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Using smartphones as hydrophones: two experiments in underwater acoustics

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Abstract

The use of smartphone microphones in aquatic media is explored by means of two experiments. The first experiment consists of a simple time-of-flight measurement of the sound speed in water, while the second deals with the acoustic location—or ranging—of a distant object. As the underwater noise is considerable, the experimental details and the uncertainties are worth discussing.

Keywords: underwater acoustics, smartphone sensors, sound speed

Underwater acoustics. During the last few years, it has become increasingly clear that smartphones are valuable tools to be used almost everywhere. Until recently, a place that still resisted smartphone onslaught was aquatic media. Several experiments in acoustics were proposed [1–8]. However, nowadays, many modern smartphones are waterproof and the performance of their microphones is sufficiently adequate to employ them as hydrophones. This capability gives rise to several interesting applications. Here, we describe two experiments in underwater acoustics which require two smartphones—at least one should be waterproof. The first experiment consists of a simple time-of-flight measurement of sound speed in water and the comparison with the corresponding value in air. The second deals with the acoustic location—or ranging—of a distant object by comparing the time it takes for the sound to reach the object traveling in two different media (air and water in this case) with known sound speed.

Sound speed in water. The first experiment using the smartphone hydrophone, schematized in figure 1, is to determine sound speed in water. Although the idea is simple, care should be taken to avoid uncertainties coming from underwater noise. Two smartphones, A and B (at least one waterproof), and a simple app, able to register and edit the raw uncompressed sound wave, are needed.

First, to synchronize the recordings, while both smartphones are in air recording sound with their microphones as close as possible, a sound pulse is generated (top panel). This can be achieved by hitting a metal bar or using another appropriate device as a loudspeaker. Without stopping the recording, smartphone B is submerged into water and separated from A by a distance d.

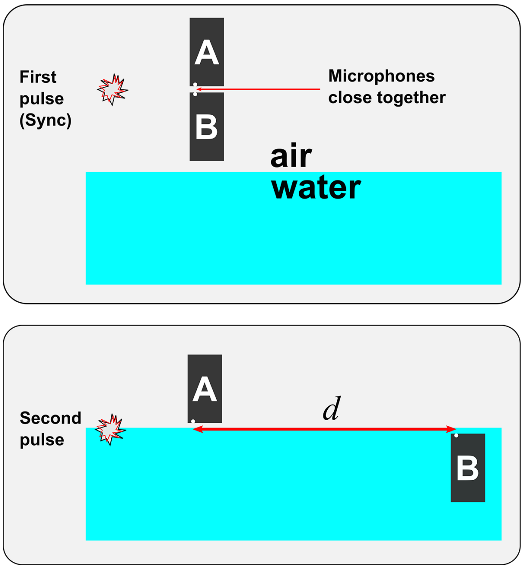

Figure 1. Experiment to measure sound speed in water. Firstly, as depicted in the top panel, with both smartphones as close as possible, sound tracks are synchronized. Then, as shown in the bottom panel, a sound pulse is registered by both smartphones separated by a known distance *d*.

This distance should be of the order of a couple of meters to minimize uncertainties. Then, a second sound pulse is generated at the surface of the water. It is important that the sound source is aligned with the smartphones, so that the sound wave arrives first to smartphone A and then to B (bottom panel). After stopping the recordings, the audio files are saved in the cloud to further process on a computer.

The results are analyzed in figure 2, which displays the sound waves as shown in the free software Audacity. The top and bottom audio tracks correspond to smartphones A and B, respectively. The considerable level of underwater noise can be appreciated in the smartphone B sound wave. The time difference in the arriving of the pulses—measured in the progressive zooms displayed in figure 2—corresponds to 82 samples and its uncertainty is estimated in four samples. As the sampling frequency is 44.1 kHz, then, the time difference results in 1.9(1) ms.

The distance is directly measured underwater as $d = 2.95(2)$ m. Its uncertainty comes from the size of the objects (source and hydrophone) and difficulty to measure underwater. Finally, the sound speed in water will simply be the ratio between the distance and time.

$$c_{water} = 1.6(1) km/s.$$

Its speed in water results in very good concordance with reference values at the temperature at the moment of the experiment. It is also worth pointing out that sound propagates four times faster in water than in air.

Acoustic ranging. A well-known problem is to determine the distance at which a sound source is located using the difference in propagation time of an acoustic pulse in two different media. For example, suppose a whale is sighted from a ship. Sound waves travel both through water and air, at different speeds, and are registered on board using a hydrophone and a microphone. From the time difference of the arrival time between both signals, the distance to the source, x, can be calculated. The time difference between both media is easily obtained as $\Delta t = t_{\text{air}} - t_{\text{water}} = x\,(1/c_{\text{air}} - 1/c_{\text{water}})$ and the distance results in

$$x = \frac{\Delta t}{\frac{1}{c_{\text{air}}} - \frac{1}{c_{\text{water}}}}.$$

With a submersible smartphone (hydrophone) placed inside the water and another smartphone outside the water—very close to the first—(microphone), the above method can be tested as shown in figure 3. As in the previous experiment, the first step is to synchronize the sound tracks. In a home pool, a pulse was produced with a semi-submerged metal bar and the time difference was detected between the hydrophone and the microphone. In the present experiment, the time difference was measured in 258 samples, equivalent to 5.9(1)ms. Then, the distance from the metal bar to the smartphones is readily obtained as $x = 2.66(6)$m. This result is in very good concordance with the direct measurement of the distance, $x_d = 2.60(2)$m between the smartphones.

Closing remarks. To sum up, we have described a simple and inexpensive experiment in underwater acoustics; an area that has been explored little in physics courses. At least one waterproof smartphone is needed and the experiments can be performed in a small pool or pond. Data analysis requires only a sound editor, however, due to the noise inherent to the aquatic media, special attention should be paid to the experimental details. As uncertainties are

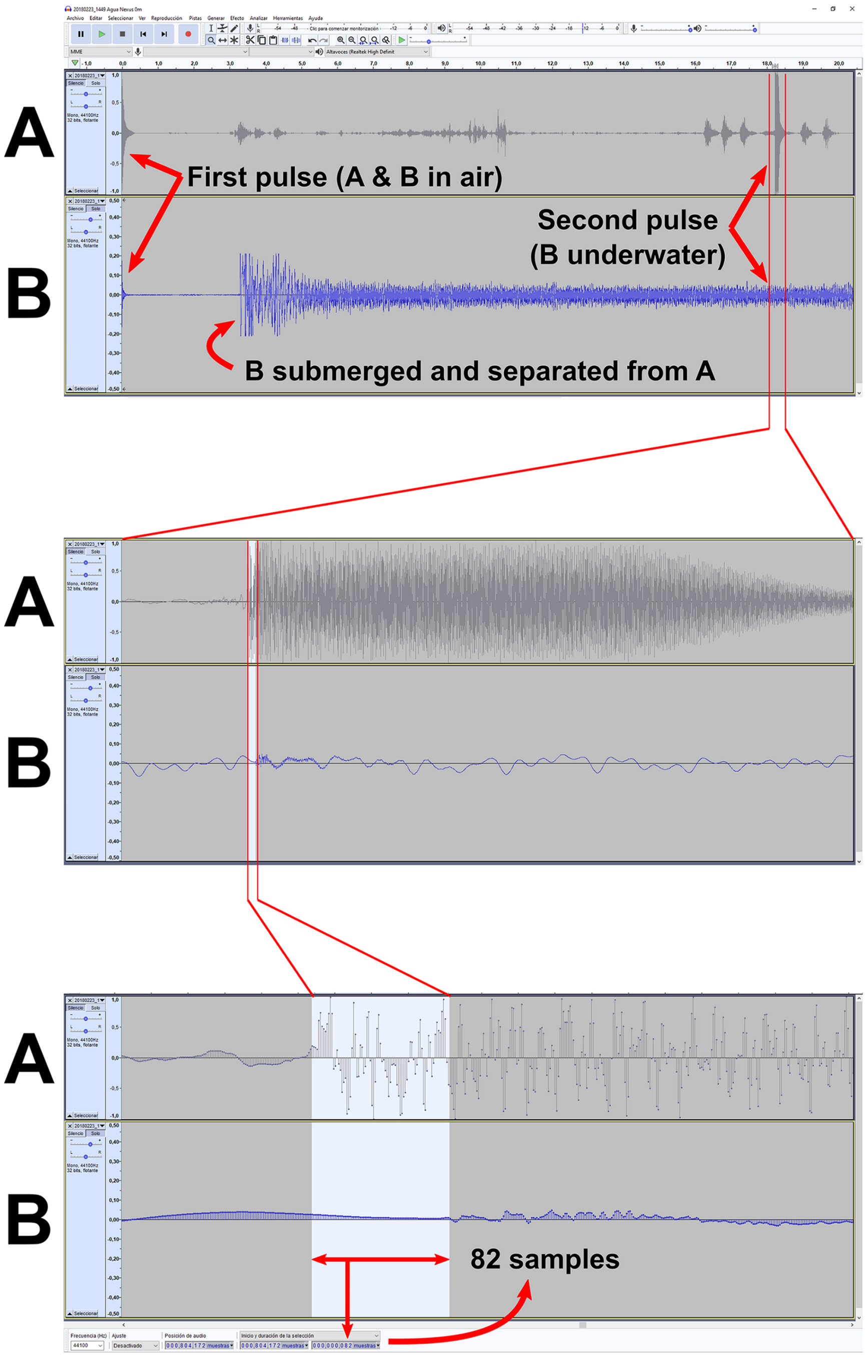

Figure 2. Sounds recorded by the two smartphones displayed on the software Audacity (full track and two successive zooms). The upper (lower) track is the sound recorded by smartphone *A* (*B*). The tracks have been moved so that the first pulse matches both recordings. The second pulse occurs when the two smartphones are separated, so that it first reaches *A* and then *B*.

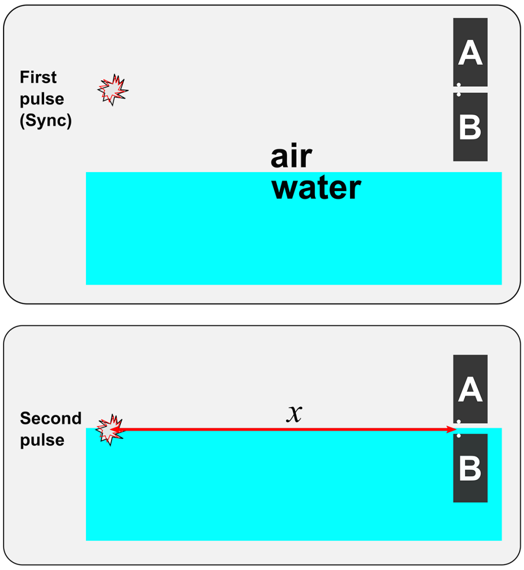

Figure 3. Acoustic ranging. Similarly to the previous experiment, sound tracks are synchronized as schematized in the top panel. Then, shown in the bottom panel, a sound pulse, propagating both in water and air, reaches the smartphones separated by an unknown distance x.

delicate here, in a classroom context, it would be interesting to discuss the experimental limitations as the characteristics of sound source and the shortest distances compatible with a given relative uncertainty.

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