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Instantaneous Measurement of the Speed of Sound in Air and Water Using Arduino

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Although schools commonly teach that sound waves propagate faster in solids than in liquids and in liquids than in gases, there is no low-cost activity that allows students to investigate if this statement is true or not. Indeed, some existing techniques simply allow them to identify the speed of sound in air and its temperature dependence.[1–3]

In this work, we present a simple and low-cost experimental apparatus that allows the determination of the speed of sound in air and water. Arduino is a controller board that requires little user experience and that has been widely used in numerous teaching activities. In robotics, the open source electronic platform Arduino associated with an HC-SR04 sensor[4] has commonly been used to obtain the distance between a sensor and an obstacle, allowing the study of movement.[5] It can also measure the total time between ultrasonic wave propagation emission and reflection. This can allow the speed of sound to be measured in air and in water with simple speed definitions.

Experimental setup

The experimental setup shown in Fig. 1 consists of a graduated cylinder containing air and water. The HC-SR04 sensor is placed near the top of the graduated cylinder, and the ultrasonic wave is directed to the bottom of the container to allow the measurement of the time over which the wave will reach the bottom and return to the sensor. The speed of sound in air is obtained using the graduated cylinder without water. The shield is placed between the trigger and the receiver; its function is to prevent the wave reflected by the water surface from being read by the sensor. We were interested in the wave reflected by the bottom of the graduated cylinder after its crossing of the water column.

This configuration permits the visualization of the time of sound propagation using the HC-SR04 sensor controlled by the Arduino UNO electronic platform. Arduino controls the 16 × 2 liquid crystal display (LCD), which permits the instantaneous visualization of both the time propagation and the speed of sound. The correct heights of the air (s_a) and water (s_w) columns are input into the source code, and the equations below are used to this end. The speed of sound in air (v_a) is calculated using the speed definition:

$$v_a = \frac{2s_a}{t}, \tag{1}$$

where t is the total time wave propagation; the factor of 2 is needed because of the wave reflection. Figure 2(a) shows the configuration of the apparatus that is used to verify the speed of sound through air. Figure 2(b) shows the setup for calculating the speed of sound through water (v_w) using the following equation:

$$v_w = \frac{2s_w v_a}{v_a t - 2s_a}. \tag{2}$$

The t in Eq. (2) represents the total time of wave propagation,

$$t = 2\left(\frac{s_a}{v_a}\right) + 2\left(\frac{s_w}{v_w}\right);$$

v_a is obtained from the configuration presented in Fig. 2(a) and Eq. (1). The equations only consider the vertical distance while ignoring the distance between the trigger and the receiver (2.6 cm).

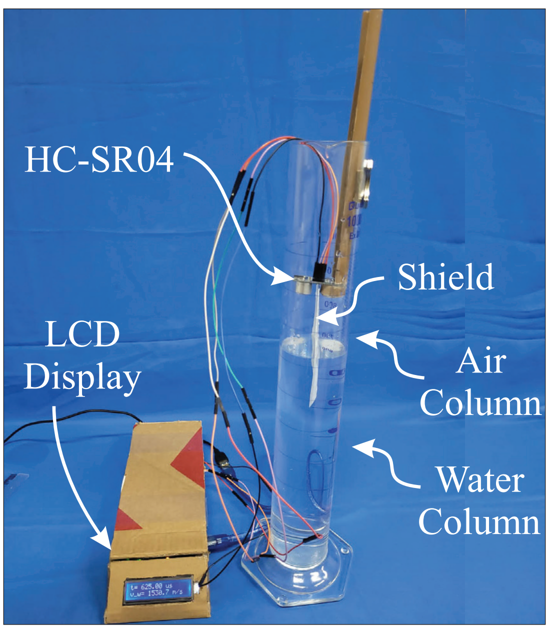

Fig. 1. Details of the apparatus used to determine the speed of sound.

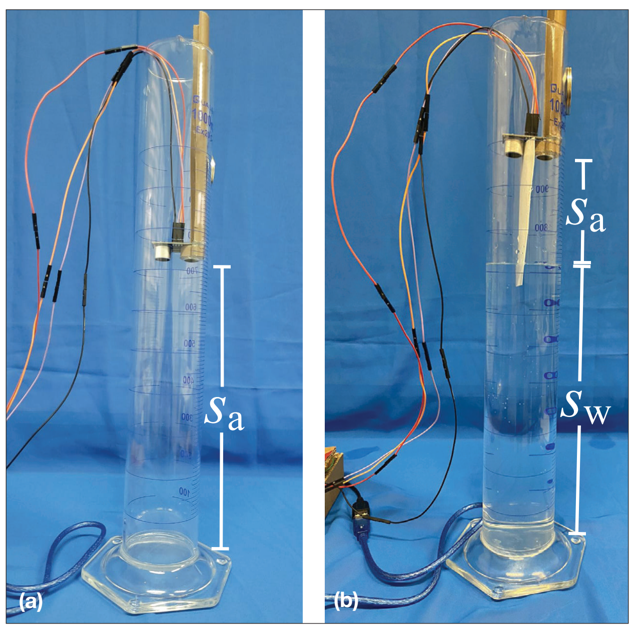

Fig. 2. Graduated cylinder with (a) air and (b) water.

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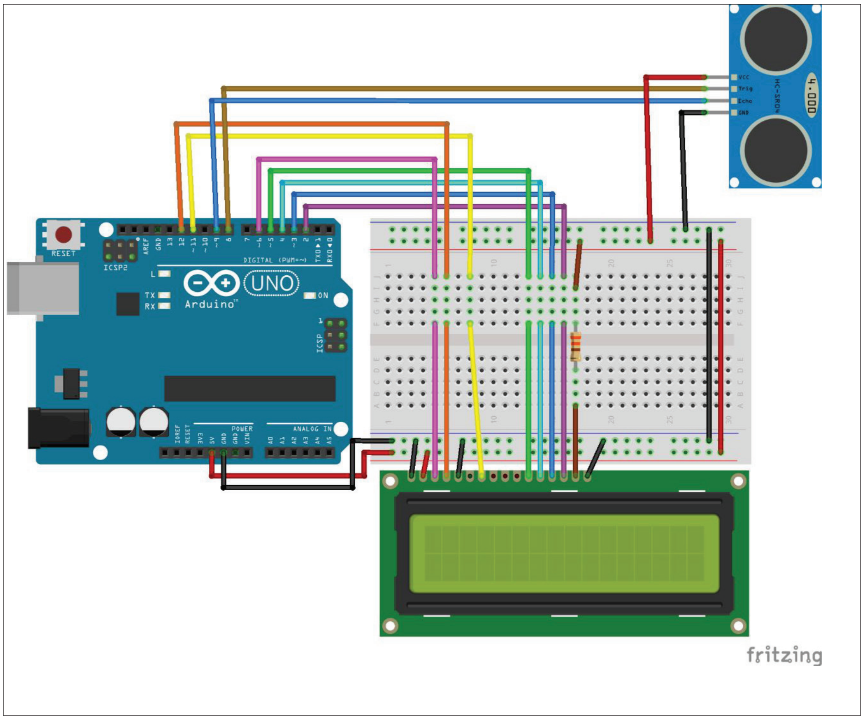

Fig. 3. Sketch of the circuit with the Arduino drawing with the Fritzing app.[7]

Table I. Some experimental results.

s_a or s_w (m)	v_a (m/s)	v_w (m/s)
0.05	358.42	1518.38
0.07	343.14	1469.67
0.10	326.26	1513.89
0.15	352.11	1464.77
0.20	353.67	1495.83
0.25	345.78	1509.39
0.30	348.63	1493.24

Figure 3 presents the schematic Arduino UNO connections with an HC-SR04 sensor and LCD 16 × 2 display circuit sketch. The two source codes for speed of sound in air and water are available in the supplementary online material.[6]

Results and discussion

The speeds of sound through air and water were obtained instantly with our apparatus. The apparatus allows students to manipulate the sensor distance and observe the sound waves' total time of propagation and speed in real time. Of course, it is necessary to introduce each new s_a and s_w, or just show the students how to calculate the speed using Eqs. (1) and (2). To test the apparatus, $n = 26$ measurements of v_a and v_w were made through the air and water columns from heights of 0.05 to 0.30 m in 0.01-m steps. Table I presents the speeds of sound we calculated for each height of the air and water columns. For v_w, $s_a = 0.07$ m was used, and its speed of sound was obtained using Eq. (2). The deviation values were calculated as

$$\rho = \sqrt{\frac{\sum_{i=1}^{26}(v_i - \bar{v})^2}{26-1}} ,$$

so $\bar{v}_a = 346 \pm 10$ m/s and $\bar{v}_w = 1493 \pm 15$ m/s. In the literature, the speed of sound at $T = 20$ °C is given as $v_a = 343.4$ m/s; in distilled water, this value is 1482.3 m/s.[8]

Conclusion

We have described a simple experimental setup to measure, in real time, the speed of sound in air and water. The measured results were a good approximation of the values found in the literature. This experiment should provide students a better conceptual understanding of sound waves propagating in different media, as well as their reflection and refraction. It is clear that sound wave speed changes when the wave medium is changed as a typical response of mechanical waves.

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