

NEW ACOUSTIC TECHNOLOGIES FOR QUANTIFYING AND IDENTIFYING FISH

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ABSTRACT

Quantification and identification methods of fish have been advanced greatly in these 20 years. But there remain problems which could not be easily resolved, because the problems are mainly related to ecology of fish and to basic property of acoustic wave. For example, *in situ* target strength measurement of fish could not be successfully made for a dense or a deep school of fish. The author and his colleagues have developed several new technologies to overcome the problems, at least to some degree. They are derivation of detection range, echo trace analysis of single fish echoes, accurate observation of frequency difference of scattering, and quantification of scanning sonar. These are briefly reviewed.

INTRODUCTION

Acoustic surveys of fisheries resources have become indispensable and produced many fruits, contributing management of fisheries resources. Also acoustic quantification techniques developed in realizing precise and accurate acoustic surveys have been succeeded by plankton acoustics and recent sophisticated echo sounders for fisheries operations.

On the other hand, there remain several severe problems unresolved, and these sometimes

prevent to conduct acoustic surveys and introduce large errors to decrease reliability of the results. Main problems are: avoidance behavior of fish to an approaching vessel introducing underestimation, difficulty in single fish echo measurement in relatively high distribution density conditions introducing erroneous single echo detection, variation of target strength (TS) of fish caused by orientation and swim bladder variation which could not be easily observed, low sampling density by a vertical sharp beam especially in broad area surveys, and difficulty of acoustic species identification. These problems are almost all related to fish ecology and basic acoustic characteristics, and therefore could not easily be resolved. But, although complete resolution might not be possible, we can expect some countermeasures, for example to show error index.

In this paper we introduce, in review style, several new studies and methods which the present author and his colleagues have been conducted.

DETECTION RANGE OF ECHO SOUNDERS

Let us start with a basic study. When we measure abundance and/or size of fish with the pulse-echo method, basic demand is a high signal-to-noise ratio (SNR). Design of instruments should be done under this imperative demand¹⁾ and research vessels should be as silent as possible.²⁾ If we are given a measurement system including a vessel, we must know what range can be used for quantitative measurements. The maximum detection range of sounders has been commonly examined, but whole range including width has hardly been investigated. Therefore, we developed a method to see the whole range (named detection range)³⁾ and have applied it.⁴⁾

The SNR, S_N , of echoes of fish at coordinates (r, θ) with TS value of T_S is³⁾

$$S_N = \frac{4\rho^3 r h W a^4 f^{5.8} \exp[-2(\rho a f / c)^2 q^2] 10^{-0.2ar} T_S}{c^3 r^4 N_{P0}^2 \Delta f}$$

where ρ is density of sea water, h is electro-acoustic efficiency of transducer, W is electrical power, a is radius of the transducer, f is frequency, c is sound speed, q is absorption coefficient, N_{P0} is own-ship noise spectrum level extrapolated to 1Hz, Δf is bandwidth of receiving system, and $\exp(-0.2ar)$ term is approximation of directivity function. From the equation, we see SNR depends heavily on f and a besides r . Giving a threshold value for S_N and determining r and θ , pairs to hold this equation give the detection range.

Figure 1 shows an application of the detection range, with changing TS values, for a two frequency (38kHz and 120kHz) quantitative echo sounder with the same beam width of 8.5 deg. The smaller the TS values, the smaller the detection range and also smaller the difference of the detection ranges between two frequencies.

ECHO TRACE ANALYSIS OF SINGLE FISH ECHOES

In single echo measurements, we observe a distribution of TS values of many fish. The information we can derive from the distribution, however, is average TS and average body length. If we have several successive echoes (echo trace) from the same fish and track the trace, we can derive more information on the fish such as swimming speed, TS pattern, body length of the individual fish. We have studied this method, started from the principle and the application to single beam sounder,⁵⁾ succeeded by application to dual beam and split beam sounders, and made up a software called TSAN.⁶⁾

Figure 2 shows the principle of the echo trace analysis. Since the split beam method gives us positions of fish seen from the origin at the transducer, the echo trace analysis becomes easy and accurate. The inner product of derived swimming vector and position vector gives an apparent tilt angle shown as α_t in Fig.2 and the combinations of this angle and measured TS value make TS pattern. From this *in situ* TS pattern, we get the maximum TS value which can then be transformed to fish length.

Figure 3 shows an example of the analysis by TSAN.⁶⁾ Once a target single echo is selected, it is automatically tracked to give a swimming track and TS pattern. The maximum TS value (TS_{max}) in this case is -24.5dB and from the relation $TS_{max} = -60 + 20 \log L$, L is body length in cm, we have 59.6cm as the body length. In this method it is necessary to be able to track echoes from the same fish for a rather long time, and this limits the method, and also this method suffers from transducer motion error.⁷⁾ How we release these limitations is our present work.

FREQUENCY DIFFERENCE OF SCATTERING FOR BROAD SPECIES CLASSIFICATION

Fishermen classify fish species in high reliability by comparatively seeing echograms by different frequencies. Also for the survey purpose, echo sounders with more than one frequency have been used, expecting the broad classification of fish species.⁸⁾ We have devised a similar but more accurate method,⁴⁾ essence of which is described below.

The echoes by different frequencies include several frequency characteristics other than scattering characteristics; those are propagation characteristics, level difference due to source level and receiving sensitivity, beam pattern difference, and noise characteristics. The mean volume backscattering strength (MVBS) as the output of echo integration is corrected for propagation characteristics by time-varied-gain (TVG) function, for level difference by calibration, and for beam pattern difference partially by using the equivalent beam angle. The residual frequency characteristics other than the scattering are the observation range when beam width is different among frequencies and noise characteristics. Equating the beam widths and comparing the MVBS at the same detection range described in the previous section, we measure genuine frequency difference of scattering. Further, since TS has different patterns among frequencies, if we compare echoes by ping base the difference varies. Therefore, the echo integration process is necessary. The integration cell should not be too large, because the possibility to include

different species becomes high to deteriorate this method.

Let us see two results obtained by the sounder whose detection range is shown in Fig.1. From Fig.1 we have the same detection range of 150m up to small TS values and we can compare MVBS in the range. Figure 4 shows the difference of MVBS between 120kHz and 38kHz in the integration cell with size of 0.1nmi horizontal and 1m vertical. Redder colors are stronger for 120kHz scattering and bluer for 38kHz. The label E in Fig.4 (upper) shows stronger strength for 120kHz by about 10dB, and this with other environmental information suggests krill and the label W shows several dB stronger for 38kHz suggesting walleye pollock. The hole like image in the lower figure suggests some interaction between krill and other organism.

QUANTIFICATION OF SCANNING SONAR

Since the quantitative echo sounder utilizes a sharp vertical beam, its sampling density is small and introduces avoidance of fish, causing random and systematic errors. Therefore, we expect to use scanning sonar which scans beam in near horizontal plane. We have studied the quantification of commercial 360deg scanning sonar⁹⁾ as the first step to develop a quantitative sonar which processes raw signal as in the quantitative echo sounder.

Receiver outputs of the sonar are AD converted and stored in computer memory with addresses of direction and range. The TVG characteristics of the sonar is adjusted aiming for good image on the display, so that it is corrected to $20 \log r$ characteristics as of the echo integration process in the quantitative echo sounder. Since changing tilt angle of the sonar beam changes source level, receiving sensitivity, and directivity, these tilt dependences are measured and corrected. The product of source pressure and receiving sensitivity, called the transmitting and receiving coefficient, is calibrated using a calibration sphere. But, since the sonar uses horizontal beam, the sphere was suspended from a float, the float was drifted at proper ranges from the ship, the highest echo level was searched by changing the tilt angle, and from the level we got the coefficient. Other processing is similar to the quantitative echo sounder and finally we get raw volume backscattering strengths.

The sonar display is renewed by each ping and if the vessel moves we have new displays shifted by the sailed distance. Therefore, by taking out crescent-shaped portions selected at where there are little reverberation from sea surface or from bottom and by connecting them, we have a strip display as an aerial photograph. Figure 5 was obtained through this process and shows fish school distribution in broad area as volume backscattering strength. The data were obtained from about 50m ahead of the ship, the avoidance effect should be small. Further quantification is very difficult because of severe directivity changes of fish TS in horizontal plane, but if we can see the swimming orientation of fish by some means, abundance estimation of broad area by the scanning sonar will be possible.

REFERENCES

- 1) M.Furusawa, "Designing quantitative echo sounders," J. Acoust. Soc. Am., 90, 26.36 (1991)..
- 2) R.B.Mitson(ed.), Underwater noise of research vessels: Review and recommendations, (International Council for the Exploration of the Sea, Coöperative Research Report, No.209, pp1-61, 1995).
- 3) M.Furusawa, T.Asami, and E.Hamada, "Detection range of echo sounders," The 3rd JSPS International Seminar: Sustainable Fishing Technology in Asia towards the 21st Century, 207.213 (1999).
- 4) M.Kang, M.Furusawa, and K.Miyashita, "Effective and accurate use of difference in mean volume backscattering strength to identify fish and plankton," ICES J. Marine Sci., in press (2002).
- 5) M.Furusawa and Y.Miyanohana, "Behaviour and target strength observation through echo trace of individual fish," Rapp.P.-v.Reun.Cons.int.Explor.Mer, 189, 283-294 (1990).
- 6) K.Sawada, "Study on the precise estimation of the target strength of fish," Bull.Fish.Res.Agen., 2, 47-122 (2002) (in Japanese).
- 7) M.Furusawa and K.Sawada, "Effects of transducer motion on quantifying single fish echoes," Nippon Suisan Gakkaishi, 57, 857-864 (1991).
- 8) L.S.P.Madureira, I.Everson, and E.J.Murphy, "Interpretation of acoustic data at two frequencies to discriminate between Antarctic Krill (*Euphausia superba* Dana) and other scatterers," J. Plankton Res., 15, 787.802 (1993).
- 9) Y.Tang, M.Furusawa, S.Aoyama, C.Fan, and Y.Nishimori, "Measuring behavior and volume backscattering strength of surface fish schools by using scanning sonar," submitted (2002) (in Japanese).

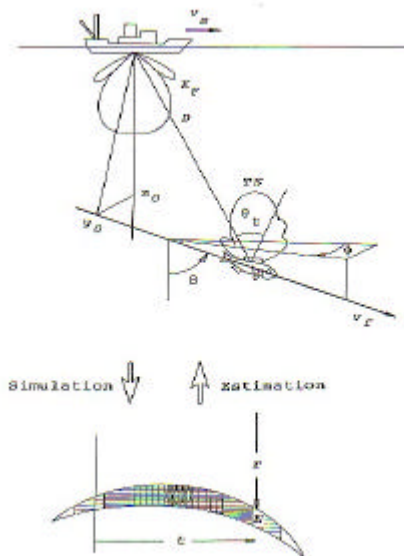
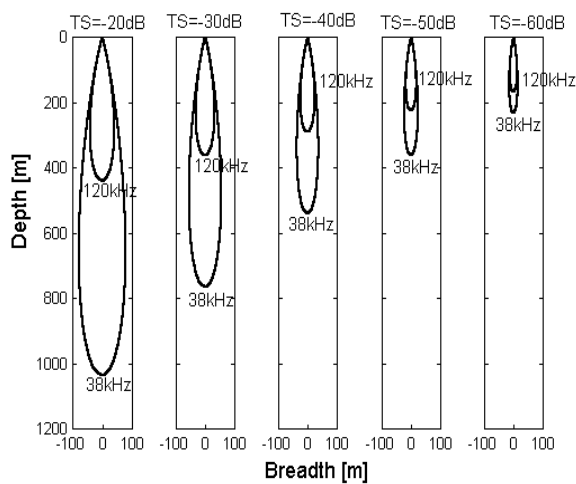


Fig.1 Detection ranges of a quantitative echo sounder with two frequencies of 38 and 120kHz single fish echo. Fig.2 Principle of echo trace analysis of sonar

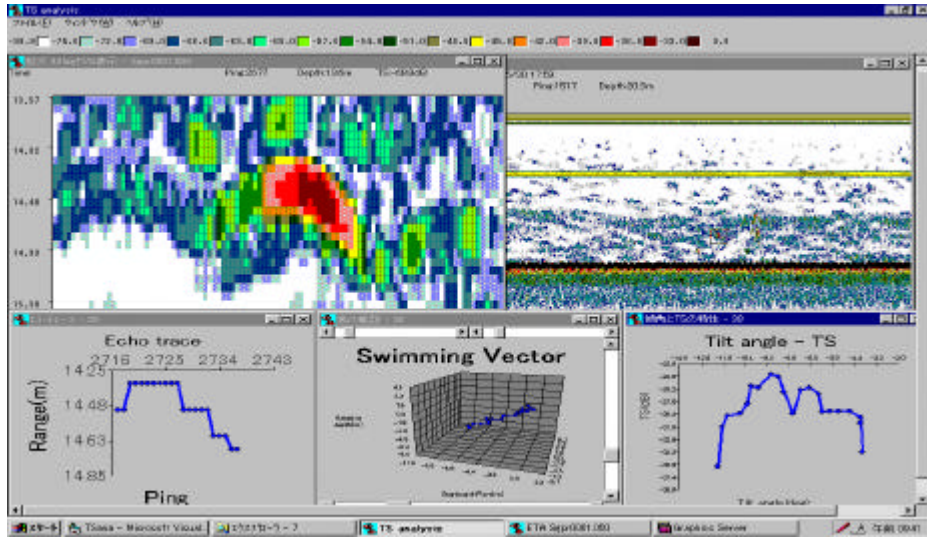


Fig.3 A result of single echo trace analysis

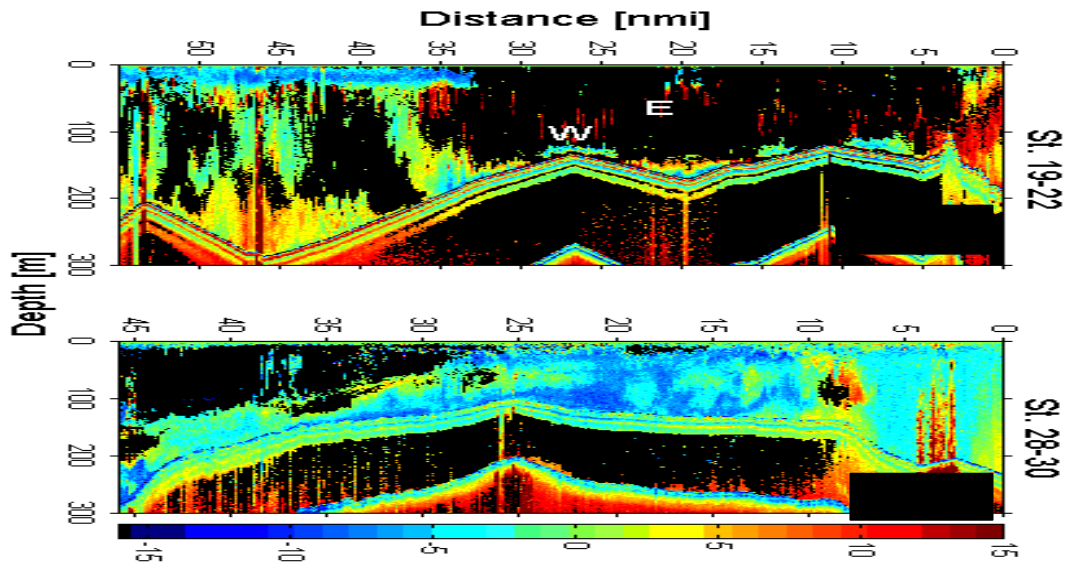


Fig.4 Difference of mean volume back scattering strength at 120kHz and 38kHz

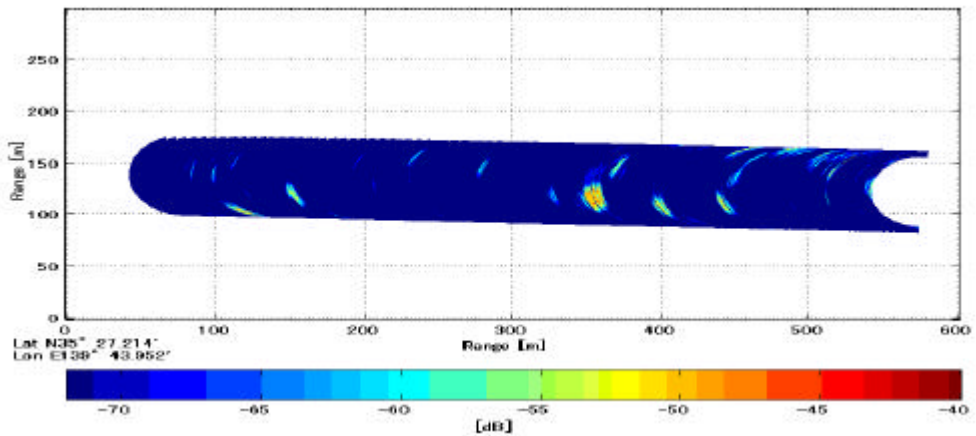


Fig.5 Image showing raw volume backscattering strength of fish schools close to the sea surface derived from scanning sonar signal.