EXPERIMENT 1
MEASUREMENT OF SPEED OF SOUND IN AIR

Pupose

The aim of this experiment is to measure speed of sound in air using echo method.

Theory

Sound is a sequence of pressure wave that propagates through compressible media. According to wave model, sound is transmitted through gases, plasma, and liquids as longitudinal waves (or also known as compression waves). The speed of sound depends on the medium where the waves pass through. In general, the speed of sound (v) is given by the Newton-Laplace equation:

$$v = \sqrt{\frac{K}{\rho}} \tag{1}$$

where

K is a coefficient of stiffness or the bulk modulus of the medium (liquid or solid). Here, the stiffness is the resistance of an elastic body to deformation by an applied force.

ρ is the density of the medium.

The speed of sound, v, in air depends on the temperature, T. An empirical function, $v(T)$, is given by:

$$v = 331.3\sqrt{1 + \frac{T}{273.15}} \tag{2}$$

The unit of v in Eq(2) is m/s when T is measured in degrees Celsius.

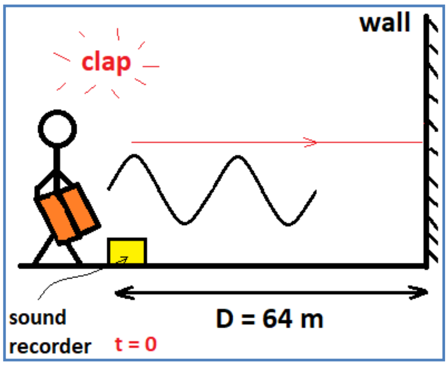
Here is some measured speed of sound data obtained at room temperature.

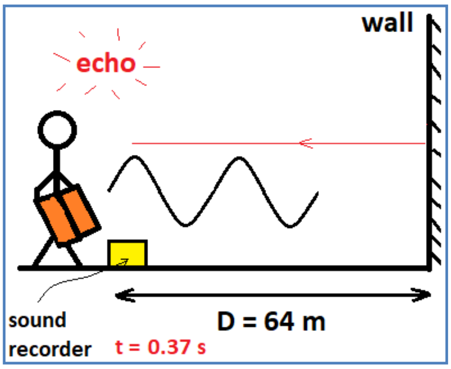
v = 343 m/s in dry air
v = 1482 m/s in fresh water
v = 5960 m/s in steel

Experiment and Data Analysis

There are many ways to measure speed of sound in air. Here we will discuss a method based on measuring the echo time. Consider you stay D = 64 m away from a wall. You produce a sound by clapping your hands (or by two wooden blocks) at time t = 0. The sound will propagate through air and will be reflected from the wall. Then, you hear an echo at t = 0.37 s. Hence, you can simply compute speed of sound as follows:

$$v = \frac{\text{distance}}{\text{time}} = \frac{2D}{\Delta t} = \frac{128}{0.37} = 346 \text{ m/s}$$





Normally, it is very difficult to measure time difference (Δt) by this way since human reaction time is about 0.25 s on average. However, we can record sound data and analyze it using **sound processing tools** in a computer. To do that, we have the following video:

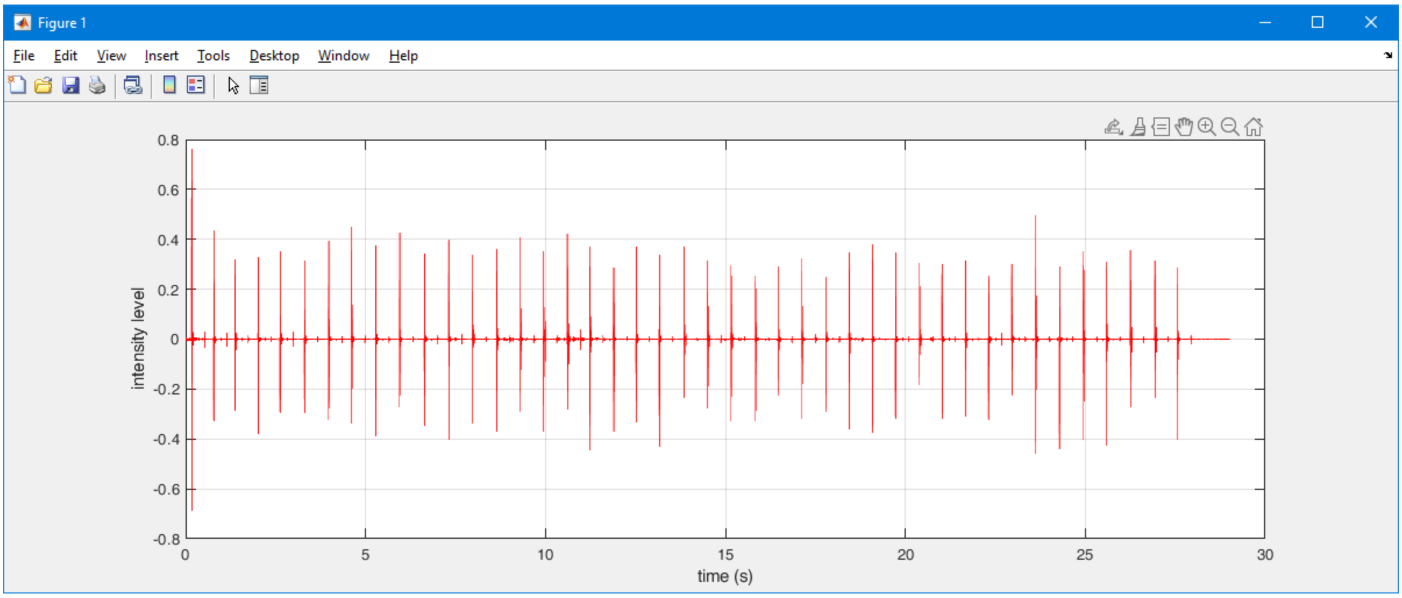
http://www1.gantep.edu.tr/~bingul/opaclab/opac310/clap.avi

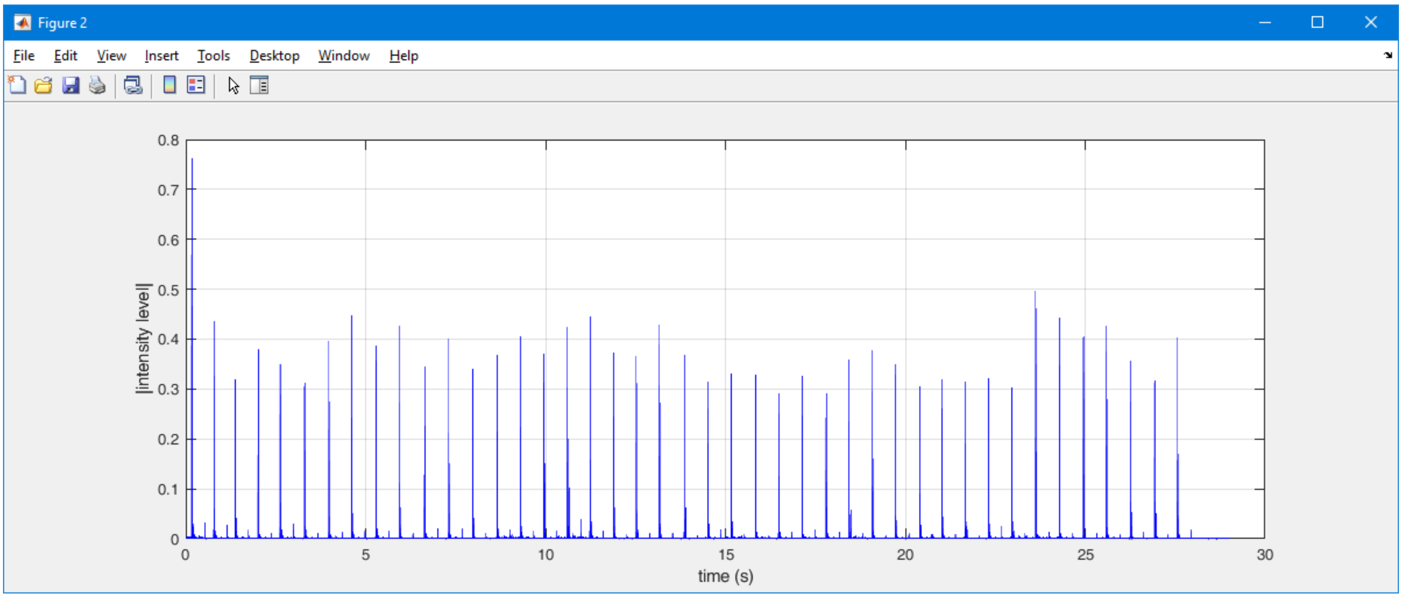
Please watch the video. The weather temperature was about T = 30 ^{o}C and D = 64.0 ± 0.5 m while we were performing experiment. You can save sound intensity vs time data via MATLAB program (or any other program). By analyzing the data, you can simply measure the speed of sound.

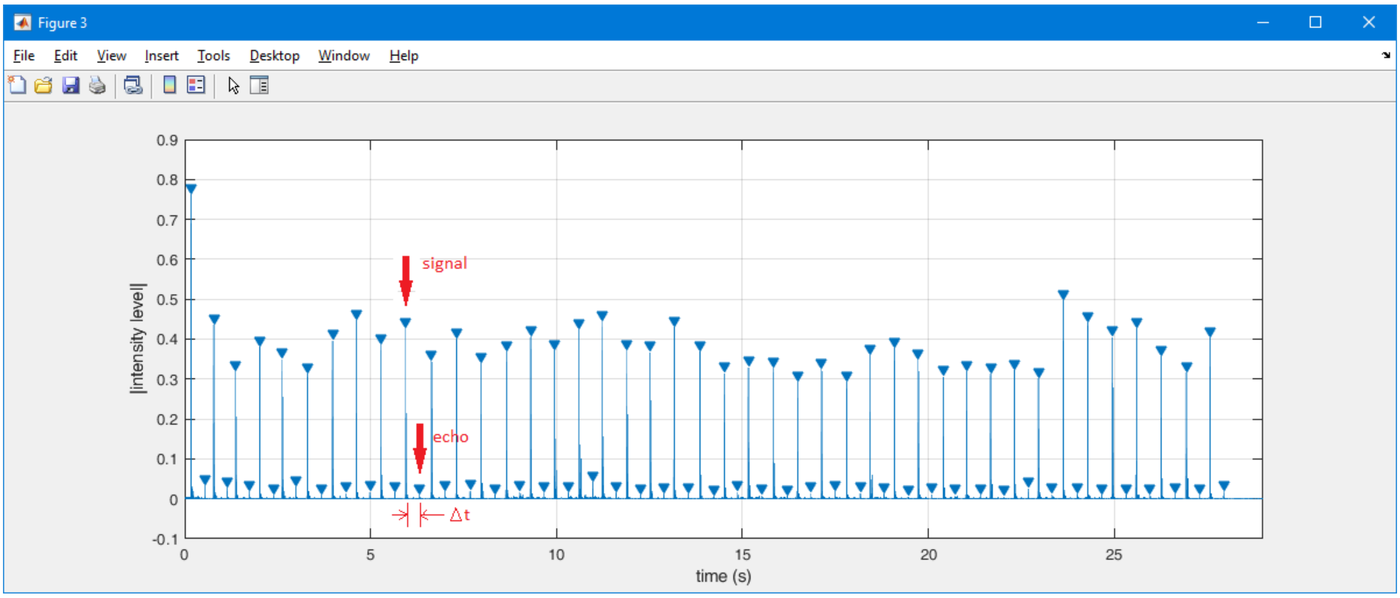
The following MATLAB program (version 2020b) reads the video, extracts the audio data and plots it. Then, after some analyses, it prints the peak locations of both signals and echoes.

```
% Evaluating speed of sound by echo method
clear; clc;

% read video and get sound data -----------------------------------------
[y, fs] = audioread('clap.avi','native'); % get audio data
y    = y(:,1);                            % Sound intensity values and
yabs = abs(y);                            %   its absoulte value
tmax = round(length(y)/fs);               % Total recorded time
time = linspace(0, tmax, length(y));      % Time values

% plot data -------------------------------------------------------------
figure(1), plot(time,y,'r'), grid on, xlabel('time (s)'), ylabel('intensity level')
figure(2), plot(time,yabs,'b'), grid on, xlabel('time (s)')
%sound(y,fs);  % play record (optional)

% Find local peaks in data ----------------------------------------------
figure(3),  findpeaks(yabs,time,'MinPeakDistance',0.22,'MinPeakProminence',0.004);
[I t] = findpeaks(yabs,time,'MinPeakDistance',0.22,'MinPeakProminence',0.004)
xlabel('time (s)')
ylabel('|intensity level|')
grid on
```

Three plots obtained by MATLAB are as follows:







A prescription for computing speed of sound is as follows.

We have totally m = 84 peak locations, namely n = 42 signal-echo data pairs.

1. Use vector **t** in the program above to calculate time difference between neighbor peaks (Δt).

   Δt_1 = t(2) – t(1) = 0.3639 s (1st data pair)
   Δt_2 = t(4) – t(3) = 0.3643 s (2nd data pair)
   ...
   Δt_{42}= t(84) – t(83) (42nd data pair)

2. Calculate speed of sound for each data pair for a distance D = 64 m.

   v_1 = 2*D / Δt_1 = 2*64/0.3639 = 351.7450 m/s
   v_2 = 2*D / Δt_2 = 2*64/0.3643 = 351.3588 m/s
   ...
   v_{42} = 2*D / Δt_{42}

3. Calculate mean, standard deviation and standard error of speed data in step 2.
   They are respectively calculated from

$$\langle v\rangle = \frac{\sum_{i=1}^{n} v_i}{n} \quad , \quad s = \sqrt{\frac{\sum_{i=1}^{n}(v_i - \langle v\rangle)^2}{n-1}} \quad \text{and} \quad e = \frac{s}{\sqrt{n}}$$

Questions

1. Evaluate $\langle v\rangle$, s and e.
2. Assuming T = 30 ^{o}C, calculate the percentage difference between expected value of speed of sound in air and your result in part 1.
3. What is your conclusion?