Design of a multimodal database for research on automatic detection of severe apnoea cases

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Abstract

The aim of this paper is to present the design of a multimodal database suitable for research on new possibilities for automatic diagnosis of patients with severe obstructive sleep apnoea (OSA). Early detection of severe apnoea cases can be very useful to give priority to their early treatment optimizing the expensive and time-consuming tests of current diagnosis methods based on full overnight sleep in a hospital. This work is part of an on-going collaborative project between medical and signal processing groups towards the design of a multimodal database as an innovative resource to promote new research efforts on automatic OSA diagnosis through speech and image processing technologies. In this contribution we present the multimodal design criteria derived from the analysis of specific voice properties related to OSA physiological effects as well as from the morphological facial characteristics in apnoea patients. Details on the database structure and data collection methodology are also given as it is intended to be an open resource to promote further research in this field. Finally, preliminary experimental results on automatic OSA voice assessment are presented for the collected speech data in our OSA multimodal database. Standard GMM speaker recognition techniques obtain an overall correct classification rate of 82%. This represents an initial promising result underlining the interest of this research framework and opening further perspectives for improvement using more specific speech and image recognition technologies.

1. Introduction

Obstructive sleep apnoea (OSA) is a highly prevalent disease (Puertas et al., 2005; Young et al, 1993), affecting an estimated 2-4% of population between the ages of 30 and 60 years. It is characterized by recurring episodes of upper airway obstruction during sleep, and it is usually associated with loud snoring and increased daytime sleepiness. OSA is a serious threat to an individual's health if not treated (Puertas et al., 2005). OSA is a risk factor for cardiovascular disease (Coccagna et al., 2006), it is usually related to traffic accidents caused by somnolent drivers (Puertas et al., 2005; Coccagna et al., 2006, Lloberes et al., 2000), and it can lead to a poor quality of life and impaired work performance. A full overnight sleep study is required to diagnose OSA, referred to as polysomnography it involves the recording of neuroelectrophisiological and cardiorespiratory variables. Polysomnography is an expensive and time-consuming test so patients usually have to suffer a waiting list of several years before the test is done (Puertas et al., 2005). At present, the most effective and widespread treatment for OSA is nasal CPAP (*Continuous Positive Airway Pressure*) which prevents apnoea episodes providing a pneumatic splint to the airway.

In this article we present the design and specification criteria of a database, for the research and study in the field of automatic detection methods for severe apneoa cases. Our multimodal database collects, for a group of apnoea patients and a group of control or healthy subjects, both voice and visual information representing both physiological as well as morphological specific features related to apnoea disease.

The acoustic properties of speakers suffering from obstructive sleep apnoea are not clear, and not much research has been made on it. However, there are some studies pointing at possible abnormalities in phonation, articulation and resonance (Fox & Monoson, 1989). Speech database design criteria were based on both, the review of previous research in this field, and a preliminary manual contrastive study on a small group of healthy subjects and apneoa patients. This contrastive study helped us to identify phonetically related acoustic characteristics of OSA voice in continuous speech. Therefore, in addition to sustained vowels which have been the standard approach concerning the analysis of pathological voices, the database corpus includes four carefully design sentences. Thus our database will offer the possibility of comparing the use of different speech processing algorithms on sustained vowels as well as on continuous speech (Parsa & Jamieson, 2001). The main advantage of using sustained vowels is that the speech signal is more time invariant and therefore the parameters for voice characterization can be better estimated. Alternatively, the analysis of continuous speech offers more possibilities than those of sustained vowels, since it seems that some of the pathological patterns of the voice (in particular, the OSA disorder) can be detected in the transitions between different phonetic units.

Related to visual information, OSA is usually associated to a variable combination of different anatomic factors (Miles et al., 1996; Cakirer et al., 2001) (i.e. the craniofacial and pharyngeal dimensions are directly related to OSA). It is for this reason that we have also considered the collection of two patients' face pictures (frontal and lateral views). The inclusion of this visual information in our database will be used to explore if morphological facial characteristics in apnoea patients could be extracted through image processing methods. Although precise maxillary morphology analysis in apneoa cases has been made using radiological analysis of lateral views, Cephalometrics (Johal & Conaghan, 2004; Ryan & Bradley, 2005), clinical examination through simple physical (visual) information can be useful to identify anatomical abnormalities that could be correlated with AHI, (*Apnoea Hypopnoea Index*) (Zonato et al, 2003). AHI represents the number of apneoas o and hypopneas per hour of sleep . In (Puertas et al., 2005), a visual exam of the patient is suggested as first step in the examination of a subject with clinical suspicion of OSA, valuing the morphotype (i.e. obesity, short neck, etc.) and facial features (i.e. malocclusions referred to bad bites, mandibular alterations, etc.). To our knowledge, no research has been made on finding evidences that could relate facial features extracted through image processing of patients' face pictures to diagnosis of the severe apnoea cases. Thus we decided to include both frontal and lateral pictures of each patient's face making it possible to research on this challenging topic.

Therefore, as far as we know, our work represents a pioneer research on automatic severe OSA diagnosis in three mayor issues:

1. To provide a physiologically founded acoustic and linguistic analysis for the design of a voice database for the research on speech processing algorithms over both continuous speech and sustained vowels.
2. To include visual data to evaluate image processing algorithms as possible correlates of facial morphology in apnoea cases.
3. To provide a complete multimodal database including audio-visual data from each person thus allowing research on the possibilities of using multimodal fusion techniques.

Furthermore, as it will be described later, another contribution of our design will be to include voice recordings in two different sessions for a specific group of apnoea patients. This will allow the analysis of voice characteristics evolution in apnoea patients after nasal CPAP treatment.

The rest of this paper is organized as follows: Section 2 addresses the physiological and acoustic characteristics in OSA patients, while morphological facial features are described in Section 3. Corpora design criteria and database collection procedures are explained in Section 4. Section 5 presents preliminary experimental results over the speech corpus, using classical speaker recognition techniques. Finally, some conclusions and future research are given in Section 6.

2. Physiological and acoustic characteristics in OSA speakers

Nowadays is still not clear neither the articulatory/physiologically settings nor the acoustic characteristics of speech in apnoea speakers. Most of the more valuable information in this field can be found in Fox and Monoson work (Fox & Monoson,, 1989) where a perceptual study with skilled judges was presented comparing voices from apnoea patients and a control group. This study showed that although differences between both groups of speakers were found, acoustic cues for these differences were somewhat contradictory and unclear. What seemed to be clear was that the apnoea group had abnormal resonances that might be due to altered structure or function of the upper airway, and theoretically, this anomaly should result not only in a respiratory but also in a speech dysfunction. Therefore, the presence of speech disorder in a sleep apnoea population should be expected, and it could include abnormalities in articulation, phonation and resonance:

- **Articulatory anomalies:** Fox and Monoson stated that neuromotor dysfunction could be found in a sleep apnoea population as a "lack of regulated innervations to the breathing musculature or upper airway muscle hypotonus" This dysfunction is normally related to speech disorders, especially dysarthria. There are several types of dysarthria, resulting in various different acoustic features. All types of dysarthria affect the articulation of consonants and vowels causing the slurring of speech. Another common feature in apnoea patients is hypernasality and problems with respiration, phonation and resonance.
- **Phonation anomalies:** The phonation anomalies may be due to the fact that the heavy snoring of sleep apnoea patients can cause the inflammation in the upper respiratory system and affect the vocal cords.
- **Resonance anomalies:** The analysis of resonance characteristics for the sleep apnoea group in (Fox & Monoson, 1989) did not yield any clear conclusion. These authors only conclude that resonance abnormalities in apnoea patients could be perceived as hyponasality or hypernasality. It is only recently that resonance disorder affecting speech sound quality has been associated with vocal tract damping characteristics distinct from airflow in balance between the oral and nasal cavities. The term applied to this speech disorder is "*cul-de-sac*" resonance and is used for a type of hyponasality, where sounds that are supposed to be nasal are not pronounced nasally.

2.1 Initial contrastive acoustic study

A manual, contrastive study of an initial version of our apnoea speech database has been made. A similar revision can be found in (Fiz et al, 1993) where an acoustic spectral analysis was applied to sustained vowels to detect possible OSA cases. Nevertheless, this study was only a very preliminary research and it doesn't investigate other possible acoustic characteristics in apnoea patients' voice. Furthermore, the use of sustained vowels excludes the study of other acoustic clues present in continuous speech and measures based on the comparison between different linguistic contexts.

For our preliminary study, a group of 16 speakers, eight in the apnoea group and eight in the control group, were recorded. All the speakers uttered a same group of 25 phonetically balanced sentences; they were extracted from the phonetic corpus of Albayzin database (Moreno et al., 1993), a resource for speech recognition technology in Spanish. The contrastive study was performed by visual comparison of frequency representations (mainly spectrographic, pitch, energy and formant analysis) of apnoea and control group speakers. Following some conclusions of previous research on acoustic characteristics of apnoea speakers we also checked nasality feature (Puertas et al., 2005). The existence and the size of one extra low frequency formant was studied (Glass & Zue, 1985) as indicator of nasalization, but no perceptual differences between the groups could be found. Studies of specific linguistic contexts were also made; for example the differences in nasalization between the two groups for vowel /a/ in different contexts and no differences in nasalization were found. As discussed in (Fox & Monoson, 1989), this fact could be explained by the perceptual difficulty in classifying the apnoea speakers' voice as hyponasal or hypernasal disorder. However, when comparing the distance between the second and third formant for the /i/ vowel, clear differences between the apnoea and control groups were found. Apnoea speakers showed a higher distance between second and third formants than speakers in the control group. This was especially clear in diphthongs where /i/ was stressed, for example in the Spanish word "Suiza" (*'suj θa*). According to (Hidalgo & Quillis, 2002) the position of the third formant might be related to the degree of velopharyngeal opening. Lowering of velum gives rise to higher frequencies of the third formant.

3. Morphological facial characteristics in OSA patients

As discussed in (Puertas et al., 2005), factors related to the existence of OSA include anatomical (i.e. narrowing of the upper airway), muscular (i.e. excessive loss of muscle tone) and neurological factors (i.e. deficiency in the spontaneous reflexes). As it was stated before, morphology analysis through radiological techniques such as Cephalometric has been highly recommended in apnoea patients as one of the most important tools in diagnosis and treatment planning (Ryan & Bradley, 2005). These facts moved us to consider the interest of including visual information of patients' faces to promote future research on practical, but also a fast and cost-efficient, automatic diagnosis of severe OSA patients using image processing techniques.

Cephalometric studies have shown subtle retropositioning and shortening of the mandible and maxilla, even in the absence of distinct craniofacial abnormalities, in apnoea patients compared to normal subjects (Fergurson et al., 1995). Shorter and more posteriorly displaced mandibles have been confirmed in up to two-thirds of apnoea patients and correlate with decreased pharyngeal size (Shelton et al., 1993). So, although precise OSA diagnosis will require precise maxillary morphology analysis, simple clinical inspections are also considered (Puertas et al., 2005) as a first step when evaluating patients with clinical suspicion of OSA (Zonato et al, 2003). Visual examination of patients includes analysis of morphological facial features such as: short neck, mandibular distances and alterations, obesity, etc.. This fact leads us to believe that image processing techniques could be applied to patients' face pictures (frontal and lateral views) both to test them as information that can help in the diagnosis of severe apnoea cases, and also to combine them with voice processing results through multimodal fusion techniques.

Furthermore it is worth noting that multimodal information in our apnoea database could be also useful to research on the relationship between voice types and morphological face features. This could be useful in other application fields such as audio-visual face authentication.

4. Corpora

The database collection was performed in the Respiratory Department at Hospital Clínico Universitario of Málaga, Spain. The objective database was composed of about 80 male subjects; half of them with severe sleep apnoea (AHI > 30), and the other half healthy subjects or with mild OSA (AHI < 10). Subjects in both groups have similar physical characteristics such as age and body mass index. Furthermore, speech material for the apnoea group was recorded and collected in two different sessions: one just before being diagnosed and the other after several months under CPAP treatment. The analysis of speech characteristics in these two sessions will allow studying the evolution of apnoea patient's voice characteristics after the treatment.

4.1 Speech and Image Collection

Speech signal was recorded with a sampling frequency of 48 kHz in an acoustically isolated booth. Recording equipment was a standard laptop computer equipped with a SP500 Plantronics headset microphone that includes integrated A/D conversion and digital data exchange through USB-port.

For each subject in the database, two facial images (frontal and lateral views) were collected under controlled illumination conditions and over a white flat background. A conventional digital camera was used to obtain images in a 24-bit RGB format, without compression and with a 2272x1704 resolution.

4.2 Speech Corpus

The speech corpus consists in four sentences repeated three times and a sustained vowel /a/ also repeated three times. The four sentences were designed trying to cover all the relevant linguistic contexts where physiological OSA features could have higher impact on specific acoustic characteristics of particular phonemes. Particular emphasis has been put on:

- Sentence design that allows intra-speaker variation measurements; that is to measure differential voice features for each speaker, as, for example, the degree of vowel nasalization between vowels inside and outside nasal contexts.
- Continuous voiced sounds to measure irregular phonation patterns related to muscular fatigue of apnoea patients.
- Voiced sound in the context of guttural phonemes to analyse the specific impact of possible articulatory dysfunctions in the pharyngeal region.
- A broad range of vowel sounds to allow the accurate modelling of the articulation space and other measures related to our preliminary contrastive study.

All sentences where designed to exhibit a similar melodic structure, and speakers where requested to read them following this rhythmic structure. We hope this controlled rhythmic recording procedure could help in avoiding non-relevant inter-speaker linguistic variability. Each sentence is presented in the following paragraphs where the melodic groups have been underlined.

1. **Francia, Suiza y Hungría ya hicieron causa común.** (*'fraN θja 'suj θa i uŋ 'gri a ya j 'θje roŋ 'kaw sa ko 'mun*).
2. **Julián no vio la manga roja que ellos buscan, en ningún almacén**.(*xu 'ljan no 'βjo la 'maŋ ga 'řo xa ke 'e λoz 'βus kan en niŋ 'gun al ma 'ken*).
3. **Juan no puso la taza rota que tanto le gusta en el aljibe**. (*xwan no 'pu so la 'ta θa 'řo ta ke 'taN to le 'γus ta en el al 'xi βe*).
4. **Miguel y Manu llamarán entre ocho y nueve y media. (***mi 'γel i 'ma nu λa ma 'ran 'eN tre 'o tʃo i 'nwe βe i 'me ðja*).

First phrase, taken from Albayzin database (Moreno et al., 1993), was chosen because it contains an interesting sequence of successive /a/s and /i/s vowel sounds. This sentence also includes stressed vowels /i/ in diphthongs where (according to our preliminary contrastive study, see 2.1) differences between the second and third formant could be distinctive characteristics in apnoea speakers.

Second and third phrases, both negatives, have similar grammatical and intonation structure. They could be useful to make contrastive studies of vowels in different linguistic contexts. Some examples of these contrastive pairs are: a nasal context, "m**a**ng**a** roj**a**" (*'maŋ ga 'řo xa*) versus a neutral context, "t**a**z**a** rot**a**" (*'ta θa 'řo ta*). These contrastive analyses could be indeed very interesting as our previous research review revealed that apnoea speakers might have an overall higher nasality level due to velopharyngeal dysfunction. So far, this anomaly, related to difficulties in making changes of nasality, could be measured through intra-speaker differences between neutral and nasal vowels, which would be small in apnoea patients. Also the third sentence includes word "ningún" (*niŋ 'gun*) which was specifically added to get good samples of nasalized /i/s sounds.

Fourth phrase includes a relatively long sentence mainly composed of voiced sounds read as one single melodic group. The rationality for this fourth sentence is that apnoea speakers usually present fatigue in upper airway muscles. Therefore this sentence can help to discover different abnormalities during the sustained generation of voiced sounds. These phonation-related features for harmonic voice parts could be characterized using different measurements such as Harmonic to Noise Ratio-HNR or pitch dynamics (i.e. jitter). The fourth sentence also contains several vowel sounds embedded in nasal contexts that could be used to study phonation and the articulation in nasalized vowels. Finally, related to resonance anomalies, one of the possible characteristics of apnoea speakers could be dysarthria (see section 2), therefore this sentence can be used to analyzing dysarthric voices that generally present differences on vowel space with regard to normal speakers (Turner et al., 1995).

The three repetitions of the sustained vowel /a/, including onset and offset, could be used to study phonation measures (two good parameters to detect anomalies in the phonation are the jitter and shimmer) that detect the variations in amplitude and frequency of the speakers, but in a more controlled way.

5. Preliminary experiments and results over the Speech Corpus

In this section we present experimental results of a preliminary study performed on a population of 50 individuals in the apnoea speech database. Following a similar approach for other pathological voice assessment studies (specifically dysphonia analysis in Fredouille et al., 2005), our experimental set-up was intended to test the potential of applying standard Automatic Speaker Recognition (ASR) techniques to the automatic diagnosis of apnoea disease. The ASR technique we used is based on the GMM-based approach, which represents the state-of-the-art for speaker recognition. A speaker verification system is a supervised classification system able to discriminate speech signals into two classes (genuine and impostor). In our case, the classes will not correspond to a given speaker, but a sleep apnoea class and a control class (referred to healthy subjects). This method is suitable for keeping track the evolution of voice dysfunction among the patients, is easy-to-use, quick, non-invasive for the patients and affordable for the clinicians. The proposed method is not expected to replace the existing OSA diagnosis methods (for instance Polysomnography), but to help in an early detection of severe apneoa cases, Early severe OSA detection can enable more efficient medical protocols, giving higher priority to more risky cases (i.e. there is a high risk of car accident due to somnolence in severe apneoa patients) and thus optimizing both social benefits and medical resources.

5.1 GMM Classification System

As we mention above, the ASR technique used in this study rely on Gaussian Mixture Models (GMMs) and adaptation algorithms (Reynolds et al., 2000.). These are effective and efficient techniques suitable for sparse data and well suited to observing of the apnoea pathology evolution of a subject. All the experimental results were obtained using BECARS open source ASR system (Blouet et al., 2004). Details on parameterization, model training and classification phases for the BECARS baseline system are the following:

- Parameterization consists in extracting information from speech signal (in our case, 39 MEL frequency cepstral coefficients –MFCC-, delta MFCCs and delta-delta MFCCs).
- GMMs for apnea and control groups were trained as follows. First, a generic GMM model was estimated on a subcorpus of Albayzin Database (Moreno et al., 1993) which is entirely separate from the apnoea speech database. Next, speech data from apnoea and control group speakers was used to train the apnoea and control group GMM models. Both Apnoea and control grups GMMs were trained using MAP adaptation from the generic GMM model trained using Albayzin. Obviously, speech data from speakers used to train apnoea and control GMMs was not included in the test set. As these preliminary experiments were made on a relatively small population (50 subjects), the standard *leave-x-out* testing protocol was used. This protocol consists in discarding x speakers from the experimental set, training some models on the remaining data and testing with that x speakers. This scheme is replicated until reaching a sufficient number of tests (Fredouille et al., 2005).
- During the classification, an input speech signal is presented to the system, compared with the each GMM model (apnoea and control) and assigned to the closest one in terms of likelihood measure.

5.2 Results

In these initial experiments the task of control and apnoea voice classification have been investigated. Table 1 provides the correct classification rates obtained. An overall correct classification of 82 % is reached on this task.

Correct Classification Rate in %	Control Group	Apnoea Group	Overall
	80 % (20/25)	**84 % (21/25)**	**82 % (41/50)**

Table 1: Correct Classification Rate on the Speech Apnea Database.

Considering the correct classification rates achieved, there are some aspects to comment. The results are encouraging and it seems that apnoea information may be caught by a GMM based-approach, even with few training speech. These promising results have been obtained without particular attention to the choice of acoustic parameters used, so best results can be expected with a representation of the audio data optimized for pathology discrimination. Evidently, these experiments have to be validated with a higher population, but the results have already given us a preliminary notion of the discriminative power of this approach for the automatic diagnosis of severe apnoea cases.

6. Conclusion and Future Research

In this paper the design criteria of a database for the research in automatic detection methods for severe apnoea cases has been presented. This study represents a pioneer research in the field of automatic diagnosis of obstructive sleep apnoea disease that includes both acoustic characteristics and morphological facial characteristics in apnoea patients. Preliminary experimental results using state-of-the-art GMM speaker's recognition techniques shows that it is worth continuing the research of the acoustic and morphological facial characteristics of apnoea speakers.

Future research will consider phonetic GMM models (Hebert &Heck, 2003) to evaluate possible benefits from modeling apneoa voice characteristics for specific phonetic units compared to the use of single GMM model for the whole utterance. Furthermore, bearing in mind the speech database design criteria, based on previous research on the acoustic properties of the apnoea voice, we plan to investigate the use of other acoustic measures usually applied over pathological voices (jitter, Harmonic to Noise ratio, nasality index, differences between formant values as we saw in the initial contrastive acoustic study, etc.). These techniques could also be applied over different linguistic and phonetic contexts, and could be fussed to GMMs to improve our initial discrimination results.

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