THREE-DIMENSIONAL VISUALIZATION OF FISH SCHOOLS USING SECTOR SCANNING SONAR

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Commission V, Working Group IC WG V/III

KEY WORDS: Scanning Sonar, Echo-sounder, Fisheries Acoustics, Acoustical Imaging

ABSTRACT

Sonar images obtained from a scanning acoustical beam are usually two-dimensional sectional images. However, since sectional images can be easily obtained as an observation vessel moves forward, we can reconstruct three-dimensional images of underwater objects by analyzing stacked two-dimensional sectional images.
The echo survey was conducted in Funka Bay aboard the R/V Ushio Maru, which is equipped with a 180-degrees sector scanning sonar (model KCH1827, Kaijo Co. LTD). The sonar beam was directed downward perpendicularly to the ship's course. Vertical sectional sonar images were digitized every 1.5 seconds while the vessel was cruising at 10 knots. The stacked sectional images were analyzed to determine the spatial distribution and shape of fish schools using the three-dimensional image processing software SLICER.
The distribution of fish schools was displayed by simultaneous expression of both horizontal and vertical projections. This expression method enabled us to observe fish avoidance from vessel, which can not be observed using ordinary vertical echo sounders. The reconstructed solid shape of fish schools by volume rendering could be observed by changing the visual point freely. This allowed to determine scale, features, and swimming direction of the fish schools.
Three-dimensional display of sector scanning sonar images is a useful tool not only for a commercial fishing, but also for scientific surveys of fish resources and underwater drifters.

1. INTRODUCTION

Observations of the undersea are important for determining the distribution and shape of fish schools. However, since visibility is poor due to the low penetration of light in seawater, current optical techniques have a limited underwater observation range. A promising method for undersea observation is the use of underwater acoustic waves with low propagation loss. One representative application is the use of an echo-sounder that detects fish by the pulse-echo method using ultrasound. However, ordinary vertical echo-sounders can detect insonified fish only in a narrow acoustic beam directed downward.

On the other hand, since a sector scanning sonar turns its acoustical beam electronically, it enables rapid visualization of the underwater world around a ship, and wide detection of fish schools (Mitson, 1983). Generally, the scanning sonar beam is set near the horizontal plane directed in front of a ship to search for fish schools. If the beam is set vertically downward and perpendicular to the ship's course, we can get sectional images under the ship, which can then be combined to form three-dimensional images of fish schools (Iida et al., 1996). Information on the spatial distribution and shape of fish schools can then be used in fish-resource and behavioral studies (Misund et al., 1995, Cervenka and Moustier, 1993).

This paper discusses the method and application of three-dimensional analysis of sector scanning sonar images we used in an area of Funka Bay where pelagic species are abundant.

2. METHOD

2.1 Sonar Image Sampling

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The sonar survey was conducted during daytime in December 1995 at Funka Bay using the R/V Ushio-Maru, which is equipped with acoustic instruments. The sonar used was a 180-degree sector scanning sonar model KCH-1827 (Kaijo Co. LTD.), with a receiving beam width of 8 degrees using the acoustical frequency of 164 kHz. Sonar images were displayed in 16 colors according to the echo levels. The sonar beam was directed downward and perpendicular to the ship's course to obtain vertical sectional images while the ship was cruising (Figure 1).

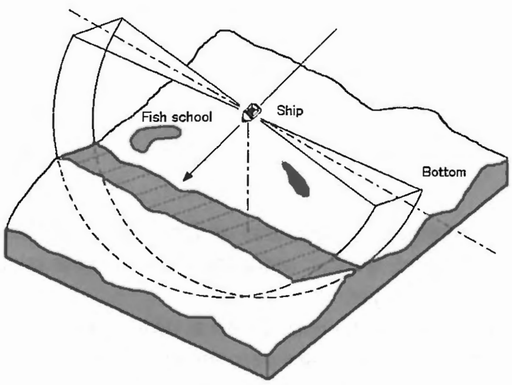

Figure 1 Cross sectional image sampling by the vertical use of sector scanning sonar beam.

Analog RGB video signals of the sonar images were converted to NTSC video signals through a video scan converter and recorded on videocassette. The video signal was then replayed and digitized once every 1-2 seconds with a resolution of 256 by 256 pixels with 18 bits using a video capture interface to a personal computer. Ordinary echograms were also recorded using a vertical scientific echo-sounder (model KFC200, Kaijo Co. LTD).

2.2 Three-Dimensional Analysis of Sonar Image

Since digitized sonar images contain noises and color distortion, a median spatial filter was used to eliminate noise and to emphasize the edges of the images. The data value was also reduced from 262,144 (64 x 64 x 64) to 256 to hasten the three-dimensional processing. About 600 pre-processed sonar images were stored as one volume file and then analyzed using the three-dimensional processing software SLICER (Fortner Research LLC).

Volume data was composed of stacked sectional images sampled every 1.5 seconds (Figure 2). The thickness of volume data D is expressed by the product of the sampling period, ship speed, and number of images. However it was still impossible to observe fish schools or the sea bottom because of the

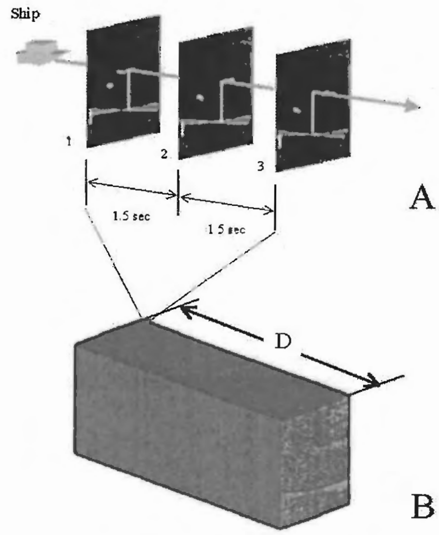

Figure 2 Continuous image sampling and volume data file of sonar image.

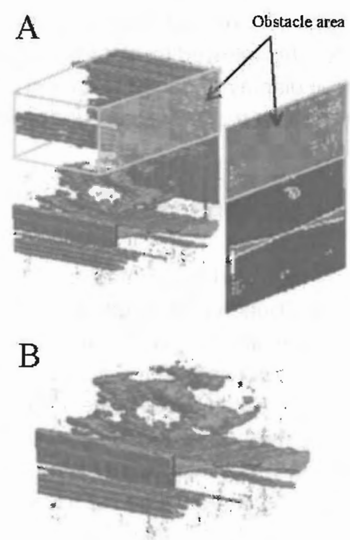

Figure 3 Extraction and reconstruction of three-dimensional fish school image by sonar image processing.

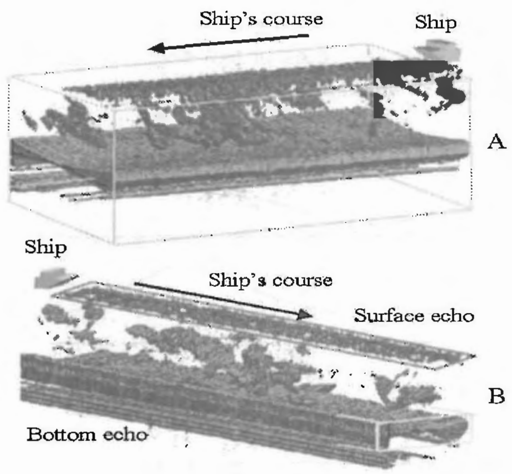

Figure 4 Perspective images observed from the left side (A) and the right side (B) of the bow.

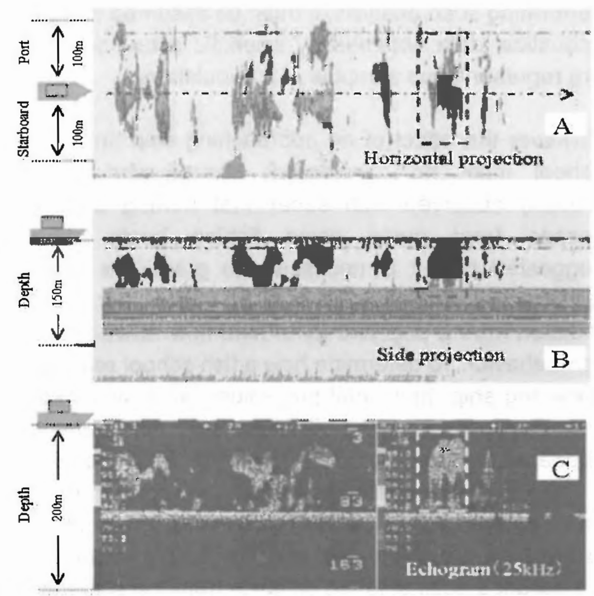

Figure 5 Spatial distribution of fish school by horizontal projection (A), and vertical projection (B), and echogram obtained by vertical echo-sounder (C).

opaqueness of the background, so the threshold level was set to the data value based on the histogram of the echo level to transparentize the volume data (Figure 3). This volume data could be enlarged, rotated, moved, and painted to facilitate processing the three-dimensional images. Figure 4 is perspective image observed from the left (A) and right sides (B) of the bow, respectively.

3. RESULTS

3.1 Spatial Distribution of Fish School by Two Perpendicular Plane Projections

Figure 5 shows the spatial distribution of a fish school and the sea-bottom features from the top-view projection and the side-view projection. The upper chart (A) indicates the top-view projection, and the horizontal central broken line represents the course of the ship. As the ship proceeded from left to right in the figure, the vertical axis over the track line indicates the horizontal distance to the left broadside, and the lower vertical axis indicates the distance to the right broadside. The middle chart (B) indicates the side-view projection. The horizontal axis indicates the cruising distance, and the vertical axis indicates the depth.

These displays help us easily understand the spatial distribution of fish schools. For example, an apparent single fish school in the vertical projection seems to consist of several fish schools in the horizontal projection, and vice versa. On the other hand, the echogram of the vertical echo-sounder (C) resembles the vertical projection display, but the vertical projection provides more information about the depth of the image. The echogram of the vertical echo-sounder is only a vertical cross section of the ship's track.

Thus, the display method proposed here helps us to understand the precise distribution of fish schools.

3.2 Three-Dimensional Shape of Fish School

As mentioned above, it is impossible to determine the spatial distribution and solid shape of fish schools using only echograms from a vertical echo-sounder. The three-dimensional analysis technique described above can be used to determine the shapes of underwater objects. As the vertical sectional images are sampled every 1.5 seconds, the distance between each section is 7.7 m when a ship cruises at 10 knots. Figure 6 shows the solid shape of the fish school cut down from Figure 4 by surface rendering techniques.

The upper figure (A) shows the perspective image of a fish school from the right side of the bow, middle figure (B) shows the perspective image of side direction, and the lower figure (C) shows the image from the bow.

performing such analysis, it must be assumed that the acoustical data obtained by scientific echo-sounders are representative samples of a population.

However the effect of an approaching ship on a fish school must be considered. Misund and Aglen (1992a) observed with sonar that herring schools escape from purse seine fishing boats. They suggested that it is necessary to grasp the three-dimensional directivity pattern of underwater noise radiated from a ship and determine how noise affects fish behavior. To determine how a fish school reacts to a moving ship, horizontal projections were sliced into 10m-deep layers, and counted the fish schools appeared by the distance from the ship's course (Figure 9). In the figure, the horizontal projection (B) is made by the specified layer from 20m to 30m in depth in the side projection (A), and the histogram of fish appearance against to the distance from the ship (C).

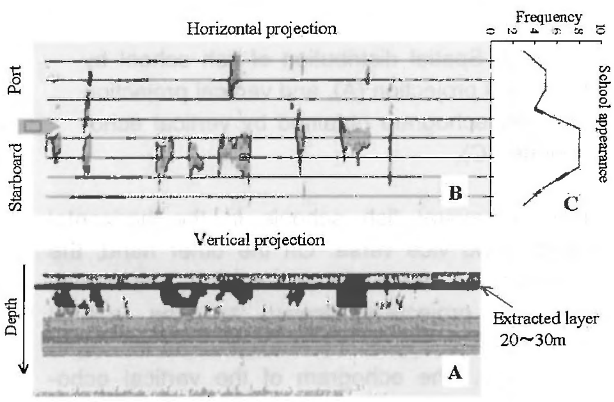

Figure 9 Fish school distribution obtained by horizontal projection of specified layer.

Figure 10 displays the frequency distribution of fish schools that appeared in each layer. The vertical axis indicates the number of fish, and the horizontal axis indicates the distance from the ship track. The central vertical broken line denotes the area just under the ship. If fish did not avoid the ship, each chart would show a flat distribution despite of distance from the ship. However it is clear in the top three charts that the shallower fish schools showed a large bias from the center, while the bottom two charts show nearly flat distributions. These figures suggest that fish schools possibly avoid ships, especially in shallow waters (Misund, 1990, 1993a).

Misund (1994) observed the swimming direction of herring schools during trawl fishing and found that the schools escaped in the same direction as the ship was moving, not to the sides. He suggested that the directivity of underwater noise emitted by ships is strong in the broadside direction and weak forward and to the rear of the ships. By determining the three-dimensional directivity pattern of underwater noise emitted by ships, the bias of fish school distribution patterns just under ships will be elucidated.

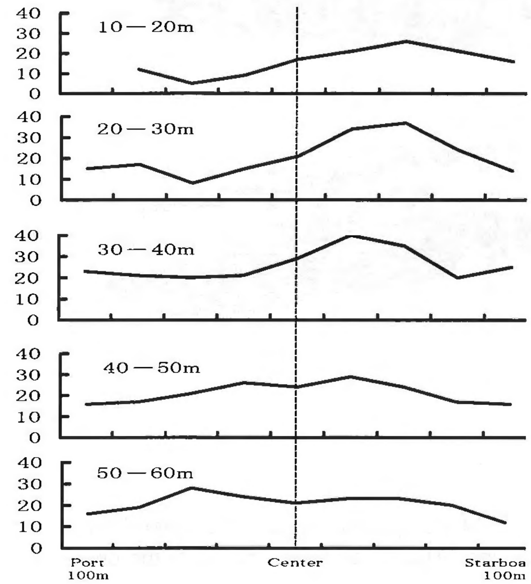

Figure 10 Frequency distribution of fish school appearance in relation to fish avoidance.

4.2 Species classification by characteristics of fish school shape

If a fish school is observed, it is useful to identify the species and to predict the behavior of the school (Weill et al., 1993, Lu and Lee, 1995, Reid and Simmonds, 1993). Unfortunately, optical observation using underwater cameras is limited to close range because of the rapid attenuation of light in seawater (Pitcher and Partridge, 1979).

Hara (1985) observed from an airplane that moving sardine schools are crescent shaped, with the convex side facing forwards the direction of movement. In this study, fish schools observed by sonar were classified into several shape types. In order to test the relationship between the shape and species or behavior, the volume, lengthwise-to-crosswise ratio (elongation), circularity, fractal dimension, and fish school depth were extracted as characteristic parameters of each fish school shape.

Figure 11 shows the scattergram matrix of three representative parameters: school depth, elongation, and school volume (logarithmic value). The relationship between these parameters show that small fish schools often occurred in deep water, and

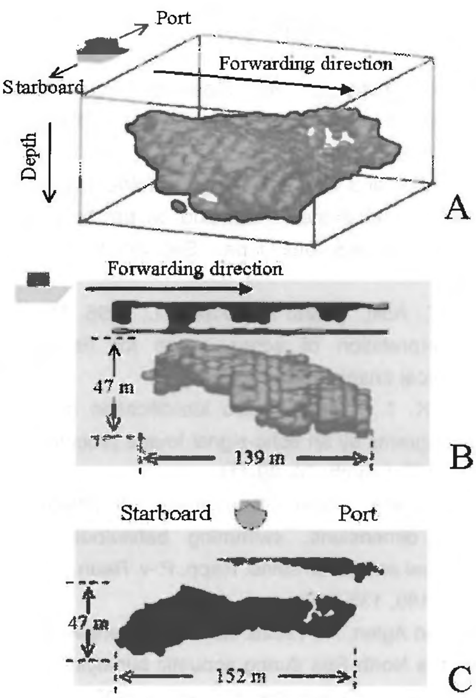

Figure 6 Perspective image of plate type fish school by surface rendering.

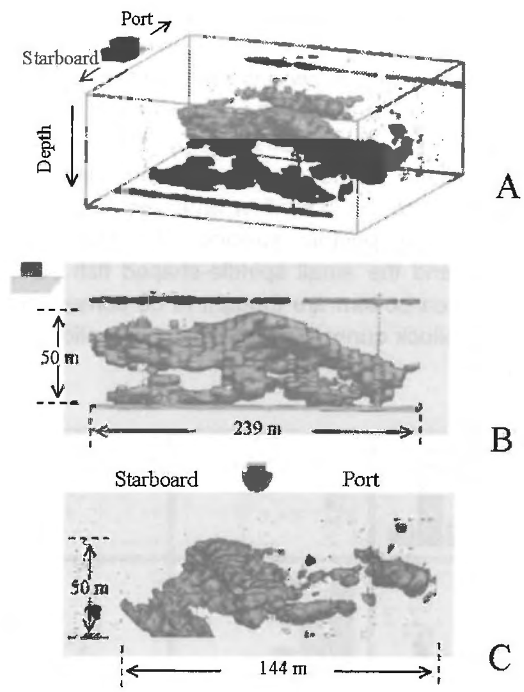

Figure 7 Perspective image of mixture type fish school by surface rendering.

Viewpoint, lighting angle, shading, cropping, cutout can all be controlled to produce the best expression. Fish schools, observed and analyzed by three-dimensional shape analysis were classified into three types: plate type. stick type. and mixture type.

The plate type fish schools were thin vertically, but covered large areas (Figure 6). The scale of the fish schools in the horizontal plane was 139m x 152m. Such fish schools were abundant at 10-30 m depth. The mixture type fish schools (Figure 7) were composed of several small schools. The shape of perspective image changed drastically with changing viewpoint. The mixture type fish schools frequently occurred between 30-m depth and the sea bottom. The stick type fish schools were long and narrow, and parallel to the sea surface (Figure 8). The shape of the perspective image also changed deepening on the viewpoint angle. These fish schools measured 556 m long and 30 m long in diameter, and occurred at all depths.

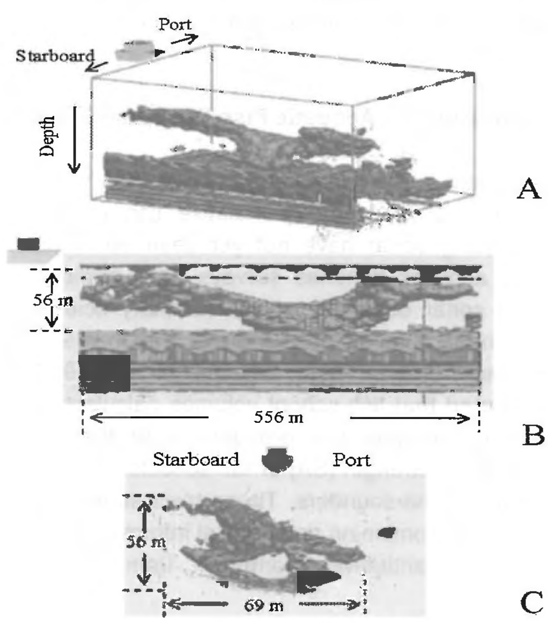

Figure 8 Perspective image of stick type fish school by surface rendering.

4. DISCUSSION

4.1 Three-Dimensional Distribution of Fish School and Avoidance Behavior to the Ship

In general acoustic fish resource surveys, fish school echoes are sampled with a vertical echo-sounder that has about a 10-degree beam width. However, as shown in Figure 5, the echogram only scans a vertical cross section under the ship's course. So when large schools often in shallow water. Also, schools in deep water formed thick layers that covered small areas, schools in shallow water formed thin layers that covered large areas. Since commercial fishing of walleye pollock, sardine and anchovy by set nets and gillnets occurs in the survey area, the large plate-shaped fish schools in shallow water are thought to be correspond of pelagic species, like sardine and anchovy, and the small spindle-shaped fish schools near the sea bottom are thought to be correspond of walleye pollock during their spawning migration to the coast.

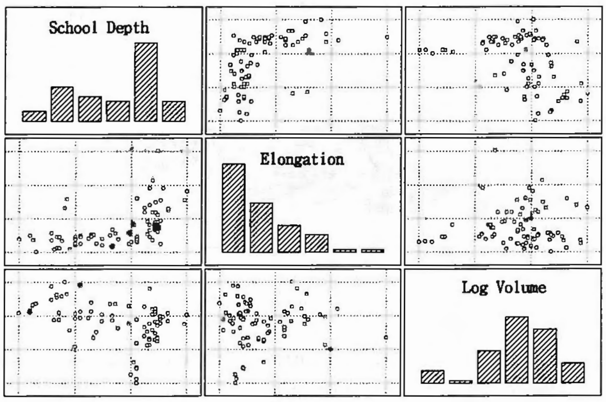

Figure 11 Scattergram matrix of three representative parameters of fish school shape.

4.3 Application for Acoustic Fish Resource Survey

Scanning sonar can survey larger areas than vertical echo-sounders. However quantitative fish resource surveys using sonar have not yet been developed. Recently acoustic fisheries surveys have combined scanning sonar observations with ordinary scientific echo-sounder observations (Misund, 1993b, 1993c, Misund and Floen, 1993). Misund et al. (1992b) demonstrated that fish-school volumes calculated by sonar data analysis are proportional to the area backscattering strength (SA) of fish schools calculated by scientific echo-sounders. These trials suggest the importance of combining geometrical information from sonar with quantitative information from scientific echo-sounders.

Finally, if fish avoid survey ships, as shown in Figure 10, we may underestimate fish abundances, especially for pelagic species. Scanning sonar provides three-dimensional information of the distribution and movement of fish schools to ensure more precise estimates of fish school size.

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