OPTIMISING ACOUSTIC FIELD INTENSITY ALGORITHMS USING THE SOUND RAY SURFACE DENSITY METHOD

ALEKSANDRA RAGANOWICZ, JACEK GAWRYSIAK, ROMAN SALAMON, LECH KILIAN

Gdansk University of Technology
Faculty of Electronics, Informatics and Telecommunications, Department of Acoustics
ul. Narutowicza 11/12, 80-952 Gdańsk
ragola@eti.pg.gda.pl

The paper presents ways to optimise computer algorithms for the calculation of acoustic field intensity distribution in a body of water for specific hydrological conditions while aiming to reduce the computation time. Examples are given including an algorithm that minimises the number of range section zones. Other examples include ways to eliminate some of the time-consuming activities by determining parabola sectors instead of circular sectors as fragments of range profiles. The consequences, i.e. the possibility of varying results, are discussed. Other optimising possibilities are explored, as well.

INTRODUCTION

Central to the operation of the majority of modern underwater acoustics systems is their ability to predict sound propagation routes and acoustic field intensity distribution. When based on an accurate and up-to-date measurement of sound velocity range distribution, prediction becomes a valuable tool for the operator giving him information about the actual range of target detection, spatial distribution of detection zones and zones of acoustic shadow leading to an optimal choice of settings.

Underwater acoustics systems built by the Department of Acoustics come with a meter (designed by the Department) for measuring sound velocity range distribution. Installed in a computer, the meter calculates the spatial distribution of wave intensity using the sound ray density method [1]. The method helps to eliminate the indefiniteness of intensity in caustics and includes field distribution for actual beam patterns of acoustic antennas. The essence of the method lies in the fact that it determines a big number of sound rays, which despite the advances of computer technologies, takes up too much time compared to user expectations.

Developed almost a decade ago, what is actually a computer system for predicting sound propagation routes and target detection conditions in a specific hydrological profile, is becoming obsolete. Its updated version must first of all use the Windows operating system, known to all users, use a commonly accepted protocol for external communications, and use a link other than RS (some laptops no longer have it) but should also ensure optimised calculation routines. The method for determining sound propagation routes and intensity in the particular zones of the body of water involves a lot of computation. Despite the fast progress in computer technology and new computers being 10 times more powerful than when the project first started, the results are not displayed instantly. Hence the need to reduce the computation time by optimising the algorithms.

1. EXAMPLES OF OPTIMISATIONS

Computation time can be significantly shortened by cutting back on the measurement data, selecting the right number of rays and optimising the algorithm for determining sound ray routes.

Using the ray density method, sound ray routes are determined under the assumption that the velocity gradient is constant in subsequent layers of the water. Compared to the algorithm that assumes constant velocity in every layer, this solution ensures a much higher computation accuracy. The result is a curving of the ray's path inside each layer, with the path becoming a section of the circle.

To determine the path of each ray in each layer, we must calculate the co-ordinates of the centre of the circle and its radius. The total number of mathematical operations is proportional to the number of layers, number of rays and the number of numerical operations necessary to determine the parameters of the sound ray's path in each layer.

It follows from the operating principle of the sound velocity distribution meter that the number of layers is equal to the number of velocity measurements taken by the meter. The meter measures velocity every 20 cm, which for deep waters yields a big number of layers. That number can be reduced, when the velocity gradient in adjacent layers is identical to the assumed error. To that end, an algorithm was developed that allows automatic determination of the number and width of layers and the value of the gradient in the layers.

This is how the algorithm operates. Let $v(n)$ denote measured gradient values and $u(n)$ – the values of the velocity trend in a specific layer. The values of the trend $u(n)$ are on a straight line selected to ensure that the mean $v(n)$-$u(n)$ is equal to zero in that layer and that mean square variance $v(n)$-$u(n)$ is the lowest.

The sequence $u(n)$ is treated as linear approximation of the sequence $v(n)$, and the tilt of the trend's straight line – as the velocity gradient in the given layer. The trend is determined first for samples from $n=1$ to $n=4$ to compute the standard deviation ε_s r of the variance between sequences $\{v(n)\}$ and $\{u(n)\}$.

If $\varepsilon_s>\varepsilon$, where ε means the assumed computational error, the error will be the greater of the numbers ε_s and ε. When $|v(4)-u(4)|<\varepsilon$, the next trend is determined in the range $n=1$ to $n=5$ and checks are made to see if $|v(5)-u(5)|<\varepsilon$. The procedure is repeated until $|v(n)-u(n)|>\varepsilon$. The number $n=N_1$, for which the inequality occurs denotes the boundary of the first layer. Beginning from the sample of that number the above procedure is repeated until the criterion is fulfilled $|v(n+N1-1)-u(n+N1-1)|>\varepsilon$. The cycle is repeated until all data are exhausted.

The result is that the narrowest layers are 60 cm wide, while the others differ in width depending on how fast the velocity gradient changes. The number of layers goes down as the assumed error ε goes up.

Fig.1 shows the measured distribution of sound velocity and how it was approximated using straight lines determined under the assumption that ε=0.4 m/s. Please note, that the algorithm has helped to reduce the number of layers from 180 to 13. Fig. 2 shows the approximation error in the function of depth. The mean square error of the approximation is 0.24 m/s, which given the error of meter readings at 0.2 m/s is quite satisfactory. A bigger error ε reduces the number of layers even further.

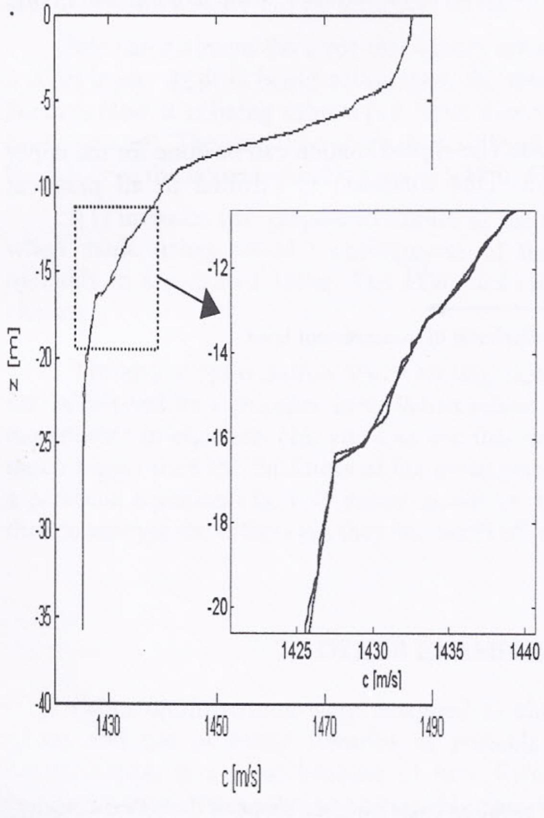

Fig.1. Profiles of sound velocity: as measured and following approximation

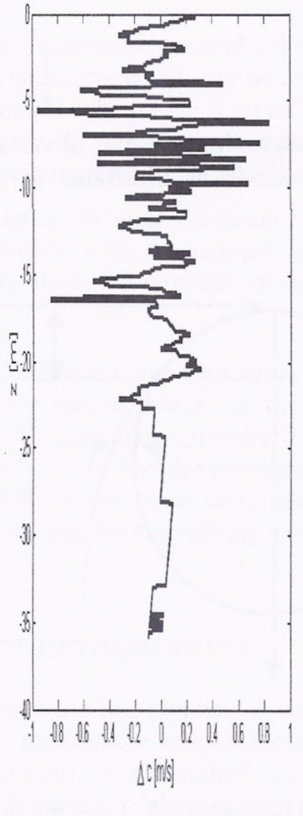

Fig.2. Approximation error

In an analysis of algorithms used for computer computations it was found that the time can be significantly reduced by avoiding the numerous extractions of roots required for computing the profile of sound velocity, described with the circle equation. The extraction of roots may be skipped by approximating the segment of the circle with a segment of a parabola.

If the sound velocity gradient is constant, the ray of sound coming out horizontally from the source lies on a circle, described with the equation:

$$\left(z-\frac{R}{2}\right)^2+x^2=\frac{R^2}{4} \tag{1}$$

where z is the current depth, x – horizontal co-ordinate of the source distance, $R = c_0/g$ is the radius of the circle, c_0 – sound velocity at sources depth, $g=\Delta c/\Delta z$ – sound velocity gradient. Similar formulas for subsequent layers and varying beginning tilt of the rays will be left out for reasons of space.

The circle described with formula (1) can be approximated with a parabola in the equation:

$$z=\frac{1}{R}(x')^2 \tag{2}$$

where x' is the approximated value of variable x. The approximation can be done for the upper segment of the circle as illustrated in Fig.3. This condition is fulfilled in all practical computations.

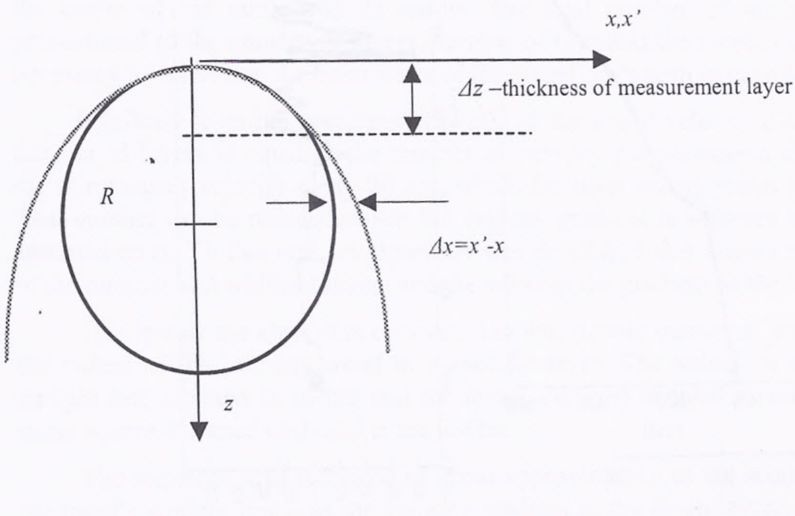

Fig. 3. A pictorial representation of how the circle equation describing the shape of the sound velocity profile in the measurement layer is replaced with a parabola equation

An important consequence of the approximation is the deviation as shown in the Figure $\Delta x=x'-x$ between the values of both functions for the same values of depth z. It can be shown that the value of deviation Δx is given in the formula:

$$\Delta x = \frac{z}{2}\sqrt{\frac{z}{R}} = \frac{z}{2}\sqrt{\frac{zg}{c_0}} \qquad (4)$$

By inserting the thickness of the layer with a constant gradient z=Δz and g =Δc/Δz, we can determine the error in the layer, the error being introduced to predict propagation routes resulting from the change from circle to parabola:

$$\Delta x = \frac{\Delta z}{2}\sqrt{\frac{\Delta c}{c_0}} \qquad (5)$$

As you can see, the error is proportional to the thickness of the layer and increases only along the root of the relative change of sound velocity in the layer. As the number of layers goes up (depth of the water), the errors do tend to sum up. On the other hand, sharp gradients cannot be found in the entire section of the water and tend to occur in thin layers, close to the surface in summertime. Because the algorithm matches the thickness of the layer to the value of the gradient (the bigger the gradient the thinner the layer), the total error introduced by the approximation usually has no technical effect.

We can estimate the error that occurs for strong increases in sound velocity Δc=1m/s in a 0.2m layer. As it is being submerged, the meter takes sound velocity measurements every 20cm (unless it is being submerged faster than 0.4m/s in which case it takes 2 measurements every second). The deviation Δx is then 2.58mm, while the radius of the circle cuts across the boundary of the layer at the distance x=5.48m. The relative error is then $4.7^{\circ}/_{oo}$ only.

[1] includes two graphic examples of the variances between the results of computations when made using actual measurements of the profile with an acoustic duct using both methods in a space of 300m. The examples clearly show the minimal effect of the method chosen.

The above optimisation which replaces a circle segment with a parabola segment should not be viewed as a peculiar idea. When raised to the second power, i.e. the contents of the parenthesis in equation (1), you can see that with the assumption usually fulfilled, ray R is much bigger than the thickness of the measurement layer Δz, and the circle equation becomes a parabola equation (3). It is easier, however, to analyse the errors using the above method than to analyse the effects (as they happen?) of introducing the simplifying assumption.

2. OTHER EXAMPLES OF OPTIMISATIONS

Other optimisations were designed to eliminate the big number of computations and create and use as many libraries as possible to replace the computations. This sort of multiplication is a must because of how field intensity is determined, i.e. by adding the number of rays that cut through a possibly narrowest segment of the water.

One possibility is to check the values of gradients in the layers and rule out computations for zero gradients (very frequent) or when gradients are repeated. The end effect is a reduced number of measurement layers (which are now unequal), i.e. their thickness is extended to match the changing values of the gradients.

A spectacular example of how libraries can be put to work is a table of values of trigonometric functions that lend themselves very difficult to compute. The functions occur when the emission angles of the rays from the layers are taken into account. The tables also include the values of other recurring parameters of equations.

Another example of how computations can be optimised is a complete reversal of how they are done – the value of the function *x(z)* is computed rather that of *z(x)*.

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