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Numerical simulation of effects of fish school density on multiple scattering inside fish school and echogram

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1. Introduction

Hydroacoustic measurement technique and devices are often used to observe fish behavior in water even in turbid or low light condition[1,2]. To detect school of fish from onboard a ship, fish finders are used[3]. The abundance of fish can be estimated based on intensities of the backscattered echoes from fish[4] because the intensities are proportional to fish density below certain density limits[5]. At high fish density, due to acoustic interaction of the individual fish, the echo intensity from fish is not proportional to fish density and the fish of the deeper part of the school are shadowed by the fish nearer the transducer[5]. This shadowing effect cause under estimation of the abundance of deeper part of the fish within school. In addition, multiple scattering inside fish school may cause reverberation and echoes detected from a position deeper than the range where the fish school exists, leading to false detection of fish. However, these effects of multiple scattering inside fish school on measured echoes from the school such as shadowing effect and reverberation has not been studied well.

In this study, the effect of fish school density on multiple scattering inside fish school and measured echoes are investigated by numerical wave propagation simulations.

2. Materials and methods

To simulate the wave propagation for echo measurements from fish school in water, two-dimensional finite-difference time-domain (FDTD) method was employed. **Figure 1** shows the conditions of the simulation. Wave propagation was calculated for two-dimensional space filled with water which has cross section of 260 × 260 (cm^2) with mesh size of 0.2 cm, and sound velocity was assumed to be 1,497 m/s. Time step was 0.94 µs. The boundary condition of the cross section was set as Mur 1st-order absorbing boundary condition. To simulate the echo from fish, scatterers with diameter of ϕ=1.5 cm were arranged in a square grid of 40 cm on each side. Swim bladder of fish responsible for 90% of the reflected echoes[6]. The distances d between the scatterers arranged in a grid were 20, 10, 5, and 2 cm, and the densities were 56.25, 156.25,

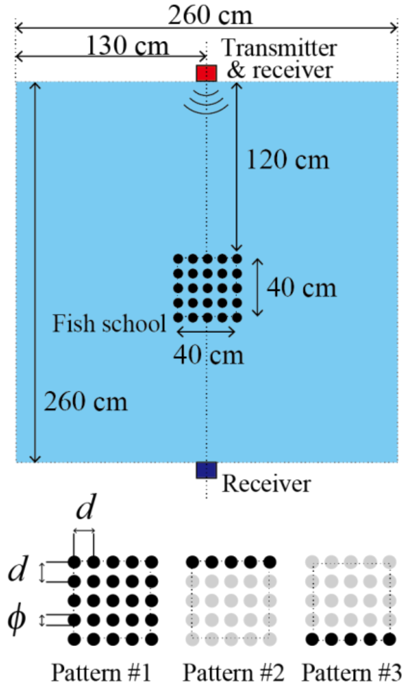

Fig. 1 Schematic view of simulation.

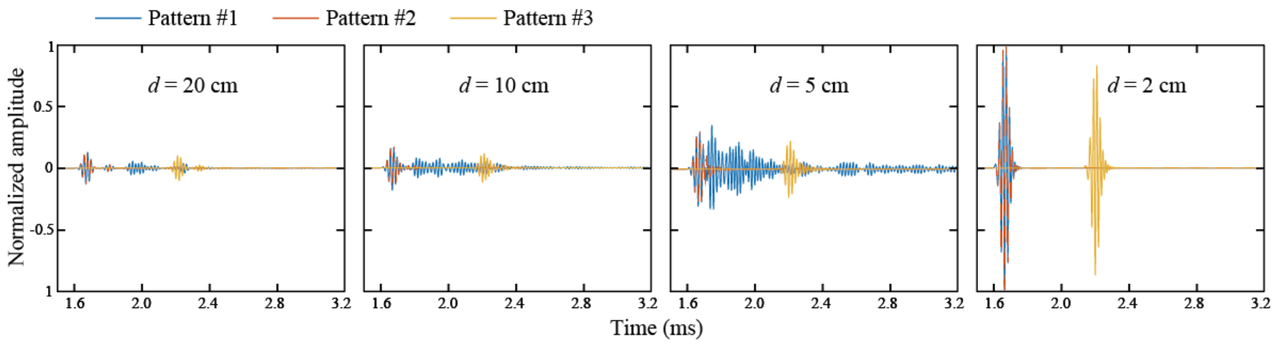

Fig. 2 Waveforms of echoes measured for each pattern of fish school when distance d is 20, 10, 5, and 2 cm.

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506.25, 2756.25 fish/m^2, respectively. The input signal was burst signal, whose frequency was 50 kHz with duration of 0.1 ms windowed by Hann window. The distance between a transmitter and the nearest part of the fish from the transmitter was 120 cm. The echoes from the fish were measured by a receiver at same position as the transmitter. Transmitted waves were also measured by another receiver at the opposite sides of the cross-section with the transmitter. The apertures of the transmitter and the receivers were 10 cm. Echoes and transmitted waves for three kinds of school pattern of fish #1, #2 and #3 with four kinds of *d* were measured as shown in Fig.1.

3. Results and discussion

Figure 2 shows the echoes measured for three pattern of fish school at each *d*. As *d* decreases, which means density increases, larger amplitudes of echoes were observed. When *d* was 20 and 10 cm, most of the echoes from fish school pattern #1 were observed between the timing of the echoes observed from pattern #2 and #3, which are nearest and farthest part of fish school. When *d* was 5 cm, the amplitude of the echoes from pattern #1 decreases as the depth increased, even though fish were present at same density between the depths where the echoes of patterns #2 and #3 were observed. In addition, the echoes from pattern #1 were observed even after the echoes of pattern #3 were observed, while the amplitude of the echoes were relatively small compared from the depth where they actually exist. This may lead to false detection of fish at deeper position than they exist. When *d* is 2 cm, the echoes from patterns #1 and #2 were almost same. This means that shallowest part of the fish in school reflected most of the echoes and the echoes from other parts of the fish school were not observed when the gap between the scatterers is 0.5 cm, which is smaller than the wavelength of the transmitted signals of about 3 cm.

Figure 3 shows the transmitted waves measured for three pattern of fish school at each *d*. As *d* decreases, which means density increases, smaller amplitudes of transmitted waves around 1.8 ms were observed regardless of the patterns. When *d* is 10 and 5 cm, the transmitted waves through pattern #1 were observed after direct wave propagating straight between transmitter and receiver were observed around 1.8 ms. This means that multiple scattering was occurred inside the fish school when *d* is around wavelength of the transmitted signal.

4. Conclusion

In this study, the effect of fish school density on multiple scattering inside fish school and measured echoes were investigated by numerical simulations of two-dimensional wave propagation. When the distance *d* between the fish is around the wavelength of transmitted waves, the echoes from fish school were observed even after the timing of echoes of the farthest part of the fish should be observed, while the amplitude of the echoes were relatively small compared from the depth where they actually exist. This may be caused by multiple scattering inside fish school, and these phenomena lead to false detection of fish at deeper position than they exist.

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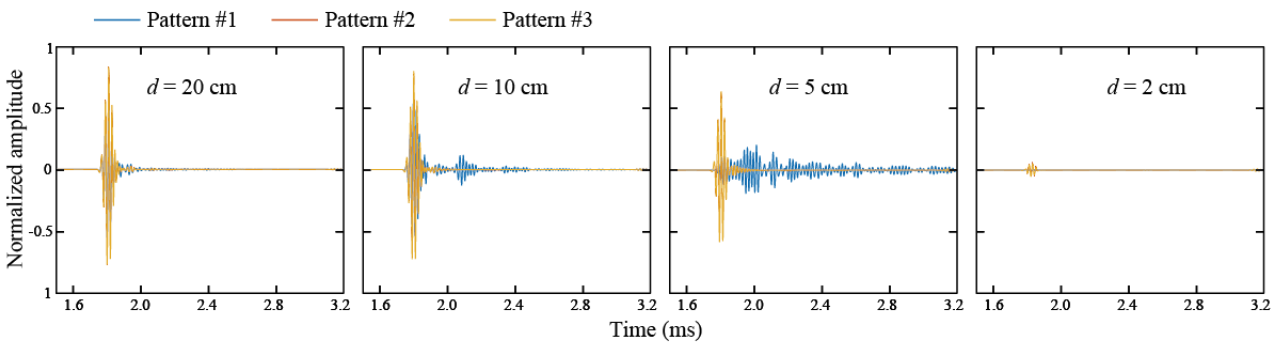

Fig. 3 Waveforms of transmitted waves measured for each pattern of fish school when distance *d* is 20, 10, 5, and 2 cm.