Ultrasound

Purpose

Using “Borderless Lab 365” platform to conduct ultrasound A- and B-scans for demonstrating the principle of ultrasound imaging and determining structures under water.

Introduction

- Formation of images is usually associated with electromagnetic waves (including visible light and other invisible forms of electromagnetic radiation such as x-rays or ultrasound). Many animals use sound (or ultrasound) to image their environment. For example, bats use sonar ranging to detect obstacles and potential food (insects) or threats (predators).

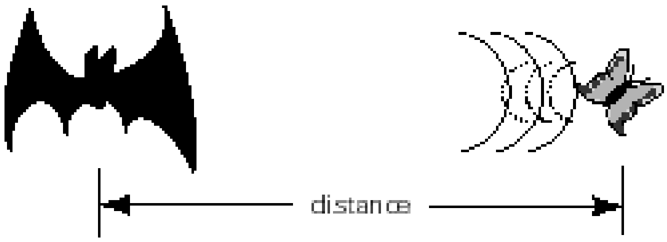

Fig. 1 Bats rely on sonar ranging method for finding preys.

- Ultrasonic testing is a family of non-destructive testing techniques based on the propagation of ultrasonic waves in the object or material tested. In most common ultrasonic testing applications, very short ultrasonic pulse-waves with center frequencies ranging from 0.1-15 MHz, and occasionally up to 50 MHz, are transmitted into materials to detect internal flaws or to characterize materials. A common example is ultrasonic thickness measurement, which tests the thickness of the test object, for example, to monitor pipework corrosion. Similar principles can be used for producing images, which is important for medical applications

- Ultrasonic testing technique can be classified based on
  (1) Detection method: Pulse Echo Method and Transmission Method
  (2) Sight generation method: Straight Beam Method (Normal Incidence Method) and Angle Beam Method (Oblique Incidence Method)
  (3) Scanning: A – Scan, B – Scan and C – Scan

Theory

- Sound waves are longitudinal waves involving the alternating compression and rarefaction of a medium, with the power determined by the wave’s amplitude. The speed of sound in a medium is a constant independent of frequency, wavelength and direction of sound transmission. Some typical values of the speed of sound for various materials are shown below.

Material	**Speed of sound (ms^{-1})**
Air	344
Acrylic (polyacrylate) plastic	2690
Water	1500
Soft tissue (average value)	1540
Muscle	1570
Fat	1440
Bone	3500

- Consider a pulse of sound wave travelling outward from the source at a speed *v* to the surrounding. If the sound wave is reflected by an object, it travels back to the source and is detected as an echo. In the process, the sound wave travels a distance equal to ***twice*** the distance from the source to reflecting object *L*, in a time *T*. Therefore, we can write the following equation:

$$v = 2L/T \text{ --- } (1)$$

<u>Ultrasound A- and B-scans</u>

- There are two typical ways of presenting the pulse-echo signals, ***A- & B-scan***. The ***A-scan*** displays the amount of received ultrasonic energy as a function of time. The amount of received energy (or sometimes voltage of the detector, as in this experiment) is plotted along the vertical axis, and the elapsed time (which is related to the sound energy travel time within the material) is displayed along the horizontal axis. Presence of boundaries between different materials allow reflection of sound waves, the depth of sample which can be determined by the position of the signal on the horizontal sweep (which represents the time for the echo to come back to the detector). If the speed of sound in the medium is known, the *x*-axis can be converted to the depth, and the presence of any boundaries can be identified.

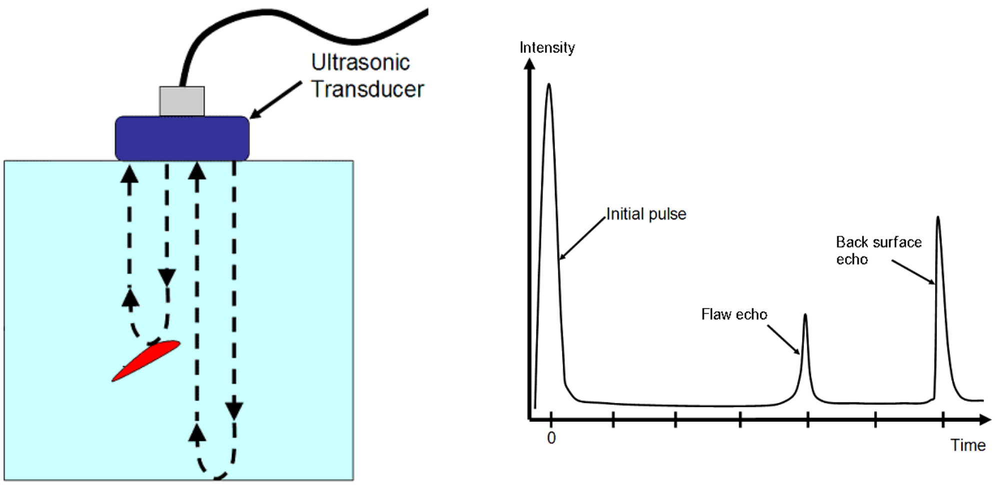

Fig. 2 (a) Principle of pulse-echo detection in ultrasound A-scan; (b) Intensity vs. time ultrasound scan (A-scan)

An A-scan plot of amplitude vs. time/depth is not very revealing for imaging purpose. However, if one moves the transducer along a straight line, one can measure the locations of objects: the depth (*y*) comes from sonar ranging and the transducer's position represents the second (*x*) dimension. In this way, one can collect the side view of the hidden structures. This is typically displayed reflected intensity as a function of *x* (transducer position) and y (depth). The echo intensity is indicated by a gray-scale of white to gray to black. This map of echo intensity vs. position is called a ***B-scan***.

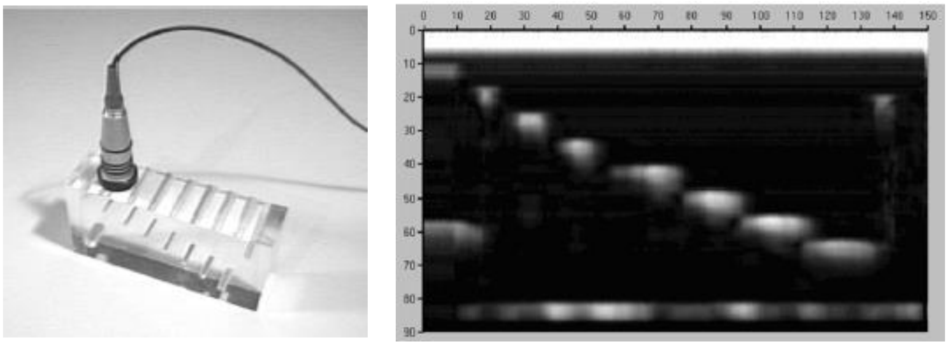

Fig. 3 Scanning the transducer along a test sample (left figure) forms a plot of time (equivalent to depth) vs. horizontal distance, resulting in a B-scan. Grayscale of each pixel correspond to the intensity of echo, an indicator for presence of reflecting surfaces.

Apparatus

- "Borderless Lab 365" Platform
- Ultrasound transducer: for generation and detection of ultrasound
- Digital oscilloscope
- Pulse generator

It should be noted that the samples and the transducer are all placed inside a water bath. The large difference of acoustic impedances between air and solids in general means strong reflection of sound waves at the top surfaces, preventing any sound from entering the structure and examine the underlying structures. The acoustic impedance of water, being closer to solids, allow more efficient energy transfer across the solid surface and therefore efficient detection of hidden structures.

Procedure

1. Log in the experiment module "Ultrasound" on the Borderless Lab 365 platform. https://stem-ap.polyu.edu.hk/remotelab/

<u>Detection of pulse-echo in water: A-scan</u>

2. By looking at the video image, place the transducer above a particular location by sliding "Transducer Position" left or right.
3. For the sample, there are two steps. Locate the transducer above the first step.

4. Press “MEASURE” to initiate the transducer to produce a graph of sound intensity vs. time.
5. Download the graph by pressing “DOWNLOAD” in csv. file or clicking “Menu” and choose a format (.svg, .png, .csv) of your choice.
6. Identify the peaks that correspond to the initial and echo pulses. Measure the time of echo pulse.
7. Repeat from procedure 2 for other steps and calculate the sound speed in water.

Scanning of surface profile along an axis: B-scan

8. Place the transducer before the boundary of sample.
9. Press the “B-scan” button. This will initiate the transducer to start the tracing.
10. Capture the image obtained from the scan.
11. Press “LOGOUT” when you complete the experiment.

Data

A-scan

Time for the echo pulse from the step:

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Time for the echo pulse from the other step:

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Distance between two steps is 1cm. Calculate the sound speed in water.

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Discussion

1. In the absence of water bath, what can be done to improve the ultrasound transmission efficiency from the transducer to human body in case of medical imaging?

2. How the ultrasound frequency affects the imaging?