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Notes

Wide-band echo-integration: simulation results

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Echo-intégration large bande : résultats d'expériences de simulation.

INTRODUCTION

Echo integration is an assessment technique for marine organisms, which has been described by many authors such as Marchal (1985), Johannesson and Mitson (1983). The hypothesis from which this technique has been developed is that there is a linear relationship between the reflected energy and the number of fishes. This assumption has been verified using narrow-band systems (Foote, 1983), wide-band systems have been used only (up to now) for experimentation in species identification (Simmonds and Armstrong, 1987; Lebourges, 1990).

In order to evaluate the interest of using wide-band signals for echo integration and before starting systematic experiments, we have set up a simulation software that could be used, for a given fish population, to predict the reflected echo, for various transmitted signals with various bandwidths.

METHODS

Simulation model

In order to reduce the computation time, we started up with a simple software that operates in a two-dimensional plane and neglects the effects of both transducer and fish directivity patterns. The water column is divided into horizontal layers (*fig.* 1). For each layer and for each fish, the angular position is a random variable. As we have no *a priori* information about the position of the fish in the beam, the variable is supposed to possess a uniform distribution.

It is defined by its limits θ_{min} and θ_{max}, its mean value and the number of realizations.

Signal characteristics

The received signal is modelled by a Gaussian envelope and a constant frequency carrier:

$$S(t) = \cos(2\pi\nu_0 t)\exp\left\{-\frac{t_2}{\sigma^2}\right\}$$

The carrier provides the signal central frequency (ν_0) and the Gaussian variance ρ provides the signal duration and thus its bandwidth:

$$B_{-3dB} = \frac{0.38}{\sigma}$$

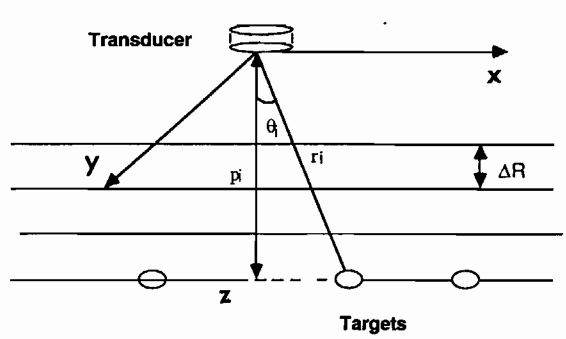

Figure 1. – Random positioning of fish in each layer.

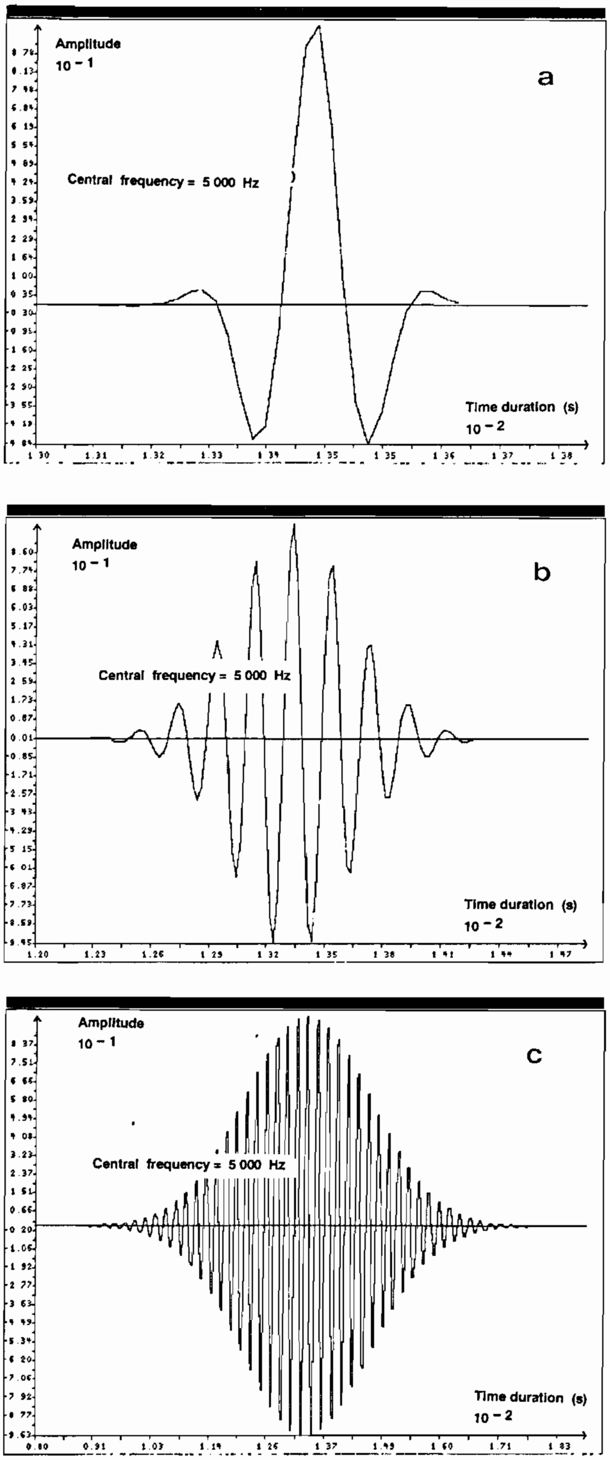

Figure 2. – Isolated echo. (*a*): wide-band 1 octave (at –3 dB), (*b*): medium-band 1/4 octave (at –3d B), (*c*): narrow-band 1/16 octave (at –3 dB).

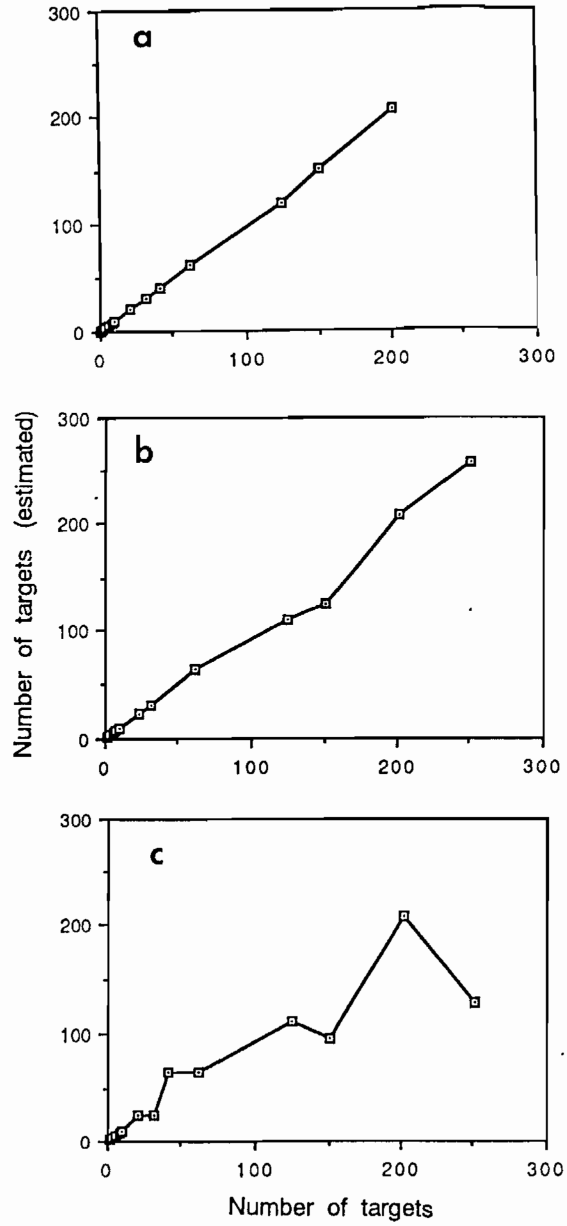

Figure 3. – Echo integration linearity estimation. (*a*): wide-band, (*b*): medium-band, (*c*): narrow-band

Such a signal can be used to model in a simple way the transmitted signal, for both wide-band and narrow-band systems. It can also be used to model the output of the matched filter in the case where both chirp signals and pulse compression are used (Zakharia *et al.*, 1990).

According to the simplification hypothesis previously mentioned, the elementary echo can be expressed as:

$$S_r(t-\tau_i) = \cos(2\pi\nu_0(t-\tau_i)) \exp\left\{-\frac{(t-\tau_i)^2}{\sigma^2}\right\}$$

where $\tau_i = \frac{2r}{c}$, is the time delay corresponding to the target range.

As range variations are small compared to the average range, echo absorption can be neglected.

The echo reflected by a shoal of n fishes can be written as:

$$S_n(t) = \sum_{i=1}^{n} S_r(t-\tau_i)$$

Figures 2 shows the plot of the signal we have used for simulation.

RESULTS

Several simulations have been conducted for various fish school densities. For each case the number of estimated fish can be plotted as a function of the actual number. *Figure* 3 shows such plots for the three cases investigated: wide-band, medium band and narrow-band. In these figures the horizontal axis is the actual number of targets (all simiular) and the vertical axis is the one estimated by energy computation (under echo integration assumption). The figures show a better linearity for the wide-band system, as echoes from the same school may be separated in this case and overlap in the case of narrow-band. Performances are summarized in the table.

The simulations have been achieved with the following parameters: $f_0 = 5$ kHz, $R_{min} = 10$ m and $R_{max} = 40$ m.

In order to evaluate the precision of estimation, we have run simulations with the same population of fish and with various random positions (16 realizations with overlapping echoes) in a given angular sector ($-10° < \theta < 10°$). For a confidence interval of 95%, the precision of estimation is 14%. This gives an idea of the precision that could be expected in the case of dense schools.

We have also investigated the influence of the fish school in the beam. This investigation is only a statistical one on the geometry, as the transducer directivity pattern has been neglected and supposed uniform. For the same fish population, the position, in the beam axis can lead to very large variations (up to 300%) on the received energy. These variations are reduced, in a real case, by the directivity pattern of the transducer but can still be important when approaching a school.

Table 1. – Echo-integration performance; narrow band vs wide band.

	Case 1	Case 2	Case 3	Case 4
	1 to 10 fish	10 to 80 fish	80 to 200 fish	200 to 2 000 fish
1 octave	isolated echoes	isolated echoes	isolated echoes	echo overlap
1/4 octave	isolated echoes	isolated echoes	echo overlap	echo overlap
1/16 octave	isolated echoes	echo overlap	echo overlap	echo overlap

CONCLUSION

The simulations we have conducted are simple ones, as we have neglected the directivity pattern of both the fish and the transducer. Even in such a simple case, the results show that one has to be very careful when interpreting integration data in the case of dense schools. The use of wide-band is interesting as it can help in increasing the resolution and thus resolve individual echoes in school echo. These simulations will have be continued and improved by including the directivity patterns; it also has to be confirmed by experimental data obtained in controlled conditions on real fish shools.

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