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Determination of the shadow zone area in the ocean computationally by simulating the propagation of acoustic rays

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ABSTRACT

Simulation of acoustic wave propagation to determine the shadow zone area using computational methods has been carried out using negative value gradients. The study was conducted by varying the angle of incidence and variations in the length of the beam used. This research was conducted by comparing analytical results with computational results. The results of this study indicate that at a depth of 500 meters with a sound speed of 1493.1 m/s, a beam length of 1 meter, and a gradient pattern of -0.1, a maximum angle of 0.255 radians is obtained with the shadow zone area being at a depth of 0 to 800 meters and a distance of 5000 meters of wave source. The value of the difference or error in analytical data and computational data is 0.0817%.

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1. INTRODUCTION

As technology advances, many foreign submarines are currently using underwater areas to carry out transnational operations. One of the underwater areas that is used is the shadow zone [1, 2]. A shadow zone is a zone that is formed because sound waves cannot enter a medium because they are deflected due to differences in the speed of sound waves [3-5]. This bending of sound waves occurs due to differences in temperature, salinity, and depth of seawater in the water column [6-11].

A Shadow Zone is an area where sound waves cannot enter a medium because they are deflected due to differences in the speed of sound waves [12, 13]. In the water column, sound waves experience bending of sound waves (refraction) which occurs due to differences in depth, salinity, and temperature of seawater [14-16].

The most obvious effect is that if there is an increase in seawater temperature of 1°C, it will cause an increase in sound wave speed of 1 m/s, while in the surface layer the increase in sound speed increases due to an increase in temperature of 3 $m.s^{-1}$/°C. As a result, if the temperature increases with depth, the sound waves emitted will tend to be bent towards the surface of the water where the temperature is higher [17, 18]. On the other hand, if the temperature decreases due to depth, the sound waves will continue to travel toward the bottom of the water and slowly bend towards the bottom of the water [19]. The national defense system uses sound navigation and ranging (Sonar) technology in underwater detection patrols. However, sonar installed on national defense system patrol ships is still very limited, so other efforts are needed in defense development [20].

One of these efforts is determining the shadow zone using computational methods. It is important to carry out this research because we cannot directly detect the presence of submarines underwater. So the researchers carried out shadow zone detection using a computational method that will indirectly detect the presence of a submarine hiding in the shadow zone.

2. LITERATURE REVIEW

Acoustics means everything related to hearing in a room condition that can affect the quality of sound. Acoustics has the aim of achieving perfect sound hearing conditions, namely pure, even, clear, and not buzzing so that it is the same as the original, free from defects and noise [21, 22]. Acoustic wave equation:

$$\frac{\partial^2 \Delta p}{\partial t^2} = c_0{}^2 . \frac{\partial^2 \Delta p}{\partial z^2} \quad (1)$$

The speed of sound as a function of depth can be described by a simple linear equation. These results can be used to find functions for the sound ray radius of other quantities. The sound speed gradient g is shown as a dotted line. The speed of sound at layer i + 1 is expressed by the following equation:

$$c_{i+1} = c_i + g_i \Delta z_i \quad (2)$$

$$\frac{\cos(\theta 1)}{c1} = \frac{\cos\theta}{c} \quad (3)$$

$$\frac{\cos(\theta 1)}{c1} = \frac{\cos\theta}{c1+gz} \quad (4)$$

$$gz \cos\theta 1 = c1 \,(\cos\theta - \cos\theta 1) \quad (5)$$

$$z = R\,(\cos\theta - \cos\theta 1) \quad (6)$$

where $R = \frac{c1}{g \, Cos\, \theta 1}$ is the radius of curvature of the sound ray [23].

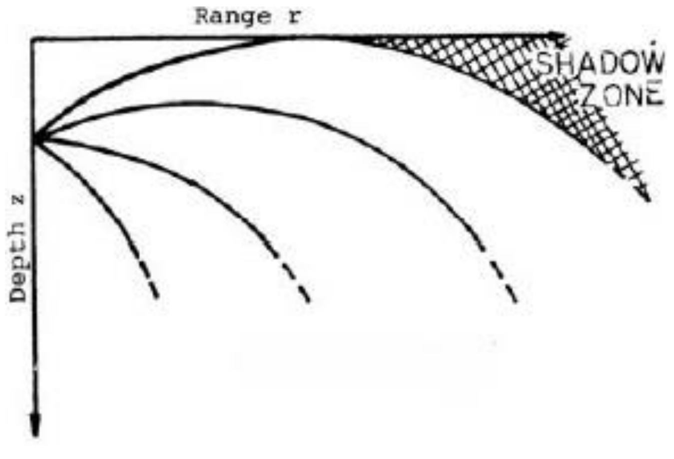


Figure 1. Formation of the shadow zone under the sea [24].

A shadow zone is an area where sound waves cannot propagate in a medium (see in Figure 1). In the water column, sound waves experience bending of sound waves (refraction) which occurs due to differences in depth, salinity, and temperature of seawater.

A shadow zone is a zone that is formed because sound waves cannot enter a medium because they are deflected due to differences in the speed of sound waves. This shadow zone is important to detect because it can be used or exploited by foreign submarines to approach surface contact without being detected [6, 25].

3. RESEARCH METHODS

This research was carried out in April – July 2019 at the Computational Physics Laboratory, Faculty of Mathematics and Natural Sciences, Riau University, Bina Widya Campus, Simpang Baru, Tampan District, Pekanbaru. The research material used is program-based data processing software, namely Matlab R2018a. Meanwhile, the equipment used is a Personal Computer (PC) or Laptop. This research uses sound speed data per sea depth with a negative gradient pattern (sound speed decreases with depth). The parameters of this research include depth (m), distance (m), beam length (m), angle (rad), and gradient.

4. RESULTS AND DISCUSSIONS

Figure 2 (a) is a sound speed profile in sea layers or depths from 1 m to 1000 m. This layer is between the surface and the bottom of sea waters (between the surface channel and the deep channel). This layer is also called the thermocline layer. The vertical distribution of sound speed in the graphic profile appears to be relatively uniform in the surface area, but as the depth approaches a depth of 100 m - 200 m the sound speed decreases sharply and then decreases with the depth of the water until it reaches a depth of 700 m. At a depth of less than 60 m, the speed of sound tends to be constant because at this depth it is a mixed layer where there is still penetration of sunlight and mixing of water masses due to stirring by the wind so that the temperature tends to be uniform as a result the sound speed obtained will be relatively constant.

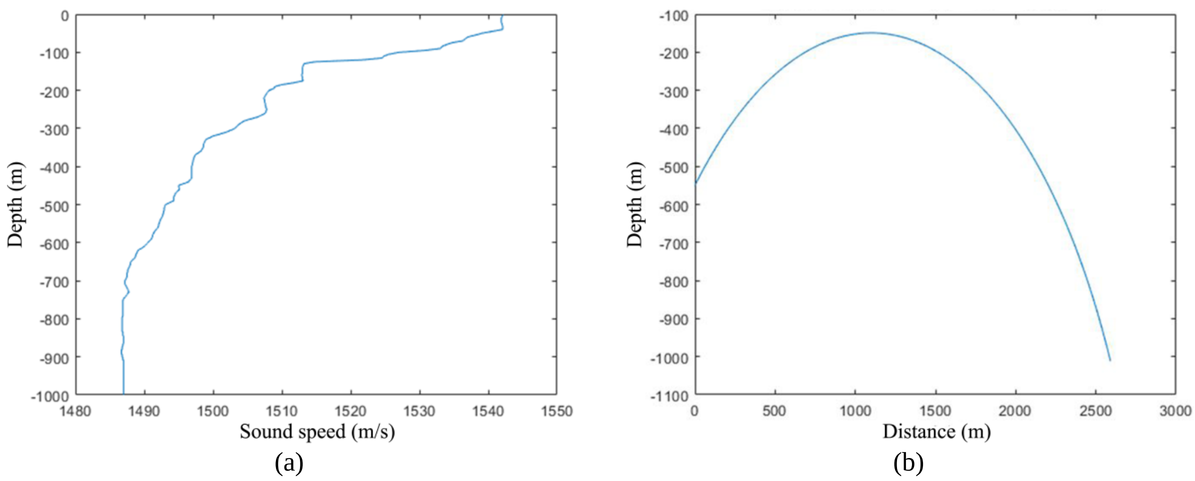
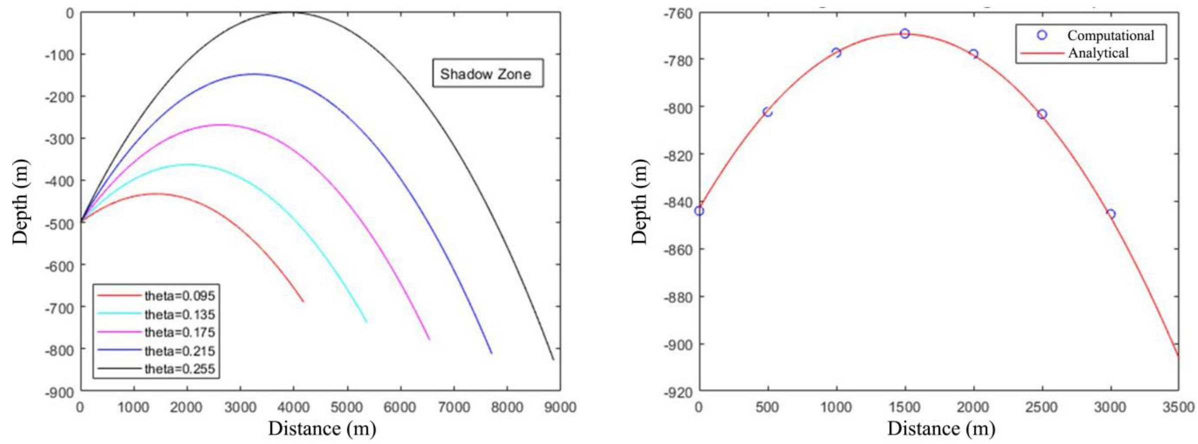


Figure 2. (a) Sound speed profile per sea depth [2] and (b) wave simulation resulting from a negative gradient.

Below the mixed layer, the speed of sound experiences a relatively sharp decrease at a relatively short depth due to the presence of a thermocline layer where at the same time there is an increase in salinity values. Below a depth of 700 m, the speed of sound will increase with increasing depth, where depth (pressure) is a determining factor in this area because the decrease in temperature and increase in salinity proceed very slowly.

Changes in wave propagation speed with depth will be manifested through wave refraction. As the light gets deeper, the light will begin to refract. When rays move into a medium that has a slower propagation or propagation speed, the rays tend to become more vertical. Overall, the rays will bend downwards in a negative gradient (Figure 2 (b)). The simulation above illustrates that if the negative sound velocity gradient increases, the sound will be refracted downwards at a greater angle and will cause a reduction in the direct path range to the target below the surface layer. The changes in sound speed mentioned above are often seen as sudden changes in the sound speed profile.

Variations in layer depth cause changes in the speed of sound (can increase or decrease) (Figure 3 (a)). This change in sound speed causes the sound to bias as it travels between areas with different sound speeds, bending or refracting towards regions with lower sound speeds. The greater the sound speed gradient between regions, the greater the amount of refraction. Refraction of sound in seawater is an important aspect of acoustic propagation because certain refraction patterns lead to characteristic propagation paths.



(a) (b)

Figure 3. (a) Simulation of the formation of a shadow zone area and (b) simulation comparing analytical data with computational data.

In this situation, there is a negative vertical gradient in the speed of sound, and the layer depth is at zero depth. Negative sound speed gradients are usually caused by decreasing temperature at depth. Waves will always be refracted or bent towards areas with slower sound speeds so that in a negative sound speed gradient they bias downwards. In this case, the wave will tend to propagate downwards until the temperature becomes isothermal and increasing pressure will increase the speed of sound. Negative sound speed gradients are usually caused by decreasing temperature at depth. Waves will always be refracted or bent towards areas with slower sound speeds so that in a negative sound speed gradient they bias downwards. In this case, the wave will tend to propagate downwards until the temperature becomes isothermal and increasing pressure will increase the speed of sound. In the case where the gradient is negative, rays that have reached the boundary will be reflected back to the center, regardless of whether the rays are rising or falling. When light penetrates below the layer, it is bent downwards. Because of this, the rays diverge above and below the layers. Beyond a certain minimum range, rays from the source will never reach the location directly below the layer, this is called the shadow zone. This is the preferred depth for submarines to operate. The optimal depth for operating a submarine is called the best depth. This depth will be very dangerous if it cannot be detected.

Analytical data and computational data were both taken at a certain depth (Figure 3 (b)), the aim being to show differences during the simulation, where acoustic waves were both fired from a depth of 844 m below sea level with a sound speed of 1486.9 ms-1, gradient 0.1, beam length 2 m, and with an angle of 0.1 rad. The two waves both propagate as far as ±3500 m and a depth of more than 900 m with the peak of the wave at a depth of ±770 m. The results obtained can be said to be the same without any differences, but after calculating the percentage error, it is still adapted to a fraction of a percent error in the analytical data, but in the formation simulation graph the difference will not be visible at all. Based on analytical and computational comparison calculations taken on seven data points or at a distance of several meters, the error percentage obtained at the first point or a distance of 0 m is 0%, at the second point or a distance of 500 m is 0.0708%, at the third point or a distance of 1000 m by 0.0200%, at the fourth point or a distance of 1500 m by 0.0268%, at the fifth point or a distance of 2000 m by 0.0684%, at the sixth point or a distance of 2500 m by 0.1124%, and at the seventh point or a distance of 3000 m by 0.1546%. So we get an average error percentage of 0.0817%.

The speed of sound decreases drastically due to the thermocline area. In the open sea, this layer is characterized by a negative sound velocity gradient which can refract sound waves. Technically, this layer protects against discontinuous acoustic impedance created by sudden changes in density. This unique characteristic is what makes it important to know the thermocline layer, especially in the field of defense and security (submarines). The thermocline layer has the characteristic of being able to reflect and deflect incoming sound waves. As a result of the decrease in the speed of sound, sound waves deflect to the surface and to the bottom of the water, so there is an area where sound waves do not propagate, which is called the shadow zone, and because of refraction, vertical variations in the speed of sound in the sea then produce what is called the shadow zone. The shadow zone is an area where sound waves cannot propagate or are bent so that they can barely propagate in a medium, due to various factors, such as reflection, refraction, and absorption of sound waves by the water column.

5. CONCLUSION

Based on the research results, it can be concluded that the average shadow zone area is found at a depth of 0 to 800 m with a distance of between 4000 to 9000 m and forms a triangular area, and the relative error percentage between analytical data and computational data is 0.0817%.

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