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DESCRIPTION OF AN EXPERIMENTAL BROAD-BAND (20-140 KHZ) SONAR SYSTEM AND FIRST RESULTS OBTAINED IN ECHOGRAPHIC DISCRIMINATION OF 6 DIFFERENT SPECIES OF FISH.

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1. INTRODUCTION

In existing acoustic systems for fish stock assessment and management, like echo-sounders and echo-integrators, single frequency or narrow bandwidth signals are used. The only information given by such systems is related to the energy reflected by the fish and no indication about the species concerned can be obtained. It is therefore necessary to speculate, on the basis of the fish behavior and habits, or use some extra-equipment, such as an underwater camera or sampling nets, to obtain the required information about the species involved.
Because of the frequency dependance of the sound reflectivity of a given target, a broad-band echo can theoretically carry a signature of the ensonified target, giving information about its shape and structure, and it is well know that many animals such as bats or dolphins use a natural broad-band sonar with very great efficiency, for ranging and identification (1). The major obstacle to the development of broad band systems lies in the difficulty of constructing a suitable transducer which must be unidirectional, without secondary lobes, and have a high power capability in transmission to give a satisfactory signal to noise ratio in the appropriate overall frequency band. Technically, these needs are difficult to satisfy for a reasonably low cost and, until now, existing broad band sonar systems have been mainly experimental (2, 3).
For ichthyological applications, broad-band sonar systems can thus help in species identification, but they can also improve the target strength measurements by smoothing out the frequency variations due to fish orientation changes (4, 5). For these reasons we believe that, in spite of the practical difficulties mentioned, the broad band sonars offer good potential for development in the near future.

2. MATERIALS AND METHODS

2.1 Description of the system

The experimental system described here provides, in a rather simple structure, (see Fig. 1A), the major requirements for a broad-band sonar.
The signal generation and echo-acquisition processes are controlled by a PC.
A range of signals of up to 8 k-samples each can be used. They are stored in the read-only memory of a programmable (I3E-488) arbitrary waveform generator (W 75) and played back at each transmission. After power amplification (FA800) they are applied to the transducer for acoustic emission. The transducer works in a monostatic fashion ie. as emitter and receiver in turn. The reflected signal is then amplified by a low noise voltage amplifier (Deg.), applied to a digital oscilloscope (2430A), sampled and transferred to the storage memory of the P.C. The transducer is of great importance for the overall performances of the system. This system uses a constant

beamwidth transducer (CBT), similar to that described by A.L. van Buren et al. (6), constructed by Actran Systems Inc. It consists of an array of 849 piezo-electric elements, (zirconate-titanate), each being 8.05 mm in diameter and 6.23 mm in thickness, which are encrusted in a spherical aluminium cap of 30 cm diameter and 34.9 cm radius of curvature, forming 16 concentric circular bands.
An array of capacitors is used to produce a shading function (close to a Legendre P5 function) giving a reciprocal nearly constant directivity of 22°, in the whole frequency band from 20 kHz to 140 kHz. The maximum pressure level obtained with this system is 192 dB/µPa.

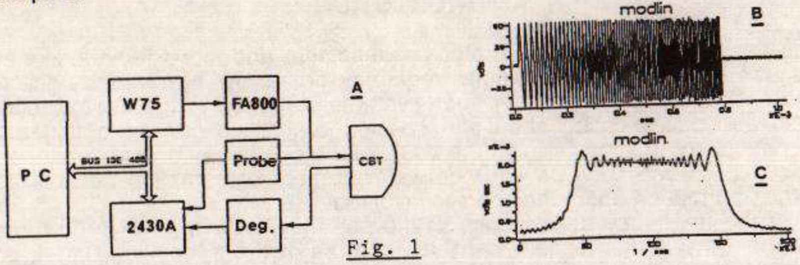

Fig. 1

We have used this system to record echografic signatures of various individuals of 6 species of freshwater fish placed in a controlled environment. The experimental features, the analytical methods used for discrimination and the results are described below.

2.2 Experimental set-up and materials
45 individuals of the 6 following species : Pike *Esox lucius* (Br.), Carp *Cyprinus carpio* (a distinction has been made, between a carp with scales (Ce) and without scales (Ca)), Arctic charr *Salvelinus alpinus* (Om), Perch *Perca fluviatilis* (Pe), Tench *Tinca tinca* (Ta) and Trout *Salmo trutta* (Tr). The number of individuals of each species tested, their length and mass and the number of echos used in discrimination are given below.

Species	Br	Ca	Ce	Om	Pe	Ta	Tr
Nb. of Indiv.	9	5	2	9	5	10	5
Length (cm)	40-60	39.5-42	25-50	35-45	29-37	38-49	31.4-48.1
Weight (gr)	370-1461	1200-1430	800-2075	450-1025	398-930	833-2010	356-1596
Nb. of acquis.	90	80	59	76	90	189	250

The tested animal was anaesthetised with phenoxyethanol just before the experiment, then placed 1.5 m below the transducer and maintained horizontally in the emission axis with 2 thin nylon threads, which could be manipulated from the surface. The horizontality of the animal was verified visually through the portholes of the tank. An aluminium bar, 30 cm long, attached in the same way to the fish (around the tail and behind the operculas) by two 1.5 m long identical threads, was used as stabilizing ballast.
The waveform used in these experiments and his spectrum are represented in Fig. 1B and C. It is a constant amplitude, linearly frequency modulated (between 20 and 140 kHz) in 0.8 ms. signal. A transmission rate of 2 s. was chosen to ensure complete attenuation of multi-reflected echos. This way, only the first dorsaly reflected echos from the tested animal were considered. The acquisition of the echos was carried out during the period of anaesthesia before the animal recovered and at least 50 measurements were made with each animal. In this study, we have used only the echo sets corresponding to motionless sleeping. Also, because of electromagnetic interference noise at the receiver, the receiving bandwidth has been restricted to between 60 kHz and 140 kHz, by a high pass filter (multimetric-AF-120).

3. RESULTS

3.1 Individual echographic responses

From each echo the individual spectral responses - $IS(f_k)$ versus discrete frequency f_k were calculated according to the following formula :

$$IS(f_k) = 10^{\frac{Ind(f_k)}{10}}$$

where : $Ind(f_k) = Lr(f_k) - Le(f_k) - Sv(f_k) - Sh(f_k) - G - K + 40 \log r + 2\, r.a(f_k)$

Le : spectral density value of the transmitted signal
$Lr(f_k)$: spectral density value of the received signal
$Sv(f_k)$: transmitting response of the CBT
$Sh(f_k)$: receiving response of the CBT
G : amplification of the received signal
K : attenuation of the emitted signal
$a(f_k)$: absorption coefficient
r : transducer to target range

The frequency resolution obtained in the calculation of the spectra (FFT) was 512.8 Hz, so that in the 60-140 kHz bandwidth each spectrum is represented by 156 discreet values of f_k. An example of the echo and corresponding IS (f_k) obtained for each of the 6 species examined is given in Plate 1.

3.2 Intraspecific responses

To remove the effects of size (length and mass) and behavior (respiration, tail beating), we have considered the normalized individual spectral responses $NIS(f_k)$:

$$NIS(f_k) = \frac{IS(f_k)}{IS(f_m)}$$

Then the mean normalized individual spectral response MNIS (f_k) as well as the associated individual variability response $IV(f_k)$ were calculated according to the following formulae :

$$MNIS(f_k) = \frac{1}{n} \sum_{j=1}^{n} NISj(f_k)$$

$$IV(f_k) = \frac{\sigma(f_k)}{MNIS(f_k)}$$

where :

$1 \leq k \leq 156$
n : is the number of individual echos taken into account
fm : the value of f_k when $ISj(f_k)$ is maximum

and $\sigma(f_k)$: the standard deviation for the n $ISj(f_k)$ plots.

These mean normalized individual spectral responses show that the differences observed are much greater between the interspecific than between the intraspecific plots where some gross similarity exists.
On the other hand, the rapid and large variations in $IV(f_k)$ related to the movements of the animal show the high dependance of the responses on its angular orientations within the transmitted sound beam (5,7,8). See examples for Esox lucius in Plate 2.

3.3 Mean specific responses

The interspecific frequency response differences are demonstrated by the mean normalized specific spectra : $MNSS(f_k)$, obtained from the corresponding mean specific spectra : $MSS(f_k)$. See Plate 3.

The calculations made are the following :

$$MSS(f_k) = \frac{1}{m} \sum_{j=1}^{m} MNISj(f_k)$$

and

$$MNSS(f_k) = \frac{MSS(f_k)}{MSS(f_m)}$$

where :

m : is the number of individuals in the species concerned
fm : is the value of f_k where $MSS(f_k)$ is maximum.

3.4 Spectral specific discrimination

Various statistical methods of classification and discrimination were applied to a set of 834 normalized individual spectra $NIS(f_k)$, for specific discrimination.

The results obtained, and given elsewhere (9), are summarized here.

3.4.1 Use of classification methods
The aggregationnal method gave no useful results, whatever criterion was used. However, the "k means method", where the intra-group variance is minimized by successive repositionning of the individuals in the specific groups, gave rather satisfactory results as shown by the following table.

Spec.	Nb. sig.	Classification rate (%)						
		Br	Ca	Ce	Om	Pe	Ta	Te
Br	90	33	18	33	16	0	0	0
Ca	80	9	50	8	18	11	2	0
Ce	59	0	8	66	0	17	8	0
Om	76	22	0	0	22	0	38	16
Pe	90	0	0	0	0	50	29	21
Ta	189	14	5	7	5	8	45	19
Tr	250	0	0	0	0	17	21	60

The general classification rate here is 50 % whereas it would be only 14 % by a random assigment.

3.4.2 Use of discrimination methods
Various discrimination methods were also used in the same set of 834 NIS(f_k), values such as : linear or least squares discrimination methods, with or without the smoothing of data by weighting (0.25, 0.50, 0.25) and resampling, or by step by step selection of the variables. All the direct results obtained are good, the classification rate generally being > 90 %, but cross validation reduces significantly that figure to about 60 %.
It also appears clearly from the above described calculations, that the methods used can be improved by employing a more convenient variable to individual ratio (actually 156/45). If for example, only 16 variables are selected, step by step, the linear discrimination method gives 98 % of good classification of the considered individuals, a results which is reduced to 66 % by a cross validation. In this case the best discrimination frequencies are obtained for the following values of k : 1, 4, 17, 20, 21, 24, 28, 31, 32, 33, 35, 86, 120, 151, 152 and 155.
These results support and extend the similar work of A. Lebourges (10) using 15 fish from 2 species (*Morone labrax* and *Salmo gairdneri*).

3.4.3 Results obtained with a neural network
Neuronal methods were also applied to classify a set of 191 echos from the 6 species concerned. First, significant parameters were extracted from each echo by auto-regressive modelling and wavelet decomposition. Then, Neuroclass^{TM} software,

which allows comparison beetwen classical and neural methods of classification was applied to these preprocessed data.
The classification was done in two steps : the learning step, where the classifier was configured for data recognition, and the generalisation step, where the preprocessed data, not used in the previous step, were classified.
The results obtained by these different methods, with the preprocessed data, are much better then those obtained previously, on the direct spectral responses, since at least 90 % of correct classification was obtained, whatever the method used. But the best results were given by the multilayer perceptron neural network, with 95,9 % of correct overall classification as shown by the following classification table.

Spec.	Nb. sig.	Classification rate Br	Ca	Om	Pe	Ta	Tr
Br	18	93,0(±2.1)	2,3(±1.4)	2,2(±1.4)	1,0(±0.8)	1,0(±0.6)	0,4(±0.4)
Ca	13	0,0(±0.0)	97,2(±2.0)	0,0(±0.0)	0,0(±0.0)	0,0(±0.0)	2,8(±2.0)
Om	13	0,6(±0.6)	0,0(±0.0)	98,0(±1.1)	0,8(±0.7)	0,6(±0.6)	0,0(±0.0)
Pe	13	0,0(±0.0)	0,0(±0.0)	0,0(±0.0)	97,2(±1.1)	2,8(±1.1)	0,0(±0.0)
Ta	18	1,4(±0.8)	0,7(±0.8)	3,4(±1.6)	1,2(±0.7)	93,2(2.3)	0,0(±0.0)
Tr	18	0,0(±0.0)	1,3(±0.8)	0,0(±0.0)	0,0(±0.0)	0,4(±0.4)	98,2(±0.9)

4. CONCLUSION

The interest of a broad band sonar system for fisheries acoustics and fish biomass estimation lies principaly in :

- the potential of species identification
- the improvement of biomas estimation

We have developed an experimental system which presents in a rather simple structure, the essential properties which required in a broad band sonar i.e.:

- transmitting and receiving angular patterns which are frequency independant,
- no secondary lobes in the transmission diagram,
- great adaptability in the waveform generation and in the signal acquisition and processing.

A large illustration of the individual, as well as the specific, spectral and temporal responses for 45 animals belonging to 6 different fresh water species have been obtained. We have shown, using classical statistical methods applied to the only energy spectrum distribution of the echos of dorsaly ensonified fish, that it is possible to classify 45 individuals into their 7 different species with an error of only 34 %. We have then shown that the previous results might be highly improved if the classification methods are applied to preprocessed data since this reduce the error to 10 %. Finally we have shown that the neural method of classification, compared to classical ones, seems to be the most appropriate to this particular classification problem.
These results comming after others (11) are very encouraging. The work will now be extended to *in situ* studies to obtain a data base as a reference pattern for the species of interest.

5. REFERENCES

(1) R G BUSNEL & J F FISH (Editor), 'Animal sonar systems', Plenum Press, New York (1980)
(2) E J SIMMONDS & P J COPLAND, 'A wide-band constant beam-width echo-sounder for fish abundance estimation', Proceedings of the Institute of Acoustics., 8 (3) p173-180 (1986)
(3) M E ZAKHARIA, P J CORGIATTI, F JOLY ET R PERSON, 'Description et performances d'un sondeur de pêche large bande (20 kHz à 80 kHz). Colloque de Physique, 1er Congrès Français d'Acoustique, 51 (supl. 21) (1990).
(4) E J SIMMONDS & P J COPLAND, 'Species recognition, results from a wide band echo-sounder 27-54 kHz', Proceedings of the Institute of acoustics, 1 (3) (1989)
(5) M E ZAKHARIA, 'Variations of fish target strength induced by its movement ; a wide-band experiment', International Symposium on fisheries acoustics, Seattle, (1987)
(6) A L VAN BUREN, L D LUCKER, M D JENNAGER & A C TIMS, 'Experimental constant beamwidth transducer', J Acoust Soc Amer, 73 (6) p2200-2209 (1983)
(7) K G FOOTE, 'Effect of fish behaviour on echo energy : the need for measurements of orientation distributions', J Cons CIEM, 39 (2) p195-201 (1980)
(8) D N MACLENNAN, A E MAGURRAN, T J FITCHER & C E HOLLINGWORTH, 'Behavioural determinants of fish target strength', Intern Symp on fisheries acoustics, Seattle, (1987)
(9) A DZIEDZIC, C CHABANET ET P ROUX, 'Premiers résultats en discrimination spectrale des échos sonar large bande (60-140 kHz) de 6 espèces de poissons', Proceedings 14 ICA Beijing, sept (1992)
(10) A LEBOURGES, 'Utilisation de la spectroscopie ultrasonore en vue d'identifier les espèces de poissons', Thèse Univ. Paris VI (1990)
(11) P DEGOUL, P FLANDRIN, N GACHE, M ZAKHARIA, 'Fish echoes classification via auto-regressive modelling', Proc IOA, 11 (3) (1989)

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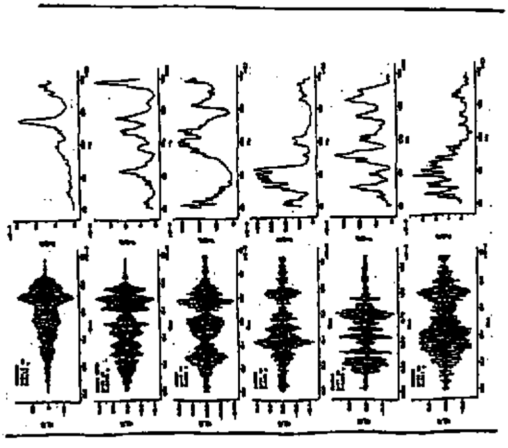

Plate 1. Echo and spectral response IS(fk) samples for the 6 examined species

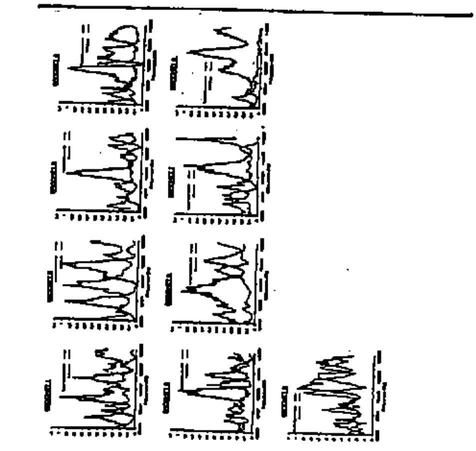

Plate 2. Mean normalized individual spectral responses MNIS(fk) for 9 fishes of the same species (*Esox lucius*)

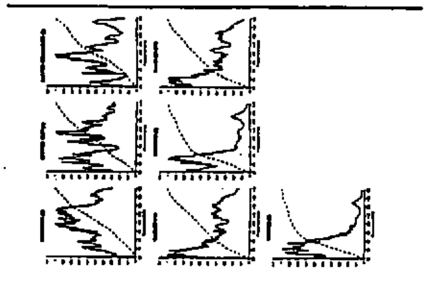

Plate 3. Mean, normalized specific spectra MNSS(fk) and associated cumulated energy curves for the examined species