In-Situ Determination of Acoustic Average Speed in Underwater Environment

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ID: 2012-2-60-038

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A project submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Computer Science and Engineering to the Department of Computer Science and Engineering At the

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Abstract

In water, sound travels more rapidly and with l mess energy absorption than in air. Thus, it is efficient medium for sound transmission compared to air. This low is developing a wide range of submarine acoustic applications with benefit for navigation. Best known applications are vertically operating echo sounders for depth determination or range finders in the horizontal. While a mean value of 1500 m*s-1 for the speed of sound in seawater is sufficient for a couple of operations, scientific applications of ten require higher accuracy. The transmission speed is affected by elasticity and density, which in turn is influenced by pressure, temperature and salinity. Using profiling sensors to measure these parameters it is possible to determine the speed of sound indifferent depths. In this paper, I study the speed problem in underwater. I have presented a method to calculate the average speed in underwater. Mackenzie Theorem is used to determine the average speed of the acoustic signal considering three factors**: Temperature**, **Salinity** and **Depth.** In this study, I have determined the underwater average speed of acoustic signals, which has better benefit than knowing the speed for one point. Triple Integration is used to determine the speed of every point in an area. The simulations and field evaluations show a good estimation of speed positions. Computing coordinates of speed with negligible errors. Sonar (originally an acronym for SOund Navigation And Ranging) is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or detect objects on or under the surface of the water, such as other vessels. (SONAR is a technique that uses sound propagation to navigate)

Declaration

We hereby declare that, this project was done under CSE497 and has not been submitted elsewhere for requirement of any degree or diploma or for any purpose except for publication.

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Letter of Acceptance

We hereby declare that this thesis is from the student's own work and best effort of mine, and all other source of information used have been acknowledge. This thesis has been submitted with our approval.

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Acknowledgement

Firstly our most heartfelt gratitude goes to our beloved parents for their endless support, continuous inspiration, great contribution and perfect guidance from the beginning to end.

We owe our thankfulness to our supervisor Dr. Anisur Rahaman for his skilled, almost direction, encouragement and care to prepare myself.

Our sincere gratefulness for the faculty of Computer Science and Engineering whose friendly attitude and enthusiastic support that has given me for four years.

We are very grateful for the motivation and stimulation from my good friends and seniors.

We also thank the researchers for their works that help me to learn and implement the Determination of average acoustic speed in underwater Environment.

Abbreviation and Acronyms

2D = Two Dimensional

3D = Three Dimensional

4D = Four Dimensional

UNESCO = United Nations Educational Scientific and Cultural Organization

XBT = Expendable Bathy Thermograph

SVP = Sound Velocity Profile

AUV = Autonomous Underwater Vehicles

UUV = Unnamed Underwater Vehicles

GPS = Global Positioning System

LPS = Local Positioning System

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Chapter 1

Introduction

1.1. About Acoustic Channel

Acoustics is defined as the science that deals with the production, control, transmission, reception and effects of sound. Applications include sonar to locate submarines, underwater communications, Oceanographic data collections etc.

Acoustics was originally the study of small pressure waves in air which can be detected by the human ear: sound. The scope of acoustics has been extended to higher and lower frequencies: ultrasound and infrasound. Structural vibrations are now often included in acoustics. Also the perception of sound is an area of acoustical research. In our present introduction we will limit ourselves to the original definition and to the propagation in fluids like air and water. In such a case acoustics is a part of fluid dynamics [1]. Underwater acoustic channels are generally recognized as one of the most difficult communication media in use today. Acoustic propagation is best supported at low frequencies, and the bandwidth available for communication is extremely limited. As the history of underwater acoustic communications testifies, major advances in signal processing were made when the physical nature of propagation was respected through proper channel modeling [2]. Acoustic propagation is characterized by three major factors: attenuation that depends on the signal frequency, multipath propagation, and low speed of sound (1500 m/s). At this time, it is not certain in which direction the underwater networks will develop, as possible applications depend on the network capabilities, which are still developing, and the question of network capacity remains open [3]. A major problem of fluid dynamics is that the equations of motion are non-linear. This implies that an exact general solution of these equations is not available. Acoustics is a first order approximation in which non-linear effects are neglected. In classical acoustics the generation of sound is considered to be a boundary condition problem. The sound generated by a loudspeaker or any unsteady movement of a solid boundary are examples of the sound generation mechanism in classical acoustics [1].

1.2. Historical Perspective in Underwater Acoustic Communications & Networking

The first successful measurements of the speed of sound in water were not made until the early 1800s. Using a long tube to listen underwater, as suggested by da Vinci, scientists in 1826 recorded how fast the sound of a submerged bell traveled across Lake Geneva [5].

Undersea acoustic communications dates back to the development of manned submarines and the need to communicate with them. The "Gertude", or underwater telephone was developed for audio communication using analog modulation at carrier frequencies between 2 and 15 kHz, and this hardware is still in use on submarines around the world, both large military systems and small industrial or scientific submersibles such as Alvin. The design of these analog systems simply employ analog filters for the voice band plus spectral shaping and single-sideband modulation to the transmit carrier. The development of digital communications for undersea applications dates back to simple ping-based use of sonars that operate in the audible band. The use of "one ping only" in the fictional Hunt for Red October that was used to communicate from submarine to submarine is an example of digital communications, which while primitive, certainly is sufficient when only one bit is necessary. The advent of digital communications in the 1960s brought about a general awareness of the principles of signaling and modulation for imperfect channels. The feature of the ocean acoustic channel that was exploited by Williams and Battestin is the temporal coherence that is high enough to allow channel estimation and subsequent compensation. In the nearly 40 years since their early work, other researchers have been able to use more sophisticated processing methods for channel estimation and implement algorithms on digital computers, but the principles that were demonstrated in this seminal work remain the same [4].

1.3. Facing Problem to Generate the Speed of Acoustic Signal

In this research, average speed has been determined by mathematical calculation. Since the speed vary for different factors of different layers the accurate ranges of these factors measurement is tough. There have some seasonal effect also for which the speed is varied in different atmosphere. On the other hand there have been faced some problems in simulation. Actually this speed is in 4D plot which is not visible. So by ignoring one factor 3D plot is shown in this paper.

Traditional underwater communication systems are point-to-point based in most cases. In other words, a network is not formed in such kind of systems. Resource sharing is not a concern and most of the research is performed for the physical layer. In contrast, the research of UANs should always investigate how to optimize the whole system performance across different layers [6]. .

To measure the speed of sound in water, the most widely used tool is an Expendable Bathy Thermograph or XBT [7]. There have also problem to measure accurate speed by this process that the sound speed is measured by considering depth and temperature where salinity is negligible. But salinity also effect on the speed in underwater. This is a problem to measure accurate speed by neglecting salinity considering the factors for only one single point value.

1.4. Techniques of Solving Average Speed Measurement of Acoustic Signal

In this paper there has been focused on the measurement of average speed of sound controlling different factors in underwater using Mackenzie Theorem. In chapter: 3 there will have discussed about Mackenzie theorem.

To measure the speed of sound in water, the Navy has developed several tools to measure the temperature of the seawater as a function of depth or the velocity of sound directly.

For example, the most widely used tool is an Expendable Bathy Thermograph or XBT. XBTs are launched from submarines, surface ships and even aircraft. These measure the temperature of the water as the device sinks at a known rate and transmits this back to the launching platform. This provides a detailed plot of temperature as a function of depth. Neglecting salinity, the Sound Velocity Profile or SVP can be calculated as a function of depth and temperature (since these causes. The limitation of this technique is there the speed is measured considering the factors only one single point neglecting salinity [7].

1.5. Objective of Research

Mackenzie Theorem requires the need of the value of different factors to measure the speed of sound. Sound occurs because of the properties of sound and the temperature and salinity varies at different depths in the ocean. So, here is assumed three factors for this research: **temperature**, **salinity** and **depth**. Measuring the average speed of sound in under water I have used the ranges of different factors. For simplicity also used the approximate ranges of those different factors.

To obtain the average speed of sound for different layers by measuring the area in 3D is the objective of Mackenzie Theorem. To measure the speed we need more factors with ranges. But here the three factors are used for different three layers underwater. And Matlab code is also shown for simulation the proposed calculation for different three layers.

1.6. Methodology of Research

In this paper, there have been applied the triple integration on the Mackenzie Theorem to measure the 3D area in underwater correspond with speed and then get away the average speed of acoustic signal in that area.
There has been described speed measurement in chapter 3.

For simplicity I have used the approximate ranges of different factors for the measurement of the average speed of sound in underwater.

Equation of Mackenzie

c(D,S,T) = 1448.96 + 4.591T 5.304 x 10 2T 2 + 2.374 x 10 4T 3 + 1.340 (S35) + 1.630 x 10 2D + 1.675 x 10 7D 2 1.02 x 10 2T(S 35) 7.139 x 10 13TD 3

T = temperature in degrees Celsius
S = salinity in parts per thousand
D = depth in meters

1.7. Significance of Research

Mainly the determination of average speed of acoustic signal will be beneficial for navigation or localization. GPS or LPS are used for localization. Now-a-days the localization is plays an important role all over the world for various necessary issues for which investigation is easy also.

Absolute position measurement is an important issue. Such as: Submarine navigations, industry sectors, military navigations, army operations etc. There have also many techniques to localize underwater. In underwater localization system we need to measure the distance for which must require the speed.

Generally we know, **Distance = Speed x Time (s = vt)**

From this general equation it can be seen that, speed is must require for determining the distance of any localized thing. For example, To localize anything in underwater there can be used AUV or UUV which send us the info about temperature, salinity and pressure. From the value of pressure we can detect the depth value considering the latitude or seasonal effect underwater. By using the value of these factors we measure the speed value of signal which is needed to measure the distance of localized position.

In this paper actually proposed about determining the average speed. In previous work there have many solutions for single point value of factors. But the significance of this paper is that here the determination of average speed in underwater acoustic signal.

Chapter 2

Related Work

2.1. The first successful measurements of the speed

The first successful measurements of the speed of sound in water were not made until the early 1800s. Using a long tube to listen underwater, as suggested by da Vinci, scientists in 1826 recorded how fast the sound of a submerged bell traveled across Lake Geneva.

Colladon and Sturm measured the water temperature in the lake to be 8° centigrade. At this temperature, they determined the speed of sound in fresh water to be 1435 meters per second, which differs from the currently accepted value by only 3 meters per second. Their published results also reported earlier measurements in sea water made in 1820 near Marseilles by François Sulpice Beudant, a French physicist. Beudant's measurements averaged about 1500 meters per second, approximate results expected for sea water

At about this same time, scientists began to think about the practical applications of underwater sound. One of the first applications that scientists explored was to determine the depth of the sea by listening for echos. At the time, water depth was measured by lowering a weighted line from the deck of a ship, which is tedious, dangerous, and not very accurate**.**

Mackenzie (1981) developed his algorithm based on temperature, pressure and depth with 9^{th} term equation. My solving method based on Mackenzie algorithms.

There have also many algorithms related to acoustic speed in underwater signal. Snell's Law, Coppens and The UNESCO equation are popular algorithm in this field [5].

2.2. Snell's Law for the Angle of Speed of Sound

Sound as a ray and using Snell's Law. We can look at either the grazing angles, referenced to the horizontal and used when looking at refraction, or incidence angles, referenced to the vertical and used for refraction and backscattering.

In the below sketch, a plane wave is moving towards a boundary beyond which the speed of sound is much slower. As the wave fronts hit the boundary they slow down and bend more normal to the boundary. Specific examination of the wave after the right edge hits the boundary at point A shows that the left side of the wave front must travel a distance from B to D expressed as the product of the sound speed c1 and sometime interval Δt. In that same time interval the right edge of the wave front moves from A to E expressed as the product of sound speed c2 and sometime interval Δt. Using trigonometry we see that the ratio of the cosine of the grazing angle to the speed of sound remains constant across the boundary. This observation is called Snell's Law.

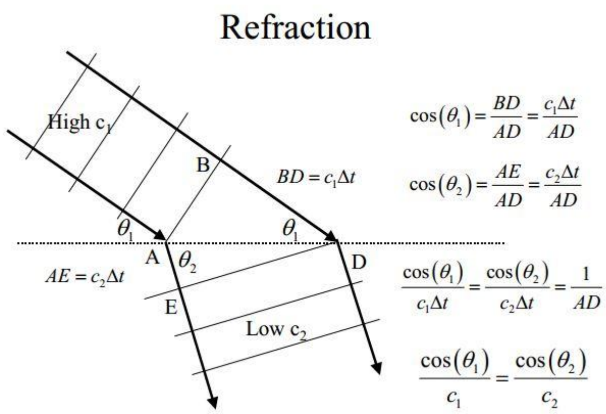
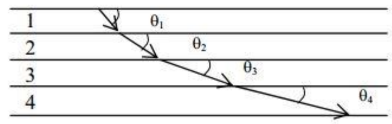


Figure 2.1: The Ratio of the Cosine of the Grazing Angle to the Speed of Sound

Snell's law and ray theory are well suited for each other. Imagine that a sound ray is transmitted through a series of mediums label 1 through 4 with sequentially increasing sound speed. In each medium, the angle the ray makes with the horizontal, θ, will depend on the angle it has in the previous medium and the speed of sound for each medium. The figure below depicts the relation.



where $c_1 < c_2 < c_3 < c_4$ and $\theta_1 > \theta_2 > \theta_3 > \theta_4$

According to Snell's Law

$$\frac{cos(\theta_1)}{c_1} = \frac{cos(\theta_2)}{c_2} = \frac{cos(\theta_3)}{c_3} = ... = \frac{cos(\theta_n)}{c_n} = \text{constant}$$

Figure 2.2: The Speed of Sound of Horizontal Ray

Notice that when a ray is in a layer and horizontal, θ= 0°andthe cos(θ) =1. We call the speed of sound when the ray is horizontal, co[7] .

2.3. Coppens Algorithm

$c(D,S,t) = c(0,S,t) + (16.23 + 0.253t)D + (0.2130.1t)D^2 + [0.016 + 0.0002(S-35)](S-35)tD$

$c(0,S,t) = 1449.05 + 45.7t-5.21t^2 + 0.23t^3 + (1.333-0.126t + 0.009t^2)(S-35)$

t = T/10 where T = temperature in degrees Celsius
S = salinity in parts per thousand
D = depth in kilometers

Range of validity: temperature 0 to 35 °C, salinity 0 to 45 parts per thousand, depth 0 to 4000 m The above equation for the speed of sound in seawater as a function of temperature, salinity and depth is given by Coppens equation (1981) [8].

2.4. The UNESCO Algorithm

The international standard algorithm, often known as the UNESCO algorithm, is due to Chen and Millero (1977), and has a more complicated form than the simple equations above, but uses pressure as a variable rather than depth. For the original UNESCO paper see Fofonoff and Millard (1983). Wong and Zhu (1995) recalculated the coefficients in this algorithm following the adoption of the International Temperature Scale of 1990 and their form of the UNESCO equation is:

$c(S,T,P) = Cw(T,P) + A(T,P)S + B(T,P)S^{3/2} + D(T,P)S^2$

$Cw(T,P) = (C_{00} + C_{01}T + C_{02}T^2 + C_{03}T^3 + C_{04}T^4 + C_{05}T^5) +(C_{10} + C_{11}T + C_{12}T^2 +$

$C_{13}T^3 + C_{14}T^4)P +(C_{20} +C_{21}T +C_{22}T^2 + C_{23}T^3 + C_{24}T^4)P^2 +(C_{30} + C_{31}T + C_{32}T^2)P^3$

$A(T,P) = (A_{00} + A_{01}T + A_{02}T^2 + A_{03}T^3 + A_{04}T^4) +(A_{10} + A_{11}T + A_{12}T^2 + A_{13}T^3 +$

$A14T4)P +(A_{20} + A_{21}T + A_{22}T^2 + A_{23}T^3)P^2 +(A_{30} + A_{31}T + A_{32}T^2)P^3$

$B(T,P) = B_{00} + B_{01}T + (B_{10} + B_{11}T)P$

$D(T,P) = D_{00} + D_{10}P$

T = temperature in degrees Celsius

S = salinity in Practical Salinity Units (parts per thousand)

P = pressure in bar

Range of validity: temperature 0 to 40 °C, salinity 0 to 40 parts per thousand, pressure 0 to 1000 bar (Wong and Zhu, 1995).

Please note that for consistency, within the interactive version, the pressure must be input in kPa [8].

Chapter 3

Solvability in Underwater Average Speed Determination

3.1. Problem Field

The speed of a wave propagating through a medium is not a constant. This is especially true for the non-homogeneous medium, the ocean. The speed of sound through water has been found to be mainly a function of three factors. They are temperature and salinity and depth . Because the speed is not constant, sound does not travel along straight paths [7].

Temperature: In general, for most areas of the ocean, the water temperature decreases from the surface to the bottom, but there are many local variations .Shallow layers see the most variation with time and depth (i.e. Surface mixing, solar heating, currents, seasonal variation etc) [7].

Salinity: The change in the mix of pure water and dissolved salts effects sound velocity. Most salinity variation takes place near the surface where these environmental influences occur. Salinity is expressed in practical salinity units (p.s.u.) [7].

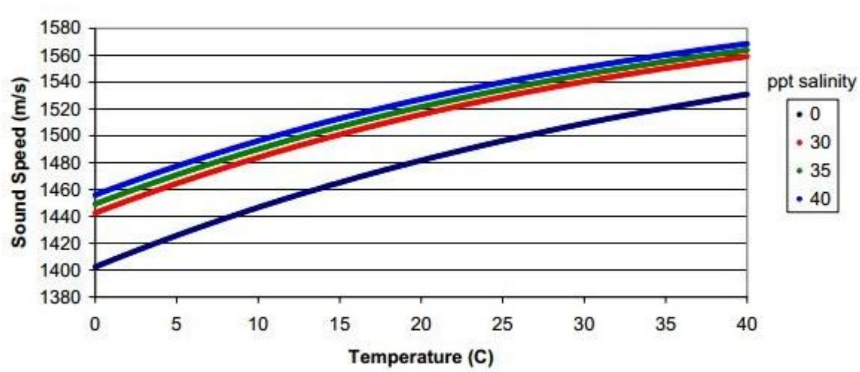


Figure 3.1: Sound Speed Variation with Temperature and Salinity

Depth : Hydrostatic pressure makes sound velocity increase with depth. Temperature and salinity vary with respect to depth in underwater. If depth is increased the temperature will decrease and salinity will increase with the specific range [7].

Density: Density of seawater is primarily determined by two factors: temperature and salinity. Warmer water is less dense than colder water. Therefore, warm water floats near the surface. While cold water will sink toward the bottom. Salinity also affects density. Higher salinity (more salt in the water) leads to higher density. So salty water sinks while fresh water float at the surface[7].

3.2. A Solvable Determination of Average Speed in Underwater Acoustic

In this proposed model there has been considered at least three factors for research: **temperature**, **salinity** and **depth**. Traditional underwater communication systems are work point-to-point based speed measurement. Measuring the average speed of sound in under water I have used the ranges of different factors. For simplicity there has been used the approximate ranges of those different factors. To obtain the accurate average speed of sound for different layers by measuring the area in 3D is the objective of Mackenzie Theorem.

According to this theorem the assumption of approximate speed in underwater is 1500 ms^{-1}.

Table 3.1: Ranges of three factors

Range of Temperature (^0C)	Range of Salinity(PSS)	Range of Depth (m)
2 - 30	25 – 40	0 – 8000

Using the ranges of three factors from Table 3.1 I have calculated the average speed for general purpose by Mackenzie Theorem

$$\iiint c\ dt\ ds\ dd = \int_{0}^{8000}\int_{25}^{40}\int_{2}^{30} 144.96 + 4.591T - 5.304 \times 10^{-2}T^2 + 2.374 \times 10^{-4}T^3 + 1.340(S-35) + 1.63010^{-2}D + 1.675 \times 10^{-7}D^2 - 1.025 \times 10^{-2}T(S-35) - 7.139 \times 10^{-13}TD\ dt\ ds\ dd$$

$$= \int_{0}^{8000}\int_{25}^{40} -\frac{6186357758320831 \times D^3}{19342813113834066795298816} + \frac{44295797609317275 \times D^2}{9444732965739290427392} + \frac{1141 \times D}{2500} + \frac{4116 \times S}{125} + \frac{18485484934100662454150349}{4503599627370496000000} ds\ dd$$

$$= \int_{0}^{8000} -\frac{92795366374812465 \times D^3}{19342813113834066795298816} + \frac{664436964139759125 \times D^2}{9444732965739290427392} + \frac{3423 \times D}{500} + \frac{569023264554700303622590 47}{900719925474099200000} dd$$

$$= 5.2801e + 09$$

Here, I have triple integrated the Mackenzie theorem using ranges of three factors for measuring the 3D area in underwater in which I get the average speed. Dividing this area by 2D surface I have calculated the average speed.

Average speed = (5.2801e+09) / ((30-2)*(40-25)*(8000-0))

= 1.5715e+03

= 1571.50 ms^{-1}

3.3. Environmental Limitations

In this proposed model there has been assumed for the whole area in underwater considering three factors. But these factors are varies for different layers. There have actually three layers underwater: **Mixed Water Layer , Thermocline Water Layer** and **Deep Water Layer.**

Surface layer (sometimes referred to as the mixed layer). The surface layer is the top layer of the water. This layer is also known as the mixed layer and is well stirred from the wind and other forces. This top ocean layer tends to be the warmest layer due to heating from the sun. Below the surface layer is the thermocline, the layer between warm surface water and cold Deep Ocean. Its size varies based on latitude and season, but it will rarely occur deeper than 1,000m^2. In this layer, temperature changes rapidly with depth. This layer often coincides with the halocline, the region where salinity changes sharply with depth. Below the thermocline is the deep ocean. Water here is cold and dense. Temperature and salinity tend to remain relatively constant below the thermocline [9].

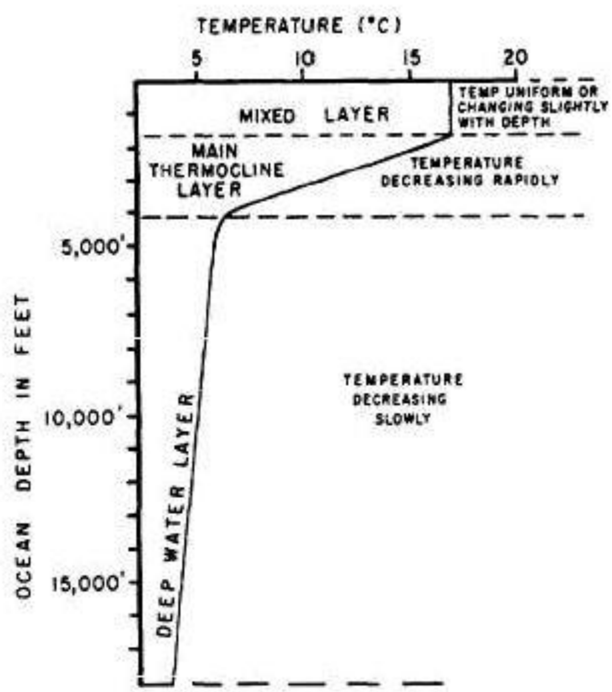


Figure 3.2: Underwater Three Layer

Here has been collected the ranges of three factors for different three layers:

Table 3.2: Ranges of factors for different layers

Underwater Layers	**Range of Depth (m)**	**Range of Temperature (^{0}C)**	**Range of Salinity (p.s.u.)**	**Average Speed (ms^{-1})**
Mixed Water Layer	0 – 450	30 – 25.5	25 – 25.045	1533.70
Thermocline Water Layer	450 – 1000	10 – 4	34 – 34.5	1489.00
Deep Water Layer	1000 – 8000	4 -2	34.8 – 35.1	1539.50

3.4. Mixed Water Layer

The mixed layer is the upper layer of the three-layered ocean model. It is a layer of fairly constant warm temperatures which, in middle latitudes, extends from the surface to a maximum depth of about 450 meters, or 1,500 feet. This layer gets its name from the mixing processes that bring about its fairly constant warm temperatures.

There is an increase in surface salinity owing to evaporation or the formation of ice, or by a decrease in the surface water temperature. A temperature decrease of .01°C or a salinity increase of 0.01 ‰ [16].

The ocean mixed layer is characterized as having nearly uniform physical properties throughout the layer with a gradient in properties at the bottom of the layer. The mixed layer links the atmosphere to the deep ocean and plays a critical role in climate variability.

Atmospheric fluxes of momentum, heat and freshwater through the ocean surface drive vertical mixing that generates the mixed layer. The depth of the mixed layer varies with time owing to variability of the atmospheric forcing, and the thickness of the mixed layer indicates the amount of water (as well as heat) that directly interacts with the atmosphere [19].

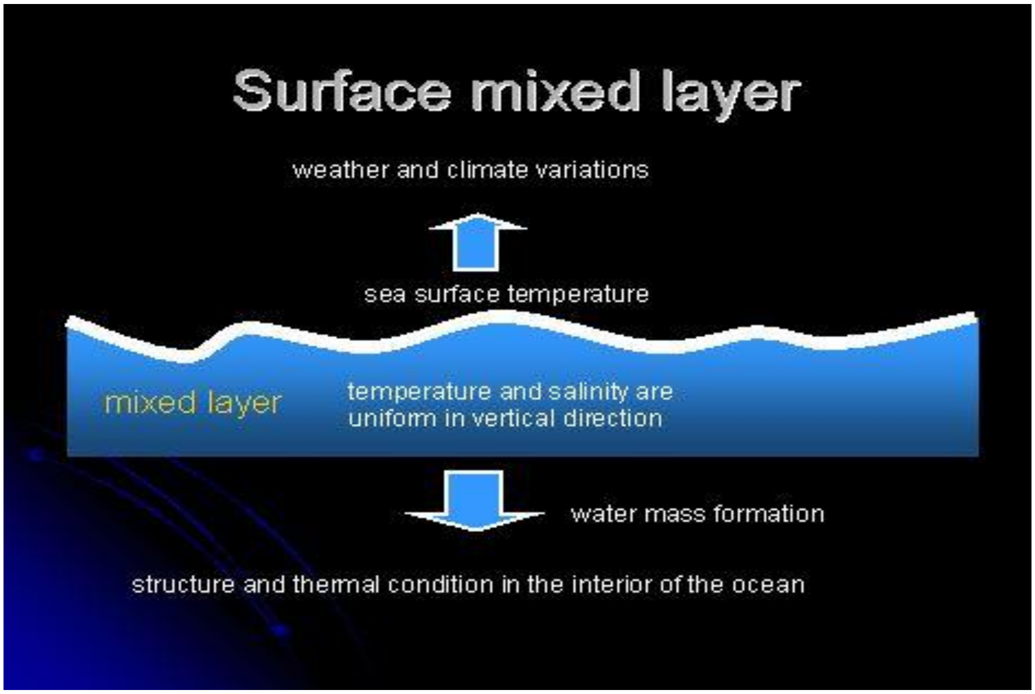


Fig 3.3: Mixed Water Layer

The barrier layer thickness (BLT) is a layer of water separating the well-mixed surface layer from the thermocline. Barrier layer formation in the subtropics is associated with seasonal change in the mixed layer depth [17].

3.5. Average Speed Determination for Mixed Layer

Using the ranges of three factors from Table 3.2 [10], [11], [12], [13], [14], [15], [16] I have calculated the average speed for mixed water layer by Mackenzie Theorem

$$\iiint c\;dt\;ds\;dd = \int_{0}^{450}\int_{25}^{25.045}\int_{25.5}^{30} 144.96 + 4.591T - 5.304\times10^{-2}T^2 + 2.374\times10^{-4}T^3 + 1.340(S-35) + 1.63010^{-2}D + 1.675\times10^{-7}D^2 - 1.025\times10^{-2}T(S-35) - 7.139\times10^{-13}TD\;dt\;ds\;dd$$

$$= \int_{0}^{450}\int_{25}^{25.045} -\frac{882881628651787167\times D^3}{9903520314283042199192993792} + \frac{56951739783407925\times D^2}{75557863725914323419136} + \frac{1467\times D}{20000} + \frac{152001\times S}{32000} + \frac{49925357063466589120640552469}{73786976294838206464000000}\,ds\;dd$$

$$= \int_{0}^{450} -\frac{7945934657866084503\times D^3}{1980704062856608439838598758400} + \frac{20502626322026853\times D^2}{604462909807314587353088} + \frac{13203\times D}{4000000} + \frac{457221345975653523396280450749}{1475739525896764129280000000}\,dd$$

$$= 1.3976\times10^{5}\;ms^{-1}$$

Average speed = $(1.3976\times10^{5})/((30-25.5)\times(25.045-25)\times(450-0))$ = $1533.7\ \mathrm{m}s^{-1}$

From result, we get the average speed for mixed layer is 1533.7 ms^{-1} which is slightly large than our approximate speed value (1500ms^{-1}). In this layer temperature is higher than other two layers and salinity is in lower range. So, the density is low rate in mixed layer (Density is the function of temperature and salinity). For this reason the speed of acoustic signal is high in mixed layer as well.

From simulation we can see the speed of this layer in graph that will discussed in Chapter 4.

3.6. Thermocline Layer

A thermocline is a thin but distinct layer in a large body of fluid (e.g. water, such as an ocean or lake, or air, such as an atmosphere) in which temperature changes more rapidly with depth than it does in the layers above or below. In the ocean, the thermocline divides the upper mixed layer from the calm deep water below. Depending largely on season, latitude and turbulent mixing by wind, thermoclines may be a semi-permanent feature of the body of water in which they occur or they may form temporarily in response to phenomena such as the radiated heating/cooling of surface water during the day/night. Factors that affect the depth and thickness of a thermocline include seasonal weather variations, latitude and local environmental conditions, such as tides and currents [16].

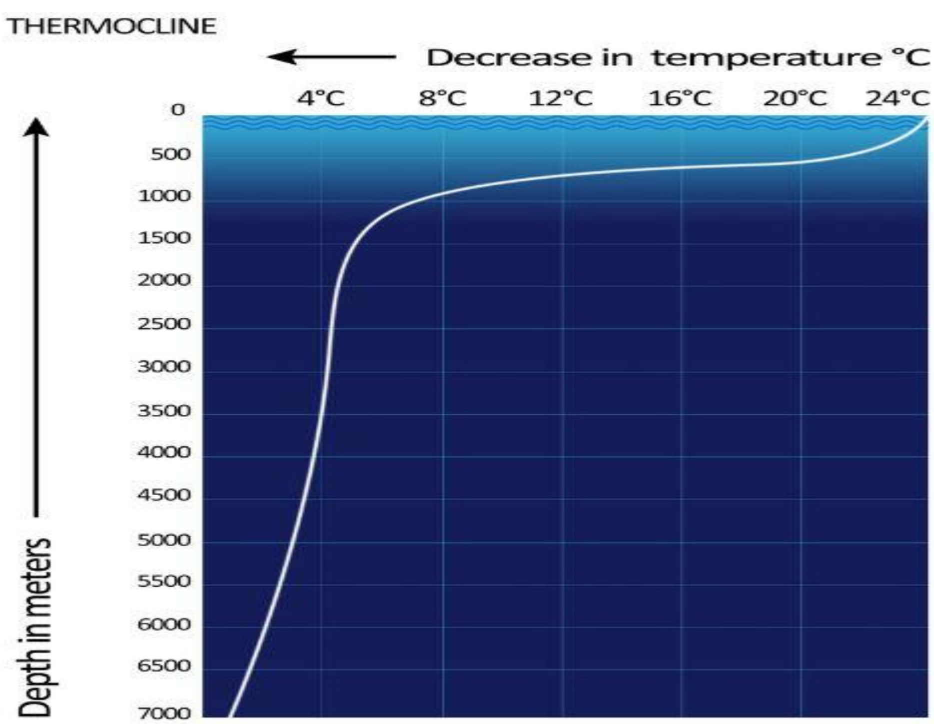


Fig 3.4: Thermocline Layer

3.7. Average Speed Determination for Thermocline Layer

Using the ranges of three factors from Table 3.2 [10], [11], [12], [13], [14], [15], [16] I have calculated the average speed for thermocline layer by Mackenzie Theorem.

$$\iiint c\ dt\ ds\ dd = \int_{450}^{1000}\int_{34}^{34.5}\int_{4}^{10} 144.96 + 4.591T - 5.304\times10^{-2}T^2 + 2.374\times10^{-4}T^3 + 1.340(S-35) + 1.63010^{-2}D + 1.675\times10^{-7}D^2 - 1.025\times10^{-2}T(S-35) - 7.139\times10^{-13}TD\ dt\ ds\ dd$$

$$= \int_{450}^{1000}\int_{34}^{34.5} -\frac{18559073274962493\times D^3}{618970019642690137449562112} + \frac{18983913261135975\times D^2}{188894659314785808547840} + \frac{489\times D}{5000} + \frac{15219\times S}{2000} + \frac{248001466676266894886924763}{288230376151711744000000}\,ds\ dd$$

$$= \int_{450}^{1000} -\frac{18559073274962493\times D^3}{1237940039285380274899124224} + \frac{18983913261135975\times D^2}{377789318629571617095680} + \frac{489\times D}{1000} + \frac{2555134816633599879041151 63}{576460752303423488000000}\,dd$$

$$= 2.4575\times10^{6}\ ms^{-1}$$

Average speed = $(2.4575\times10^{6})/((10-4)\times(34.5-34)\times(1000-450))$ = 1489.4 ms^{-1}

From result, we get the average speed for mixed layer is 1489.4 ms^{-1} which is smaller than our approximate speed value (1500ms^{-1}). In the ocean, the thermocline divides the upper mixed layer from the calm deep water below. In this layer temperature is rapidly decreased (temperature changes more rapidly with depth) than other two layers and salinity is increased. So, the density is increase in thermocline layer. For this reason the average speed of acoustic signal is low in this layer than others two.

From simulation we can see the speed of this layer in graph that will discussed in Chapter 4.

3.8. Deep Water Layer

The deep sea or deep layer is existing below the thermocline and above the seabed at a depth of 1000 fathoms (1800 m) or more [18]. The deep water layer is the bottom layer of water. This layer is characterized by fairly constant cold temperatures, generally less than 4°C. At high latitudes in winter, the water is cold from top to bottom. The vertical temperature profile is essentially isothermal (no change in temperature with depth). At any given depth, the temperature is practically unvarying over long periods of time. There are no seasonal temperature changes, nor are there any annual changes. No other habitat on earth has such a constant temperature. Salinity is remarkably constant throughout the deep sea, at about 35 parts per thousand [16].

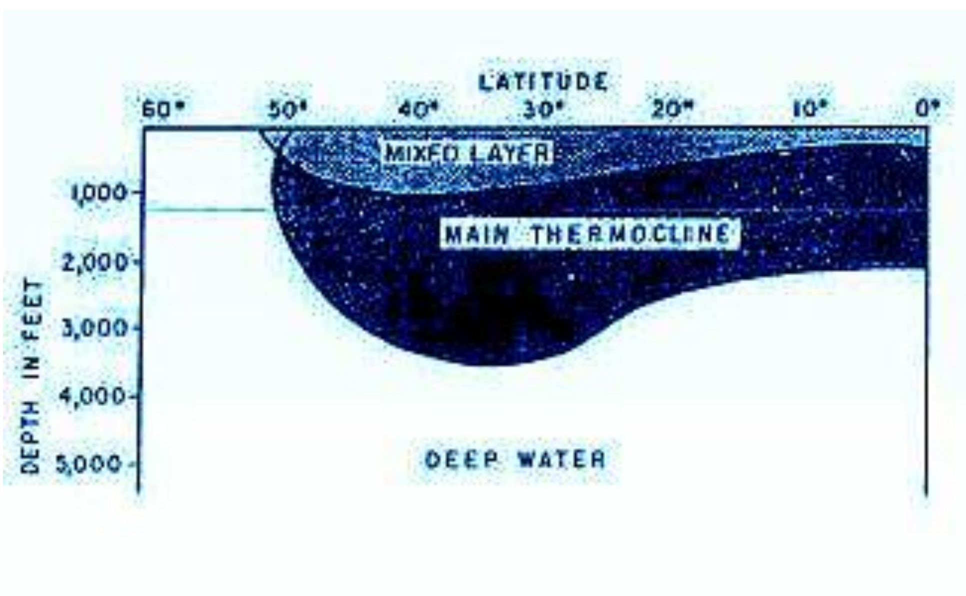


Fig 3.5: Deep Water Layer

3.9. Average Speed Determination for Deep Water Layer

Using the ranges of three factors from Table 3.2 [10], [11], [12], [13], [14], [15], [16] I have calculated the average speed for deep water layer by Mackenzie Theorem

$$\iiint c\ dt\ ds\ dd = \int_{1000}^{8000}\int_{34.8}^{35.1}\int_{2}^{4} 144.96 + 4.591T - 5.304 \times 10^{-2}T^2 + 2.374 \times 10^{-4}T^3 + 1.340(S-35) + 1.63010^{-2}D + 1.675 \times 10^{-7}D^2 - 1.025 \times 10^{-2}T(S-35) - 7.139 \times 10^{-13}TD\ dt\ ds\ dd$$

$$= \int_{1000}^{8000}\int_{34.8}^{35.1} -\frac{2651296182137499 \times D^3}{6189700196426901374495621 12} + \frac{6327971087045325 \times D^2}{944473296573929042 7392} + \frac{163 \times D}{5000} + \frac{5237 \times S}{2000} + \frac{816511306623337165032 99573}{28823037615171174400000}\ ds\ dd$$

$$= \int_{1000}^{8000} -\frac{7953888546412497 \times D^3}{618970019642690137449562 1120} + \frac{3796782652227195 \times D^2}{3777893186295716170 9568} + \frac{489 \times D}{5000} + \frac{252866749037911051269345759}{288230376151711744000000}\ dd$$

$$= 6.4650 \times 10^6\ ms^{-1}$$

Average speed = $(6.465 \times 10^6)/((4-2) \times (35.1 - 34.8) \times (8000 - 1000))$ = 1539.3 ms^{-1}

From result, we get the average speed for mixed layer is 1539.3 ms^{-1} which is large than our approximate speed value (1500ms^{-1}). The vertical temperature profile is essentially isothermal (no change in temperature with depth). This layer is characterized by fairly constant cold temperatures, generally less than 4°C. Salinity is remarkably constant throughout the deep sea. For this reason the average speed of acoustic signal is increased than thermocline layer.

From simulation we can see the speed of this layer in graph that will discussed in Chapter 4.

Chapter 4

Experimental Results and Analysis

A simulation of the proposed method to determinate area of the average acoustic signal as described in chapter 3 was performed to verify the method. The experiment was designed based on 3-D plot using surf() function in Matlab.

Actually there have been used three factors each factor is consider as each axis and speed is considered as 4^{th} axis, So from graph 4D plot will be presented which is not visible. For this limitation there has been considered one factor variable as constant when speed will be seen with respect to other two factors and that is the 3D plot of speed.

Generally the variation of salinity is small than temperature so small. So, the constant value for salinity there didn't saw the major effect on resulting value. There has been seen nearly proper result of speed in 3D plot by considering the salinity as constant. There also be simulated considering the temperature as constant. But depth should not be constant in this case because the salinity and temperature are varied with respect to depth. And speed also varies with the variation of these three factors as well. Simulation of the equation is performed for in general case and for each layer individually.

In Matlab,

X-axis is considered as depth

Y-axis is considered as speed

Z-axis is considered as salinity or temperature

- ⇨ when salinity is considered as constant then Z-axis is considered as temperature
- ⇨ when temperature is considered as constant then Z-axis is considered as salinity

When salinity is considered as constant, the speed of acoustic with respect to depth and temperature of my simulation result is like that--

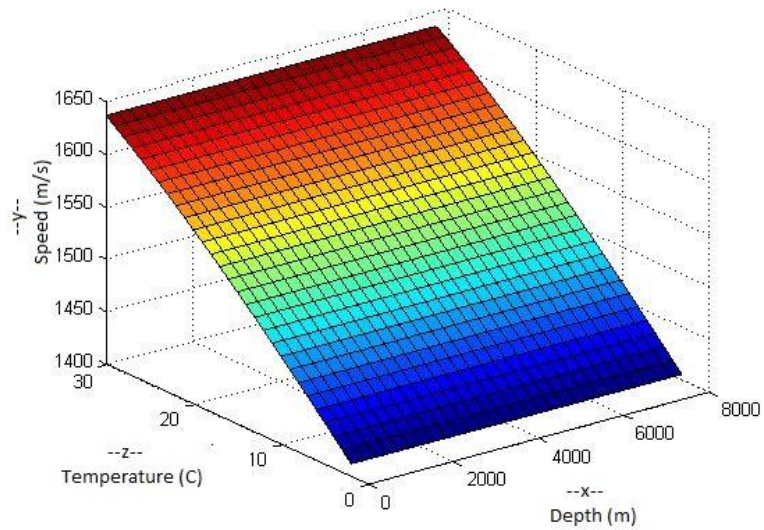


Fig 4.1: Speed With Respect to Temperature and Depth

When temperature is considered as constant, the speed of acoustic with respect to depth and temperature of my simulation result is like that--

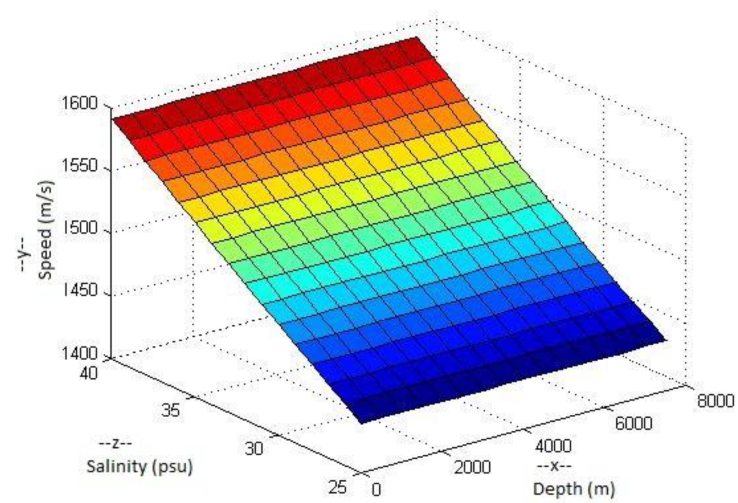


Fig 4.2: Speed With Respect to Salinity and Depth

Mixed Layer Simulation

When salinity is considered as constant, the speed of acoustic with respect to depth and temperature of my simulation result is like that--

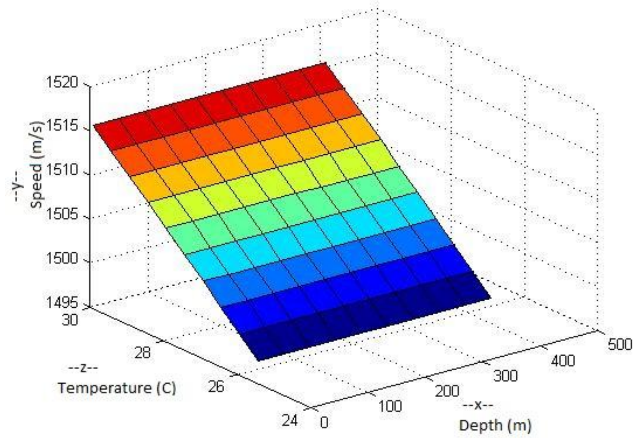


Fig 4.3: Speed With Respect to Temperature and Depth for Mixed Layer

When temperature is considered as constant, the speed of acoustic with respect to depth and temperature of my simulation result is like that--

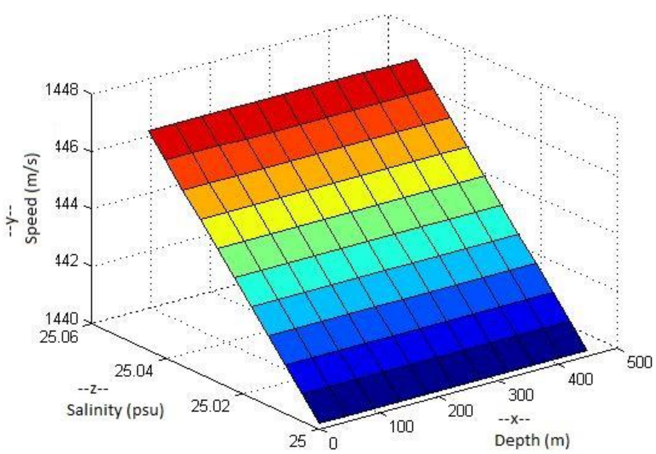


Fig 4.4: Speed With Respect to Salinity and Depth for Mixed Layer

Thermocline Layer Simulation

When salinity is considered as constant, the speed of acoustic with respect to depth and temperature of my simulation result is like that--

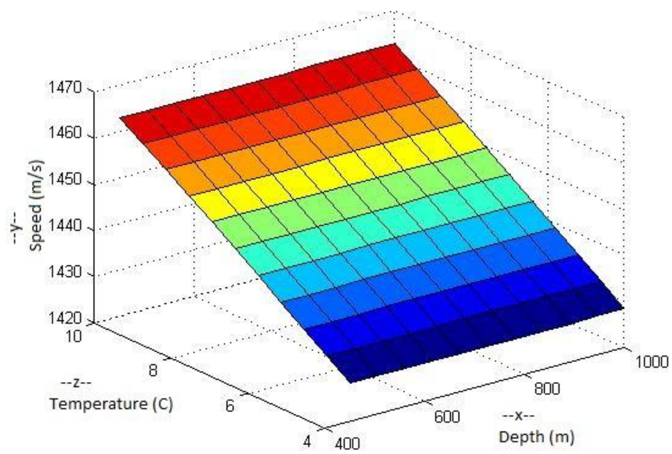


Fig 4.5: Speed With Respect to Temperature and Depth for Thermocline Layer

When temperature is considered as constant, the speed of acoustic with respect to depth and temperature of my simulation result is like that--

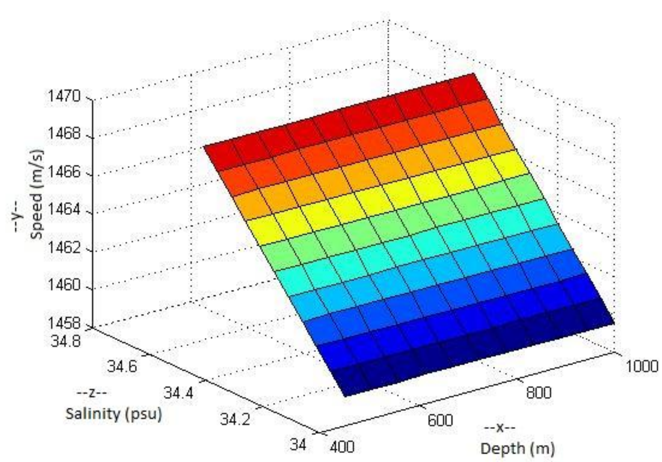


Fig 4.6: Speed With Respect to Salinity and Depth Thermocline Layer

Deep Layer Simulation

When salinity is considered as constant, the speed of acoustic with respect to depth and temperature of my simulation result is like that--

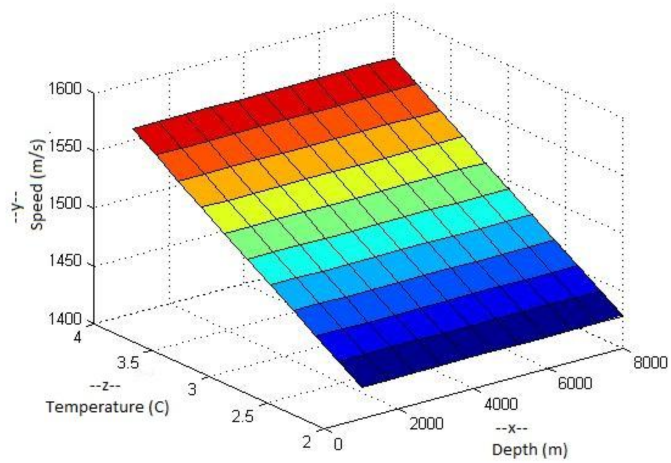


Fig 4.7: Speed With Respect to Temperature and Depth for Deep Layer

When temperature is considered as constant, the speed of acoustic with respect to depth and temperature of my simulation result is like that--

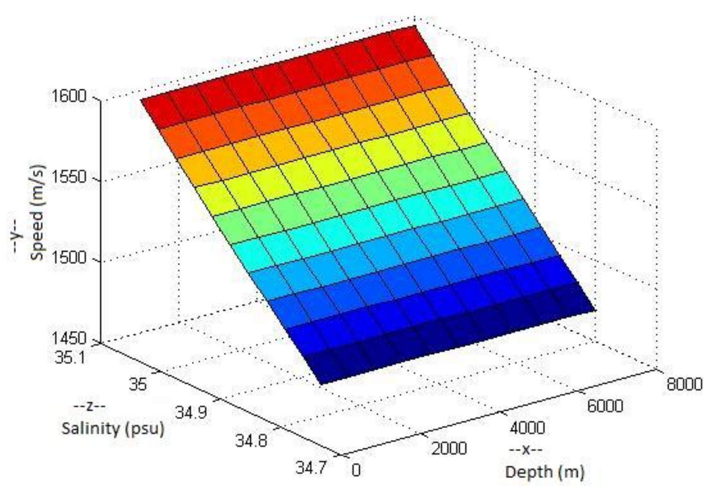


Fig 4.8: Speed With Respect to Salinity and Depth for Deep Layer

Chapter 5
Conclusion and Future Work

5.1. Conclusion

I have described the measurement techniques in underwater acoustic average speed. Mackenzie Theorem requires the need of the value of different factors to measure the speed of sound. Sound occurs because of the properties of sound and the temperature and salinity differences at different depths in the ocean. Measuring the average speed of sound in underwater I have used the ranges of different factors. For simplicity I have used the approximate ranges of those different factors. In this proposed model I assumed at least three factors for my research: **temperature**, **salinity** and **depth**. Measuring the average speed of sound following results are found which are nearly to approximate speed $1500ms^{-1}$ ---

General average speed is $1571.5\ ms^{-1}$.
Mixed layer average speed is $1533.7ms^{-1}$
Thermocline layer average speed is $1489.4ms^{-1}$
Deep layer average speed is $1539.3ms^{-1}$

5.2. Applications

Here I have calculated the average speed of acoustic signal which will be beneficial for localization and navigation system. For localization it very important to measure the distance os object for which speed measurement requires must. Now-a-days localization system plays an important role in various necessary issues such as ---

Submarine Navigations
Military Operations and surveillance
Oceanographic data collection etc.

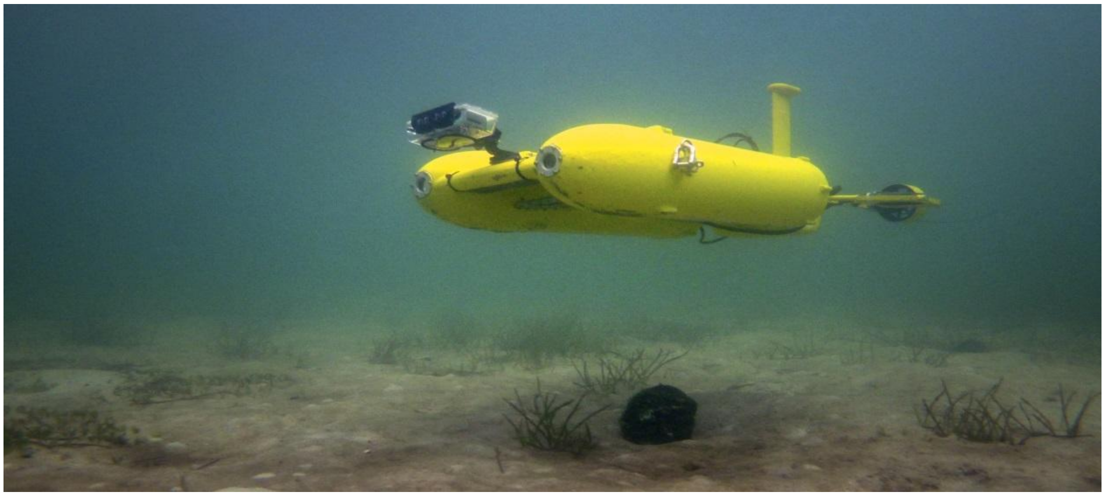


Figure 5.1: Autonomous Underwater Vehicle (AUV)

There have been used many numbers of devices or vehicles for localization system. For calculating the speed it is needed to collect the ranges values of different factors i.e. temperature, salinity and depth. For getting these values different sensors are attached with the devices or vehicles. By using these values of different factors the average speed can be calculated which will be beneficial for localization.

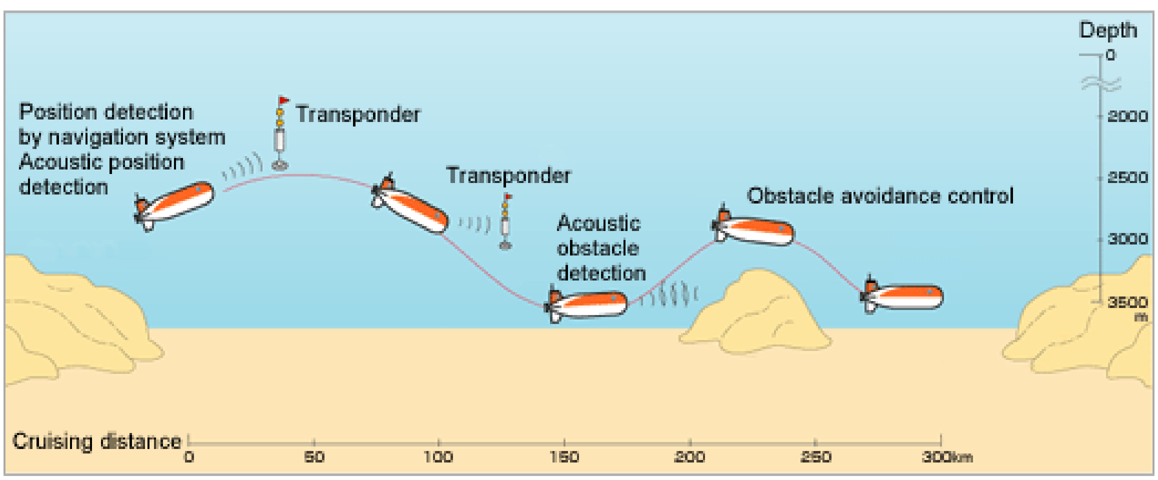


Figure 5.2: Functions of AUV for Localization

5.3. Future Work

Underwater wireless communications links have almost exclusively been implemented using acoustic systems. Optical links have proved impractical for many applications. Although underwater radio links were experimentally evaluated in the pioneering days of radio, they did not meet the requirements of the time. Given modern operational requirements and digital communications technology, the time is now ripe for re-evaluating the role of electromagnetic signals in the underwater environment [21].

Underwater electromagnetic communications have been investigated since the very early days of radio and again received considerable attention during the 1970s [21].

I have measured the average speed of acoustic signal which possible to determine in-situ by considering environmental factors collected by the sensors.

In future I will try to explore the propagation model of radio signal in underwater.

References

[1] An Introduction to Acoustics S.W. Rienstra & A. Hirschberg Eindhoven University of Technology 5 May 2016,

[2] M.Stojanovic, J.Catipovic and J.Proakis, "Adaptive multichannel combining and equalization for underwater
acoustic communications," Journal of the Acoustical Society of America,vol.94 (3), Sept. 1993, pp.1621-1631.

[3] M.Stojanovic, "Frequency reuse underwater: capacity of an acoustic cellular network," in Proc. Second ACM International Workshop on Underwater Networks (WuwNet/MobiCom), 2007

[4] Mandar Chitre1 , Shiraz Shahabudeen1 , Lee Freitag2 , Milica Stojanovic3 1 Acousti Research Laboratory, National University of Singapore 2 Woods Hole Oceanographi Institution 3 Massachusetts Institute of Technology, (Recent Advances in Underwater Acoustic Communications & Networking)

[5] http://www.dosits.org/people/history/1800s/

[6] Underwater Acoustic Networks – Issues and Solutions-- Zaihan Jiang INTERNATIONAL JOURNAL OF INTELLIGENT CONTROL AND SYSTEMS VOL. 13, NO. 3, SEPTEMBER 2008,152-161

[7] Lurton, X. An Introduction to Underwater Acoustics, 1st ed. London, Praxis Publishing LTD, 2002, p3(https://www.usna.edu/Users/physics/ejtuchol/documents/SP411/Chapter4.pdf).

[8] 1996 - 2003 M. Tomczak. Last updated 23/4/03

[9] United States Naval Academy-SP411(Chapter4)

[10] References Craig, H (1969) Abyssal carbon and radiocarbon in the Pacific, Jour. Geophys. Res., 74, 5491-5506.

[11] Mann, K.H. and J.R.N. Lazier (1991) Dynamics of Marine Ecosystems, Blackwell Sci. Pub. , Boston, 466 p.

[12] Munk, W.H. and G.G. Carrier (1950) The wind-driven circulation in the ocea basins of various shapes, Tellus, 2, 158-167.

[13] Munk W.H. (1966) Abyssal recipes, Deep-Sea Res.,13, 707-730.

[14] Pond, S. and G.L. Pickard (1983) Introductory Dynamical Oceanography, 329 p. Pergamon, N.Y.

[15] Stommel, H. (1958) The abyssal Circulation, Deep-Sea Res., 5, 80-82.

[16] Questa pagina è stata realizzata da Vittorio Villasmunta Ultimo aggiornamento: 27/02/16

[17] JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, C06013, doi:10.1029/2006JC004051, 2008

[18] Navy Supplement to the DOD Dictionary of Military and Associated Terms (PDF). Department Of The Navy August 2006. NTRP 1-02.

[19] Craig, H (1969) Abyssal carbon and radiocarbon in the Pacific, Jour. Geophys. Res., 74, 5491-5506. Mann, K.H. and J.R.N. Lazier (1991) Dynamics of Marine Ecosystems, Blackwell Sci. Pub. , Boston, 466 p. Munk, W.H. and G.G. Carrier (1950) The wind-driven circulation in the ocean basins of various shapes, Tellus, 2, 158-167. Munk W.H. (1966) Abyssal recipes, Deep-Sea Res., 13, 707-730. Pond, S. and G.L. Pickard (1983) Introductory Dynamical Oceanography, 329 p. Pergamon, N.Y. Stommel, H. (1958) The abyssal Circulation, Deep-Sea Res., 5, 80-82.

[20] Sprintall, J., and M. Tomczak, Evidence of the barrier layer in the surface-layer of the tropics, Journal of Geophysical Research-Oceans, 97 (C5), 7305-7316, 1992.

[21] Underwater Electromagnetic Propagation - 01/01/2008 Mark Rhodes, engineering manager, Wireless Fibre Systems Ltd, UK

Appendix

CODE

//Average Speed for General Case:

```
syms s
syms d
syms t


A1=1448.96;
A2=4.591;
A3=5.304e-2;
A4=2.374e-4;
A5=1.340;
A6=1.630e-2;
A7=1.675e-7;
A8=1.025e-2;
A9=7.139e-13;

fun1=A1+(A2*t)-(A3*t^2)+(A4*t^3)+(A5*(s-35))+(A6*d)+(A7*d^2)-(A8*t*(s-35))-
(A9*t*d^3);

fun2=int(fun1,2,30);

fun3=int(fun2,25,40);

fun4=int(fun3,0,8000);

result=double(fun4/(28*15*8000));
```

Average Speed for Mixed Layer:

```
syms t
syms s
syms d

A1=1448.96;
A2=4.591;
A3=5.304e-2;
A4=2.374e-4;
A5=1.340;
A6=1.630e-2;
A7=1.675e-7;
A8=1.025e-2;
A9=7.139e-13;
```

```
fun1=A1+(A2*t)-(A3*t^2)+(A4*t^3)+(A5*(s-35))+(A6*d)+(A7*d^2)-(A8*t*(s-35))-
(A9*t*d^3);

fun2=int(fun1,25.5,30);

fun3=int(fun2,25,25.045);

fun4=int(fun3,0,450);

result=double(fun4/(4.5*0.045*450));
```

Average Speed for Thermocline Layer:

```
syms t
syms s
syms d

A1=1448.96;
A2=4.591;
A3=5.304e-2;
A4=2.374e-4;
A5=1.340;
A6=1.630e-2;
A7=1.675e-7;
A8=1.025e-2;
A9=7.139e-13;

fun1=A1+(A2*t)-(A3*t^2)+(A4*t^3)+(A5*(s-35))+(A6*d)+(A7*d^2)-(A8*t*(s-35))-
(A9*t*d^3);

fun2=int(fun1,4,10);

fun3=int(fun2,34,34.5);

fun4=int(fun3,450,1000);

result=double(fun4/(6*.5*550));
```

Average Speed for Deep Layer:

```
syms t
syms s
syms d

A1=1448.96;
A2=4.591;
A3=5.304e-2;
A4=2.374e-4;
A5=1.340;
A6=1.630e-2;
```

```
A7=1.675e-7;
A8=1.025e-2;
A9=7.139e-13;

fun1=A1+(A2*t)-(A3*t^2)+(A4*t^3)+(A5*(s-35))+(A6*d)+(A7*d^2)-(A8*t*(s-35))-
(A9*t*d^3);

fun2=int(fun1,2,4);

fun3=int(fun2,34.8,35.1);

fun4=int(fun3,1000,8000);

result=double(fun4/(2*.3*7000));
```

Matlab Code for Graph

Speed with Respect to Temperature and Depth

Function Code:

```
function [ speed ] = test_of_speed_T_D(t,d)
A1=1448.96;
A2=4.591;
A3=5.304e-2;
A4=2.374e-4;
A5=1.340;
A6=1.630e-2;
A7=1.675e-7;
A8=1.025e-2;
A9=7.139e-13;

speed=A1+(A2*t)-(A3*t^2)+(A4*t^3)+(A5*(-35))+(A6*d)+(A7*d^2)-(A8*t*(-35))-
(A9*t*d^3);
end
```

//General:

```
t=2:.2:4;
d=1000:700:8000;

speed=zeros(length(t),length(d));

for j=1:length(d)
    for i=1:length(t)
    speed(i,j)=test_of_speed_T_D(t(i),d(i));
    end
end

surf(d,t,speed);
```

//Mixed layer:

```
t=25.45:.5:30;
d=0:45.1:450;

speed=zeros(length(t),length(d));

for j=1:length(d)
    for i=1:length(t)
    speed(i,j)=test_of_speed_T_D(t(i),d(i));
    end
end

surf(d,t,speed);
```

//Thermocline layer:

```
t=4:.6:10;
d=450:55:1000;

speed=zeros(length(t),length(d));

for j=1:length(d)
    for i=1:length(t)
    speed(i,j)=test_of_speed_T_D(t(i),d(i));
    end
end

surf(d,t,speed);
```

//Deep layer:

```
t=2:.2:4;
d=1000:700:8000;

speed=zeros(length(t),length(d));

for j=1:length(d)
    for i=1:length(t)
    speed(i,j)=test_of_speed_T_D(t(i),d(i));
    end
end

surf(d,t,speed);
```

Speed with Respect to Salinity and Depth

Function code:

```
function [ speed ] = test_of_speed_S_D(d,s)
A1=1448.96;
A2=4.591;
A3=5.304e-2;
A4=2.374e-4;
A5=1.340;
A6=1.630e-2;
A7=1.675e-7;
A8=1.025e-2;
A9=7.139e-13;
speed=A1+(A2)-(A3)+(A4)+(A5*(s-35))+(A6*d)+(A7*d^2)-(A8*(s-35))-(A9*d^3);
end
```

//General:

```
s=25:1:40;
d=0:500.0625:8000;

speed=zeros(length(s),length(d));

for j=1:length(s)
    for i=1:length(d)
    speed(i,j)=test_of_speed_S_D(d(i),s(i));
    end
end

surf(d,s,speed);
```

//Mixed layer:

```
s=25:.0045:25.045;
d=0:45:450;

speed=zeros(length(s),length(d));

for j=1:length(s)
    for i=1:length(d)
    speed(i,j)=test_of_speed_S_D(d(i),s(i));
    end
end

surf(d,s,speed);
```

//Thermocline layer:

```
s=34:.05:34.5;
d=450:55:1000;

speed=zeros(length(s),length(d));

for j=1:length(s)
    for i=1:length(d)
    speed(i,j)=test_of_speed_S_D(d(i),s(i));
    end
end

surf(d,s,speed);
```

//Deep layer:

```
s=34.8:.03:35.1;
d=1000:700:8000;

speed=zeros(length(s),length(d));

for j=1:length(s)
    for i=1:length(d)
    speed(i,j)=test_of_speed_S_D(d(i),s(i));
    end
end

surf(d,s,speed);
```