Determining the Speed of Sound as a Function of Temperature Using Arduino

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Determining the Speed of Sound as a Function of Temperature Using Arduino

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When sound waves are taught at the secondary level, the speed of propagation of sound is one of the most important characteristics to be analyzed. However, it is very common in textbooks that the value of sound speed in air is considered constant regardless of the experimental conditions. The great question is that since sound is a mechanical wave, its speed is influenced by the medium of propagation and also by the temperature. In most cases, the techniques reported for that goal usually make use of expensive equipment and techniques that may not be affordable and/or easy to implement in schools,[1-3] which is an experimental limitation for the teachers to show this influence on their students. In this work, we present a low-cost experimental apparatus, controlled by the open source electronic platform Arduino®, with which it is possible to determine the speed of propagation of sound as a function of the temperature for a short measuring region, thus enabling the students to verify experimentally this important feature of sound waves.

Experimental setup

The experimental apparatus is fully controlled by the Arduino UNO electronic platform. The program, whose code is available to the readers,[4] executes two operations simultaneously: (1) the measurement of the environment temperature where the experimental setup is located, and (2) the measurement of the speed of sound.

In the assembly of the apparatus, shown in Fig. 1, the following components are used: a \$30.00 (USD) Arduino UNO unit, four \$10.00 temperature sensors of type DS18B20, which are water resistant and operate in the temperature range of -55 °C to 125 °C,[5] a \$4.00 ultrasound emitter/receiver sensor HC-SR04[6] used for measuring distances between two centimeters (2 cm) and four meters (400 cm), and a \$3.00 contact matrix (breadboard) and wires.

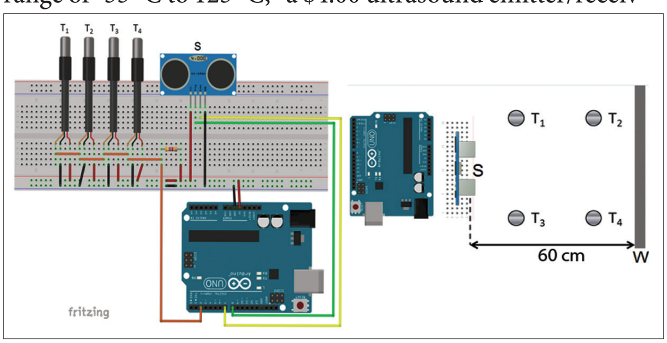

Fig. 1. Experimental setup, drawn with Fritzing app.[7] The left and right images are different perspectives of the setup. T_1, T_2, T_3, and T_4 are the temperature sensors, E/R is the emitter/receiver sensor, and W is the wall located at 60 cm from the sensor.

The four temperature sensors T_1, T_2, T_3, and T_4 were used to determine the environment temperature during the experiment. The temperatures were obtained with the help of the DallasTemperature library[8] at 12 bits, enabling two decimal digits. The choice of four sensors makes it possible to carry out an average temperature T_a measurement throughout the experiment, allowing one to minimize possible large temperature variations in the environment. The maximal temperature deviation among the four sensors was always lower than 0.20 °C.

To obtain a more precise measurement of the sound speed, the emitter/receiver sensor was placed at a distance of 60 cm from a flat wall. The sound speed v was then calculated from the average of the speeds determined within a range of 0.05 °C around T_a.

Results and discussion

The experimental data were collected during a long interval of 14 hours and for a total temperature variation of about 9 °C. The acquisition of data was possible through the use of the program CoolTerm,[9] which records data obtained in real time by the temperature and ultrasound sensors, in a file with the extension ".txt". Each line of the file contains the average temperature T_a coming from the readings in the four temperature sensors, and the average speed v calculated from 500 readings of the echo time with the ultrasound sensor.

Opening the file in a spreadsheet (we used MS Excel), we selected all the lines within a range of ± 0.05 °C around T_a for increments of 0.3 °C, and determined the speed of sound v_a at each temperature T_a as an average of the speeds v.

After collecting the experimental data of $v(T_a)$, we built a plot of the speed of sound as a function of the temperature (Fig. 2), and fit the experimental data to the general expression[10]

$$v = v_0\sqrt{\frac{T + 273.15}{T_0}} \qquad (1)$$

using SciDavis software,[11] where v is the speed of sound at a given temperature T (in °C) and v_0 is the speed of sound at the reference temperature T_0 = 273.15 K.

Although we can perceive some dispersion, it is also clear that the fit line follows quite well the experimental data, which gives some confidence in the fitting parameter v_0

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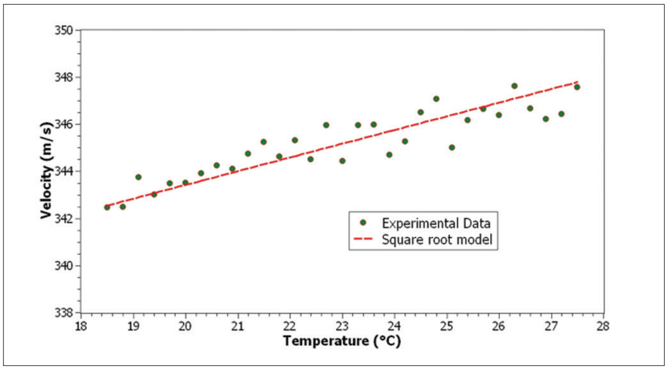

Fig. 2. Experimental data (round points) and corresponding curve fitting (dot line) to Eq. (1). The fit was done with freeware SciDavis software.[11]

obtained. In the literature, the speed of sound at $T = 0$ °C is referenced as $v_0 = 331.45$ m/s,[10] while experimentally we obtained $v_0 \simeq 331.49 \pm 0.12$ m/s ($R^2 = 0.78$), which corresponds to a deviation much lower than 1%.

There are two relevant pieces of information for the experimental procedure that should be avoided when implementing this experimental activity:

1. Do not place the experimental setup in boxes or closed devices, because we noticed that this confinement influences the way the speed of sound is obtained and produces a strong mismatch between the experimental results and the expected speed of sound in the air. A plausible justification is that the walls end up producing reflections of the ultrasound waves emitted by the emitter/receiver sensor, which produce results different than those expected.
2. Do not use fans or heaters to vary the temperature in the measurement region; this does not produce good results because it generates great fluctuations in the temperature that strongly affect the calculated speed and can be very frustrating for the students.

Conclusion

Although it is a common practice aimed for students at the secondary level, the study of the speed of sound can be done in laboratories of introductory physics courses for training students in the area of exact sciences. The experiment here described makes use of current technology. Even when the courses have a short time available for laboratory activities, the experiment can be adapted to obtain the speed of sound in a friendlier procedure making use of automatic data acquisition and without losing the physical interest of the experiment. Teachers should also encourage the students to fit the experimental data to physical models, to enable a scientific explanation and interpretation of the results obtained.

The results attest that it is possible to get reliable results with simple, low-cost equipment that is affordable to schools, and draw students' attention to the fact that temperature is a very important parameter to control in experimental procedures.

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