.1. System Integration.
T.7.2. System Implantation and extension to other Areas of the Community of Madrid Health Services.

Workplan Flow Chart

Id	Tarea	Duración	Comienzo	Fin
1	T.1.1	60 días	ma 07/01/03	lu 31/03/03
2	T.1.2	65 días	ma 01/04/03	lu 30/06/03
3	T.1.3	125 días	ma 07/01/03	lu 30/06/03
4	T.1.4	109 días	ma 01/07/03	vi 28/11/03
5	T.1.5	109 días	ma 01/07/03	vi 28/11/03
6	T.1.6	65 días	lu 01/12/03	vi 27/02/04
7	T.2.1	110 días	lu 01/03/04	vi 30/07/04
8	T.2.2	130 días	lu 02/08/04	vi 28/01/05
9	T.2.3	130 días	lu 02/08/04	vi 28/01/05
10	T.2.4	109 días	lu 31/01/05	ju 30/06/05
11	T.3.1	152 días	ju 01/05/03	vi 28/11/03
12	T.3.2	175 días	lu 01/12/03	vi 30/07/04
13	T.3.3	239 días	lu 02/08/04	ju 30/06/05
14	T.4.1	82 días	ma 07/01/03	mi 30/04/03
15	T.4.2	66 días	ju 01/05/03	ju 31/07/03
16	T.4.3	239 días	vi 01/08/03	mi 30/06/04
17	T.4.4	86 días	ju 01/07/04	ju 28/10/04
18	T.4.5	180 días	ju 01/07/04	mi 09/03/05
19	T.4.6	152 días	ju 01/05/03	vi 28/11/03
20	T.4.7	239 días	lu 01/12/03	ju 28/10/04
21	T.5.1	211 días	lu 02/08/04	lu 23/05/05
22	T.6.1	211 días	lu 02/08/04	lu 23/05/05
23	T.7.1	125 días	vi 01/07/05	ju 22/12/05
24	T.7.2 Ir	206 días	ju 10/03/05	ju 22/12/05



Means to achieve the objectives

The group at Universidad Politécnica de Madrid is devoted to the development of the signal processing and pattern classification algorithms, and to the design of the telematic services. The group at Universidad Jaume I is devoted to the design of Automated Pathology Classificators using Artificial Neural Networks. The group at Universidad de Alcalá de Henares is devoted to the

recording and evaluation of clinical databases, coordinated with the Hospitals of Principe de Asturias and Gregorio Marañón (Health Areas 3 and 1 in the Autonomous Community of Madrid). The equipment used by the group at Universidad Politécnica de Madrid is composed by an Applications and Database Server, a network of workstations for simulation under MATLAB ® used in signal processing and pattern classification, a set of toolboxes to develop Web services under JAVA/CORBA, and the software Medivoz/Captura, as well as a development package with Compiler C-C++ and Borland Builder both for WINDOWS and LINUX. The equipment used by the group at Universidad Jaume I is composed by a network of workstations for simulation under MATLAB ® for pattern classification using Artificial Neural Networks. The equipment used by the group at Universidad de Alcalá de Henares consists in a fixed workstation for data recording and storage running Medivoz/Captura, a videoendoscopic camera, a cold light stroboscopic illumination source, telelaryingo-endoscope and fibroscope, and spirometer. For the collection of data from centres associated within the network a portable station running Medivoz/Captura is also used. Another fixed workstation is set up at Hospital Gregorio Marañón.

2. Level of success achieved

2.1 Development of a *body-cover* model for the vocal folds from *mucosal wave dynamics*

The model developed is inspired in earlier *k-mass* models, and has been fully described and simulated in MATLAB ® yielding natural samples of synthetic voice. The availability of this model has shown to be an important contribution, as it allowed to estimate the *Power Spectral Density* of synthetic voice, to be contrasted against recorded voice, resulting in one of the most important scientific contributions of the project (see 2.4), opening the possibility of direct Biomechanical Parameter Estimation from voice. Preliminary results have been published in [7] and [20].

2.2 Detection of the *Mucosal Wave Correlate* from the voice record

The extraction of the *Mucosal Wave Correlate* from voice is done by Inverse Filtering using Concurrent Lattices, removing the channel and the vocal tract, yiending the *glottal source*. A method to remove the *body masses* was devised, which contributed to accurately detect the *Mucosal Wave Power Spectral Density*. Through the comparison of the synthetic and recorded *Power Spectral Densities* it may be inferred that their features are a direct consequence of the underlying biomechanical system, this result leading from the voice record (local or remote recording) to the estimation of the vocal cord biomechanical parameters (mass, elasticity and viscosity distributions) with application in non-invasive detection of pathologies, and in the biometric characterization of the speaker. This result has been presented at the highly specialized *International Conference on Voice Physiology and Biomechanics ICVPB'04*, held in Marseille, France, August 17-21, 2004 [21], and in [19].

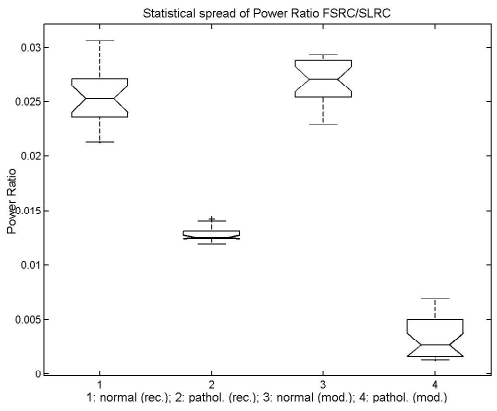


Figure 1. Ratio between the energy of the mucosal wave correlate (FSRC) and the average component of the glottal source (SLRC) for normophonic and pathologic voice in recordings (rec.) and synthetic voice (mod.).

2.3 Detection of Pathologies of the Vocal Apparatus from the *Mucosal Wave Correlate*

The relative energy distribution of the *mucosal wave* vs. the *body wave* may be used to infer the relative presence of *mucosal wave* in a specific case, this being a clear correlate of pathology in voice as documented in the literature. The proposal of a ratio between the *SLRC (Slow and Long Range Component)*, and the *FSRC (Fast and Small Range Component)* parts of the *mucosal wave* has been another important scientific contribution of the Project. The results shown in Fig. 1 illustrate the statistical distribution of this ratio among real normophonic (1), real pathologic (2), synthetic normophonic (3) and synthetic pathologic (4) recordings. It may be appreciated that normophonic voice is related with a higher value of the *ratio* in contrast with pathologic voice. The confidence intervals between normophonic and pathologic values show that this coefficient is a good marker of pathology. These results have been confirmed by the classification experiments carried out using Artificial Neural Networks, having been published in [19], [20], [21] y [22].

2.4 Spectral Characterization of the *Mucosal Wave Correlate (MWC) Power Spectral Density (PSD)*

The study of the *mucosal wave* spectral characteristics from actual recordings (Fig. 2.b) when contrasted with the results from the *k-mass* biomechanical model (Fig. 2.a) revealed that the *PSD* of the *MWC* shows features which can be used as descriptors of a specific glottal source, as the notch appearing at f_n, the maxima at f_{m1} and f_{m2}, and the trends at low and high frequencies. It has been found that each "V" grooved pattern in the *MWC PSD* can be associated with a particular mass-body sub-model, and a direct method to estimate the biomechanical parameters may be established. This is also a nuclear result of the Project, published in [20] y [21].

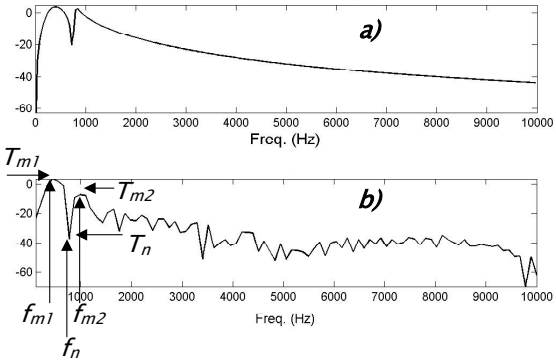


Figure 2. a) Spectral Behavior of the mechanical trans-admittance of the model for a vocal cord. b) *Power Spectral Density* of the *Mucosal Wave Correlate* for a specific case of normophonic voice.

2.5 Features of the *MWC-PSD* as biometric fingerprints for speaker identification

The specific features of the *Power Spectral Density* (as the amplitudes and positions of the first "V" groove given by $\{T_{mi}, f_{mi}, T_n, f_n, T_{mj}, f_{mj}\}$) may be used for speaker identification, as the influence of the channel, vocal tract and body masses have been removed, leaving the cover model to witness the personality of the speaker, as this pattern can not be counterfeited by voice forging maneuvers. The first experiments carried out reveal a high degree of hits, above 99,8%, the method pending of further refinement. Early work have been published in [20], [22] y [31].

2.6 Detection of pathology in vocal cords by Artificial Neural Networks

Early experimental work has been carried out in this field yielding promising results. A DataBase of synthetic voice has been generated using the biomechanical model above referred, as the biomechanical parameters associated to the traces are well known in advance. The characteristic parameters obtained from inverse processing have been classified against the biomechanical parameters generating the traces, for which *Multilayer Feedforward* y *Backpropagation* networks were used. The early research results have been published in [8], [9], [10], [26], [27], [28], [29] y [30].

2.7 Direct Estimation of the Biomechanical Parameters of the Vocal Cords from voice

The direct estimation of the Biomechanical Parameters of the Vocal Cords from the spectral features of the *MWC-PSD* has been fulfilled recently. Explicit relations between the complex *T-f* and the Biomechanical Parameters could be established in the frequency domain. A case study is presented in Table 1, showing the values for the *T-f* parameters for the normophonic case in Fig. 2.b, and the estimated values for cover masses (M_1, and M_2), and elasticities (K_1, K_2, and K_{12}).

T_{m1} (dB)	T_n (dB)	T_{m2} (dB)	f_{m1} (Hz)	f_n (Hz)	f_{m2} (Hz)	M_1 (g)	M_2 (g)	K_1 ($g.sg^{-2}$)	K_2 ($g.sg^{-2}$)	K_{12} ($g.sg^{-2}$)
16,2	8,4	-16,7	252	588	504	0,019	0,012	229	229	11600

Table 1. Characteristic *MWC-PSD* parameters (*T-f*) and biomechanical parameters for the case in Fig. 2.b.

These results are congruent with measurements carried out on real samples from physiological samples. The preliminary results have been published in [7], [14], [15], [20] y [21].

2.8 Patient exploration and DataBase collection

A nuclear requirement in the study is the availability of reliable, contrasted and normalized data, both under the protocol and the specialized expert point of view, containing normophonic and pathologic samples from a large population, for the sake of generalization. This task is carried out by the *Laboratorio de Biomecánica del Aparato Fonador (LABAF)*, created under the sponsorship of the Project in the Facultad de Medicina of Universidad de Alcalá de Henares, under the responsibility of the Prof. of Human Biomechanics and Anatomy D. Francisco Javier Fernández, and the Specialist in Oto-rhyno-laryngology Dr. Alberto Nieto. A program for voice care have been launched including the Specialized Assistance Services in ORL and an external unit for patient *screening* by voice to evaluate and re-address pathological cases to specialized treatment. Three scenarios have been foreseen: Two ORL-SAS Units in Hospital Príncipe de Asturias (Area 3), and Hospital Provincial de Madrid (Area 1), a Field Collecting Data Unit (FCDU) in different centers as PAC's, schools, high schools, call-centers, etc., and the Coordination Center for the Diagnose of Voice Pathologies at LABAF, for data collecting and evaluation, deriving the pathologic cases to the ORL-SAS. The number of samples collected and cases studied was in the range of 571 at the end of July 2004. The preliminary results of this task have been published in [7], [16], [17] y [18].

2.9 Preventive Program for Voice Health Care in Comunidad Autónoma de Madrid

Many pathologies appearing at an adult age find their causes in childhood due to bad speech learning practices. A program has been launched to act in schools of Comunidad Autónoma de Madrid. Currently 5 centers have joined the initiative, others pending. Another line of action is focused to the Primary Attention Centers. In these cases the initiative is carried out by General Practicioners, who can ask for a *screening* analysis using e-mail or videoconferencing through the LABAF Web Services, or by phone. The analysis procedure takes a sample of the patient's voice, which is evaluated using Medivoz/Captura. Pathological cases found are derived to ORL-SAS by LABAF. Currently 3 CAP's in Comunidad Autónoma de Madrid and 1 CAP in Comunidad Autónoma de Castilla-La Mancha have joined the initiative. More areas in Madrid and in other Communities are being considered for the Program to be extended. Under the same premises the Program has also been extended to other public and private institutions, as the Center for the Education of Voice, the Center for Brain Damage, Theatre and Opera Companies, and a call-center from a telephone company. Preliminary results of the Program have been published in [7].

2.10 Processing and labeling of the Normophonic and Pathologic DataBase

Data capture and DataBase organization is carried out under the specifications of Medivoz/Captura, which is in part a result from a prior Research Project, being validated using the protocols and procedures defined in the present Project. The referred environment is organized as

a relational Object-Oriented Multimedia DataBase guiding in the classification and storage of patient data including the anagnosis of each exploration, comprising voice and electroglottographic signal recording, and image diagnose (high-speed cold-light video-tele-laryngoscopy), keeping a record of each medical act, and automatically generating precise medical reports for later action. Preliminary results of this work can be found in [16][17][18].

3. Result markers

3.1 Personnel under training

Manuel Rubio Rodríguez. Ph. D. Student working in the Project till last March 2004, in which date he defended his Ph. D. Thesis [1]. Carlos Lázaro Carrascosa. Ph. D. Student working in the Project since its start up. Francisco Rodríguez Dapena. Ph. D. Student working in the Project since its start up till last May 2004, in which date he obtained a contract from a private company. Roberto Fernández Baíllo. Graduate Student working in the Project since its start up. Joaquín Torres Sospedra. Ph. D. Student working in the Project since October 2003. Emil Raul Malutan. Ph. D. Student from Romania working in the Project since February 2004. Catherine Murphy. Ph. D. Student from UK working in the Project since February 2004.

3.2 Publications carried out fully or in part under the Project Sponsorship

Publications [19][20][21][22][25] have to see with the Signal Processing Techniques to obtain the *mucosal wave correlate*, and its *power spectral density*, and to identify the main *characteristics of the mucosal wave* for Biomechanical Parameter Estimation. Publications [7][16][17][18][21][13][11][6][12] have to see with the medical applications of the methods developed, showing some of the most important achievements in Automated Diagnose of Vocal Pathologies. Publications [8][9][10][26][27][28][29][30][1] have to see with Pathology Classification and Biomechanical Parameter Extraction by Artificial Neural Networks. Publications [14][15] have to see with the new line opened in Biometrical Voice Fingerprint for Speaker Identification. Publications [2][4][5][23][31][24][3] have to see with robust speech processing and recognition, benefiting from the results obtained in Inverse Filtering.

3.3 Patents and Technology Transfer

The software "Medivoz/Captura", was registered at the Registro Territorial de la Propiedad Intelectual de la Comunidad de Madrid (Record No. M-007576/2003) in October 3rd, 2004. This User Interface and DataBase Platform was in part developed under a previous Project, and is being evaluated and re-designed under the framework of the present Project. It is being distributed commercially by a company of medical services and products (TGH Endoscopia). Other results which will be registered within the next months are the Diagnose-Aid software using the Biomechanical Parameters of the Vocal Cords and estimating the Biometric Parameters for Speaker Recognition in Forensic Applications, and the contents of the Pathological DataBase with voice, EGG and Videoendoscopic Recordings from 800 subjects, both normophonic and pathophonic. Agreements are being made for this DataBase to be distributed through ELRA.

3.4 International Projects, Collaboration with national and foreign groups

The research group is working in a proposal to the next Framework Programes of the EC, oriented to e-Health. A previous Expression of Interest was issued under the name of ESCASPRA (E-Health Services for Computer-Aided Diagnose of Speech and Voice Pathologies in Remote Areas). Its aim is the extension of the developed methods and standards for medical DataBase production in ORL to other European Health Services. The following partners have been engaged: Department of Electronics and Communications, Università degli Studi de Firenze, Italy; Group of

Neuroinformatics, University of Regensburg, Germany; Department of Electrical Engineering and Electronics, The University of Liverpool, U. K.; Karolinska Institute, Dept. Logopedics & Phoniatrics, Huddinge University Hospital, Stockholm, Sweeden; Department of ORL- Head & Neck Surgery Université Catholique de Louvain, Belgium, and the Department of Otolaryngology - Head & Neck Surgery, Vrije Universiteit Medisch Centrum (VUMC), Amsterdam. The Dept. of Physics & Electronic Science, Guangxi Normal University, ENT Department of Hospital Attached to Guilin Medical College, China, would also be engaged in the Initiative as a non-European partner.

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