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A computational model of acoustic ray propagation in the deep-sound channel axis ocean region based on the Euler-Cromer method

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ABSTRACT

Research on the model of sound wave propagation in the ocean on the axis of the deep sound channel has been carried out using discrete acoustic ray propagation with varying beam lengths. This study aims to obtain parameter values in the form of maximum angle of incidence and effective beam length to simulate acoustic wave propagation around the axis of the deep sound channel. The research was conducted by simulating the acoustic beam at a depth with the minimum acoustic velocity value by varying the angle of incidence and the length of the applied beam. In this study, constant acoustic velocity gradient and gradient data were used. Calculation of the velocity gradient from discrete data using the Euler-Crommer formula. From this research, it can be seen that at a depth of 854 m the minimum acoustic velocity is 1487.53 m/s. For a constant gradient with a value of 0.054 and variations in beam length from 1 m to 4 m, the maximum angle of incidence is 0.4 radians. Analytically, the radius of curvature of the rays is 28107.12 m. Comparing the analysis and computation results, there is a very small error of 0.02%, so this model can be used to simulate acoustic wave propagation based on real data gradients. The gradient pattern based on real data and variations in beam length from 1 m to 4 m, obtained a maximum angle of incidence of 0.4 radians.

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1. INTRODUCTION

Sound is one of the physical phenomena that we often encounter in everyday life. Sound is widely used for various purposes [1-3]. Along with the development of the world today, sound waves can be used in various fields, one of which is in the marine field, for example to measure the depth of the sea [4], look for groups of fish [5], and look for shipwrecks [6]. This is inseparable from the application of the principle of acoustic waves to current marine technology.

Acoustic waves or sound that propagates in the ocean can carry information over long distances, therefore acoustic waves are used as a medium for carrying messages in water media [7-9]. A unique condition that appears at a certain depth under the sea can be used as a carrier of information or long-distance communication, this condition is called the deep-sound channel axis (DSCA) [10, 11]. Long-range can help good detection to get targets that are in the DSCA area.

The purpose of this research is to model the acoustic wave propagation in DSCA with various angles using MATLAB and determine the maximum wave propagation angle. The method used is the Euler-Cormer iteration method with a derivative of Snell's law.

2. LITERATURE REVIEW

Sound waves are longitudinal mechanical waves that can propagate in solid, liquid, and gaseous mediums [12]. Sound in air is a longitudinal wave, whereas the speed of sound waves in air is a particle that applies to sound waves in solid media [13]. Sound can propagate in seawater, the deeper the seawater the greater the air density or air pressure increases. Changes in air density will make the speed of sound waves also change [14]. The physical factors of sea air that are the most decisive in influencing the speed of sound in sea air are temperature, salinity, and pressure [15]. In sea air, the speed of sound waves is close to 1,500 m/s (generally ranging from 1,450 m/s to 1,550 m/s, depending on temperature, salinity, and pressure) [16]. The sound that propagates in a homogeneous medium such as in seawater will be deflected because it experiences a deflection of direction. This deflection is caused by variations in temperature, salinity, and depth [13].

The speed of sound against the depth of sound velocity profile can be obtained by hydrographic observations in the form of measurements of temperature, salinity, and depth [17]. The depth at which there is a minimum speed value is called the DSCA. This depth is the beginning of the thermocline and the beginning of the isothermal layer [18]. Snell's law plays a very important role as a boundary condition for each layer. Snell's law states that there is a relationship between the angle of the wave formed and the speed of sound for a medium having a constant velocity layer [17].

The speed of sound as a function of depth can be described by a simple linear equation. The speed of sound, shown as a dotted line, can be expressed as (c_i is the speed at layer i):

$$c_{i+1} = c_i + g_i \Delta z_i \tag{1}$$

where g is the gradient from Snellius and plugging in the equation for c, we get:

$$\frac{cos\,\theta_1}{c_1} = \frac{\cos\,\theta}{c_1+gz} \tag{2}$$

$$gz\cos\theta_1 = c_1(\cos\theta - \cos\theta_1) \tag{3}$$

$$z = R(\cos\theta - \cos\theta_1) \tag{4}$$

$$R = \frac{c_1}{g\,\cos\,\theta_1} \tag{5}$$

Equation (5) is the radius of curvature of the sound ray.

3. RESEARCH METHODS

The mathematical equation used in this study is the Euler-Cromer iteration equation of Snell's law. The Euler-Cromer method is a method for solving ordinary differential equations by utilizing the description of the Taylor series. In this study, the Euler-Cromer method was applied to determine the value of the speed of sound at a depth of layer $i + 1$ to be:

$$c_{i+1} = c_i + \frac{g_i+g_{i+1}}{2} \Delta z_i \tag{6}$$

In the Euler-Cromer method, to determine the value of the speed of sound at layer $i + 1$, it is calculated using the average value of the gradient g between layers i and $i + 1$.

The data to be used is the speed of sound data against the depth of seawater. The data used in this study were obtained from the website of the National Oceanic and Atmospheric Administration. From these data, the parameters to be used will be determined, namely the surface speed of sound (c_0), the minimum speed of sound (c), depth (z), the location of minimum sound velocity, and gradient (g). The flow diagram of this research simulation program can be seen in Figure 1. The analysis is carried out by drawing conclusions from the results displayed in the form of sound wave propagation in the DSCA area and will determine the maximum sound wave propagation angle.

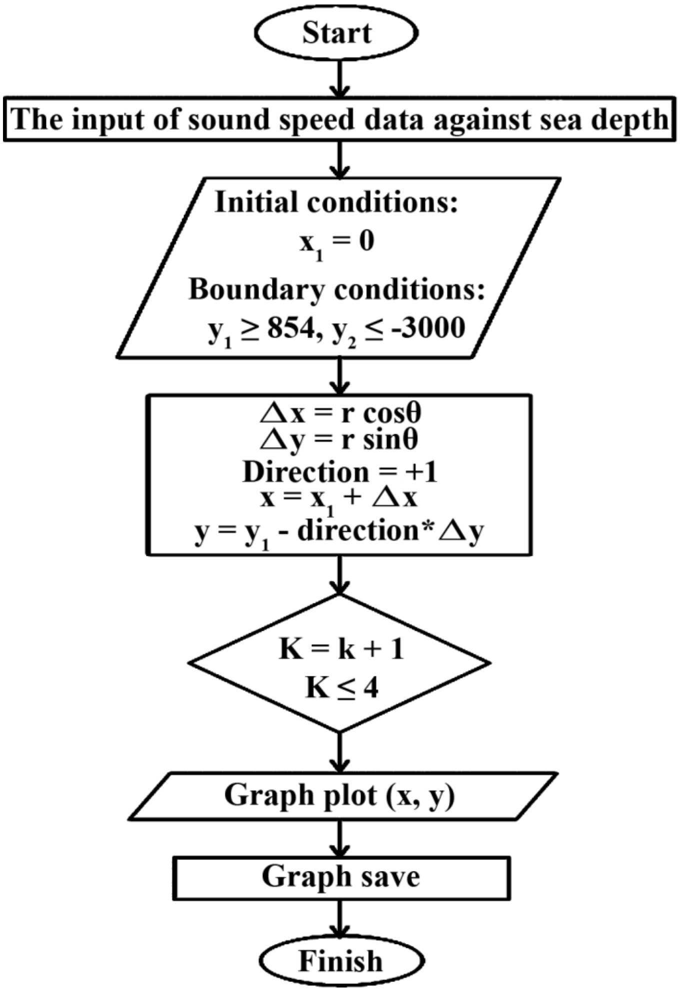

Figure 1. Simulation program flowchart

4. RESULTS AND DISCUSSIONS

Based on Table 1, it can be seen that the minimum velocity is at a depth of 854 m and the gradient can be determined by:

$$g = \frac{c_1 - c_0}{\Delta z} = \frac{1487.53\frac{m}{s} - 1533.86\frac{m}{s}}{854\ m} = 0.054\ sec^{-1} \tag{7}$$

Table 1. Speed of sound by depth

Depth (m)	Speed of Sound (m/s)
0	1533.86
50	1531.02
200	1514.71
460	1495.20
646	1489.28
854	1487.53
1000	1487.87

The simulation in Figure 2 shows that the propagation of waves emitted from the same point at different angles will expand the propagation area. The bigger the angle, the farther away the wave is. The greater the distance (radius) the more surface area covered or the farther the distance traveled, which is proportional to the square of the radius [19]. This model shows a maximum propagation angle of 0.4.

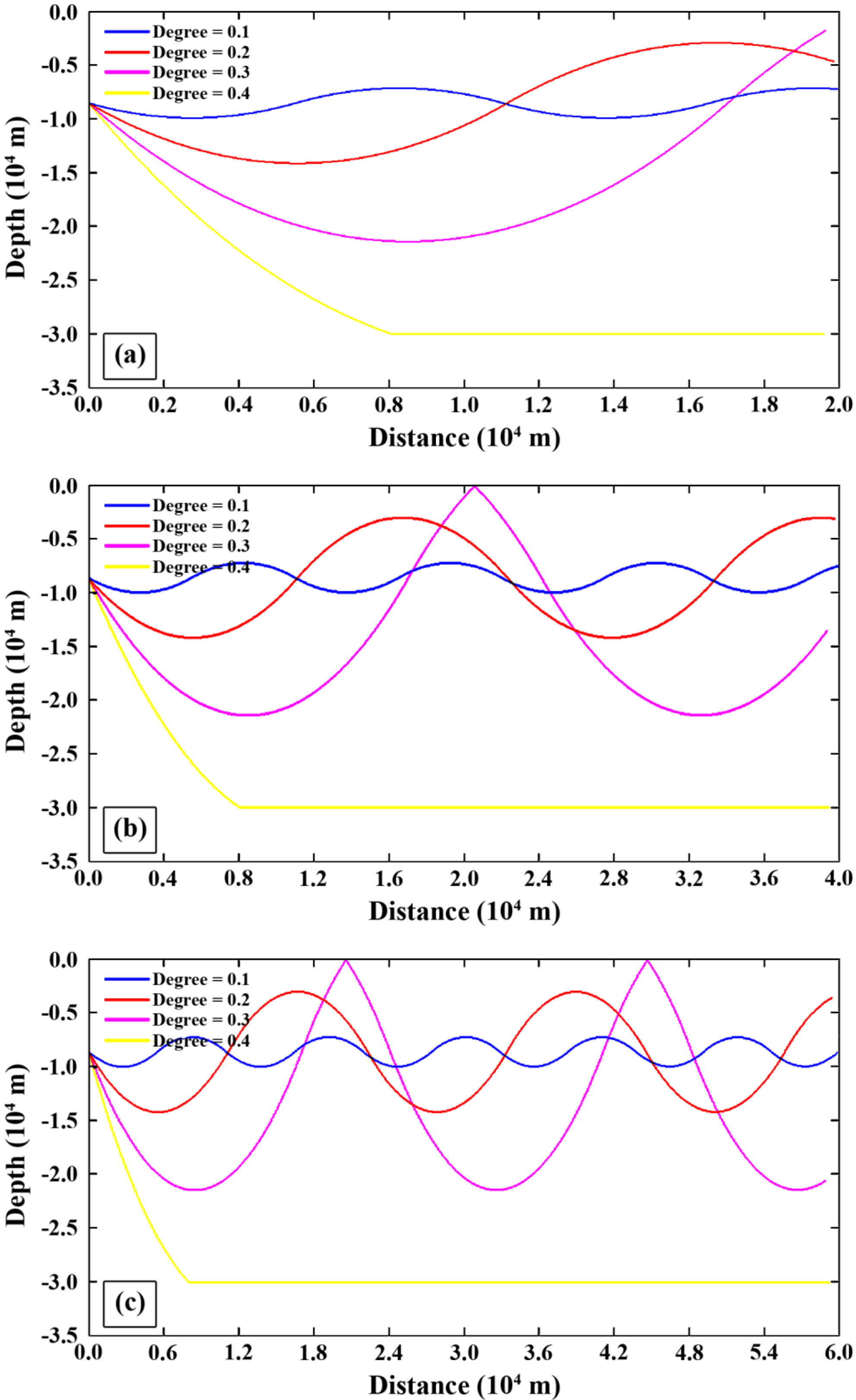

Figure 2. Sound wave propagation model with distance (a) 2 × 10^4 m, (b) 4 × 10^4 m, and (c) 6 × 10^4 m

The comparison between the analytical and numerical as shown in Figure 3 uses an angle of 0.1 with a gradient of 0.054 sec^{-1}. Computational modeling is carried out with radius variations, but it does not affect the results obtained. The result will be different if vary the angle. The graph shows a comparison with a fairly small error, expressed in percent, which is about 0.0461%.

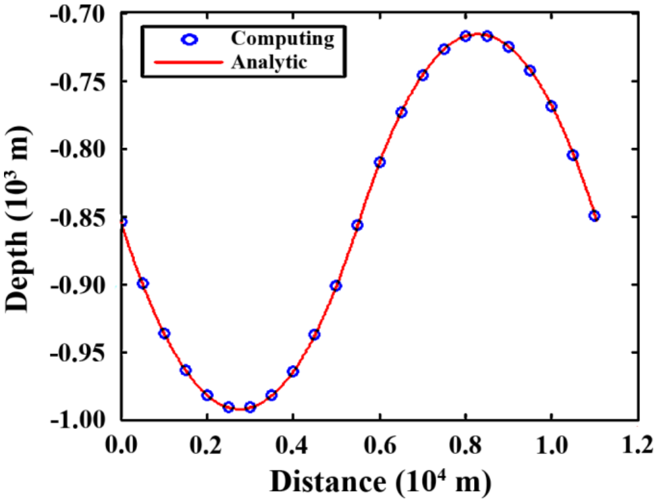

Figure 3. Analytical and numerical comparison graph

The maximum angle referred to in the explanation above is where the sound wave experiences transmission losses or transmission losses. In propagating in air, sound waves lose their transmission energy which is the accumulation of the decrease in acoustic energy when the acoustic pressure propagates. The intensity of the acoustic wave will decrease with increasing distance from the sound source [20].

5. CONCLUSION

The propagation of waves emitted from the same point at different angles will experience an expansion of the propagation area. The larger the radius, the further the distance traveled, which is proportional to the square of the radius. The maximum propagation angle of the wave is 0.4. Sound waves experience transmission losses. In propagating in water, sound waves lose their transmission energy which is the accumulation of a decrease in acoustic intensity energy when the acoustic pressure propagates.

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