A Computer-based Framework to Process Audiometric Signals using the Tomatis Listening Test System

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Abstract: Some kinds of audio information are usually represented by images that need to be processed. This is the case of audiometric signals which are obtained from some devices that hardly produce quantifiable data. The current paper describes a computer-based framework able to process audiometer images in order to extract information which can be useful to analyse subject's hearing levels. Such information is complemented with additional data sources that allow a more comprehensive view of hearing issues either disorder symptoms or treatment results. These data sources are provided by the TLTS (Tomatis Listening Test System) device. The proposed framework is based on the use of OpenCV libraries that provide image processing functionalities together with scripts to manage audiometry spreadsheets. An experiment has been developed to test auditory stimulations in the context of a collaboration project with the Isora Solutions company where the proposed system was applied. Obtained results show the framework accuracy and adequacy to retrieve and process information from several audiometric data sources.

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1 INTRODUCTION

Audiometry deals with the need of measuring hearing acuity for variations in several audio parameters. Such audiometric process can be based on objective measurements coming from physical or acoustic signals, or relying on subjective user responses. This second scenario represents the work context of this paper that involves several signal sources when determining the subject's hearing levels. Audiometer devices used for evaluating this hearing acuity are usually based on embedded hardware units which barely produce charts called audiograms as a result of the audiometric process.

The current work focuses on the processing of the images and spreadsheets that record the audiogram information as data sources provided by the Tomatis Listening Test System (TLTS). Moreover, there are several types of tests that can be addressed in this context such as Pure Tone Audiometry (PTA), Masking Level Difference (MLD) or Speech audiometry that requires different data types to be processed. The computer-based framework proposed in this work intends to combine and integrate those data sources that enable a more comprehensive and holistic view of audiometry outcomes in a context of auditory stimulations to improve listening skills.

Computers are quite useful to help the hearing assessment when several multimedia signal sources are combined. For example, Mackersie et al., (2001) presented the evaluation of speech perception through a computers-assisted test called CASPA (Computer Assisted Speech Perception Assessment). This work was extended in the system CasperSent (Boothroyd, 2006) as a multimedia program whose main purpose was sentence-level speech-perception training and testing.

A set of auditory assessment tests based on integrating phonetic discrimination and word recognition were described (Eisenberg et al., 2007). Fernandez et al., (2014) used detection of eye gesture reactions as a response to sounds in order to provide computer aided hearing assessment. Therefore, a combination of multiple data sources is essential to get a global view of the specific auditory scenario. In this sense, processing audiogram charts

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is a key issue in the current work together with the collection of spreadsheets data provided by audiometers.

Another aspect is about the intervention of experts in the audiometric process. Automated tests have been developed to check hearing issues in specific audiometry fields using air conduction tests (Convery et al., 2014). In this sense, there is a systematic review of works that check the validity of automated threshold audiometry compared with the gold standard of manual threshold audiometry (Mahomed et al., 2013). Therefore, there is a need to allow human experts to participate in this process by providing them with several audiometry data sources and enabling their analysis. The current work presents a framework able to process audiometer images in order to extract information which can be useful to analyse subject's hearing levels.

The remainder of the paper is structured in the following sections. The second section depicts the audiometry context in which the proposed framework has been developed and tested. This framework is outlined in section 3 and the fourth section reports the obtained Results. Section 5 describes some related works Finally, some Conclusions and further works are drawn.

2 AUDIOMETRY CONTEXT

Audiometry can be considered as a tool to measure the subject's hearing capability according to different sound frequencies. There are several methods to measure this capability and they can be divided into subjective and objective audiometry. Mendel (2007) emphasized the need for both subjective and objective documentation of hearing aid outcomes. In this case, the current work focuses on subjective measures as a way to get audiometry information by means of specific hearing tests. Pure tone audiometry (PTA) is measured in dB HL (Hearing Level) and this value is used to identify the hearing threshold level of an individual. This level represents the higher intensity of sound to be perceived by a subject, compared with people who have a normal hearing level.

For this work, a modified audiometer called TLTS (Tomatis, 2016) has been used, which is based on the use of de SPL (Sound Pressure Level) values as the difference between the pressure produced by a sound wave and the barometric pressure. TLTS was designed by Dr. Alfred Tomatis using a curve of absolute hearing threshold values and it is used for performing a specific listening test that registers hearing levels once these are almost inaudible. The listening test evaluates an individual's auditory thresholds in terms of frequency, ability to identify the source of sounds, ability to discriminate between frequencies, and auditory laterality. The analysis of the resulting curves serves to determine the person's quality of listening and from this to induce a psychological profile. This kind of tests has been performed by professionals of the Isora Solutions company who are participating in a research project about the effect of neurosensory stimulation to improve listening skills (Perez et al., 2016). There are multiple types of actions which can be performed to determine subject's hearing levels in this context. Next subsections describe such actions and the obtained outcomes to be further processed.

2.1 Audiometric Tests

Four main types of audiometric behavioural tests have been performed which address different hearing parameters:

- Thresholds
- Laterality
- Selectivity
- Availability

Threshold of hearing is the minimum sound of level that a human ear can perceive in a certain frequency band and it is considered as a measure of hearing sensitivity. This kind of sensitivity can be represented using a chart called audiogram that displays the audible threshold intensity for standardized frequencies. Figure 1 shows an example of audiogram that represents intensity thresholds measured using dB SPL values (displayed on the vertical axis), which change as frequency ranges from 250 to 8000 Hz (horizontal axis). In this audiogram, blue lines are associated to the air conduction while red line symbols refer to the bone conduction and the green line to the availability. Both via air and via bone conduction (using a vibrator placed on the top of the head) are the main data sources in the TLTS tests. It is important to remark the difference in the sound speed of the two mediums since the travelling time of the bone conduction to the brain is assumed to be faster that the air conduction. According to Dr. Tomatis, the bone conducted sound serves as a wakeup call to prepare the brain for incoming sound. Then, the delay between bone and air-conducted sound has to be measured.

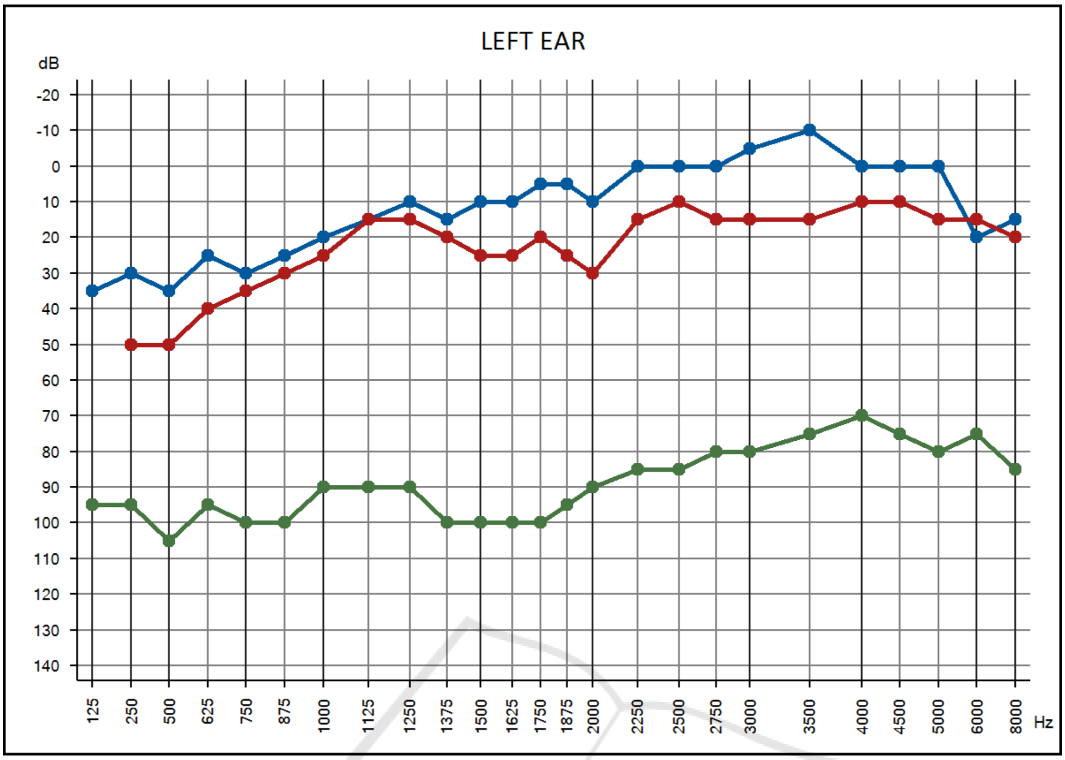

Figure 1: Sample of TLTS audiogram to display Threshold curves.

The second test is based on checking laterality, which is only obtained from a TLTS device, as a measure to observe how humans focus their hearing on one ear (left or right). This measure uses two main values called Extraction (Ext.) and Resistance (Res.) representing the laterality profile. Figure 2 shows a table that allows the matching between these two values and the laterality levels.

Lat.	OG	Ext.	Res.	OI	Lat.
10	40	**18**	**2**	40	10
10	35	**17**	**3**	35	10
10	30	**16**	**4**	30	10
10	25	**15**	**5**	25	10
10	20	**14**	**6**	20	10
9	15	**13**	**7**	15	9
8	10	**12**	**8**	10	8
7	5	**11**	**9**	5	7
7	**0**	**10**	**10**	**0**	**7**
6	-5	**9**	**11**	-5	6
5	-10	**8**	**12**	-10	5
5	-15	**7**	**13**	-15	5
4	-20	**6**	**14**	-20	4
4	-25	**5**	**15**	-25	4
3	-30	**4**	**16**	-30	3
3	-35	**3**	**17**	-35	3
3	-40	**2**	**18**	-40	3

Figure 2: Laterality TLTS dataset.

Selectivity refers to the ability to differentiate the pitch of sounds in relation to each other, but also the direction of variation in pitch. The selectivity test determines the maximum opening of the subject's auditory that is obtained by the frequencies in which some kind of barrier is detected.

In this case, selectivity is obtained from 35 frequency options. Each of these values can be marked when a hearing misunderstanding is detected. An overall percentage of marks can be computed from this test. The higher is this percentage, the lower is the subject's level of listening and memory abilities. Figure 3 shows a sample of this test where a barrier mark is observed for the left ear in the 3250 Hz frequency,

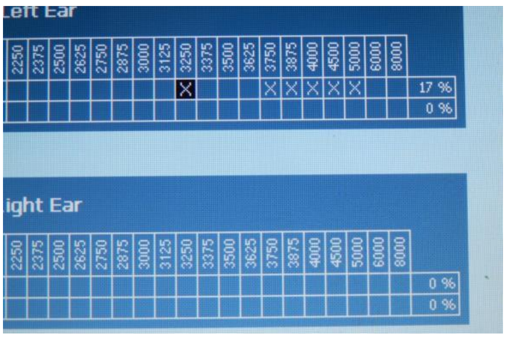

Figure 3: Selectivity test sample.

These tests were implemented with the help of the TLTS device, such as the one displayed on Figure 4. This type of device determines hearing levels, but also measures the ability to discriminate between different sound intensities. The TLTS offers built-in wavefiles for a variety of speech extended high frequency evaluation and PTA calculations. It provides features to process speech information through live voice, mp3 recordings and wavefiles as well as word recognition capabilities. For tone analysis, several air conduction and bone condition mechanisms are addressed, and the possibility to manage masking information.

Figure 4: Picture of a TLTS device.

2.2 Test Outcomes

This subsection describes some of the outcomes obtained in the TLTS process. Such outcomes are divided in two categories: spreadsheets files and image files. Intensity thresholds and availability are represented by means of audiogram charts such as the one displayed on Figure 1. The upper area shows two polygonal lines that represent those threshold diagrams associated to the air conduction (blue line) and bone conduction (red line) for the right ear in this case. The lower area shows a set of characters that represent special situations in a hearing scenario

Laterality and selectivity data are stored on spreadsheets files in a tabular format such those displayed on Figure 5. The first table shows part of the values returned by the audiometer that compute selective frequencies for the left ear either in air conduction test (LAC) or bone conduction (LBC), and, similarly, for the right ear (labelled as RAC and RBC, respectively).

	125	250	500	625	750	875	1000	1125	1250	1375	1500
L AC		X	X	X	X	X		X			
L BC		X				X	X	X	X	X	
R AC		X	X	X							X
R BC		X		X	X	X	X	X	X		X

	LEFT	RIGHT
LATERALITY	+9	+14

Figure 5: Selectivity and Laterality data tabular display.

3 FRAMEWORK DESCRIPTION

The framework proposed in this work deals with processing the different signal sources mentioned in previous sections. Figure 6 shows an overview of the framework functionality. It is structured in two main flows: the first one addressed to process the audiogram images and the second one in charge of selecting spreadsheet data. The results of both flows are integrated in order to analyse and interpret them.

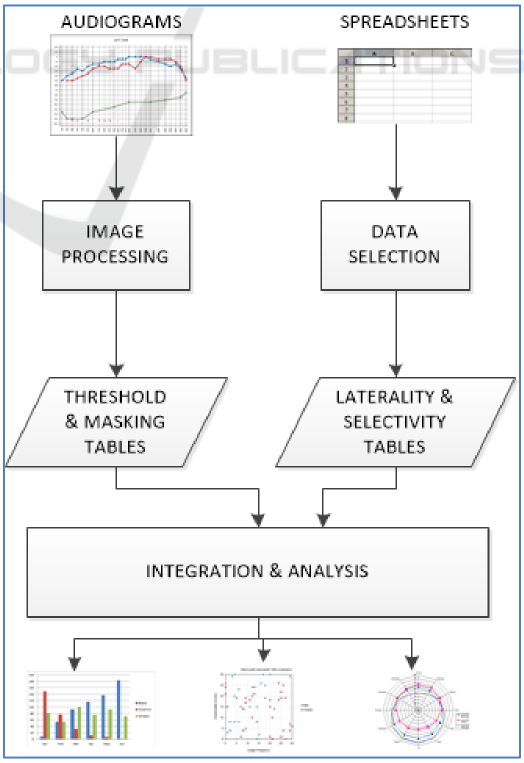

Figure 6: TLTS Framework overview.

3.1 TLTS Processing

TLTS processing is based on the use of OpenCV (Open Source Computer Vision Library). OpenCV is an open source computer vision and machine learning software library that was built to provide a common infrastructure for computer vision applications. It has C++, C, Python, Java and MATLAB interfaces and works on multiple operating systems. This library provides several features that help to gather quantitative information from different kinds of images. In the current case, images come from audiograms such as the one displayed on Figure 1 and the use of OpenCV enables to get the locations of points that compose the audiometric lines.

These locations assign values of intensity thresholds (measured in dB) for each frequency value in the horizontal axis. Original audiogram images are bitmaps of resolution 1200x850 pixels. A first processing step consists in identifying each of the lines by colour, and segmenting it from the rest of the image. Figure 7 shows the red line that represents the threshold bone conduction line in the target audiogram.

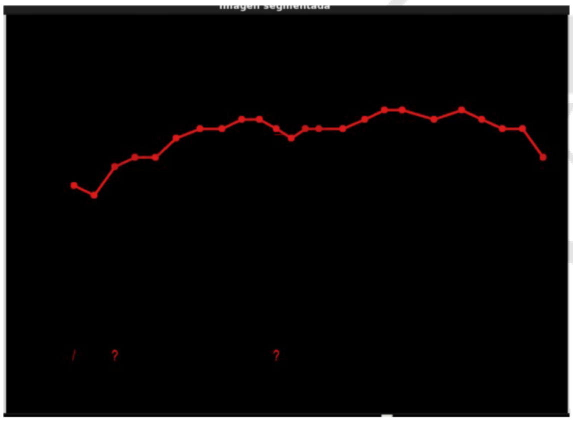

Figure 7: Segmented TLTS image.

The second step is about computing the measured values of each point of a segmented line. Checked points for each of the values of the frequencies can be located from the analysis of the labels in the horizontal axis, providing a frequency value in Hz. By projecting these point locations in the vertical axis, the dB value can be computed. In order to find such points a template matching process is performed do detect the point shapes. The coordinates of the center of mass of these shapes are returned using an iterative sequence over the audiogram colour lines. Figure 8 shows a part of the audiogram in which a green line is marking the detected points.

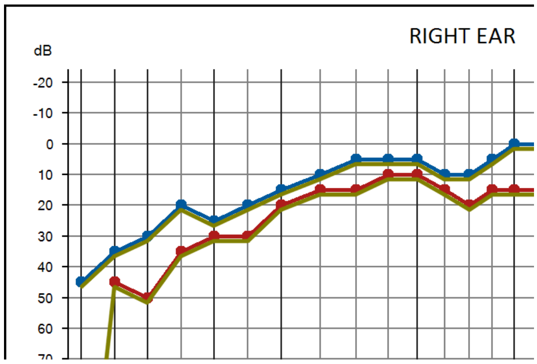

Figure 8: Point shape detection.

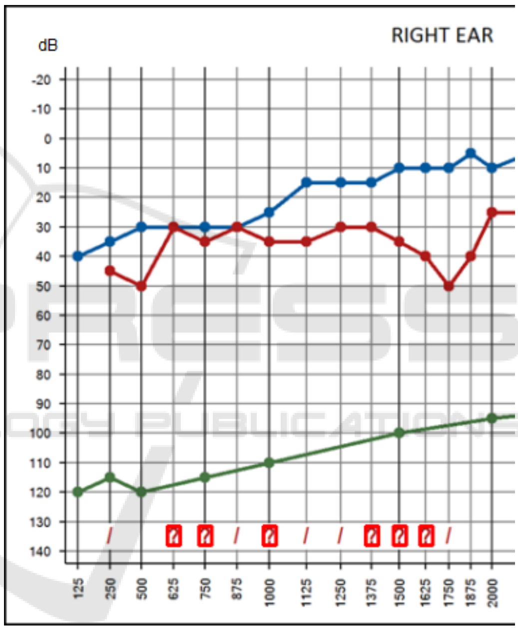

Figure 9: Segmentation of sound TLTS spatialization.

A similar matching procedure is used to filter the spatialization symbols as they are displayed on Figure 9, in which "?" characters are marked within red squares. At the end of the image processing, tabular formats with the collected data are produced and converted to text files (e.g. csv documents).

3.2 Spreadsheet Processing

The process of gathering information from spreadsheets is based on the use of scripts which allow researchers to get a web view of audiometric data.

Figure 10 shows an example of screenshot that displays Laterality values from a selected dataset.

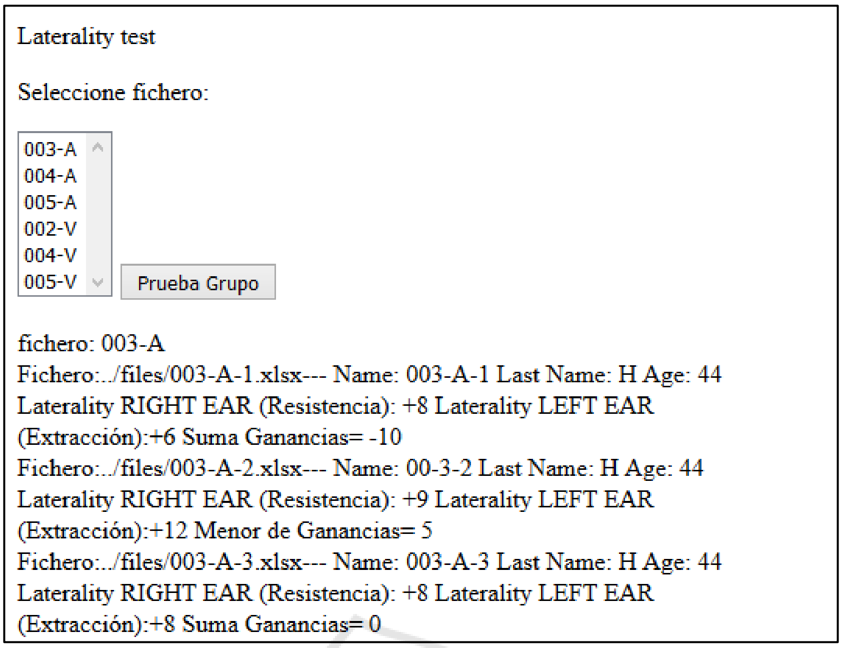

Figure 10: Script outcomes for selecting laterality data items.

These scripts provide access to spreadsheet files either individually or gathering a set of them, in order to get and retrieve the relevant data items and store such items in tabular formats ready to be analysed in further steps.

4 RESULTS

Results obtained by the framework components are evaluated in this section. With this aim, several experiments have been implemented that check the framework accuracy and adequacy for processing audiometry TLTS signals. These samples represent different measures of audiometric tests that were available in a tabular format after the framework application.

A first evaluation consisted in comparing values obtained from processing audiograms with original tabular values. Table 1 shows a list of threshold values coming from audio conduction tests for a specific subject whose audiograms were processed using the framework. These values are structured into several columns that display the audiogram frequency, the threshold data for the Left ear on Air Conduction (LAC), or Bone Conduction (LBC), the extracted points (Ext.) from both graph audiograms, and the Average difference between these data.

Table 1: List of threshold values (measured and extracted).

Freq.	LAC	Ext.	LBC	Ext.	Avg.Dif..
125	55	54,915	0	0	0,0425
250	40	39,783	50	49,953	0,132
500	50	49,953	60	59,876	0,0855
625	30	30,109	45	44,744	0,0735
750	30	29,86	45	44,744	0,198
875	35	34,822	40	39,783	0,1975
1000	35	34,822	40	39,783	0,1975
1125	15	14,729	35	34,822	0,2245
1250	15	14,729	20	19,69	0,2905
1375	15	14,729	20	19,69	0,2905
1500	10	9,767	25	24,899	0,167
1625	15	14,729	20	19,69	0,2905
1750	15	14,729	15	14,729	0,271
1875	20	19,69	25	24,899	0,2055
2000	15	14,729	25	24,899	0,186
2250	0	-0,155	20	19,69	0,2325
2500	5	4,806	15	14,729	0,2325
2750	10	9,767	15	14,729	0,252
3000	15	14,729	15	14,729	0,271
3500	15	14,729	15	14,729	0,271
4000	20	19,69	15	14,729	0,2905
4500	25	24,899	20	19,69	0,2055
5000	20	19,69	30	29,86	0,225
6000	35	34,822	30	29,86	0,159
8000	35	34,822	30	29,86	0,159

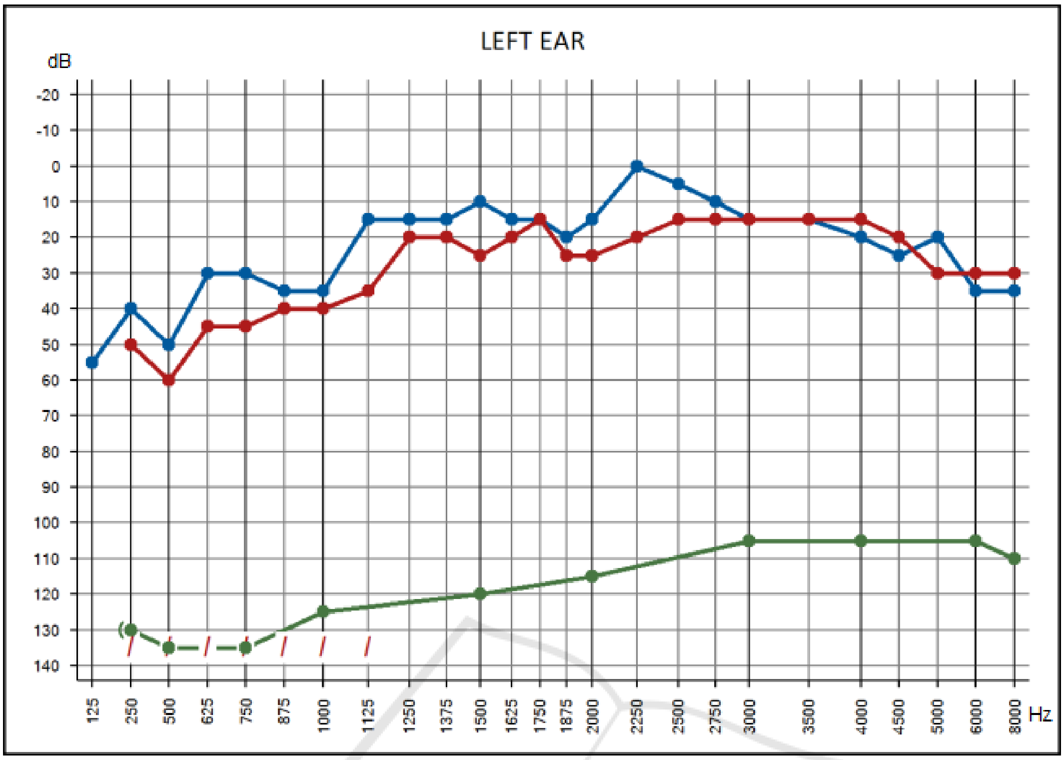

Figure 11: Audiogram processed sample with detection of threshold curves.

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Such list of values is based on the audiogram sample displayed on Figure 11 and the average difference is less than 0.3 in every processed data item either for air or bone conduction. These threshold data items can be further processed to analyse their correlation using a scatter chart such the one displayed on Figure 11 that displays the relationship between air and bone sound conduction.

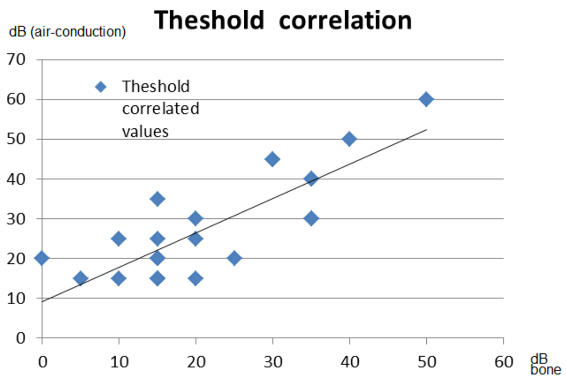

Figure 12: Correlation of TLTS threshold curves.

The results of processing spreadsheets files are also addressed in the framework evaluation. These files store information about audiometric parameters such as Laterality and Selectivity issues together with additional user information (e.g. Age). An example of Laterality profile regarding a specific subject is displayed on Figure 10. The framework can provide a collection of different subject profiles in order to allow their analysis. Figure 12 shows a radar chart that displays the relationship between the values of Resistance and Extraction as Laterality parameters and the age of nine subjects in a study sample.

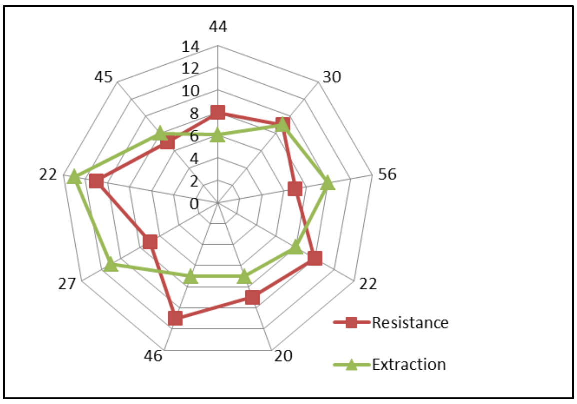

Figure 13: Analysis of TLTS laterality information.

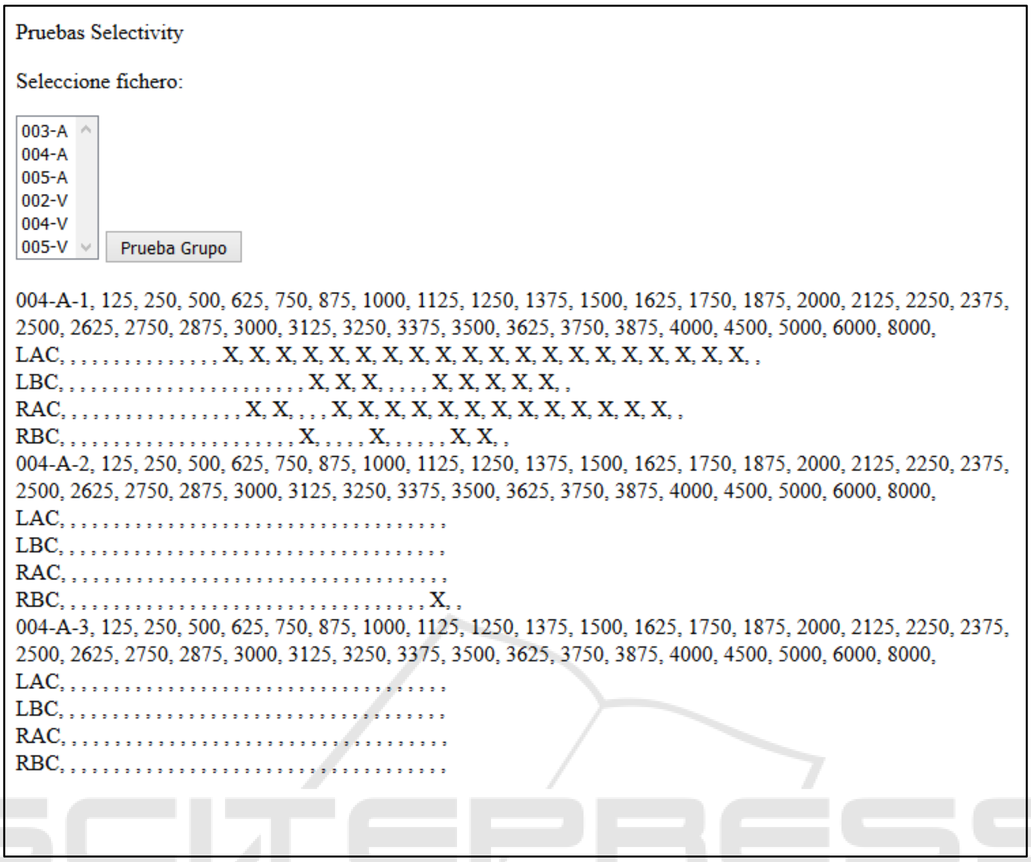

Figure 14: Script outcomes displaying the collection of selectivity data items.

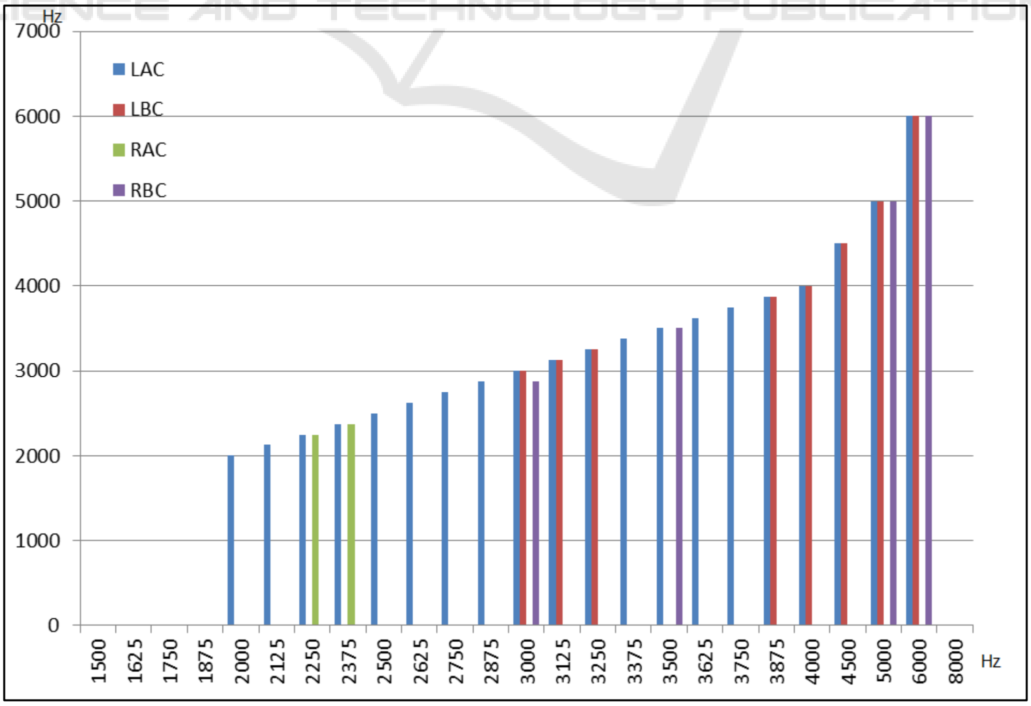

Figure 15: Selectivity bar chart to display threshold distribution.

selectivity information can also be analysed using the spreadsheets processed in the framework.

For example, Figure 14 shows the display of frequencies that were marked in a specific Selectivity case and

Figur represents the bar chart for that case in which frequencies associated to air sound conduction in the left ear (LAC) and the right ear (RAC) are compared with those produced via bone sound conduction (LBC and RBC, respectively).

5 RELATED WORKS

Computer-based frameworks for managing and processing audiometry signals are rather unusual as long as these signals have a strong link with audiometers or specific devices that generate and produce them. Some organizations such as NCHAM at Utah University or HIMSA[1] have implemented software to provide audiology professionals with systems to manage patient information. In the case of NCHAM, they provide HiTrack[2] as an Early Hearing Detection and Intervention (EHDI) Data Management System to screen and register relevant hearing information.

One of the HiTrack main advantages is the possibility to connect with screening equipment coming from multiple manufacturers. HIMSA has developed NOAH as an integral framework allowing "hearing instrument fitting, audiologic measurement and database management system". This software is able to store patients' audiologic profiles from different suppliers and also record notes regarding patient sessions.

Additionally, the Audiology and Speech Pathology Software Development Group at Memphis State University developed a program for the Abbreviated Profile of Hearing Aid Benefit (Cox and Alexander, 1995) to document the outcome of a hearing aid fitting and to compare and evaluate the same fitting over time.

Otherwise, manuals and audiometry guides can be found (NCHS, 2016) but they are usually limited to establish procedures and recommendations in the use of instrumentation or how to record audiometry results. There are authors such as Dau (2008), and Jepsen et al., (2008) who have proposed models for auditory processing and, in the last case, their authors include a Computational Auditory Signal Processing (CASP) framework that was implemented in Matlab / Octave scripting language.

However, these models are usually focused on specific aspects like masking in human listeners. In this sense, Heinz (2010) also presented a computational model of sensorineural hearing loss. This work focused in the context of a sensorineural stimulation project with the aim to process a wide spectrum of audiometry signals beyond the typical hearing loss situations. Therefore, the priority was to introduce a framework that could be adapted to process alternative source of data, either in tabular format or using image files, and provide audiology researchers with computer tools to analyse them.

6 CONCLUSIONS

The current work has presented a computer-based framework that deals with the processing of audiometry signals coming from different data sources. These audiometry signals have been based on audiogram images and spreadsheet files produced by the TLTS device that were addressed to specific hearing tests. Obtained outcomes show the wide range of possibilities of the proposed framework to compute these data sources and contribute to improve the assessment of hearing tests using them. For example, by determining the accuracy in the processing of audiogram charts whose data can be used for statistical studies. Another framework contribution is its potential to retrieve multiple data sources and combine them to produce graphic charts that allow audiologists to easily envision hearing test outcomes. This feature remarks the framework adaptability to fit processing functions according to the required needs. Further works plan to incorporate new processing procedures and integrate them in a Web portal that enables a universal access to the framework services.

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[1] https://www.himsa.com/

[2] http://www.hitrack.org

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