**Artículo de investigación científica y tecnológica**

# Diseño y desarrollo de una aplicación móvil para caracterizar y clasificar sonidos pulmonares basada en análisis espectral y Transformada Wavelet

## Design and development of mobile application to characterize and classify lung sound based on Frequential Analysis and Wavelet Transform

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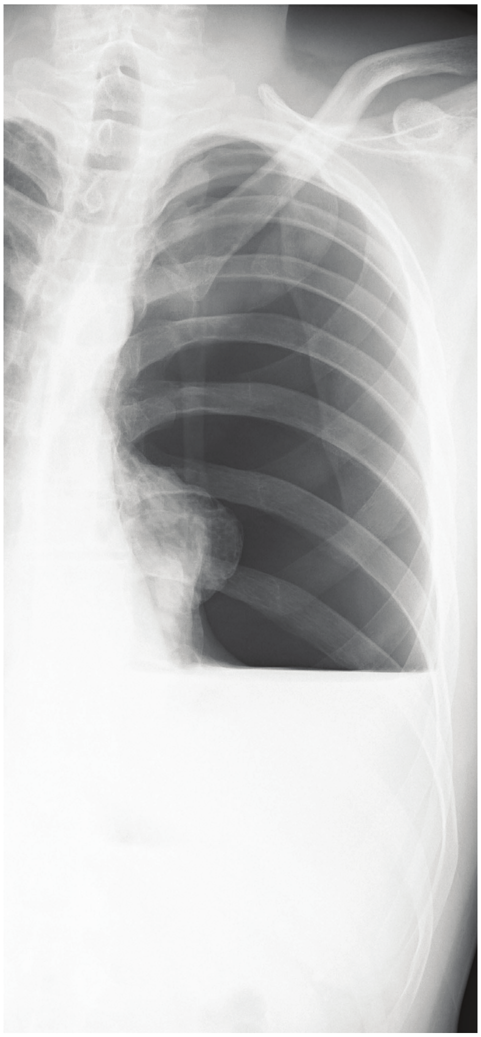

## ABSTRACT

Throughout the last decades, the lung auscultation has been used as one of the most popular procedures to evaluate the state of the respiratory airways with relative confidence based on the interpretation of the audio signals given by the stethoscope, a medical tool that has not changed significantly over the last years.

The recent development of digital stethoscopes provides them with several capabilities that enhance auscultation interpretability with novel features like audio amplification, noise rejection and filtering. Even better is a digital stethoscope, which gives the chance of computerized signal analysis on lung sounds, which is the motivation of this work.

Based on the lung sound characterization performed by Laenec [1], we consider that it is possible for a computer-based system to detect the elemental features of a lung sound by its frequency contents and presence of discontinuities in order to classify them into its basic types: ronchi, wheezes, and stridor.

Using both traditional signal analysis tools, such as Fourier Transform, as well as novel ones like Wavelet Transform, this work proposes to implement a mobile application for the Android OS along with a digital stethoscope that, beyond just classifying the content of a lung sound signal, provides a graphical representation of its characteristics like the frequency on discontinuous sounds found in the sound that might be helpful to make the diagnosis about the respiratory state of a patient easier.

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**Keywords:** Stethoscope; lung sound; adventitious sound; ronchi; wheeze; stridor; crackle; Wavelet transform; Short-Time Fourier Transform.

## Resumen

A lo largo de las últimas décadas, la auscultación ha sido uno de los procedimientos mas usados a la hora de evaluar la condición de las vias respiratorias con relativa confiabilidad con base en la interpretación de las señales de sonidos provistas por el estetoscopio. Una dispositivo usado por médicos que no ha cambiado su esquema significativamente los últimos años.

Aún así, los últimos desarrollos en estetoscopios digitales les proporcionan funcionalidades que mejoran la interpretabilidad de la auscultación con características como amplifiación de audio, inmunización al ruido y filtros. Más aún, un estetoscpio digital proporciona la posibilidad de un análisis computarizado de señales de audio pulmonar, lo cual es la motivación de este trabajo.

Con base a la caracterización de sonidos pulmonares hecha por Laennec [1], consideramos que es posible para un sistema basado en computadora detectar las propiedades elementales de un sonido pulmonar como son su contenido frecuencial y presencia de discontinuidades con el fin de clasificaros dentro de sus clases básicas: Roncus, sibilancias y estertores.

Usando herramientas de análisis de señales tradicionales como la Transformada de Fourier y otras mas recientes como la Transformada Wavelet, este trabajo propone implementar una aplicación móvil para sistema Android que junto con un fonendoscopio digital vaya mas allá de solo clasificar el contenido de una señal de sonido pulmonar y provea una representación gráfica de las características encontradas en el sonido como frecuencia y discontinuidadesque pueden ser útiles a la hora de hacer mas fácil el diagnóstico del estado respiratorio de un paciente.

**Palabras clave:** Estetoscopio, sonido respiratorio, sonido adventicio, roncus, estridor, estertor, Transformada Wavelet, Short- Time Fourier Transform.

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## I. Introduction

Auscultation is one of the most traditional practices of medicine. Its rapid diagnosis, the ease of the procedual and the portability of a stethoscope make it a very frequent and efficient clinic procedure when assessing the health state of one of the most vulnerable systems of the body: the respiratory system.

Electronic devices helped medicine increase the variety of analysis and visualization of different diseases, e.g electrocardiogram, MRI. Etc. Regarding auscultation, the introduction of the electronic stethoscope has offered a new possibility to analyze, filter, modify, edit and store lung sounds thanks to the versatility of digital data, achieved by a computer or electronic computational device [3][4][5].

The analysis of such signals helps to gather information on its frequential content, energy, pitch, tone, etc. that allow the classification of the lung sounds in their most common terms: ronchi, wheeze, stridor and crackle. Therefore, an android application could help the ausculter to identify the type of sound, since sometimes it's very hard to perceive the frequency of low-frecuency sounds by just listening to them.

The Android application proposed is able to perform frequential analysis by using the Fourier transformation. It also performs an analysis in both time and frequency using the Short-time Fourier Transformation. Moreover the application is able to detect discontinuities by using the wavelet transformation. These techniques are intended to provide a visual representation of the signal that enhances these features and aids the diagnosis if an expert.

## 2. BACKGROUND

### 2.1 Adventitious sounds

Adventitious sounds are those produced by the lung's structures that are different than normal sounds in a respiratory cycle caused by a disfunction in the respiratory system. Its frequencies range between 10Hz to 900Hz, which hinders its auscultation without a proper tool.

Laenec was the first who defined the most common sounds in lung pathology: ronchi, wheeze, and crackles. Table 1 shows the different types of lung sounds and their features [1].

**Table 1.** Basic classification of lung sounds by ATS

| Duration | Properties | ATS Nomenclature |
|---|---|---|
| Discontinuous | soft, high pitched, short duration. | Fine crackles |
| | strong, low pitched, long duration | Coarse crackles |
| Continuous | High pitched, musical. | Wheezes |
| | Low pitched, musical. | Ronchi |

#### 2.1.1 Ronchi

Are adventitious sounds similar to snores, are usually caused by bronchial secretions or respiratory roughness. The ronchi sounds musical, i.e. not like an interrupted sound but like a continual low-pitched sound. Its fundamental frequency is around 200Hz (low-pitched).

Among the respiratory pathologies that are related to this kind of abnormalities are:

- Non-acute bronchitis.
- Broncoespasm.
- Chronic pulmonary obstruction
- Tumors.

#### 2.1.2 Wheezes

Are sounds caused by a narrowing of the airways that causes the air to flow at a higher speed, causing a whistle effect (being to inside or outside the respiratory system). Therefore, they can be heard during the inhalation or exhalation. Its fundamental frequency is around 400Hz (high pitched).

Wheezes, like ronchies, are continuous sounds; therefore they are musical, uninterrupted sounds. nevertheless, some vibrations (stridors) can be shown.

Diseases related to this kind of sound are:

- Acute bronchitis.
- Asthma.
- Stenosis.
- Lung Cancer.

#### 2.1.3 Coarse Crackles

Are found in inspiration and expiration, they have a popping feature and do not resemble the Velcro's. They are also its less audible after 3 or 4 breathes and tend to change patterns after coughing or even clear. Are related to chronic bronchitis.

#### 2.1.4 Fine Crackles

Also known as Velcro sounds, are inspiratory sounds that tend to repeat themselves in similar patters over subsequent breaths. They result from the reopening of previously closed small airways. Sometimes are heard with wheezes. They are related to the following diseases:

- Asbestosis.
- Idiopathic interstitial fibrosis.
- Heart failure

## 2.2 Characterization

The following section will give a general description of the signal analysis techniques used in the characterization of lung sounds.

Briefly stated, the *Fourier Transform* focuses on getting the frequency content of the audio signal, where as the Wavelet transform will perform a filter stage on the signal that enhances the discontinuous sounds.

### 2.2.1 Short-time Fourier Transform (STFT)

Fourier analysis is the study of how several functions can be represented by a sum of sinusoid or trigonometric functions of different frequencies [15][16].

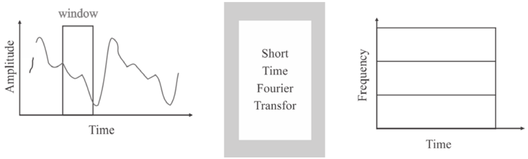
In many cases Fourier analysis is very useful due to the fact that it is important to know the frequential content of a given signal. Nonetheless, the time information is lost, since the data is transformed only into its frequency domain.

**Fig. 1.** Graphical representation of the Fourier transform

If a signal doesn't change its frequency or amplitude distribution during its duration, is said to be a stationary signal, otherwise is a non-stationary signal. Unfortunately the biomedical signals are non-stationary signals, therefore the typical Fourier transform loses the information about when such increments in frequency happen, therefore a new tool must be used, the Short-Time Fourier transform [10][11].

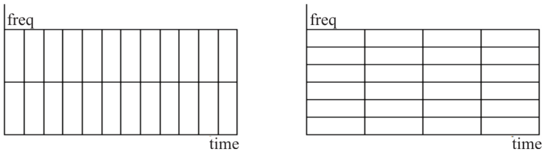
As an effort to correct the deficiencies of the Fourier transform 1946, Dennins Gabor in adapted it to analyze just a small portion of the signal in time (a technique called "windowing") and called it Short-Time Fourier Transform (STFT), which is analyzed over two dimensions: Time and frequency.

**Fig. 2.** Schematic of the STFT



The STFT provides some information about time and frequency, however its precision is limited by the window size. A short window offers good time resolution, but low resolution for detecting the frequency. On the other hand, a longer window offers a good resolution in frequency but not in time. This is called the uncertainty principle of STFT

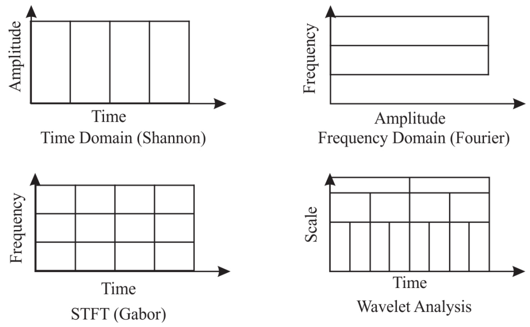
**Fig. 3.** Resolution vs size of the window



### 2.2.2 Wavelet Transform

The wavelet analysis opens the door to multi-resolution analysis. A windowing technique allows the analysis of a signal in portions of variable size. The wavelet transform uses long time intervals in which information of low frequencies are needed, as well as shorter windows for high frequency information [12].

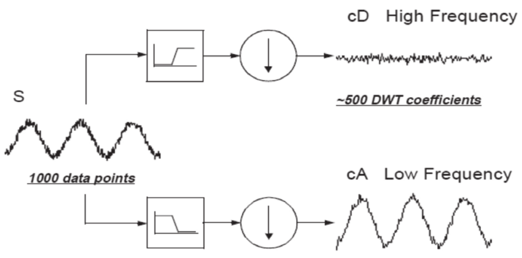
**Fig. 4.** STFT vs Wavelet transform



The wavelet transform is also capable of performing local analysis, being able to reveal specific data such as discontinuity, self-similarity, and is compressing and denoising in a very efficient way.

In 1988 Stéphane Mallat [17] proposed a new scheme to obtain the discrete wavelet transform of a signal, choosing a subset of scales in powers of 2 (also called dyadic scales), based on digital filters, a low pass filter extracts the approximation of the signal and a high pass filten extracts the details of the signal.

**Fig. 5.** A decomposition stage of discrete wavelet transform



## 3. METHOD

The method concerning the development of this work will be presented as follows: The Design section will show how the techniques mentioned above are used as computational algorithms for the purposes of the characterization of lung sounds.

Finally, the Development section will describe briefly the software and hardware platforms taken into account when the mobile application was developed.

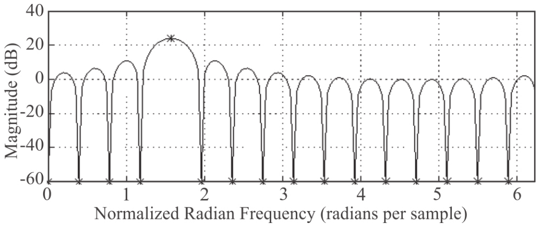
## 3.1 Design

### 3.1.1 Design of the spectrogram

One of the most important things to know from a sound is its frequency content (Frequency spectrum). It has been decided that short signals (between 1 and 4 seconds) are enough since a respiratory cycle is short, and the sound produced by it has a frequency range from 0Hz to 1000Hz. Thanks to this, it is possible to implement the STFT without too much computational cost, since the FFT has to be performed several times, as many times as the window's length fits in the signal's length.

One problem arises when using the STFT called spectral leakage. This accuns when doing windowing additional short-magnitude frequencies are produced besides the original portion of signal.

**Fig. 6.** Spectral leakage in a pure sinusoide.



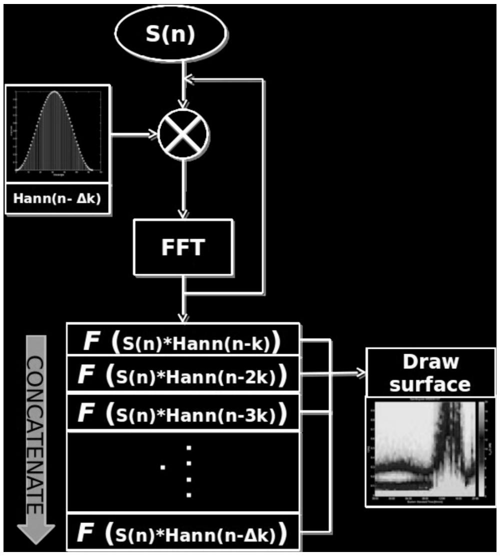
To solve this, in a similar way to [11], a window function was implemented, specifically the Hann function. For our application, a Hann Window with a length of 25 ms (200 samples at 8000 samples per second), was multiplied point by point with the original function, then the FFT was performed, then a shifted Hann function was multiplied again in order to take a different portion of the signal.

The spectrogram is represented by a surface plot where the horizontal and vertical axis represent time and frequency. The magnitude is represented by colors (blue the smaller and red the greater magnitude).

### 3.1.2 Design of the discontinuity detector

Another important feature of the lung sounds are the explosive sounds known as crackles, the-

**Fig. 7.** Flowchart of the STFT



se sounds are discontinuous, short-time and high pitched sounds that might be found by its large wavelet coefficients [6] in the wavelet domain.

Given this fact it is possible to isolate and filter the crackles, eliminating the basic components of the signal and just leaving the relevant crackle components as performed in [9].

A method far choosing the important coefficient is known as thresholding [7][8]. The thresholding rule used is the fixed threshold, which is given by the following equation:

$$T = \sqrt{2\log (N)}\sigma$$

In which N is the length of the coefficient vector, σ is the median absolute deviation (MAD).

After the threshold is obtained, hard thresholding is applied. Hard thresholding is implemented as follows: if the absolute value of the coefficient is greater than or equal to the threshold, remains unchanged; otherwiset is set to zero value.

Figure 8 shows the decomposition and reconstruction scheme used to analyze the signal; three decomposition stages were used, then thresholding was applied to every detail level with the thresholded coefficients, reconstruction was performed to obtain a signal with just the discontinuities. Figure 9. illustrates how the thresholding is done over a signal named 'S'

**Fig. 8.** Scheme of the decomposition, thresholding and reconstruction. D1, D2 and D3 are the high pitched wavelet coefficients related to crackles, then thresholding is applied and D3´, D2´ and D1' are produced. The new signal S' is reconstructed from these coefficients without taking into account the Vesicular Sound components A1, A2, A3.

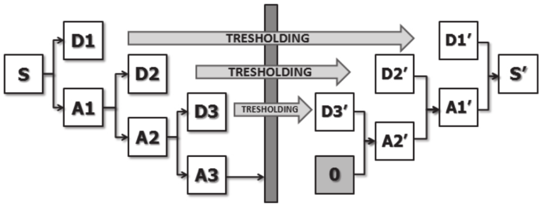
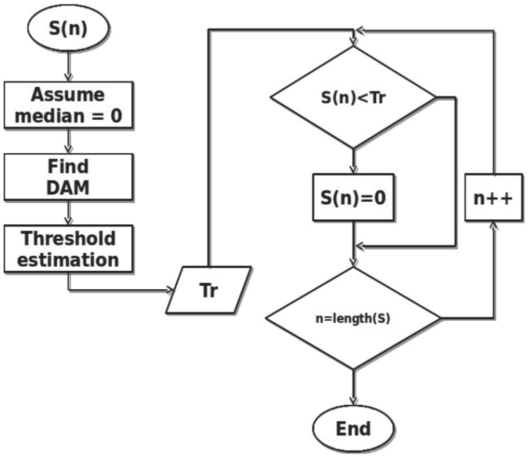


**Fig. 9.** Flow chart illustrating the algorithm used for thresholding



## 3.2 Development of android aplication

### 3.2.1 Enviroment Development

All the algorithms developed (Previous sections) were implemented and gathered jointly into the Android application "PhonoPneumo Analyzer" aimed to be used on the operating system Android 2.3.1 API level 9 and newer versions.

The application and its source-code were created using the Eclipse Integrated Development Kit (Eclipse - IDE) Juno version [20]. This IDE includes a variety of Google repositories, as well as integration with development toolkits like

Android SDK tools along with a graphic user interface for mobile applications "SDK manager" that allows the user to virtualize a variety of mobile devices with Android support and even allow the creation of custom devices like the VIA APC-8750 for a correct emulation of the app's performance before implement them physically into the Board.

As mentioned above, the application product of this work was implemented and performed into the Single Board PC: VIA APC 8750 under Android 2.3.1 API level 9 operative system under the name "PhonoPneumo Analyzer". The following table shows some technical details of this one.

**Tabla 1.** Technical specifications

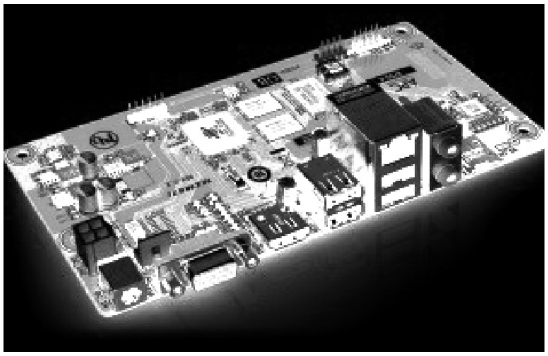
| Technical Details | Description |
|---|---|
| Installer Size | 287 KB |
| Installed File Size | 704 KB |
| RAM Usage (when running) | 4,2 MB |
| CPU usage | Based on Activity |
| First level Underlying cache | No |
| Second level Underlying cache | Yes |
| Access and licenses | Hardware Control: Sound recording |
| Data Storage | No |

### 3.2.2 Novelty of the implementation in a Single Board

One of the purposes of this project was not to perform an algorithm for the analysis and characterization of lung sounds that relied on a mere computational program built in a complicated language maybe unmanageable for most of the people. Rathert, the goal was to take these algorithms together and build a fully functional and user-friendly application under for a popular operative system, wich assures that it could be used widely by the medical community and even non-specialists.

The recent release of the Single Board PC: VIA APC 8750 with the Android Operative system [18] along with a 800MHz CPU, 2GB RAM and some of the most popular IO Ports see up as USB, VGA and HDMI allow us very good application performance and compatibility with most popular devices such USB devices and Displays with VGA or HDMI connectors. The APC 8750 is showed in figure 10.

**Fig. 10.** VIA APC 8750



furthermore, this platform can be available for future applicattions related to biomedic analysis, converting the single Board into a potential state of the Health Care Center that can support the diagnosis of the examinators for a patient.

**Fig. 11.** Icon of the application Phono Pneumo Analizer

## 4 Results

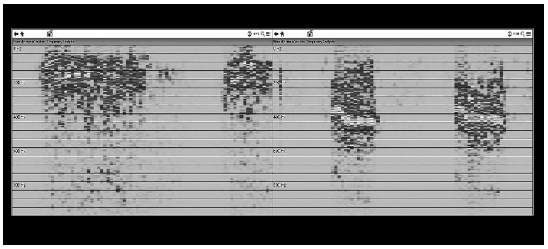
### 4.1 Continuous lung sounds (comparison between the analysis of frequencies and discontinuities)

The spectrogram function has two axes: the horizontal axis for representing time, the vertical axis for representing frequency with its origin at the upper left corner, and colors to indicate the magnitude of such frequency (blue is the lowest and red is the highest).

It is clearly noticeable that the wheezes have their energy spectrum in a higher frequency zone than the ronchi. In the case of normal breathing it should be placed between them (ronchi and wheezes).

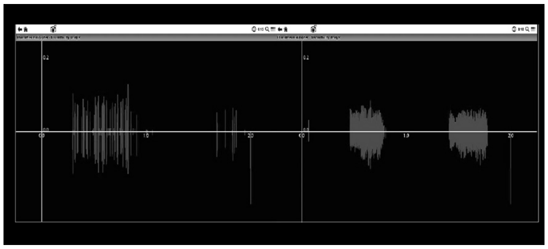
In figure 12 the frequency analysis of a ronchi and a wheeze is represented. The ronchi show the major part of their energy around 200Hz, while the wheezes have the most of their energy at frequencies above 400 Hz.

**Fig. 12.** Spectral analysis of ronchi (left) and wheezes (right).



About discontinuity analysis, its seen that for discontinuous sounds, discontinuities exist, but as seen in figure 13, such discontinuities are of low amplitude (too below 0.2 volts), having in mind that the amplitude of the original signal were of 0.8 volts and therefore do not affect the nature of the sound.

Fig. 13. Discontinuity analysis for (left) ronchi and (right) wheezes



### 4.2 Analysis of discontiouos lung sounds (coarse and fine crackles)

One could think that the discontinuity of lung sounds is something difficult to represent, but the ease with which one can filter bank perform such a task is remarkable.

After the process of decomposition of the sound sample and its reconstruction after the detail that have went through a thresholding process. The new signal is plotted in time and shows to the user the peaks that overpass the threshold level, which makes the identification of the quantity and density of discontinuities in the signal much easier.

Figures 14 and 15 show the original signals and the isolated discontinuities. The application separates the discontinuities from the vesicular sounds, which makes the identification of crackles easier.

**Fig. 14.** Crackles. The amplitude of discontinuities is about 1 volt

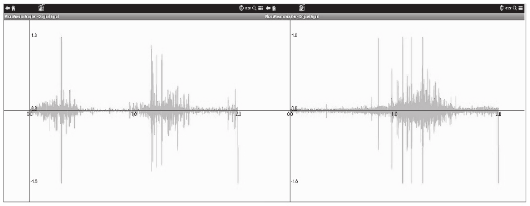
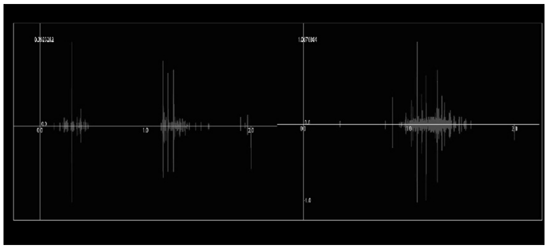


**Fig. 15.** Isolated discontinuities. Their amplitudes are very similar to the original ones, showing that its a discontinuous sound



## 5. Future remarks

The implementation and results obtained with this work are in accordance with the guidelines handled by the CORSA (Computerized Obstructive Respiratory Sound Analysis) project [19]. A framework willing to joint together all developments and research concerning analysis of digital samples lung sounds.

However, the CORSA project widens the fields of development related to analysis of these kind of audio signals.

Other approaches that can be sought by researchers, biomedic experts and engineers interested in CORSA might be, for instance, using other techniques for audio processing like Fuzzy Logic, which, although there have been several works showing lower performance in comparison to Wavelet Transform, the implementation of simpler algorithms offers the possibility of a real-time development, as well as an implementation on a micro-controller.

On the other hand, nowadays the implementation of machine learning algorithms to improve the system capability to perform classification by itself is an approach that has attracted researchers recently and, by the way, has brought into the next stage of the proposal aimed to support the diagnosis task for the medical community.

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