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Numerical Research on the Mathematical Model of Echosounder for Distance to Bottom Measurement

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Abstract: In recent years, we can observe a dynamic development of numerically tested algorithms dedicated to AUV (Autonomous Underwater Vehicle) and ROV (Remotely Operated Vehicle). Simulations can provide valuable experience at the preparation stage to avoid irregularities in research in the real environment. This article presents a mathematical model of the echosounder for measuring the distance from the bottom implemented and simulated in MATLAB. The presented algorithm's operation example confirms the correctness of the model.

Keywords: Echosounder, AUV, Trajectory-tracking.

1. Introduction

In recent years, we can observe a dynamic development of numerically tested algorithms dedicated to AUV and ROV. An example may be path planning and collision avoidance algorithms, where a much more significant amount of simulation tests has been noticeable compared to tests performed in a real environment [1]. Preparation for real-world research related to testing systems implemented in underwater vehicles is usually time-consuming. It must be preceded by an appropriate analysis, including the impact of the environment on the tested object. Making a mistake during the tests may result in unpredictable consequences, such as destruction or loss of the tested vehicle. Numerical simulations can provide valuable experience at the preparation stage to avoid irregularities in research in the real environment. Therefore, it is necessary to develop models of sensors, actuators, controllers, and propulsion [2 - 5]. Additional information about possible design or construction errors can be obtained by performing tests in laboratory conditions on specially prepared and tested stands [6].

This article presents a mathematical model of the echosounder for measuring the distance from the bottom developed in the project entitled "Development of a system for detecting underwater obstacles, mapping the environment and avoiding underwater obstacles by autonomous underwater vehicles (AUV)". The mathematical model of the echosounder was implemented and simulated in MATLAB. The simulated example of the model confirms its correct operation.

The article is organized as follows Chapter 2 presents theoretical assumptions for the hydroacoustic system. Chapter 3 shows the concept of the sonar model and describes the algorithm. Chapter 4 presents a simulation check of the operation of the echosounder model installed in the AUV moving along a given trajectory. Finally, Chapter 5 contains conclusions and future works.

2. Parameters of the hydroacoustic system

The operation of the echosounder is based on the propagation of an acoustic wave in an underwater environment. It is used to measure the distance, e.g., to the bottom or other objects, depending on the method of installation on an underwater vehicle. A frequent application of the echosounder is bathymetry, where it can be used to measure and visualize the bottom of water reservoirs. Distance measurement by the echosounder is based on transmitting acoustic pulses in an underwater environment. Part of the signal reaching the object is reflected and returned to the transducer. The detected object distance is calculated from the sound propagation time underwater according to the following equation:

$$R = \frac{ct}{2} \tag{1}$$

where:
c – speed of sound in an underwater environment,
t – time for the sound to reach the target and back to the transducer.

Sound propagation in the underwater environment can be represented by the plane wave equation (depending on spatial variations in pressure and time) as below [7]:

$$p(x,t) = A\sin\left(2\pi f t - \frac{2\,\pi\,x}{\lambda}\right) = A\,\sin(\omega\,t - k\,x); \tag{2}$$

where:
A – peak amplitude of the acoustic pressure of a plane wave,
f – frequency in Hz,
λ – wavelength,
ω – angular frequency in rad/s,
k – wave number in rad/m.

The transmitted beam takes the shape of a cone. Its aperture angle is determined by the physical parameters of the echosounder.

The basic equation representing the performance of the echosounder, taking into account the parameters of the object, the environment, and the transducer, is shown below [8].

$$SE = (SL + TS - 2PL) - N - DT \tag{3}$$

where:

SL - Source Level,
TS – Target Strength,
PL – Propagation Loss,
N – Noise Level,
DT – Detection Threshold.

Based on the above equation, it is possible to calculate the transmitter power needed to detect an object of a given size at a known distance. The equation shows the relationship for the sonar signal but is also true for the echosounder. The difference between devices such as FLS, Side Scan Sonar, and Echosounder is usually the shape of the beam, range, frequency, number of pulses, etc. A typical echosounder is characterized by a narrow beam and a respectively high power level that allows for determining the distance to an object in a particular direction.

3. The concept of the mathematical model of echosounder for distance to bottom measurement

The mathematical model is based on the parameters of the real Tritech Micron Echosounder, shown in Figure 1. The Echosounder is characterized by the following parameters:

- Operating frequency 500 kHz,
- Beamwidth 6° conical,
- Minimum range of 0.3 m,
- Maximum range of 50 m,
- Depth rating to 750 m,
- Communication protocol RS485 or RS232.

Fig. 1 – *Tritech Micron Echosounder [9]*

Like other devices of this type, the Micron Echosounder generates a conical beam with a specific opening angle, in this case, 6 °. Such a value of the aperture angle causes the AUV located 10 m above the bottom with the echosounder directed towards the bottom "examines" an obstacle in a circle whose diameter is more than 1 m. At a maximum range of 50 m, the echosounder "sees" a circular area with a diameter of more than 5 m. When AUV is tilted or trimmed examined area of the bottom will no longer be a circle but, in simple terms, a projection of the circle onto a plane close to an ellipse. Therefore, it should be noted that when examining the depth of the bottom and the height of any obstacles related to the bottom, it is essential to study a circular area with a diameter depending on the average distance from the bottom. The next important thing is the orientation of the AUV in space, particularly tilt and trim angles.

The algorithm for determining the mean and minimum distance from the seabed implemented and evaluated in the MATLAB environment is described below. The algorithm requires the following input data:

- echo sounder location coordinates (wspEcho),
- AUV orientation angles (*orien*),

- Echosounder beamwidth (*szer*),
- minimum sonar view range (*zasmin*),
- maximum sonar view range (*zasmax*),
- maps of the bottom and obstacles in the form of a depth matrix (**Map1**) and a reflections coefficient matrix (**Map2**),
- map resolution (*rozdz*),
- map dimension in the x-axis (wX),
- map dimension in the y-axis (wY).

First, the algorithm calculates the coordinates of the centre of the circular area at the maximum defined view range. The values of the previously mentioned coordinates are computed with regard to the AUV orientation angles using the Transform.m function. Then, the average value of the depth is calculated by averaging the values of the elements of the **Map1** depth matrix that are located in the area of the previous-mentioned circle. The knowledge of the current AUV immersion depth allows the calculation of the average distance from the bottom, which, in turn, is used in the next iteration of the algorithm when the circular area of view range is determined to equal the calculated average distance from the bottom. Points determined in a given circular area are examined in terms of two criteria:

1. Does the base of the cone extend beyond the environment?
2. Does the point with the given height belong to the cone?

Both conditions are verified based on the cone equation.

Finally, from the obtained set of depth matrix elements meeting the previous-mentioned conditions, the minimum value of *DnoMin* is selected, and the average value of *DnoSr* is calculated. Additionally, based on elements of the reflection coefficient matrix selected according to the same criteria, the average value of the power of the reflected signal *MocSr* is calculated. In the current version of the *MocSr* algorithm, it is not taken into account, but it is expected that this parameter will be taken into account after the planned tests in real conditions. Probably, for a certain threshold of the *MocSr* parameter, errors in measuring the distance from the bottom will be obtained. There is no information on this in the manufacturer's documentation.

4. Example of the algorithm's operation

As an example of the echosounder operation, a simulation of AUV movement was carried out according to a given trajectory in the 3D environment with static obstacles. Figure 2 shows the simulated trajectory of the vehicle, taking into account the obstacles and constraints related to the implemented propulsion models and control elements.

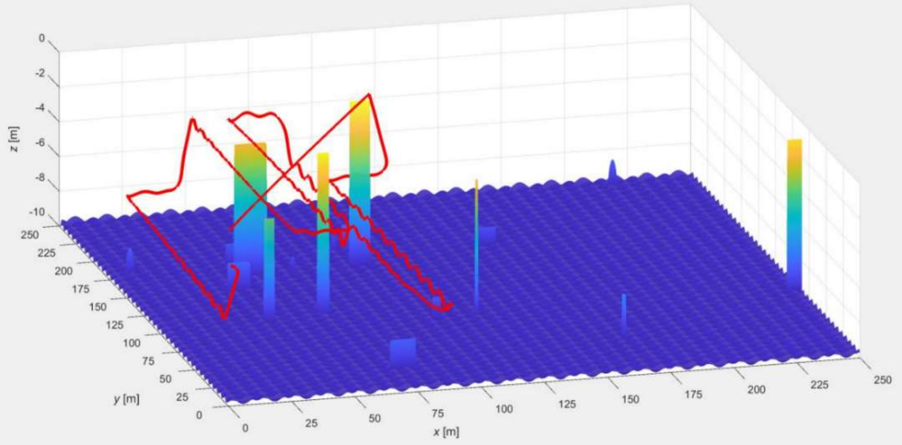

Fig. 2 – *Simulated trajectory of the AUV*

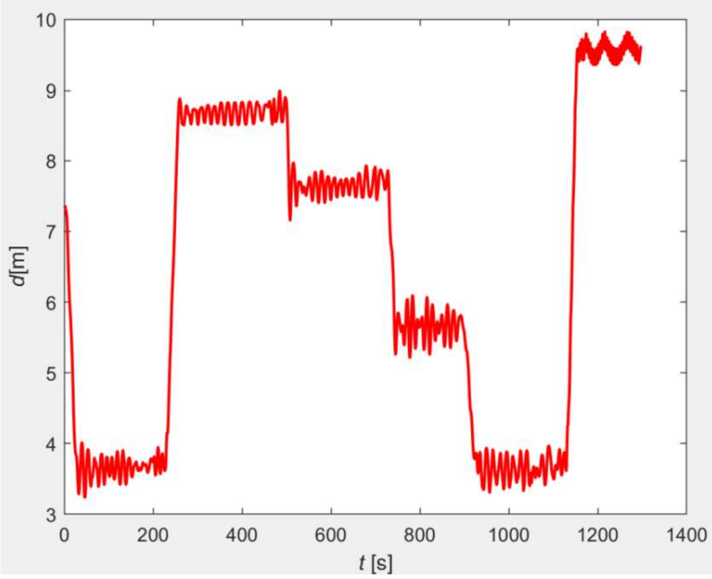

Fig. 3 – *Distance to the bottom measured by using the echosounder model*

Figure 3 presents changes in the vehicle depth based on the applied mathematical model for determining the distance from the bottom. Due to the bottom unevenness, slight fluctuations in the measured distance from the bottom are visible while the vehicle is moving. It confirms the correct operation of the echosounder model.

5. Conclusion

The article presents a mathematical model of the sonar designed to measure the distance from the bottom. The obtained results of simulation tests of the developed echosounder model for AUV moving along a given trajectory in an environment with obstacles confirm its correctness. After the research results in the real environment, further fine-tuning of the developed model is foreseen.

References

[1] Kot, R. (2022). Review of Collision Avoidance and Path Planning Algorithms Used in Autonomous Underwater Vehicles. Electronics, 11(15), 2301.

[2] Piskur, P., & Gasiorowski, M. (2020). Digital Signal Processing for Hydroacoustic System in Biomimetic Underwater Vehicle. NAŠE MORE: znanstveni časopis za more i pomorstvo, 67(1), 14-18.

[3] Przybylski, M., Szymak, P., Kitowski, Z., & Piskur, P. (2020). Comparison of Different Course Controllers of Biomimetic Underwater Vehicle with Two Tail Fins. In Advanced, Contemporary Control (pp. 1507-1518). Springer, Cham.

[4] Szymak, P., Piskur, P., Piątek, P., Muchowski, J., Trawiński, S. (2021). Modeling and simulation of innovative autonomous underwater vehicle PAST, Nase More Conference

[5] Szymak, P. (2022). Low-Level Control of Unmanned Marine Vehicle PAST, Proceedings of the Polymer Diagnosis Conference, Male.

[6] Piskur, P., Szymak, P., & Sznajder, J. (2020). Identification in a laboratory tunnel to control fluid velocity. In Advanced, Contemporary Control (pp. 1543-1552). Springer, Cham.

[7] Rascon, A. (2020). Forward-looking sonar simulation model for robotic applications. NAVAL POSTGRADUATE SCHOOL MONTEREY CA

[8] Waite, A. D. (2002). Sonar for practising engineers. Wiley.

[9] Tritech, Specification Micron Echosounder, https://www.tritech.co.uk/media/products/Micron%20Echosounder.pdf?id=8332446d

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