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How to study the Doppler effect with Audacity software

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Abstract

The Doppler effect is one of the recurring themes in college and high school classes. In order to contextualize the topic and engage the students in their own learning process, we propose a simple and easily accessible activity, i.e. the analysis of the videos available on the internet by the students. The sound of the engine of the vehicle passing by the camera is recorded on the video; it is then analyzed with the free software *Audacity* by measuring the frequency of the sound during approach and recede of the vehicle from the observer. The speed of the vehicle is determined due to the application of Doppler effect equations for acoustic waves.

Introduction

The Doppler effect is the phenomenon in which the frequency of a wave is changed when there is a relative movement between the source and the observer. This phenomenon has a wide application in science and in technology. It is a popular topic in elementary physics courses in the context of light and sound. However, in high schools and colleges, the Doppler effect is usually restricted to the theoretical and the mathematized lectures by a teacher in ideal situations; the experimental studies of the phenomenon in the lab of the majority of schools are quite rare.

There are a large number of computer simulations available on the internet to illustrate the phenomenon. These simulations usually do not involve the students in real and interactive

experiments. However, several authors [1–5] show that it is possible and desirable to contextualize the Doppler effect with acoustic waves.

In this work we present a didactic activity in which students participate actively in their own learning by quantitative study of the Doppler effect in the case of acoustic waves. The activity involves capturing the sound of the engine of a vehicle during a car race, or using a video available on the internet. The audio recordings reveal a perceptible change in the sound frequency coming from the engine, when the vehicle goes toward and away from the recording position. By means of the free software *Audacity* [6], we can measure the sound frequency with a good accuracy, and calculate the average speed of the vehicle when it passes by the sound receiver.

Determination of the speed of a race vehicle

Initially, it is necessary to select a video of a vehicle with a nearly constant speed, which can be accomplished, for example, in long straights of the race circuit. It has two advantages: 1. in this part of the circuit the vehicles reach their top and nearly constant speed, and 2. it minimizes the fact that the sound receiver and the sound source are not exactly in the same trajectory line (figure 1).

In fact, when the sound sensor is very close to the track ($d \ll D$), the frequency sound f heard by a sound receiver at rest is [7]

$$f = f_0 \frac{V_s}{V_s \pm V_e} \quad (1)$$

where f_0 is the sound frequency emitted by the source, V_s the speed of sound in the medium of propagation and V_e the speed of the source relative to the receiver. When the source approaches the receiver expression (1) will have the minus sign in the denominator and the receiver perceives a higher pitch, whereas when the source recedes from the receiver, expression (1) will have the plus sign in the denominator and the receiver perceives a lower pitch.

For this study we selected the first audio snippet of a video available on *Youtube* [8], when the car moves through a long straight (figure 2). The frequencies perceived by the receiver can be evaluated by the frequency analysis function of *Audacity* (figures 3 and 4).

By the frequency spectrum analysis of regions B and C (figures 3 and 4) we can observe a broader peak at low frequency and a sharper and higher peak with approximately twice the frequency, corresponding to the first harmonics of the sound produced. The second harmonic is more intense and easier to measure, so we chose to use that one as the reference harmonic to our analysis. Thus, the reference frequencies determined for regions B and C in figure 2 are, respectively, $f_b = 886$ Hz and $f_c = 559$ Hz. These frequencies were obtained by averaging the values of the reference peaks, and are marked by a red line in figures 3 and 4.

We can derive a relation between the frequencies f_b and f_c from equation (1), considering the invariant frequency f_0 of the sound emitted by the vehicle's engine:

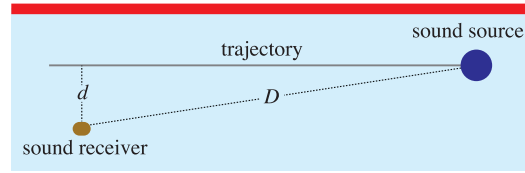


Figure 1. Scheme of the trajectory of the sound source and the location of the sound receiver. D is the distance between the receiver and the source, and d is the distance between the receiver and the track.

$$\frac{f_b}{f_c} = \frac{V_s + V_e}{V_s - V_e} \quad (2)$$

Rearranging equation (2), the speed of the vehicle V_e can be calculated by the following equation:

$$V_e = \frac{f_b - f_c}{f_b + f_c} \cdot V_s \quad (3)$$

Assuming an average temperature of 20 °C, the speed of sound in air is approximately $V_s = 343$ m s⁻¹ [9]. Using equation (3) the approximate average speed of the vehicle while moving along the long straight is $V_e = 279$ km h⁻¹.

If this activity is targeted to different groups, we may choose different positions of a circuit or racing cars and get different speeds for the speed of the vehicle, and propose a discussion about different variables that may influence the result, such as: the location of the track in the circuit, the weather conditions, the engine power, etc. Moreover, if there are two or more groups of students who make their calculations using the same video snippet, teachers can talk about experimental errors and introduce statistical analysis in research.

Conclusions

The approach presented in this work about how to calculate speed with video recording and sound analysis with *Audacity* software requires a high engagement of the students in experiments. The value obtained experimentally is in tune with the maximal speed achieved by Formula-1 cars on long straights of a racing circuit, which validates the numerical results.

It is important to highlight the approximations made in the calculus: (i) we have used the Doppler shift equation to a vehicle moving in a straight line passing by the receiver. This is not

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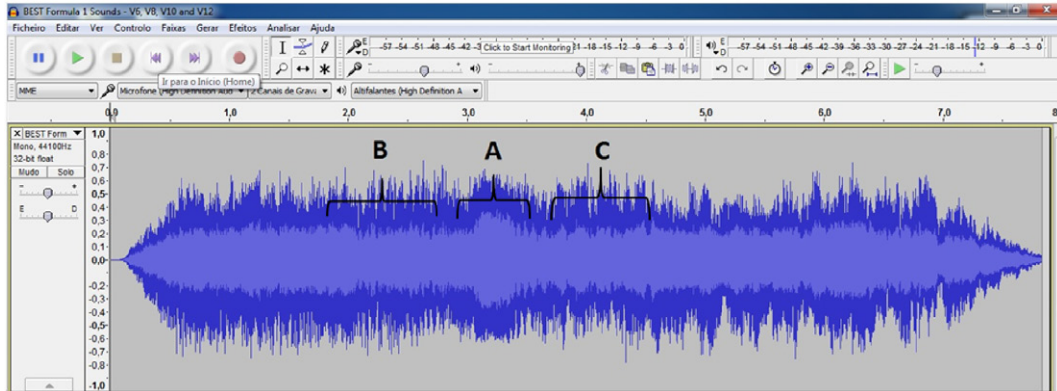


Figure 2. Sound record as seen from Audacity. Region A is the time interval when the vehicle passes close to the receiver; regions B and C are when the vehicle moves toward and away the receiver, respectively.



Figure 3. Spectral analysis of sound wave in region B (the source moving toward the receiver). The red line on the graph marks the average value.

strictly true, because what's really measured is the component of the speed of the car, in the direction of the receiver; (ii) we have also assumed that the source (the vehicle's engine) produces a sound with a constant frequency throughout the entire movement, which is not always fulfilled; (iii) we assumed that when the vehicle passed the location of the receiver it was maintaining constant speed, thus the value obtained is an average speed of the car at that time interval. These approximations are obvious limitations of the experiment, but do not diminish the merits of the approach.

The interactive activity described here presents a fair approach to contextualize the phenomenon of the Doppler Effect that makes it suitable to conduct at schools, either in the classroom or the lab, or even as an extra activity to discuss it in social forums among students. It contributes to an active participation of the students, to arouse their curiosity to the phenomena concerning sound waves, and a more effective understanding of the Doppler Effect. Necessary resources are available and easily accessible on the internet, thus the research can be performed by every student just with the aid of a computer and the guidance of a teacher.

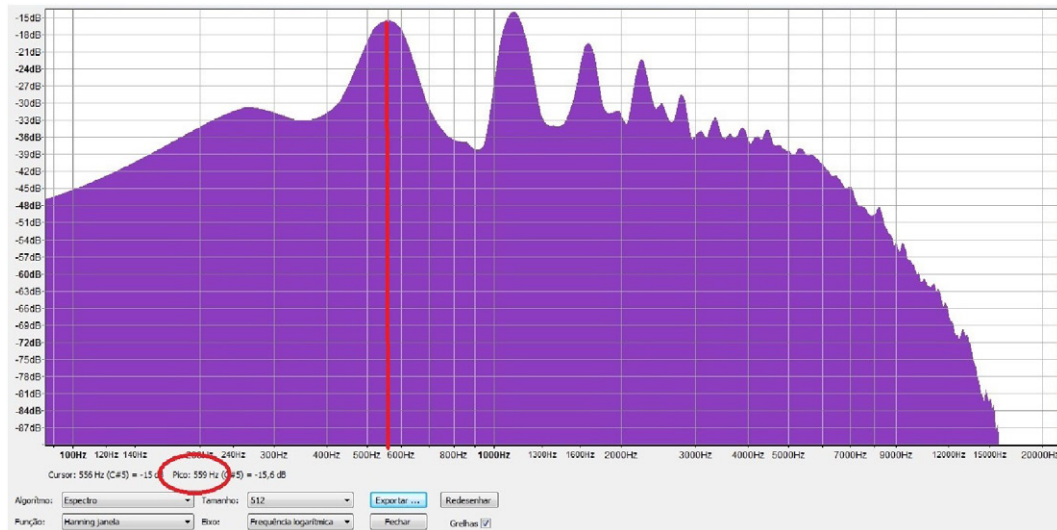


Figure 4. Spectral analysis of sound wave in region C (the source moving away from the receiver). The red line on the graph marks the average value.

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