Learning about Waves and Sound

Hear-and-See Tool for Learning Basic Acoustics

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Abstract

Learning concepts related to specific phenomena becomes easier and more effective when learners are allowed to experiment them with their own senses. In acoustics, basic phenomena can be perceived by hearing, although sight is also involved through images and text.

Therefore, a learning tool which involves also the sense of hearing should be welcomed, especially if it is easy to implement. The hear-and-see tool presented here is based on the open-source audio software Audacity. It could be also implemented with similar programs such as WaveLab or Adobe Audition, both of which are commercially available. Nevertheless, the fact that Audacity is available on the web, free of charge, makes it an ideal choice for implementing this hear-and-see tool, even as a sort of home lab.

Many learning activities can be devised using this software application with headphones and a microphone. Several existing examples are described here: an activity designed to observe how a plain sound of defined pitch consists of a periodic variation in air pressure which is recorded through the microphone as a periodic electrical signal; another that allows the learner to quantify the differences among his or her vowel sounds looking at the corresponding frequency spectra; and another that can be used to investigate the differences between sound and noise, or the differences in the fundamental frequencies between musical notes that differ by an octave.

1. Introduction

In a previous paper (Novell, 2004), one of the authors reported on the constructivist approach fostered by hear-and-see tools as another way of incorporating information technologies into science education in the form of computer-based education (CBE).

Indeed, learning concepts related to specific phenomena becomes easier and more effective when learners are allowed to experiment them with their own senses. In acoustics, basic phenomena can be perceived by hearing, although sight is also involved through images and text.

Therefore, a learning tool which involves also the sense of hearing should be welcomed, especially if it is easy to implement.

2. Hear-and-see tools in CBE-environments

Novell (2004) also analyzed the way of implementing a hear-and-see tool as a multimedia unit of definite structure and the constructivist model of learning behind this tool.

In this context, the keyword "multimedia" must be understood in terms of the 3rd. possible definition given by Guttormsen Schär and Krueger (2000), as a modality of communication or multisensory (e.g. visual, auditory, olfactory) interaction. This modality of communication allows a representation according to a cognitive model based on a combination of visual and auditory information with less cognitive load. Overload on one sense causes tiredness and reduced attention, whereas a balance between visual and auditory information reduces the cognitive load.

In a general way, CBE must be in some way more useful than traditional teaching methods, as stated by Karjalainen and Rahkila (1995, 1998). Therefore, the starting point for every CBE project is to ask if CBE can give "something extra" or "a better way" in the means of education compared to traditional methods. These papers describe the "QuickSig" environment, which is a good example of an environment that offers many possibilities for implementing hear-and-see tools. The authors reported on several CBE-applications in the form of courses, encompassing topics such as perception of pitch, loudness, timbre and duration, masking, and critical band.

Other hear-and-see tools have been implemented by Arai (2002, 2003) in the form of computer-based tools for teaching phonetics. These are software tools for analysis and resynthesis of speech sounds. These papers point out the usefulness of hear-and-see tools for teaching acoustics not only to technical students, but also to students majoring in fields such as linguistics, psychology and speech pathology. Moreover, the tools are applicable to a range of learner ages and academic levels, since they enable students to grasp contents in acoustics more intuitively.

As much of the practical work in digital signal processing is now done using computers anyway, it is only natural to apply CBE to teaching, as well. Furthermore, the issue here is sound, and the best way to teach sound is to use sound.

3. Hear-and-see tool based on Audacity

Based on the idea reported in a previous paper by one of the authors (Novell, 2004), an arrangement was created consisting of the Audacity application, the Internet and simple computer equipment including headphones and PC microphones.

Audacity is an open-source sound processor which allows easy implementation of a powerful hear-and-see tool. Whilst similar, commercially available programs such as WaveLab or Adobe Audition could also be used, the fact that Audacity is available on the web, free of charge, makes it an ideal choice for implementing this hear-and-see tool, even as a sort of home lab, where the student can perform real laboratory experiments as a remote learning activity.

There are many similarities between the aforementioned audio processors. Therefore, for this one case, the idea stated by Karjalainen and Rahkila (1995) that the emphasis of a CBE-application should always be on the subject, not on the application itself, does not apply fully: one of the objectives of the activity with our hear-and-see tool was to familiarize the students with the use of standard audio processors.

Figure 1 shows the upper, most relevant part of the Audacity environment with a sound sample and the main command buttons. The most important buttons for our purposes are No. 1 to 6 (playback, stop, etc.) and No. 11 (source selection between microphone and pre-recorded file). Screen elements nos. 16 to 20 are also very useful to reach the best display and for a better reading of data (Nr. 14, amplitude; No. 15, time).

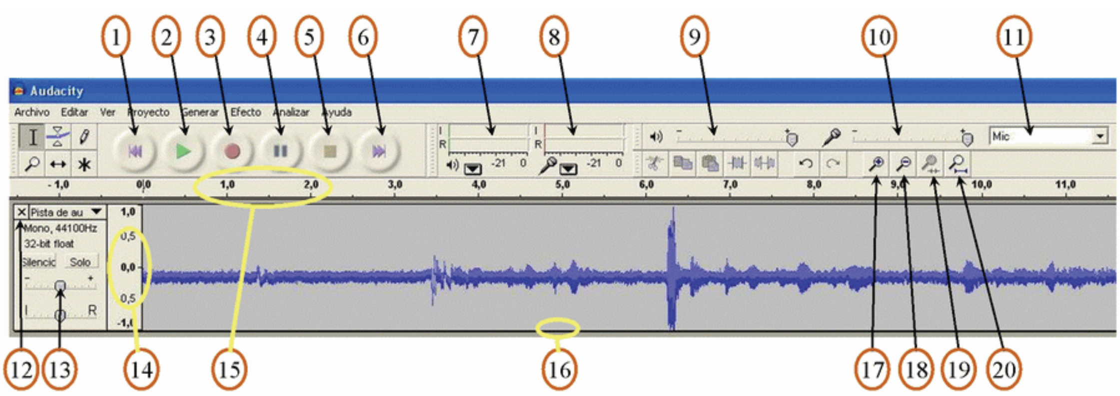

Figure 1. Buttons and handling elements of Audacity.

4. Activities on acoustics already implemented with the proposed hear-and-see tool

In the following section, we describe some learning activities which have been already implemented using our Audacity-based hear-and-see tool.

4.1. Timbre, waveform and acoustic spectrum

The aim of this activity was to observe the difference in waveforms and acoustic spectrums of different timbres. After installing Audacity, the student had to record his or her own speech (in mono) pronouncing the Catalan word "universitat" (pronounced /ˌunɪˌbersɪ'tʌt/) which has different vowels, including a repeated one ("i"). Beforehand, students had seen in the theoretical explanation that timber differentiates also the different vowels.

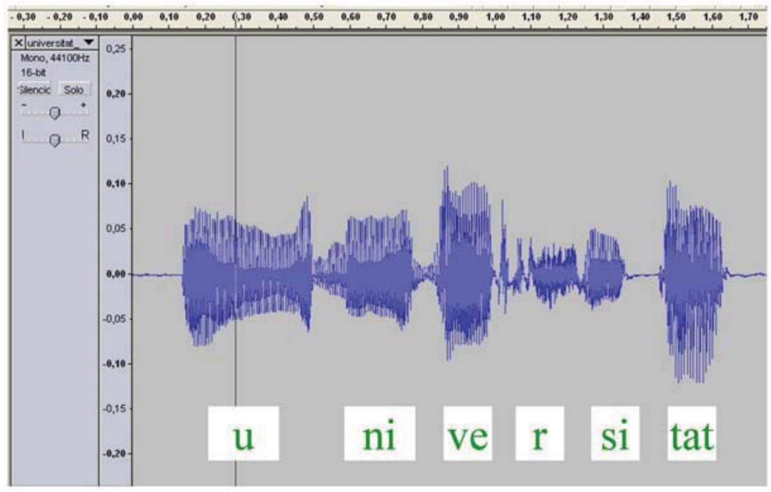

Figure 2: Waveform for the word "universitat" (pronounced /ˌunɪˌbersɪ'tʌt/) as recorded with Audacity.

Figure 2 shows the waveform of the recorded sample in the Audacity screen; the vertical line, moving from left to right, shows the exact place of the waveform being played back at each moment. The white labels with text have been added by the authors, to show what the student hears in the playback.

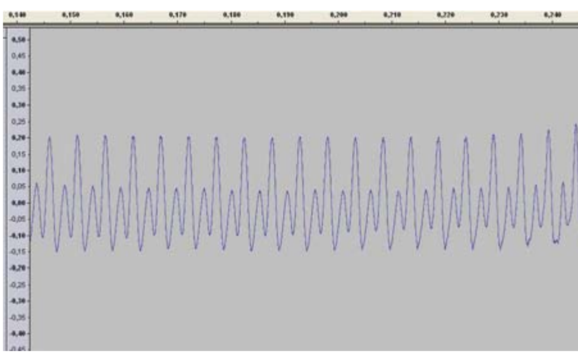

Figure 3: Waveform for the vowel "u" [/u/], after selection and enlargement from the previous Figure 2.

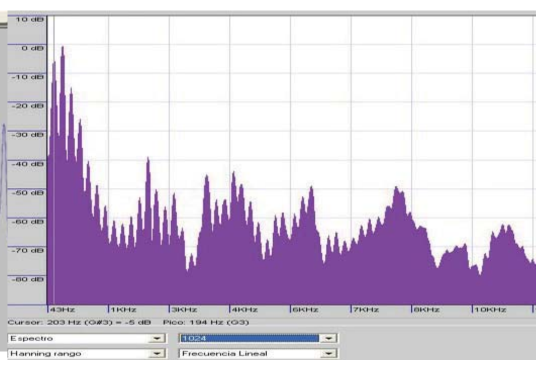

Figure 4: Acoustic spectrum for the waveform of the previous Figure 3, as obtained with Audacity.

After identifying the portion of the waveform corresponding to a given pure vowel, for example the Spanish or Catalan "u" [/u/], the student could enlarge the display in order to observe the waveform in detail and its differences with other vowels (Figure 3).

Then the student had to select the proper portion of waveform, call the function "Plot spectrum" in the View menu, and see the acoustic spectrum obtained. In our implementation, students were encouraged to “play” with the different parameters of the FFT function offered by Audacity (essentially, analysis block size and smoothing window), especially in order to obtain the clearest display of the different harmonics in the spectrum. In our example, Figure 4 shows the spectrum of the displayed waveform (portion of frequencies up to ca. 11 kHz) with an analysis block size of 1024 and a Hanning smoothing window.

The student had to use a spreadsheet to compare the frequencies of the different overtones (at least the first 8 or 10) and their intensity levels. The aim was a quantitative characterization of the spectral differences between two different vowels and the similarity between identical vowels (e.g. the two “i”s in our example).

4.2. Difference between sound an noise

The procedure described allows also to investigate the differences between sound and noise. Here, the term ‘sound’ is understood to be any sound of definite pitch, such as vowels in our speech, or a typically clear sound of musical instruments of definite pitch (most string, wood and brass instruments, for example), when they are played skillfully. In contrast, a ‘noise’ is understood here to be a sound that has no definite pitch, i.e. a continuous spectrum or a series of overtones which do not form any series of harmonics. The students themselves could experiment with any typical noise, for example that of traffic, and observe the lack of pattern repetition in the waveform, as well as the absence of relevant overtones or the lack of a series of harmonics. Figures 5 and 6 show the images for the hissing noise produced when a long “s” is pronounced, obtained in the same way as in Figures 3 and 4, respectively.

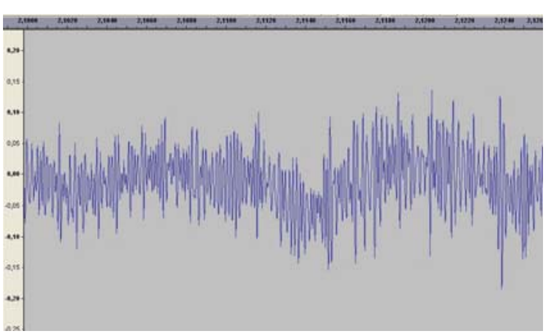

Figure 5. Waveform for a hissing noise (long “s”).

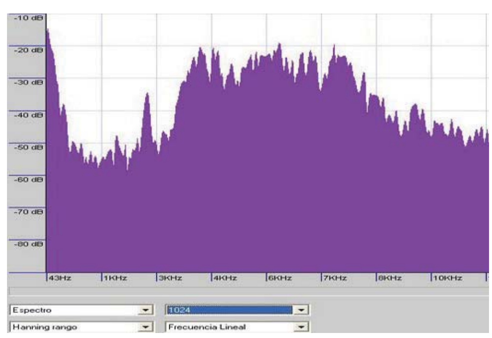

Figure 6: Acoustic spectrum for the waveform of Figure 5.

4.3. Pitch and fundamental frequency

The starting point was a music sample played on a saxophone (Figure 7), including the deepest and the highest note that can be played on this instrument (in musical notation: $D\flat_3$ and $A\flat_5$, respectively, where the sub index indicates the octave) and a two-octave ascendant and descendent scale of E♭ major, where the musical notes E♭ (at octave distances) could easily be recognized by hearing, even by students with no musical training at all. Using the aforementioned procedure, the student had to identify the portion of the waveform corresponding to the deepest sound, the highest sound, and the three notes at octave distances. He or she was then asked to calculate the respective periods and fundamental frequencies directly using the time scale of the waveform displayed. The value calculated for the fundamental frequency had to be then checked against the value taken from the spectrum obtained as before.

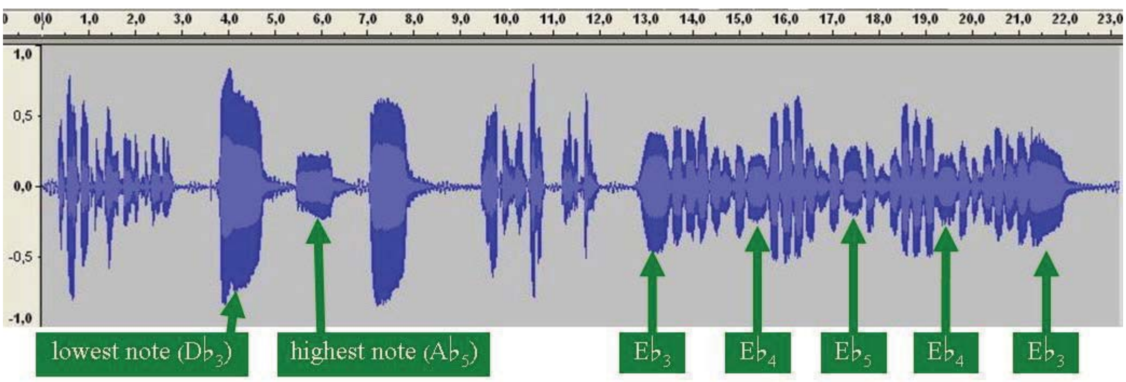

Figure 7. Sound sample with musical notes played on a saxophone, for frequency

In this way, the student could deduce the main relationship between pitch and fundamental frequency, and calculate the relationship between fundamental frequencies for sounds differing by one or more octaves.

5. Student response to this hear-and-see tool

The activities described in the preceding section were implemented within the framework of an elective subject on acoustics as a first pilot study with only nine students. Although this number did not allow us to draw any firm conclusions yet, we were able to observe (by means of a questionnaire) some meaningful facts, which we will continue to examine in future semesters with a greater number of students.

Almost all the students agreed that the activities described helped them to understand the contents of the subject better. Opinions were divided into approximately two equal groups regarding the degree of difficulty of the activities. An explanation is that this elective subject was chosen by students on different engineering degrees, ranging from telecommunications engineering to chemical engineering. Whereas the telecommunications or electronics engineering students managed quite well with the Audacity environment and the topics of acoustics, the chemical engineering students had evident difficulties both with the hear-and-see tool and the acoustics content. Nonetheless, also these students recognized that the activities had been useful for learning something new and, additionally, in an entertaining way.

6. Conclusions

The open-source sound processor Audacity was used as a free and yet powerful hear-and-see tool, which allows the relatively easy implementation of a series of activities on acoustics.

We have presented in detail an initial series of successfully implemented activities. They can be extended to other aspects of acoustics, for example the (psychophysical) Weber and Fechner's law and the decibel scale, frequency response of the human ear, synthesis of beats, etc.

Since these activities were carried out by the students in their own homes, this hear-and-see tool can also serve as a sort of home laboratory, which allows the students to experiment freely for themselves. And this is also "something extra" compared to traditional methods.

Acknowledgements

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