HSB
Hochschule Bremen
City University of Applied Sciences

UNDERWATER ACOUSTICS AND SONAR SIGNAL PROCESSING

SS 2018

ASSIGNMENT 1

SOUND VELOCITY IN THE OCEAN

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by

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Introduction

It is proved that while sound moves at a much faster speed in the water than in air, the distance that sound waves travel is primarily dependant upon ocean temperature, salinity and pressure. While pressure continues to increase as ocean depth increases, the temperature of the ocean only decreases up to a certain point, after which it remains relatively stable. These factors have a curious effect on how (and how far) sound waves travel.

This assignment consists of three parts: In the first part we develop a MATLAB program for determining the formula for the velocity of sound in ocean.The second part shows the dependence of velocity of sound in ocean on temperature, salinity and depth. Finally the dependency of the nonlinear temperature profile and the depth of the ocean is plotted.

Theory

0.1 Sound velocity in ocean

Variations of the sound velocity in the ocean are relatively small due to low absorption compared to speed of light in water. Blue-green light has the lowest attenuation in water upto 20m while sound can travel upto 100km one way and hence sonar is used to navigate, communicate with or detect objects on or under the surface of the water. Sound velocity in ocean lies between about 1450 m/s and 1540 m/s. Even though the changes of sound speed are small, i.e. $\leq \pm 3\%$, the propagation of sound can be significantly affected.

The sound velocity can be directly measured by velocimeters or calculated by empirical formulae if the temperature, salinity and hydrostatic power or depth are known. However, the error of measurements by modern velocimeters is about 0.1 m/s. The accuracy of calculations by the most complete empirical formulae is about the same. Also formulae providing such high accuracy are very cumbersome.

A less accurate but simpler equation is given by:

$$\mathrm{c} = 1449.2 + 4.6\mathrm{T} - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016\mathrm{z}$$

where temperature, T in ($°C$), salinity, S in (ppt), depth, z in (m) and sound velocity, c in (m/s)

With the following limits:

$0°C \leq$ T $\leq$ 35°C

0 ppt $\leq$S $\leq$45 ppt

0 m $\leq$ z $\leq$1000 m

The function for velocity of sound in ocean and the dependency of nonlinear temperature profile and the depth of the ocean is studied. Two sets of waveforms of c versus z for various sets of T and S are plotted in-order to investigate the dependence of c on T, S and z. Also the waveform for the nonlinear temperature profile and the depth of the ocean is obtained and discussed in the following sections.

Experimental research

0.2 Dependence of c on T, S and z

By using the formula for velocity of speed in ocean, the graph of velocity of speed in ocean versus depth is plotted for various values of temperature.

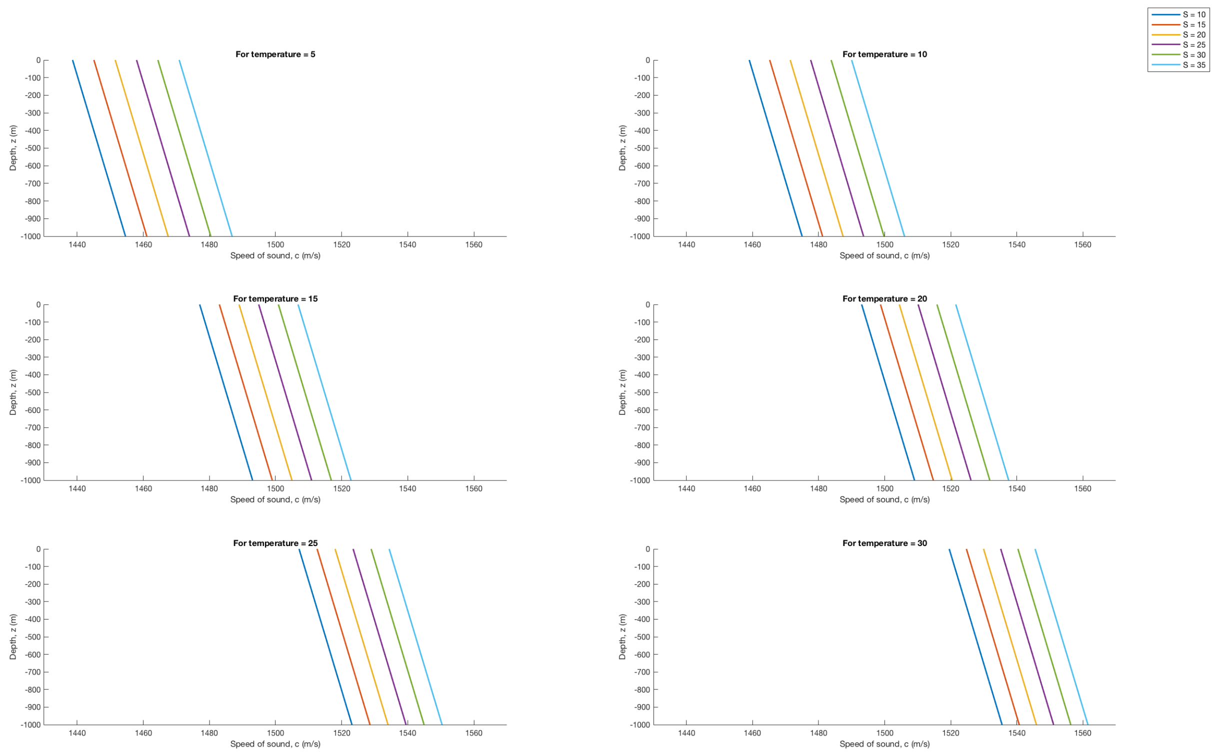

Figure 1: c versus z for various sets of T

By using the formula for velocity of speed in ocean, the graph of velocity of speed in ocean versus depth for various values of salinity is obtained.

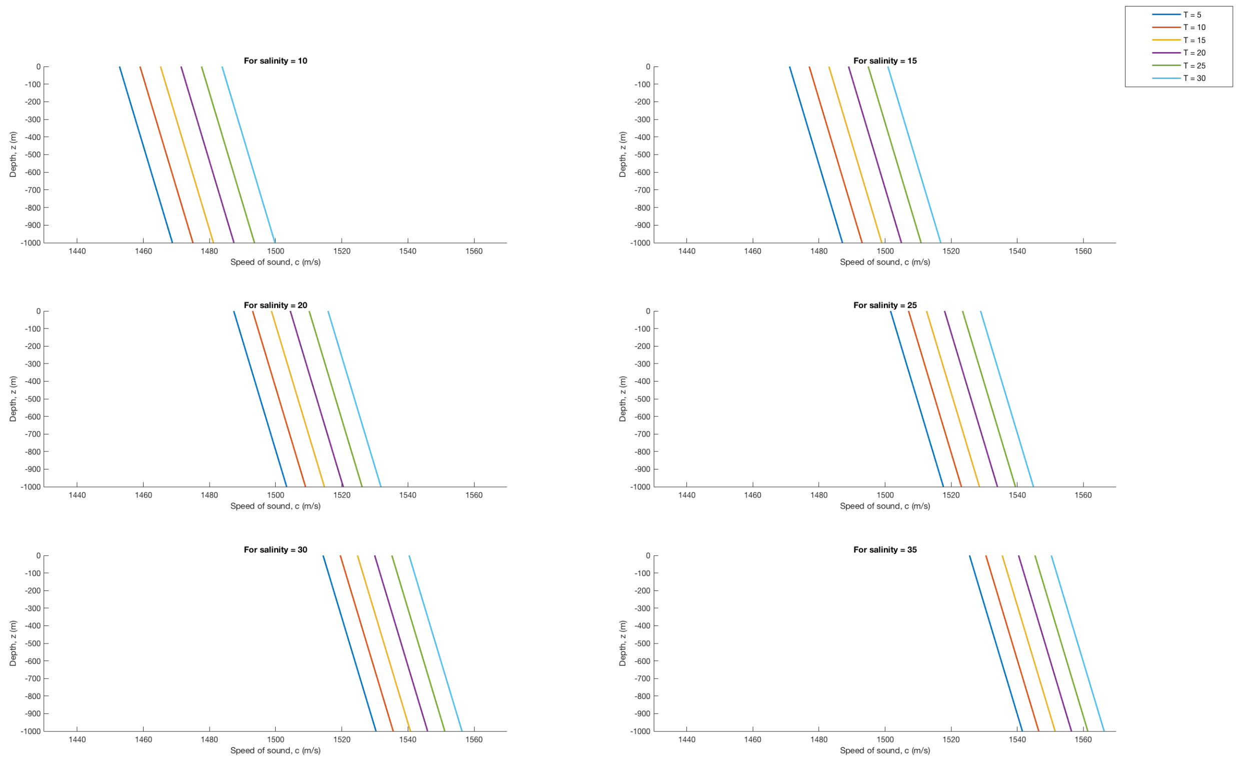

Figure 2: c versus z for various sets of S

Conclusion

It can be concluded that depth and salinity of the ocean are linearly dependent on sound velocity in the ocean while temperature has non linear dependance on speed of sound in the ocean

Appendix

0.3 MATLAB code for dependence of c on T, S and z

0.3.1 For various values of temperature

```
temperature = 5:5:30; % temperature varies in steps on 5 from 5 to 30
salinity = 10:5:35; % salinity varies in steps of 5 from 10 to 35
depth = 0:200:1000; % depth varies in steps of 200 from 0 to 1000
for i = 1:6
    u = temperature(i);
    for j = 1:6
        v = salinity(j);
        speedOfSound = c(v, u, depth); % calling the function
        subplot(3,2,i);
        hold on;
        plot(speedOfSound,-depth,'LineWidth',1.5);
        title(['For temperature = ',num2str(temperature(i))])
        ax = gca; % current axes
```

```
            ax.FontSize = 8;
            ax.XLim = [1430 1570];

            % labelling of axes
            ylabel('Depth, z (m)')
            xlabel('Speed of sound, c (m/s)')
        end
end
% labelling of waveforms
hL = legend('S = 10', 'S = 15', 'S = 20', 'S = 25','S = 30', 'S = 35')
newPosition = [0.85 0.85 0.2 0.2];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);

% only visible to all functions in this file
% Function to compute sound velocity
function speedOfSound = c(S, T, Z)
speedOfSound = 1449.2 + 4.6*T - 0.055*T.^2 + 0.00029*T.^3 ...
                    + 1.34*S - 46.9 - 0.01*T.*S + 0.35*T + 0.016*Z;
end
```

0.3.2 For various values of salinity

```
temperature = 5:5:30; % temperature varies in steps on 5 from 5 to 30
```

```matlab
salinity = 10:5:35; % salinity varies in steps of 5 from 10 to 35
depth = 0:200:1000; % depth varies in steps of 200 from 0 to 1000
for i = 1:6
    u = salinity(i);
    for j = 1:6
        v = temperature(j);
        speedOfSound = c(v, u, depth); % calling the function
        subplot(3,2,i);
        hold on;
        plot(speedOfSound,-depth,'LineWidth',1.5);
        title(['For salinity = ',num2str(salinity(i))])
        ax = gca; % current axes
        ax.FontSize = 8;
        ax.XLim = [1430 1570];

        ylabel('Depth, z (m)')
        xlabel('Speed of sound, c (m/s)')
    end
end
hL = legend('T = 5', 'T = 10', 'T = 15', 'T = 20','T = 25', 'T = 30')
newPosition = [0.85 0.85 0.2 0.2];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
```

```
% only visible to all functions in this file
function speedOfSound = c(S, T, Z)
speedOfSound = 1449.2 + 4.6*T - 0.055*T.^2 + 0.00029*T.^3 ...
                    + 1.34*S - 46.9 - 0.01*T.*S + 0.35*T + 0.016*Z;
end
```