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Development of Healthcare Applications using Facilities available in modern Mobile Devices

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ABSTRACT/ *RESUMEN*

Mobile devices have proliferated at affordable prices nowadays. These devices provide high computational power and high-quality communication facilities, with near and remote users. In addition, most mobile devices include flexible sensors such as microphones, accelerometers and cameras, which are suitable for biomedical applications. Several students in the Biomedical Engineering Program, at our research center (Center for Studies on Electronics and Information Technologies, CEETI) have taken advantage of the mobile devices internal hardware capabilities to develop health care applications. These applications have been developed for Android-based devices. In this article two applications are presented, based on mobile platform, *ECAH-M* for speech analysis and *i-Walker* a pedometer.

Keywords: Mobile, Biomedical applications, Android, pedometer, speech analysis.

Los dispositivos móviles han proliferado a precios accesibles en la actualidad. Los mismos están dotados con facilidades con alto poder computacional y comunicación de alta calidad tanto para usuarios cercanos como remotos. Además, la mayoría incluye sensores flexibles tales como micrófonos, acelerómetros y cámaras, los cuales los hacen factibles para aplicaciones biomédicas. Varios estudiantes del Programa de Pregrado de Ingeniería Biomédica del Centro de Estudios de Electrónica y Tecnologías de la Información (CEETI) de la Universidad Central "Marta Abreu" de las Villas, han utilizado las ventajas de las capacidades internas del hardware de dispositivos móviles, con el fin de desarrollar aplicaciones para cuidados de la salud. Dichas aplicaciones se han desarrollado para dispositivos basados en el sistema operativo Androide. En este artículo presentamos un par de ellas, ECAH-M para el análisis del habla y el i-Walker, un pedómetro.

Palabras Claves: Móvil, aplicaciones biomédicas, Android, pedómetro, análisis de voz.

Desarrollo de aplicaciones para cuidados de salud utilizando facilidades disponibles en dispositivos móviles

1. -INTRODUCTION

The last 50 years have been prolific in advances related to medicine in areas as diagnostic, treatment and rehabilitation. More complex equipment from the electronic, mechanic, acoustic or optic point of view, has been required. For example, most of the diagnostic techniques are based on bio signals de-codification. These signals are detected by different sensors to be processed after. In conjunction with the hardware evolution, the new technologies have been enhanced by the software improvements. They have made possible the better acquisition, processing and transmission of bio signals and medical imaging.

In the last decade, an exponential advance of mobile devices technologies and its applications has been observed. The healthcare industry is not immune from this phenomenon. Consequently, a wide range of applications, under the term e-Health (healthcare practice supported by electronic processes and communication), have been developed to support healthcare practice. Many applications (apps) are belonging to companies that are trading their products today at prices very competitive and accessible for many persons. Nevertheless, the number of apps using platforms with open code is also growing. The most currently used is *Android*, although there are many apps for *iOS, Symbian OS, BlackBerry OS, Windows Phone, Linux embedded, Web OS, Bada, MeeGo, Java ME and Windows CE* [1]. Some of these apps are free but, for others, the users have to pay.

On the other hand, thanks to the present mobile devices have an interface with facilities for different type of users and variety of sensors has been possible to develop apps for many different uses. In this work, we show two apps using *Android* for e-*Health*.

Undergraduate biomedical engineering students at Universidad Central "Marta Abreu" de Las Villas (UCLV) in Cuba, were asked to look for affordable solutions to help in some diagnostic problems. The solution could be related to any topic or matter studied during the Biomedical Engineering program. A requisite was to implement the solution as an application on a mobile device. The students were requested to develop apps with real utility to use them in the elementary health system mainly, to help the non-specialized doctors to detect diseases in early stages. The criteria should be based on the competitiveness respect to the prices of professional equipment used for helping in the diagnosis of diseases. In the following sections, we will present two of the applications developed. One of them is a pedometer and the other is a station for de voice signal analysis.

A pedometer is an electronic or electromechanical device, usually portable, used for counting the steps by detecting the motion of the person's hips. In 1780 Perrelet created the first pedometer measuring the steps and the distance while it was travelled. The pedometers measure the distance, speed, walking rate and caloric consume [2]. Looking at the internet, we can find many different types and models of pedometers [3-9]. They have been employed for medical uses but also to track the sport yield of athletes.

One of the pedometer usefulness is to help for the gait analysis. It is necessary to evaluate and treat persons with conditions affecting the gait [5]. The most common cases with gait disorders are persons with brain paralysis or ictus [9]. This device is also useful in sport biomechanics to help athletes to optimize and improve their efficiency and also in the recognition of the correct posture. This device is also useful to help in the evaluation of patients under rehabilitation by specialists from the secondary health system. Nevertheless, the patients could be also followed by the family doctor in the primary system using this device. Other application could be to track the caloric consume of obese patients as a function of the step number, etc. [6, 8].

Some of the best apps of pedometer recognized at the internet [3] for Android are the "*ProtoGeo*", which traces routes and presents his daily movements in a line of time. Another excellent application is the "*Runtastic*", which provides all the basic functions, together with the calculation of speed and the integration with all the social web sites. "*Accupedo*", has also a big popularity. It is able to motorize the daily travels on the phone screen. It also possesses intelligent algorithms of movement recognition in 3D. Another amicable pedometer is the "*Noom Walk*", which is easy and very precise, being in addition, extremely efficient in the energy use. Other option is the "*Endomodo*", which follows not only the steps, but the beating of the heart and the duration of the training. Finally, the application "Nike + Running" allows seeing a detailed separation of each one of the careers. All these apps are very good but they can be obtained from Google Play after payment. Most of them also need the GPS.

On the other hand, there are some diseases which cause alteration of the speech mechanism. Many of them are consequence of lesions in the nervous system as Parkinson or amyotrophic lateral sclerosis. Some other diseases are produced by local affections of the organs involved in the sound emission, as polyps, nodules or pharyngeal cancers [10].

Historically, voice affections have been assessed by a speech-language pathologist. They give a subjective evaluation based on their experience and analysis of the patient speech. Nevertheless, some acoustic measurements have been developed using metrics. They have the aim of offering a more objective approach about the evaluation of the vocal quality. The most common acoustic metrics are related to the speech intensity (energy of the signal), the fundamental tone and its variations [11]. The time and frequency representations in spectrograms have demonstrated the modifications in the voice signal. The intensity of the voice and their temporal evolution is showed in frequency bands. The alterations can be mainly observed in the frequencies associated to the vocalic sounds. The oscilogram is another way to show this signal. It represents the signal amplitudes in dB versus the time. The specialists have knowledge of how a normal voice pattern is as a function of the sex, the age and the language of the person. Taking into account this knowledge, they can identify the presence or not of pathologies.

Some professional software has been developed for computers, which permit objective analysis of the voice signal as for example: *Praat, MDVP*, *WaveSurfer*, or *ECAH*, among others [12-15]. Some of them, as *Praat*, have been developed using open code and are free on internet. Some others are associated to specific hardware on workstations, like *ECAH*, which has been developed by CEETI-UCLV in Cuba, and some others are in the market at several prices.

Nevertheless, the reality is that nowadays, there are few companies that take risk developing applications for telephones for speech analysis. Google, for example, has more apps for persons with visual problems than other impairment [16]. Nevertheless, some software has been developed for speech analysis, which allow to monitoring the voice signal. In our opinion, the present generation of smartphones have improvements in the processing facilities, resolution to the interface for viewing, low-power consume and higher battery efficiency, as well as the dotation with microphones with good characteristics. For this reason, we think are very suitable for apps related to the analysis of the speech disorders. Some examples have been published in the past [10, 17, 18].

2.- MATERIAL AND METHODS

2.1.- APPLICATION A: PEDOMETER, I-WALKER

With the inclusion of accelerometers as part of the smartphone devices, it is possible to use them as a pedometer. In Fig. 1, we present the diagram of our pedometer proposal, designed and implemented on a mobile.

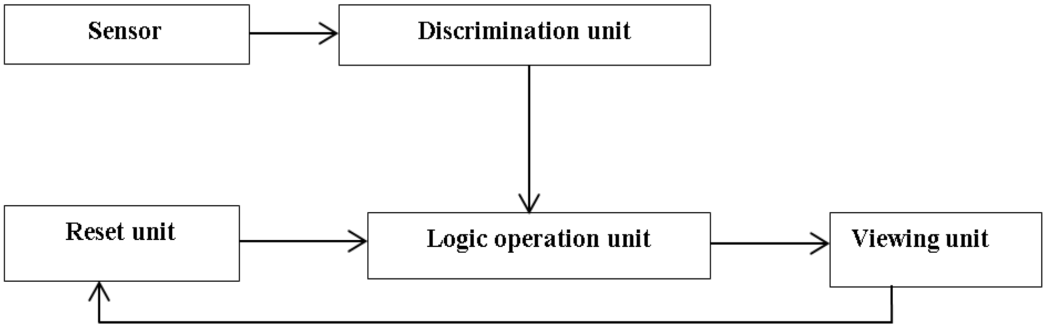


Figure 1

Pedometer Diagram.

The signal obtained from the sensor output is introduced at the discrimination unit to analyze the data. The algorithm tracks the *Z* movement (signal) in the vertical axis of the person to determine the number of steps and the average of the recorded distance between step and step. The algorithm uses the peaks detected by the sensor in the signal to be processes for the step counting. Discrimination unit is designed to ignore the possible noise or irregular pulses from the sensor due to external radiofrequency signals or other unknown causes, permitting only the pass of the useful signal to the logic operation unit. This aspect is covert using a discrimination threshold; only those peaks with surpass the discrimination level are counted. The signal is transferred to the logic operation unit to process the data to obtain the distance information, as the sum of the recorded distance between step and step for the number of steps counted, as well as the speed estimation, dividing the distance between the time and finally the number of steps by minute. This unit also controls the viewing unit which shows the number of steps. The reset unit erases the signal from the viewing unit.

The application was developed using Android Software Development Kit (*Android SDK*) [1, 9]. An *Android* project was created, selecting *AndroidProject* in *File/New/AndroidProject* from *Eclipse*. *Android 2.3* was the version used. After that, we named the application, defined the *Java* package for the class and defined the main class. These actions created all the structure of files necessary to compile the Project. The files were compiled with .apk extension. The code for the step counter was programmed in blocks. The application was copied to a mobile and installed on it. After that, it was run. A Smartphone *Samsung Galaxy S3* was used as test device.

A sample of 60 voluntary persons from both sexes was used to grade the application. They had different weight (mean value 71 kg), height (mean value 1.65m) and age (mean value 35 years). The smartphone was placed in the waist of each person and after they walked 50 m over a plain surface. The number of steps was counted by an external observer to test the application performance. The accuracy and precision of the application measurements were also estimated. Fifty measurements from two persons of different physical characteristics (one of them a man with 24 years, 1.75 m and 78 kg and the other one, a woman with 46 years, 60 kg and 1.64 m) were taken with the application when they walked 200 steps.

2.2.- APPLICATION B: VOICE SIGNAL ANALYSIS, ECAH-M

In this work, was developed a version of the software *ECAH* for mobile devices (*ECAH-M). Android* was employed; due to its *SDK* can be used with *Eclipse*. The application tracks the voice signal with the microphone and it is saved in .wav format. After that, the short-time Fourier transform (STFT) is calculated from the digital samples of the audio signal and the oscilogram and spectrogram are plotted. These operations do not require high computational resources. For this reason, *Android* 2.1 was sufficient to make the project. Fig. 2 shows the application diagram.

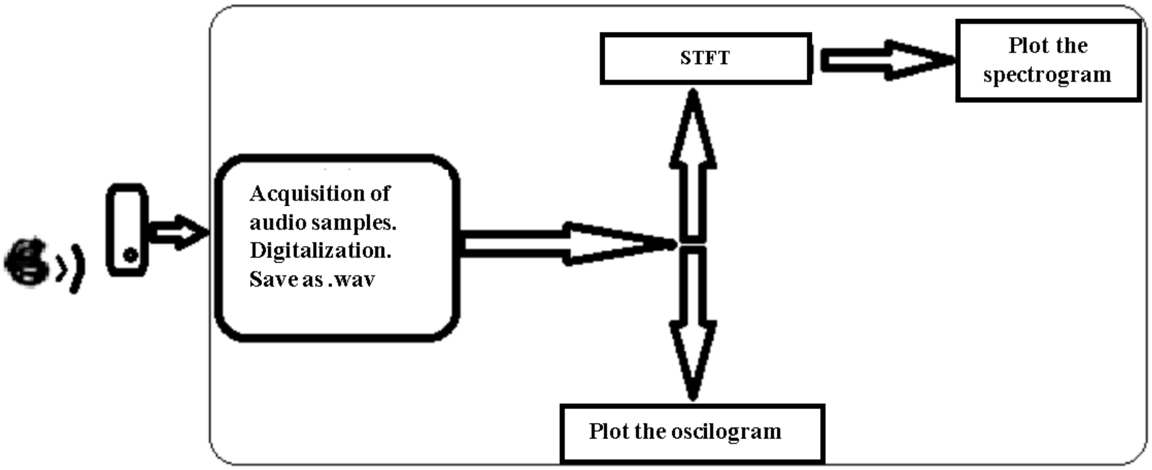


Figure 2

***ECAH-M* Diagram.**

The *AudioRecord* class manages the audio resources for *Java* applications. It recorded the audio signal from the hardware input in the platform. The class parameters are adjusted to construct the object: *audioSource*, *sampleRateInHz, channelConfig, audioFormat,* and *bufferSizeInBytes.* The range of frequencies involved was from 8000 to 44100 Hz, because the acoustic signal is included in the range of 300 Hz to 3 kHz.

Encoding_PCM_16bit was used to represent the audio data due to it has been proved the guaranty of good resolution for these devices. When the object of the *AudioRecord* class is created, its audio buffer is initialized and is ready to receive new audio data. The buffer size is specified over the class construction and determines the length of the segment that can be read by the buffer (in general, each data must be acquired from the audio hardware in segments not longer than the record buffer).

The logarithmic quantity of the voice signal spectrum was calculated in this Project, which is sampled digitally to analyze the phonetic structure of the speech through the relation between the time and the frequency. Segments of 20 to 40 ms were used. The application estimated the STFT of each segment using the *Musicg* library, with a 32 ms window. A moved window of 4 ms and 87.5 % of overlapping were employed. The functions used for the oscilogram and spectrogram gave a group of points which were plotted with the help of a *Canvas*.

In the case of the oscilogram, as the sampling frequency is high (up to 44.1 kHz) and the signal length can be of some seconds, the number of points to plot could be excessive. Nevertheless, the changes in the signal are appreciated in the relative amplitudes associated to the intonation. For that reason, not all the points were showed but only those which define the trends. They are the maximum and minimum locals, which determine the appearance of the graphic to be kept.

Three mobile devices were used to test the application: an "*HTC One mini*" model C960, a "*Samsung Galaxy Star*" model GT-S5820 and an "*HTC*" model A810e.

Samples of the voices from a woman and a man were taken separately to evaluate the application under the same conditions. The analyzed range of frequencies components were between 300 Hz and 3 kHz, related to the 5 vocalic sounds (in Spanish) and for the word "casa" (home, in Spanish).

To acquire the signals, we used the mobiles and the *ECAH-PC* Workstation on a laptop. The application on each mobile was compared to the one in the laptop, and also among them.

3.- RESULTS AND DISCUSSION

3.1.- APPLICATION A: PEDOMETER, *I-WALKER*

Fig.3 shows the user interface for the *i-Walker* implemented on a mobile. The language used in the figure is Spanish because the application was conceived in this way.

Figure 3

User interface for *i-Walker*.

The performance of the application respect the external count made by an observer was plotted in Fig. 4. We can see that practically both curves (red and blue) are overlapping. The error analysis was done. The maximum error was of 3 steps for two subjects. In 15 subjects, the error was 2 steps, in 29 subjects the error was 1 step and in 14 subjects the count was exact. The circles show the few cases without coincidence between the line in red (measurement with the pedometer) and the blue one (external observer).

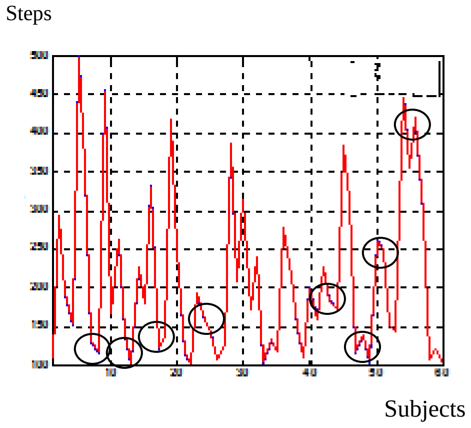


Figure 4

Measurements with the pedometer on a mobile.

The precision of the application was 99.6 % and the accuracy was 99.5 %. Using the application for an average of 10 patients per day, the smartphone will require only one energy recharge per day.

The advantages of this app are related to the fact we do not have a pedometer developed in Cuba and the prices of these devices in the international market are among 3 and 300 Euros, depending on the complexity and facilities they give. In comparison with similar applications from the network, our application is very simple; it has similar precision and accuracy than similar apps in the market, is completely free, is efficient in the use of the battery and does not need GPS. Our application can be useful to help in the evaluation of patients under rehabilitation by specialists from the secondary health system or by the own patients for the daily exercitation. It can be easily installed in a basic smartphone (*Android 2.3* is enough). The computational cost is only 2 seconds of processing.

3.2.- APPLICATION B: VOICE SIGNAL ANALYSIS, *ECAH-M*

Figs. 5 and 6 show spectrograms obtained with the application for a sampling frequency of 44,1 kHz, by a man pronouncing “a-e-i-o-u” and after the same for a woman.

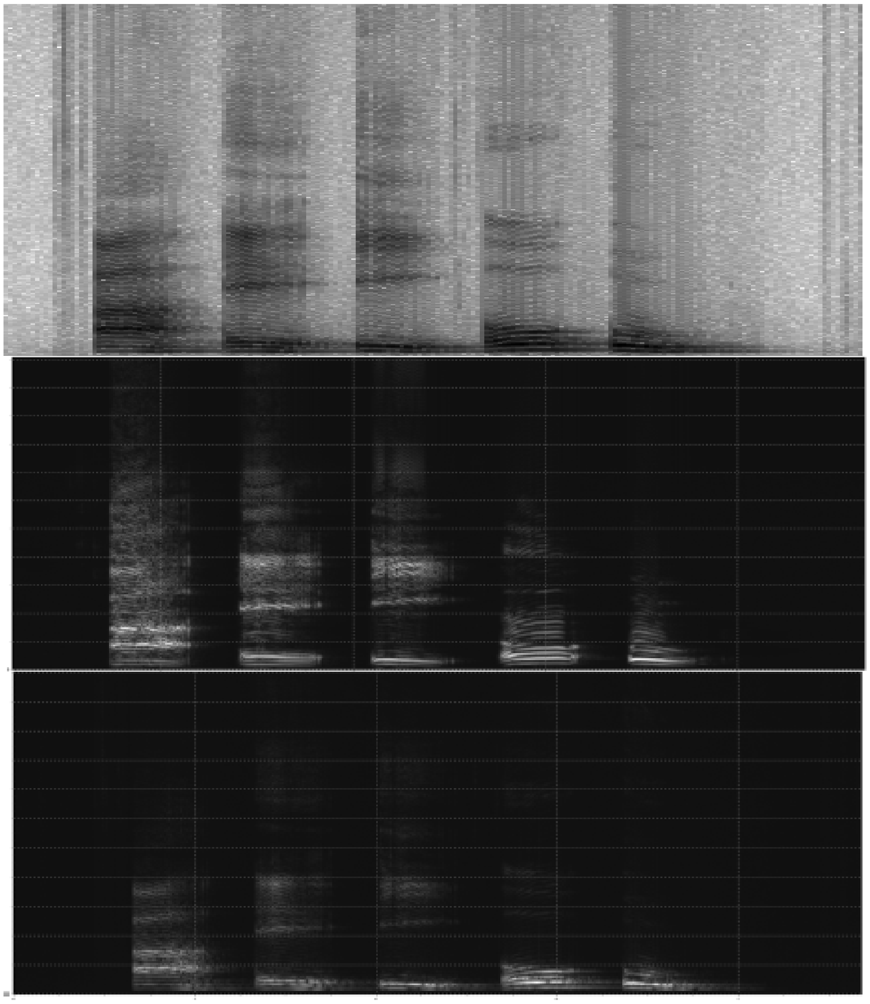


Figure 5

Spectrogram of “a-e-i-o-u” from a normal man: a) obtained from ECAH-M, b) obtained from *ECAH-PC*, c) obtained from *ECAH-PC* with the record on a mobile device.

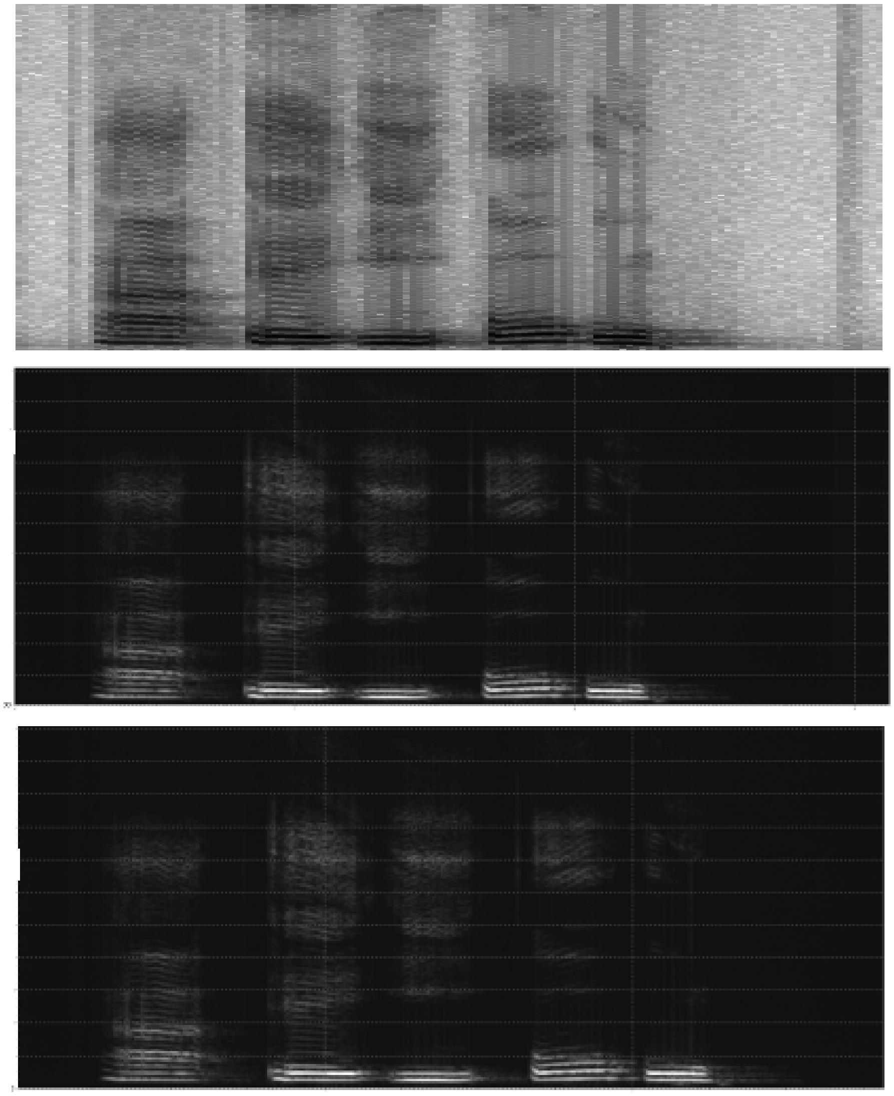


Figure 6

Spectrogram of “a-e-i-o-u” from a normal woman: a) obtained from *ECAH-M*, b) obtained from *ECAH-PC*, c) obtained from *ECAH-PC* with the record on a mobile device.

There is a good correspondence among the three patterns for both sexes. The spectrograms show coincidence in the frequency identification for the five vocalic sounds (information from the X axis) and the voice signal in Time (Y Axis). The differences in the intensity of the voice and their temporal evolution in the showed frequency bands are also observed between sexes. We would like to remark how the app shows an oscilogram with sensitivity to these small differences (Figure 5 a, and Figure 6 a). All these aspects support that the systems *ECAH-PC* and *ECAH-M* have an equivalent performance, although *ECAH-M* at the present is just a fast testing instrument and do not pretend substitute the professional station, which offers also numerical values from the signal.

Due to voluntary healthy persons were used to test the app, we cannot do inferences about the detection of abnormal patterns related to medical parameters or pathologies in this work. The aim of this research is just to test if there is good correspondence between the responses of the app respect to the professional workstation in order to consider their potential for future medical studies. In this sense, the spectrogram given by the app can be useful for the specialist, who, together with the patient clinical evaluation, as well as the familiarization of what a normal pattern is, can arrive to a diagnostic easier or facilitate the patient following.

The images in Fig. 7 were taken from a man pronouncing the word casa (home in Spanish). A sampling frequency of 44.1 kHz was used.

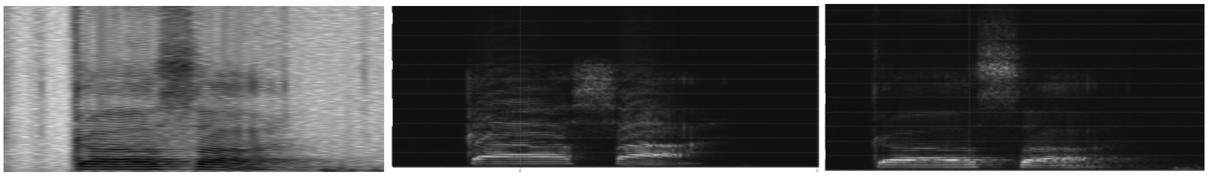
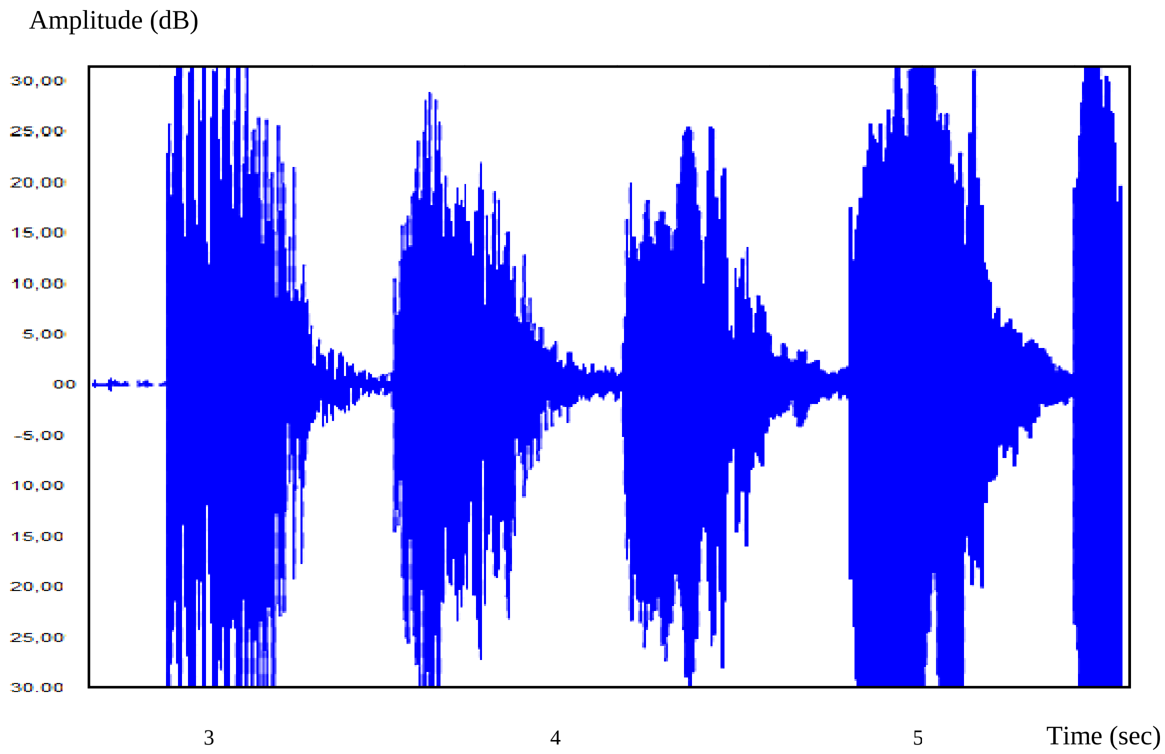


Figure 7

Spectrogram of "casa" from a man: a) obtained from *ECAH-M*, b) obtained from *ECAH-PC*, c) obtained from *ECAH-PC* with the record on a mobile device.

Once again, we can observe good correspondence among the results on a mobile device by using *ECAH-M* and on the PC Workstation, by using *ECAH-PC*. Nevertheless, when the sampling frequency was changed to 8 kHz, to reduce the computational cost of the algorithm for mobile devices, both, the man and the woman signal, pronouncing "a-e-i-o-u" and casa on *ECAH-M* had degraded patterns. It suggests this frequency is not high enough to be able to track all the voice details with the mobile devices used.

The relative equivalence between the app and the workstation for the oscilograms was also verified. Fig. 8 shows an example.



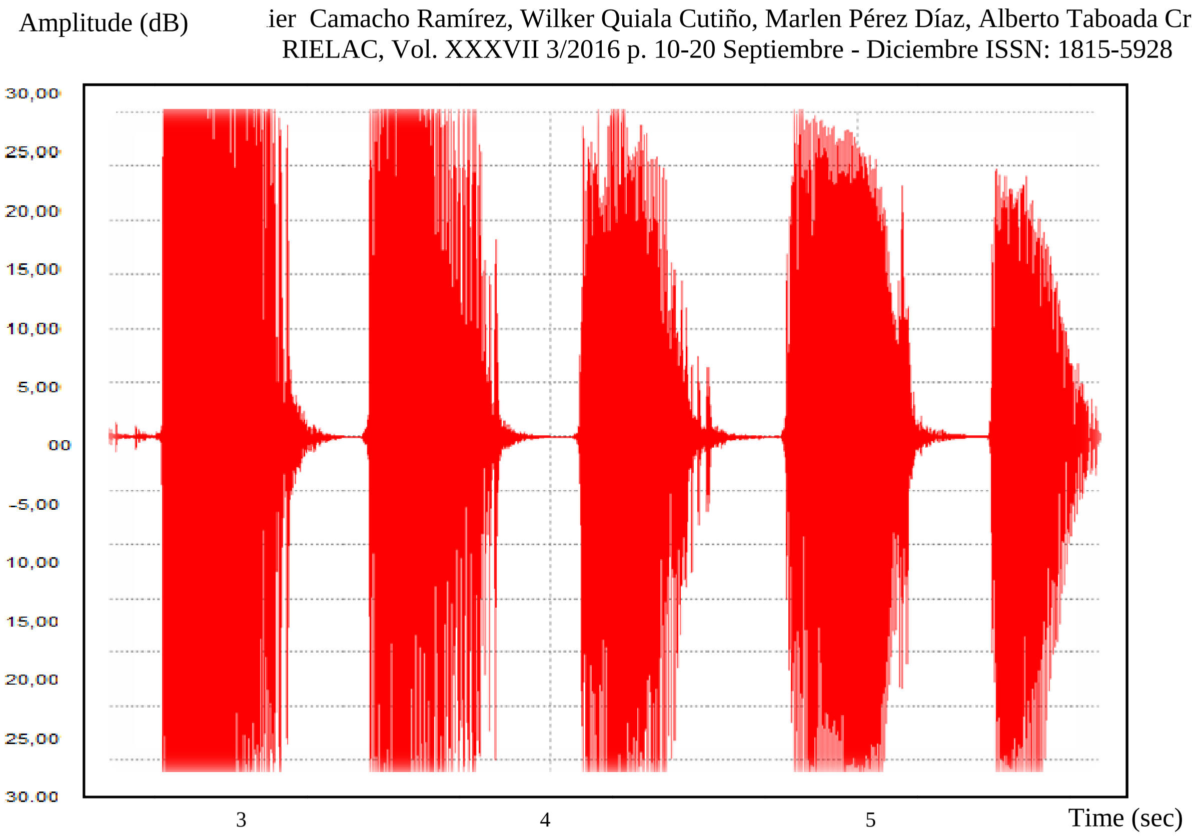


Figure 8

Oscilograms from a man pronouncing “a-e-i-o-u” on *ECAH-M* (upper signal) and *ECAH-PC* (down).

Some differences in details and amplitudes were certainly detected, but nevertheless, there were high correspondence between the envelopments of the oscilograms from *ECAH-M* and *ECAH-PC*, for which we assume that there is a potential for their use. The differences are due to the relative orientation of the mobiles, differences in the distances to the microphones and differences in the audio channels, aspects that we need to adjust in the future. From our point of view, futures studies with normal subjects and patients with voice affections will be necessary in order to test the differences among normal and abnormal patterns using de app for the training of doctors with their use. Fig. 9 shows the application *ECAH-M* displayed in two of the mobiles used in the experiment.

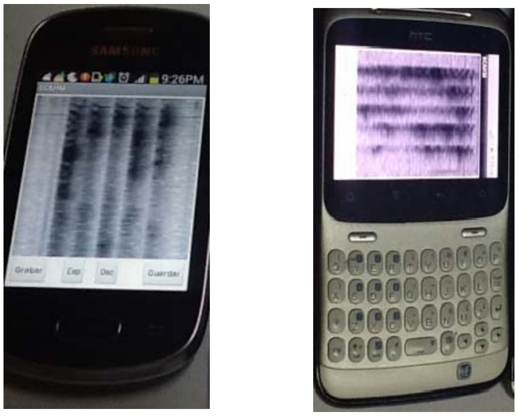


Figure 9

***ECAH-M* on mobiles.**

The possibilities of the smartphone have been used to construct a portal station for voice analysis with an acceptable performance respect the professional workstation. The computational cost is lower than 5 seconds of processing in telephones of mean-low performance. The app could be used by specialists and patients during the rehabilitation period. Is completely free and is efficient in the use of the battery. Using the application for an average of 10 patients per day, the smartphone will require only one energy recharge per day. As app, is something relatively new, with very few competitors on the network.

4.- CONCLUSION

The applications presented have a relative simplicity and they are addressed to be used on mobile devices. The proposals were developed using basic signal processing algorithms, with low computational cost, reason which permits their implementation on mobile devices. The interfaces of the applications are simple, and permit an easy and friendly interaction with users. The mobile devices with *Android* platform are adequate to run these apps which can facilitate the work of doctors, particularly in the developing world. These applications have been developed using open code and are free for everybody.

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