Development of Laboratory Activities for Teaching Ultrasound Concepts in an Undergraduate Medical Physics Classroom

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Introduction:

- Ultrasound (US) is one of the most widely used non-invasive modalities;
- It does not use ionizing radiation, so is the preferred imaging modality in obstetric and pediatric medicine.
- Medical physics courses at UFABC include physical principles of ultrasound (US);
- Courses are theoretical and our laboratories do not possess simple US equipment through which to learn these principles through experiment.

How is a B-mode US image formed?

- In Brightness mode (B-mode) US images are cross-sectional, showing boundaries between organs and structures as well as tissues [1].
- In a clinical setting (e.g. hospital), a B-mode US examination is performed by placing a transducer on the skin; bursts of mechanical energy are sent into the body, which are reflected and received by the transducer.

What causes reflection?

- Acoustic impedance of a material, z, measures the local speed of particles in the medium given a certain pressure.
- The fraction of soundwave intensity reflected as it moves across between different materials with z1 and z2 is given by the reflection coefficient, RI:

$$R_I = \left(\frac{z_2 - z_1}{z_2 + z_1}\right)^2 \quad \text{(equation 1)} \qquad d = \frac{v \cdot t}{2} \quad \text{(equation 2)}$$

How are distances to structures determined?

- The equipment measures the time, t, for the US pulse to travel from the transducer, to a site of reflection (echo), and back.
- Knowing the speed of sound in the medium, v, and time for the return journey, t, the distance to the site of reflection can be computed using equation 2.
- This is the principle of pulse echo (figure 1c).

Objectives:

1. Identify low-cost apparatus for teaching the principles of US in a university laboratory;
2. Develop a set of didactic experiments to assist in teaching some basic concepts of US.

Materials: selecting the sensor

- UFABC has PCs in the laboratory, available for student use;
- Possesses breadboards and Arduino Unos for 30 students, working in pairs;
- The HC-SR04 sensor works with this equipment and is available at low cost (figure 1b). The timing diagram for the sensor is shown in figure 2B.

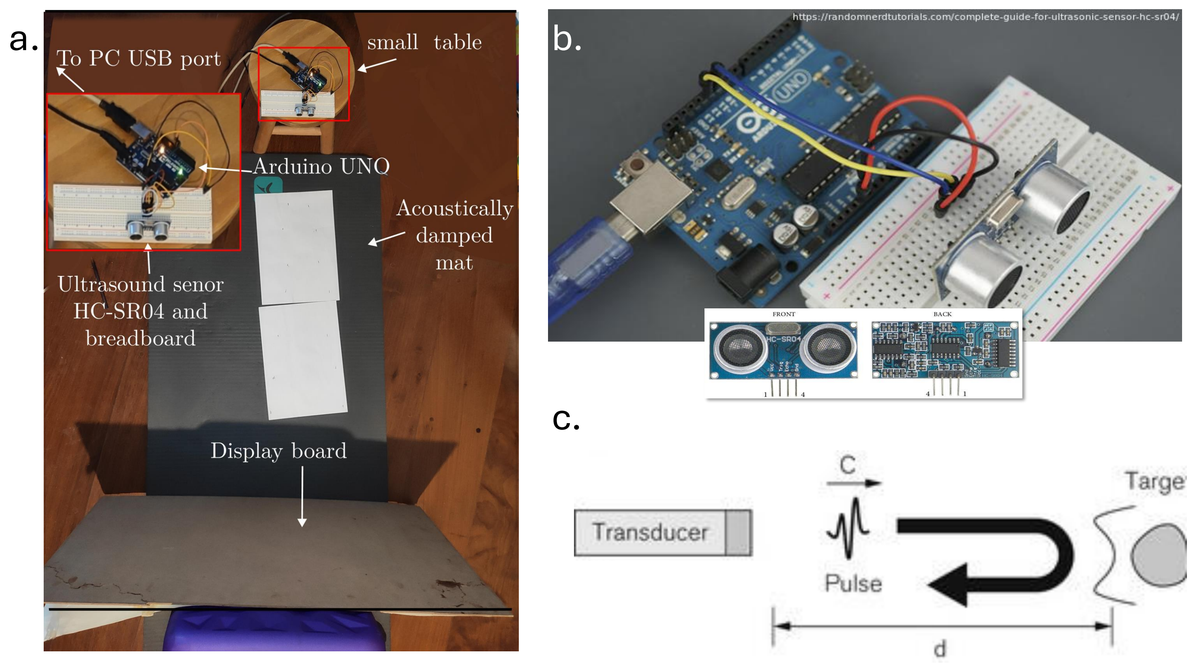

Figure 1: a. Experiment setup b. HC-SR04 with Arduino[2]; c. Principle of pulse-echo.

Methodology & Results:

Four experiments were designed for a two-hour laboratory session:

(i) Estimation of the speed of sound in air (*vair*)

- The US sensor has transmit (T) and receive (R) sensors.
- A strong acoustic reflector was placed at 91cm from the sensor, figure 1a.
- The time for a pulse, emitted from T, to arrive back at R, was determined;
- *vair* was found using equation 2.
- Software was written in Python on the PC to compute mean and standard deviation of *vair* for sets of 10 measurements, 346.4 ± 2.3 m/s.
- The accuracy of the computed value was compared with a theoretical value, a function of air temperature, of 348.4m/s at 29ºC.
- Finally, our estimation of *vair* from experiment was used in the Arduino software to convert round trip time to distance;
- The new Arduino software was used in the subsequent experiments.

(ii) Approximation of the beam profile

- Two plates were placed together at points along the scanlines (steps of 8cm) (figure 2A).
- Plates were separated symmetrically until the backboard distance was measured.
- We found a beam profile of approximately 18º, which is in good agreement with the manufacturer's profile of around 20º.

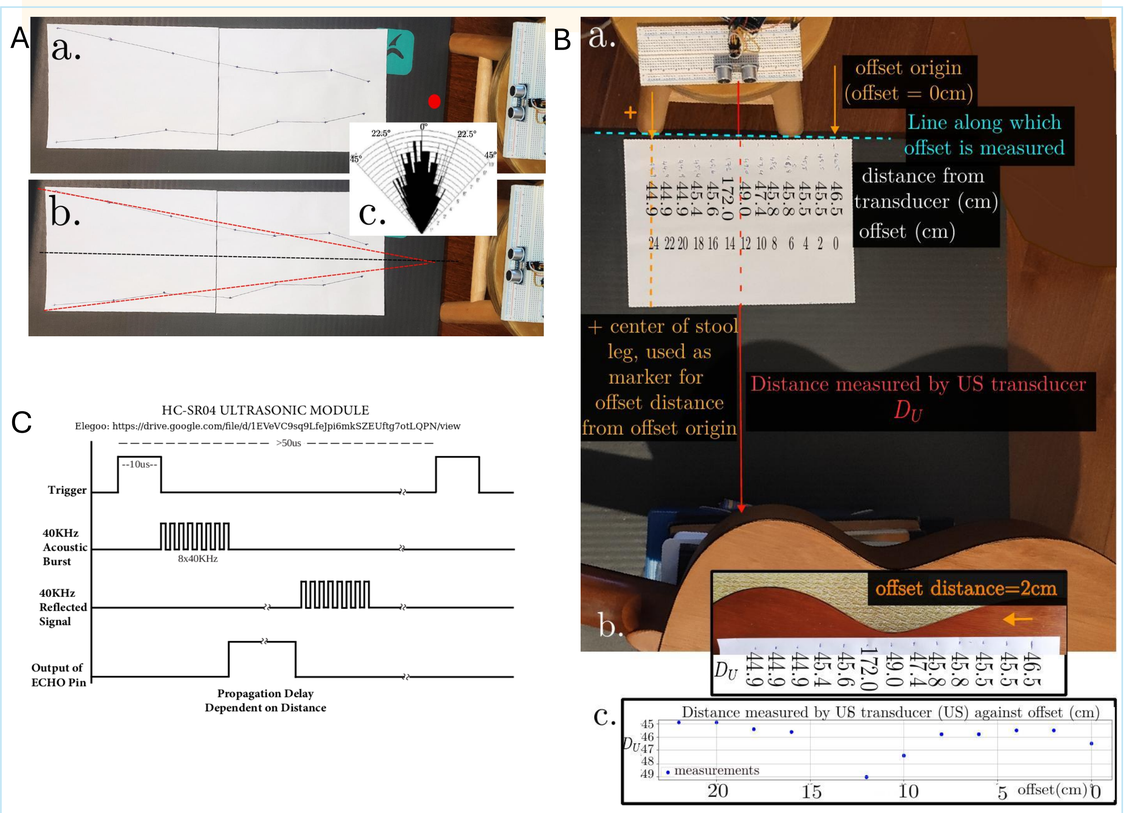

Figure 2: A. Determination of beam angle; B. Concept of B-mode ultrasound; C. timing diagram [2].

(iii) Description of acoustic properties of different materials

- Using the setup in Figure 1a, different materials were presented to the US beam to determine the interaction with US: (I) sponge; (ii) wire wool; (iii) paper serviette; (iv) surgical gauze.
- The sponge was classified as an absorber, the wire wool scatterer, the paper serviette reflector and the US beam interacted little with the surgical gauze.

(iv) Concept of B-mode US

The sensor was swept along parallel scan lines to determine distance to the classical guitar (figure 2B).
The distances were measured and found to approximate the curves of the guitar.

References:

[1] Martin Kevin. Chapter 1: Introduction to B-mode imaging in Diagnostic Ultrasound: Physics and Equipment (Hoskins P., Martin K., Thrush A.., eds.): p.1-6,CRC Press,3rd ed. 2019.
[2] Datasheet for ultrasound sensor HC-SR04 https://www.elegoo.com/pages/download. Accessed May 5, 2024

Discussion and Conclusion:

- Ultrasonography takes place in the human body with solids and a large water content, and uses US in the MHz range with speed of sound of 1540m/s;
- We used a sensor in air at 40kHz with speed of sound around 346m/s.
- However, we believe that the experiments provide a valid teaching methodology for learning the physical principles of acoustic wave propagation;
- Care should be taken to describe the limitations of the experiments to students.

1. Low-cost equipment was chosen for teaching US principles, including the HC-SR04 US sensor attached to an Arduino Uno, partially influenced by equipment already available in university laboratories.

2. A set of didactic experiments were developed to assist the teaching of basic US concepts, obtaining reasonable results.