Computer Application in Engineering Education 23:471–476, 2015
DOI 10.1002/cae.21618

Frequency Analyser: a new Android Application for high precision frequency measurement

José A. Gómez-Tejedor[1], Juan C. Castro-Palacio[2], and Juan A. Monsoriu[3]

Computer Application in Engineering Education 23:471–476, 2015
DOI 10.1002/cae.21618

[1]*Centro de Biomateriales e Ingeniería Tisular, Universitat Politècnica de València, Camí de Vera s/n, 46022, València, Spain. E-mail: jogomez@fis.upv.es*
[2]*Department of Chemistry, University of Basel, Klingelbergstrasse 80, CH-4056 Basel, Switzerland. E-mail: juancarlos.castropalacio@unibas.ch*
[3]*Centro de Tecnologías Físicas, Universitat Politècnica de València, Camí de Vera s/n, 46022, València, Spain. E-mail: jmonsori@fis.upv.es*

Abstract

We present *Frequency Analyser*, an Android™ application for measuring the fundamental frequency of a sound wave with very high precision in a frequency range between 100 Hz and 11 kHz. The application allows exporting the data of frequency as a function of time to an ASCII file. Several examples of application to Physics and Engineering teaching experiments are presented.

Key words: frequency analyser, sound wave, Physics teaching, Engineering teaching.

Computer Application in Engineering Education 23:471–476, 2015
DOI 10.1002/cae.21618

I. Introduction

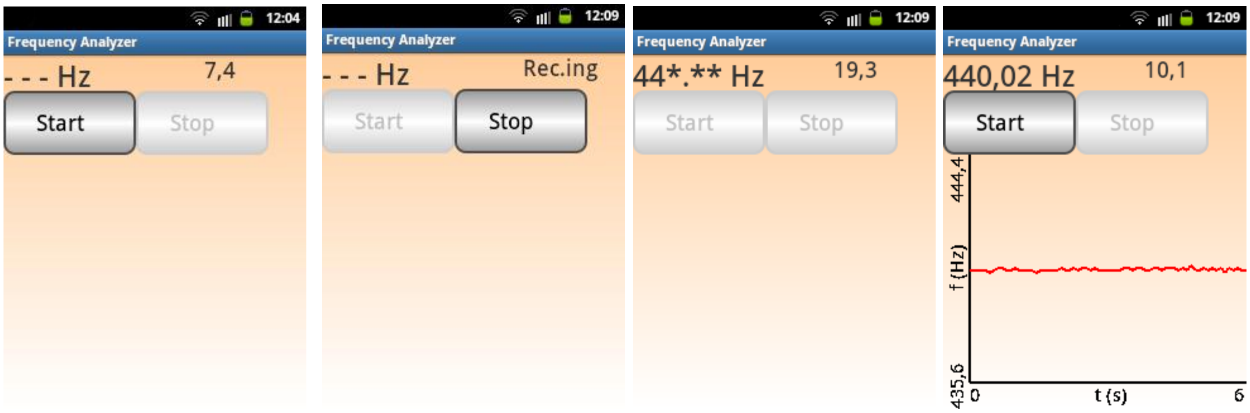
Acoustics is the science that deals with the study of sound waves and finds a wide range of technological applications nowadays. For this reason, this is an important topic which is included in Physics and Engineering syllabi. In this respect, many innovations related to Acoustics in Physics and Engineering teaching have been reported in the literature. For instance, in reference [1], three audio processors are evaluated to implement laboratory activities on Acoustics and in reference [2] Virtual Sound Laboratories are used for Acoustics teaching.

In recent years, there has been a growing interest in using smartphones in undergraduate teaching experiments [3-8]. In line with this, we present here an Android application to measure the fundamental frequency of a sound wave with very high precision and also capable to record and export the output values of the frequency *versus* time to an ASCII file for further processing. In GooglePlay™ repository (https://play.google.com) various software applications for spectrum analysis can be found. These include AudioSpectrumMonitor, Real-time Audio Analyzer Free, Waterfall Spectrum Analyzer, Speedy Spectrum Analyzer, SPL and Spectrum Analyser, and SpectralPro, among others. However, none of them is able neither to measure the fundamental frequency of sound with high precision nor to register the results as a function of time for later processing. This is the reason that has motivated us to develop a new tool capable to detect the fundamental frequency of a sound wave with a precision of less than 0.02 % of relative error for a wide frequency range and to sample the frequency as a function of time. This application is free and can be downloaded from GooglePlay repository under the name “Frequency Analyzer” [9]. It can run on any device bearing Android operating system and with a microphone incorporated, e.g., a tablet or smartphone.

The outline of the article is the following. In section II, the general features of the application “Frequency Analyzer” are explained. In section III, several examples of applications to Physics and Engineering teaching are introduced. The latter includes the determination of the frequency of a set of 8 tuning forks and of the main frequencies of the central keys of a piano keyboard, and the measurement of the frequency as a function of time in a frequency-modulated sound wave. Finally, in section IV, some conclusions are drawn.

Computer Application in Engineering Education 23:471–476, 2015
DOI 10.1002/cae.21618

II. *Frequency Analyzer* application for Android



(a) (b) (c) (d)

Figure 1. Snapshots of the Frequency Analyzer application, (a) at the start-up of the application, (b) in the process of recording data, (c) in the process of making calculations, and (d) result for one of the measurements.

In Figure 1, several snapshots of Frequency analyzer application are shown. Figure 1a shows the start-up of the application. The small number in the right-top corner of the screen is related with the intensity of the sound in a scale between 0 and 40. In order to have a good recording, a value of this number greater than 20 is required. Upon pressing the "Start" button of the application, the sound waves received at the microphone start being recorded. The maximum sampling frequency supported by the hardware containing the application is used, typically 44100 Hz for most devices nowadays. During this process the word "Rec.ing" appears on the device screen, as can be seen in Figure 1b. An example of the signal recorded by the mobile phone is shown in Figure 2. As for a better clarity, only a time interval of 0.01 s is shown, which corresponds to approximately 4 times of the period of oscillation of the sound wave.

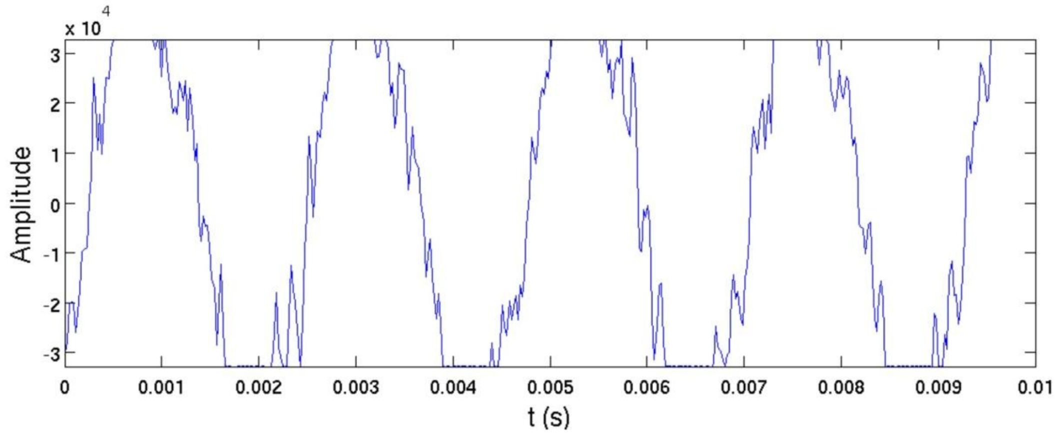


Figure 2: Example of the sound registered by the mobile phone in an arbitrary measurement.

Once the "Stop" button is pressed, data treatment starts. First, a Fast Fourier Transform (FFT) is applied [10,11] to detect the fundamental frequency of the recorded sound. In this first analysis, the frequency is not measured with very high precision however a first approximated value necessary for the next step is obtained. In the previous example, the fundamental frequency was 440 Hz (Figure 3) and other harmonic frequencies at higher frequencies could be also observed. When this first calculation finishes, the result information appears on the device screen, and the first digits of the measured frequency are shown, i.e. “44*.** Hz” for this example (Figure 1c).

Computer Application in Engineering Education 23:471–476, 2015
DOI 10.1002/cae.21618

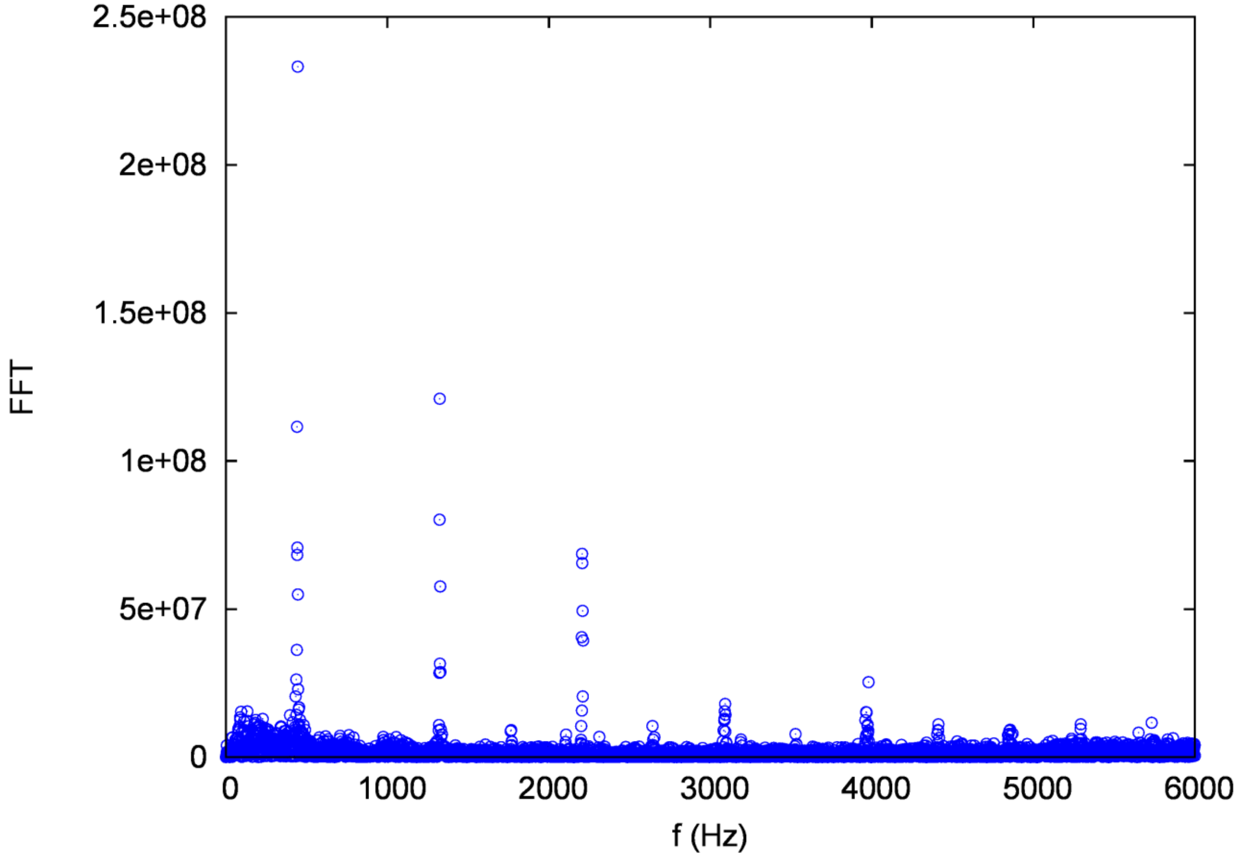


Figure 3: Fast Fourier Transform of the signal registered by the device. The main frequency can be observed at 440 Hz. Other harmonics at higher frequencies are also observed in the signal.

Following this step, two second order Butterworth filters are applied around the fundamental frequency [12,13]. One of them consisted of a low-pass filter with a cutoff frequency that equals the fundamental frequency plus a 3 % and a high-pass filter with a cutoff frequency which equals the fundamental frequency minus a 3 %. This is the way to eliminate the undesired harmonics from the signal. In Figure 4, the resulting signal from applying the filters to the initial signal in Figure 2 is shown. Later on, the signal is treated by intervals of 0.1 s. In each interval, the half of the period is determined by measuring the time elapsed between two continuous crossings through zero amplitude line and by averaging the result over the time interval. The inverse of the calculated period is the measured frequency. As for the example in previous figures, a value of (440.02 ± 0.06) Hz is obtained for the frequency, as shown in Figure 1d. The relative error in this result is obtained from the standard deviation of the measured data over the time interval. The signal emitted by the speaker was at 440 Hz, yielding a discrepancy with respect to our results of only 0.02 Hz (0.005 %).

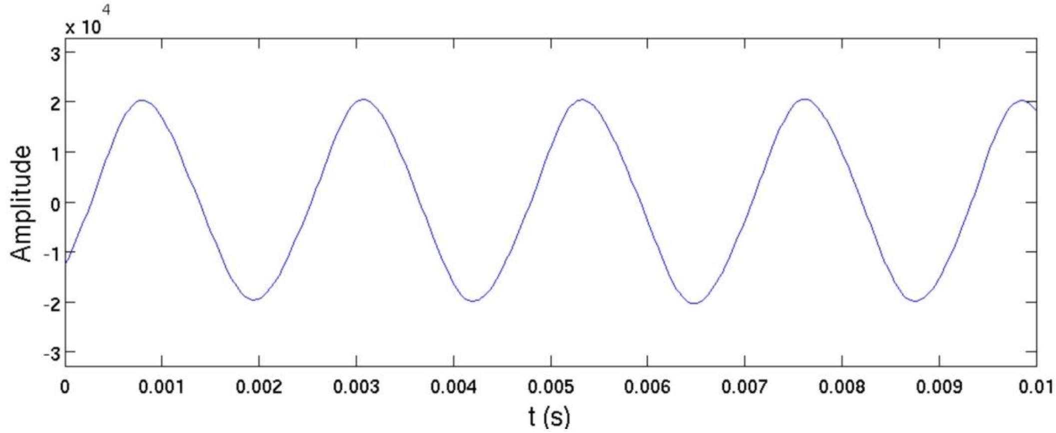


Figure 4: Resulting signal after applying the second order Butterworth filter around the main frequency.

In addition, a graphical representation of the measured frequency as a function of time is shown on the device screen. This representation is useful since it gives qualitative information about the quality of the measurement. For instance, Figure 1d indicates the high quality of the measurement since the measured frequency remains almost constant with time. Fluctuations in the graph indicate the existence of errors in the measurement. These errors may come from different sources, such as environmental noise, or low volume reception by the microphone. Furthermore, the graphical representation is useful when the interest is to follow the evolution of the frequency with time. After all calculations are done, the file containing the sound recording is erased from the system memory card. The data file containing the frequency as a function of time is saved out to the sd-card, specifically to the folder /mnt/sdcard/Android/data/fqan.frequencyanalyzer/files/. The time required to compute the results depends on the model of tablet or smartphone used and on the duration of the recording. We used a smartphone model Samsung Galaxy Mini GT-S5570 equipped with Processor Qualcomm MSM7227 / ARM1136EJ-S 600MHz and 384 Mb of RAM memory, which takes about 1 second per second of recording. In more modern devices, this time may be even smaller, what allows for the development of applications performing the calculations in real time. Even though, we have preferred the variant of recording the data for an ulterior treatment. This allows our application to run on any device using Android as operating system and not necessarily on a device with a high CPU speed.

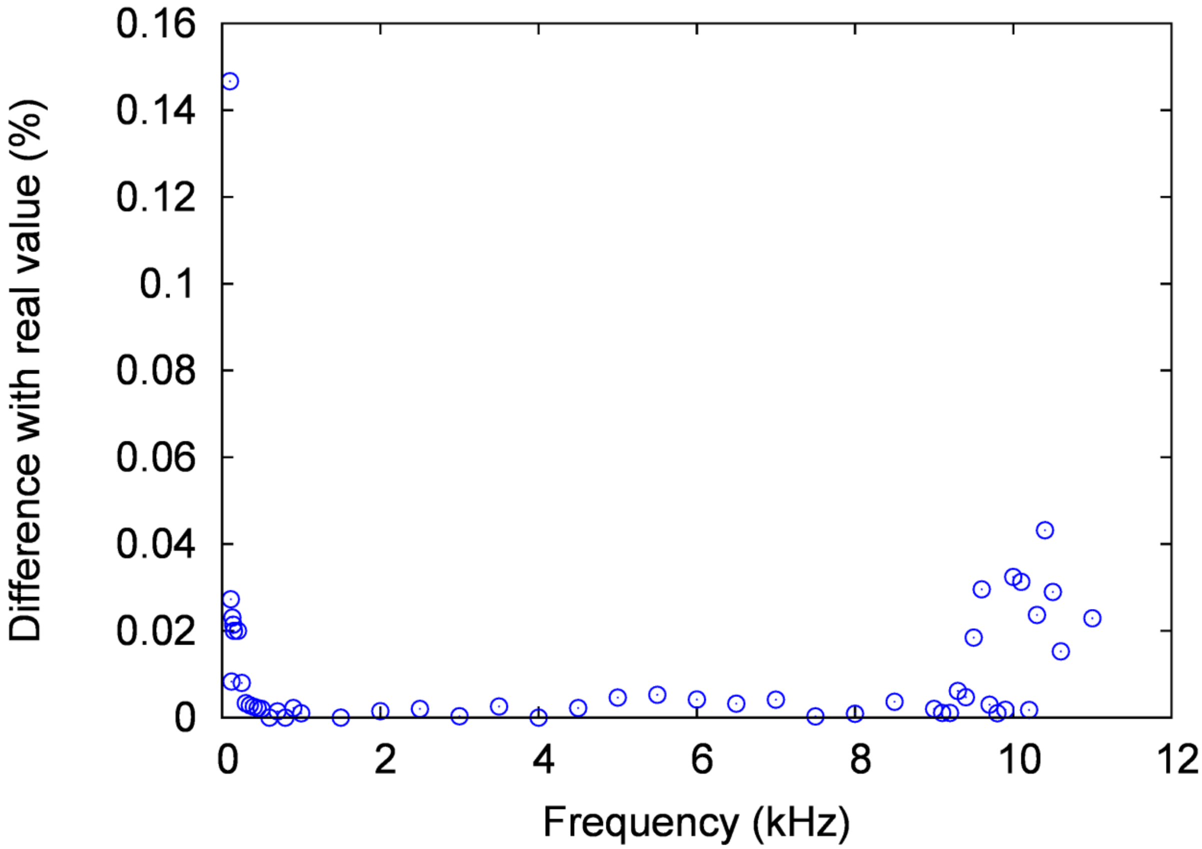


Figure 5: Difference between the measured and the real frequency, as a function of the sound frequency.

The right functioning of the application was proved by measuring the frequency of a single-frequency sound generated by means of a speaker connected to a function generator (Agilent 33120A). In Figure 5, the difference between the measured frequency and the real frequency is shown as a function of the sound frequency between 100 Hz and 11 kHz. For 100 Hz, the application yields a measured value of 100.15 Hz, which corresponds to a discrepancy of 0.15 %. For higher frequencies, the discrepancy decreases very fast to a value smaller than 0.008 % in the frequency range between 250 Hz and 9400 Hz. From this frequency up to a frequency of 11000 Hz, the discrepancy has a slightly random behaviour. In some cases the results fall within a discrepancy range between 0.02 % and 0.04 %, and in other cases, a very small discrepancy is obtained.

III. Applications

In this section, three examples of application of “Frequency Analyzer” Android app. suitable for Physics and Engineering teaching are presented. First, the measurement of the frequency of 8 tuning forks is performed and compared to the data provided by the manufacturer. The same measurement is carried out in the second experiment with the central keys of a piano keyboard. In the third, the frequency as a function of time is measured in a frequency-modulated sound wave.

Tuning fork: In this experiment, the values reported by the manufacturer for a set of 8 tuning forks are compared to the values measured with Frequency Analyzer application (see Figure 6). The results have been registered in Table I. It can be seen that the percentages of discrepancy with respect to the manufacturer's value are less than 0.35 % in all cases.

Figure 6: Set of tuning forks used in the experiments.

Table I. The manufacturer's reported values for the frequency of 8 tuning forks are registered in column 2. As for comparison, the experimental values obtained with “Frequency Analyzer” app. are included in column 3. The measurement errors and the percentage discrepancies are incorporated in the last two columns, respectively.

Note	Manufacturer´s reported value (Hz)	Experimental value (Hz)	Measurement error (Hz)	Discrepancy (%)
c1	256	256.42	0.02	0.16
d1	288	287.94	0.01	0.02

e1	320	320.97	0.03	0.30
f1	$341\ {}^{1}/_{3}$	341.70	0.06	0.11
g1	384	385.35	0.04	0.35
a1	$426\ {}^{2}/_{3}$	425.52	0.08	0.27
h1	480	480.63	0.04	0.13
c2	512	512.58	0.07	0.11

Frequency of the central keys of a piano: The frequencies of the keys of the central part of a piano keyboard have been measured using the “Frequency Analyzer” app (Figure 7). The results are registered in Table II comparatively with their corresponding note frequencies. The percentages of discrepancy are smaller than 1.75 % for all cases indicating the quality of the measurements. Note that this app. has been designed only for educational purposes for the first courses of Physics and Engineering. It is possible to obtain the frequencies with higher precision with professional tuners.

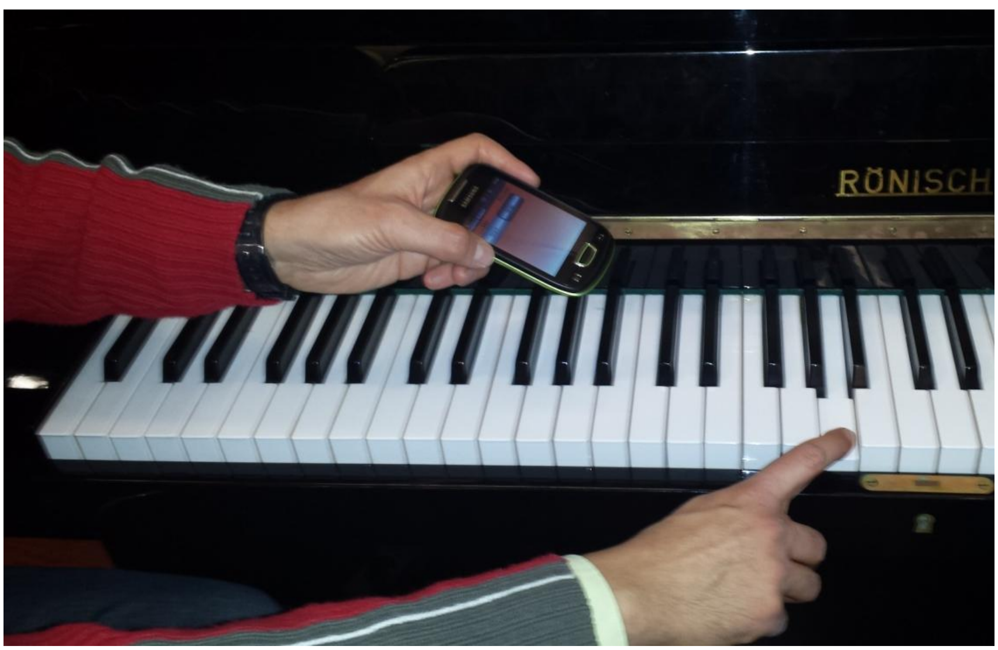


Figure 7. Photograph taken during the measurement of the frequencies of the central keys of the piano keyboard with “Frequency Analyzer” app.

Table II. The note frequencies of the central keys of a piano are registered in column 2. As for comparison, the experimental values obtained with "Frequency Analyzer" app. are included in column 3. The measurement errors and the percentage discrepancies are incorporated in the last two columns, respectively.

Note	Note frequency (Hz)	Experimental value (Hz)	Measurement error (Hz)	Discrepancy (%)
C4	261.63	260.0	0.5	0.62
D	293.67	290.3	0.3	1.15
E	329.63	326.8	0.4	0.86
F	349.23	346.1	1.2	0.90
G	392.00	387.8	0.8	1.07
A	440.00	432.3	0.4	1.75
B	493.88	485.6	0.3	1.68

Frequency modulation: In this experiment, we have generated a frequency-modulated sound signal by means of a speaker connected to a frequency generator, with a sinusoidal carrier sound wave of 3 kHz and modulated by a sinusoidal signal of frequency 1 Hz, and amplitude of 20 Hz. We have repeated the experiment also for a modulated amplitude of 40 Hz. Then, the sound frequency as a function of time is given by,

$$f(t) = f_0 + A\sin(2\pi f_{mf}t + \phi_0), \qquad (1)$$

where f_0 is the frequency of the sinusoidal carrier, A is the amplitude of the modulation, f_{mf} is the modulation frequency (mf), and ϕ_0 is the initial phase. We have measured the frequency as a function of time with the Frequency Analyzer application. In Figure 8, the measured results (points) along with the fit to the previous equation, for 20 and 40 Hz as values of the modulated frequency can be seen. The fit was carried out using the chi-squared method. All calculations were performed using Mathematica® software. In both cases, a very good agreement between the measured data and the data obtained with the theoretical equation (Eq. 1) is obtained. In table III the parameters of the fit are shown. A good agreement between the obtained parameter and the expected value is achieved. The error of the fit is very small.

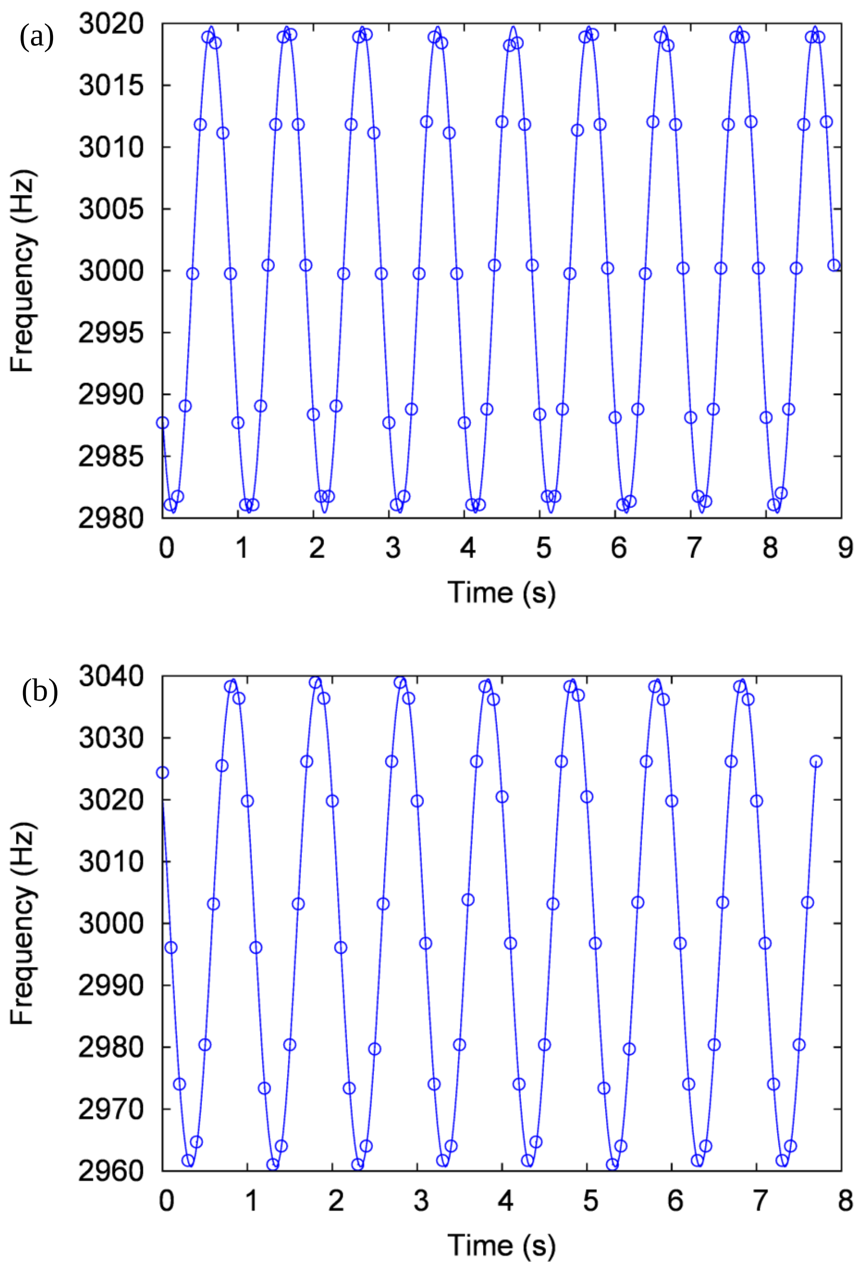


Figure 8. Measured frequency as a function of time for a modulated amplitude of 20 Hz (panel a) and 40 Hz (panel b). Circles correspond to the measured data, and lines to the results from the theoretical equation.

Table III. Parameters obtained from the fitting to equation 1. Results from taking 20 and 40 Hz as values of the modulated frequency are shown in the last two columns.

Parameter	**Expected value**	**20 Hz experiment**	**40 Hz experiment**
f_0 (Hz)	3000	3000.09 ± 0.03	3000.10 ± 0.07

A (Hz)	20 and 40	19.68± 0.05	39.425 ± 0.010
f_{mf} (Hz)	1	0.99961± 0.00016	1.00016 ± 0.00018
ϕ_0 (rad)	--	3.790 ± 0.005	2.601 ± 0.005

IV. Conclusions

The capabilities of the “Frequency Analyzer” Android app. have been presented. The effectiveness of this app. in measuring the fundamental frequency of sound has been proved by means of three simple examples. In the first, the comparison of the manufacture's reported values for the frequency have been compared to the experimental values in the case of 8 tuning forks. The percentage discrepancies of less than 0.35 % indicate the high quality of these measurements using a smartphone. In the second, the frequency of the central keys of a piano has been measured. In this case, the discrepancies with respect to the piano key note frequencies are greater than in the first example. In our opinion, the reason for this may be that the piano was not properly tuned. Finally, in a third example, the frequency as a function of time is measured for a frequency-modulated sound wave. A very good agreement between the measured (fitted) and theoretical data was obtained. This application was successfully applied in Ref. [5] to study the frequency shift in the Doppler Effect.

On the other hand, a teaching laboratory experiment which includes the examples presented in this work is currently included in the topic of Mechanical Waves of the Physics course for Electronic Engineering at the Polytechnic University of Valencia, Spain. It is interesting to point out that 95 % of the students bear a smartphone and a 100 % of them were interested in installing “Frequency Analyzer” Android app in their devices. The validation of the frequencies of the piano (located at the Events Hall of the University) and the study of a frequency-modulated sound in Physics laboratory were the most motivating examples. Results indicate that the “Frequency Analyzer” Android app. can find diverse and suitable applications in Physics and Engineering teaching experiments.

Acknowledgments: The authors would like to thank the Institute of Education Sciences, Universitat Politècnica de València (Spain), for the support of the Teaching Innovation Groups, MoMa and e-MACAFI.

References

[1] A. Pejuan, X. Bohigas, X. Jaén and C.Periago, Comparative study of three audio processors as environments for laboratory activities on wave physics and acoustics, *Comput. Appl. Eng. Educ*., Vol. 21, No. S1, 2013, pp. E89–E99. DOI: 10.1002/cae.20534.

[2] P. Martínez-Jiménez, M. Varo, M. C. García, G. Pedrós Pérez, J. M. Martínez-Jiménez, R. Posadillo and E. P. Varo-Martínez, Virtual web sound laboratories as an educational tool in physics teaching in engineering, *Comput. Appl. Eng. Educ*., Vol. 19, No. 4, 2011, pp. 759–769. DOI: 10.1002/cae.20362

[3] I. Boticki, A. Barisic,S. Martin and N. Drljevic. Teaching and learning computer science sorting algorithms with mobile devices: A case study. *Comput. Appl. Eng. Educ.*, Vol. 21, No. S1.,2013 pp. E41–E50. DOI: 10.1002/cae.21561.

[4] M. C. Rodriguez-Sanchez, J. A. Hernandez-Tamames and S. Borromeo, An embedded system course using JavaME and Android. *Comput. Appl. Eng. Educ*., 2014. DOI: 10.1002/cae.21599.

[5] J. A Gómez-Tejedor, J. C Castro-Palacio and J. A. Monsoriu, The acoustic Doppler effect applied to the study of linear motions, *Eur. J. Phys.*, Vol. 35, 2014, pp. 025006.DOI: 10.1088/0143-0807/35/2/025006.

[6] J. C. Castro-Palacio, L. Velazquez-Abad, M. H. Gimenez, and J. A. Monsoriu. Using a mobile phone acceleration sensor in physics experiments on free and damped harmonic oscillations. *Am. J. Phys*. Vol. 81, 2013,pp. 472-475. DOI: 10.1119/1.4793438.

[7] J. C. Castro-Palacio, L. Velazquez-Abad, F. Gimenez, and J. A. Monsoriu. A quantitative analysis of coupled oscillations using mobile accelerometer sensors. *Eur. J. Phys.*, Vol. 34, No. 3, 2013, pp. 737-44. DOI:10.1088/0143-0807/34/3/737.

[8] J. A. Sanz, F. J. Manjon, A. L. J. Pereira, J. A. Gomez-Tejedor and J. A. Monsoriu. Oscillations studied with the smartphone ambient light sensor.*Eur. J. Phys.*,Vol. 34, No. 6, 2013, 1349-1354. DOI:10.1088/0143-0807/34/6/1349

[9] J.A. Gómez-Tejedor, Frequency Analyzer. Retrieved May 22, 2014, from http://play.google.com/store/apps/details?id=fqan.frequencyanalyzer.

[10] W. H. S. A. Teukolsky, W. T. Vetterling, B. P. Flannery, *Numerical Recipes, The Art of Scientific Computing*. 3rd Ed. Cambridge University Press, New York 2007, Chapter 12.

[11] C. H. Chen and H. C. Lin, A distance e-learning platform for signal analysis and measurement using FFT, *Comput. Appl. Eng. Educ*., Vol. 19, No.1, 2011, pp. 71–80. DOI:

10.1002/cae.20292.

[12] S. Butterworth, On the Theory of Filter Amplifiers, *Exp. Wirel. and the Wirel. Engineer*, Vol. 7, 1930, pp. 536-541.

[13] B. Baker, *A Baker's Dozen: Real Analog Solutions for Digital Designers*, Elsevier, Oxford, 2005, Chapter 4.