

POST-PROCESSING POULIQUEN ECHO CORRECTION FOR SEABOTTOM CLASSIFICATION

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Abstract

One of the unsolved problems in seabed classification is echo correction, aimed at presenting all the pings in a standardized form to readily compare them to each other. After correction the echoes from the same bottom type would look the same, independent of the particular bottom depth. Based on a diffuse reflection model, Pouliquen suggested in 2004 to acquire the echoes scaling pulse lengths proportionally with depth. In this work, we recover Pouliquen's idea to apply it during post-processing. The signal of a single-beam echosounder is time and power adjusted, and then convolved with a structure element simulating the loss of resolution of the signal at a smaller reference depth. The resulting depth correction is consistent for sandy and muddy bottoms between 5 and 40 m deep. The results of testing this method are shown for the Ría de Cedeira (in Galicia, northwest of Spain). The results of the final classification are compared with those obtained from direct observations and from interviews with local fishermen.

Keywords: Pouliquen depth correction; seabed classification; aggregative clustering.

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1 Introduction

Acoustic methods have been broadly used for sea-bottom classification [1], in particular single-beam scientific echosounders calibrated to provide accurate scattering strength measures [2], time responses [3]) and echo shape features (moments, wavelet coefficients, fractal dimension, etc.) [4, 5] that have been related to different seabed types within a study area.

To classify the seabed from its acoustic response, the different responses from the different sea-beds characterized by the echo shape and amplitude (that depend mostly on the sea bottom depth) have to be made comparable. This first step is called correction and

compensates the power losses (power correction) and the temporal distortion (time correction) of the received echoes. The objective of this work is to improve this latter correction, which is the most important in zones with depth varying rapidly such as coastal areas.

A vertical single-beam echosounder (VBES) produces acoustic waves that propagate with spherical symmetry from its transducer, traveling at the speed of sound in water, $c \approx 1500$ m/s. The larger part of the emitted power (up to 94% for a 7° wide Gaussian beam, corresponding to a maximum directivity of 28 dB) will be directed along the main lobe of the directivity pattern. The emitted power lasts for a small time τ leading to a pulse length of $l = c\tau$. The wave packet reaches the bottom and the sub-bottom region beneath and is reflected and backscattered to the transducer, which samples the incoming wave pressure (averaged out to intensity) in sampling time bins of duration δt (usually, $\delta t = \frac{1}{4}\tau$).

The total reflected power follows the sonar equation, that adds a range R dependency caused by the wave spherical spreading, $-20 \times \log_{10} R$ (for the total echo energy), and the wave attenuation in water, $-2\alpha_w R$. The correction terms regarding the acoustic intensity, depending not only on depth, but also on time after the first bounce instant t_0 , are not so easily calculated due to the finite pulse length that does not usually scale with depth (power correction would be much easier in this case, as proposed in [6]). As the acoustic wave spreads out, the lateral parts of the main acoustic lobe, and the side-lobes of the acoustic directivity pattern, will add up to form the tail of the received ping and, for shallow depths or large pulse lengths, the former lateral lobes may become indistinguishable from the main one. The signal reflected from lobes further apart than 60° from the central lobe will not be observable with a VBES kept at the water surface, as it will become mixed with the second echo (twice reflected from the bottom, after an air-water interface reflection).

The objective of this paper is to introduce a ping correction scheme suited to perform seabed classification in coastal areas with steep depth variations, developing the idea of [6] of scaling the pulse-length with depth, but instead of modifying the echosounder, simulating this in post-processing. A physically based classification method (aggregative clustering) will also be introduced and tested in a study area.

2 Material and methods

In order to perform the sea bottom classification we will classify corrected echoes, thus the first part of the methodology will consist on echo delimitation and correction from the raw intensity ping recorded by the digital VBES. Afterwards, in order to interpret this classification, we will use direct measurements and knowledge of a study area. Finally, we will refine this seabed classification.

2.1 Echo delimitation and correction

Bottom detection is necessary to time align pings and to compute echo duration. We will use a thresholding algorithm for this: the beginning of ping first bounce will be located at the bin previous to the ping maximum which lays at less than 40 dB below that maximum; the end of that first bounce will be determined geometrically, at twice the distance from the surface as the bottom position is (the echosounder is kept right below the water surface). The 40 dB threshold was determined empirically, and may change for other echosounders or sea-water conditions or depth ranges.

The time correction of the echoes was performed in two steps. First, a deep enough depth R_0 was chosen, large compared to the depths found in the survey (we have chosen 40 m). Then all the echoes were stretched (interpolated) to fit within $2R_0/(c\delta t)$ bins to provide the simplest time correction. Then the power correction was applied adding to each normalized ping $30 \log_{10}(R/R_{ref})$ [7], where R_{ref} is the reference depth for the correction.

As suggested by Pouliquen in [6], the finite ping length τ requires further adjustments of this time correction. In particular, Pouliquen suggests to use depth dependent emitted pulses with lengths $\tau(R)=(R/R_0)\tau_0$, i.e., shorter, the shallower. Our approach will be to simulate a lengthening of the pulses of the deeper pings, i.e., we will apply a ping-lengthening Pouliquen correction (PLP).

We first observe that ping intensity $I(t)$ can be computed as the convolution of the emitted pulse $W(t)$ with a time- (t) and depth- (d) dependent bottom response function $G(ct/d)$ [8]. Then, to simulate the PLP from a deep zone (R_1), we may convolve the ping intensity $I(t)$ with a properly chosen structure element $W'(d,t)$, so that the resulting time-normalized ping resembles one measured at a shallower bottom ($R_{ref} < R_1$). If the pulse length of the R_{ref} deep ping is $\tau_{ref}=\tau$, then, the Pouliquen's suggested ping length for the R_1 ping would be $\tau_1=(R_1/R_{ref})\tau_{ref}$, that is the simulated pulse length has to be lengthened by $\Delta\tau_1=\tau_1-\tau_{ref}$. This lengthening will be simulated here using as the structure element $W'(d,t)$, a rectangular pulse function $\Delta\tau_1$ long and $1/\Delta\tau_1$ high (for energy conservation) which does not render the exact result, but is numerically convenient (see figure 1).

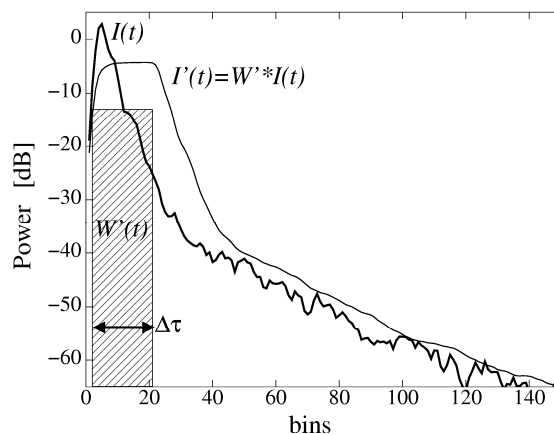


Figure 1: Ping correction: time correction and ping widening convolution.

2.2 Study area

The study area was the Ría de Cedeira, one of the smallest ones in the Galician coast (693 ha). This area has a high diversity of bottom substrate types and topographic features including a subarea with high slope (up to 20° in rocky area and up to 6° in sandy area) where the bottom attains large depths (50 m), and also a flat shallow area (<10 m), containing rocky, sandy and muddy bottoms [9].

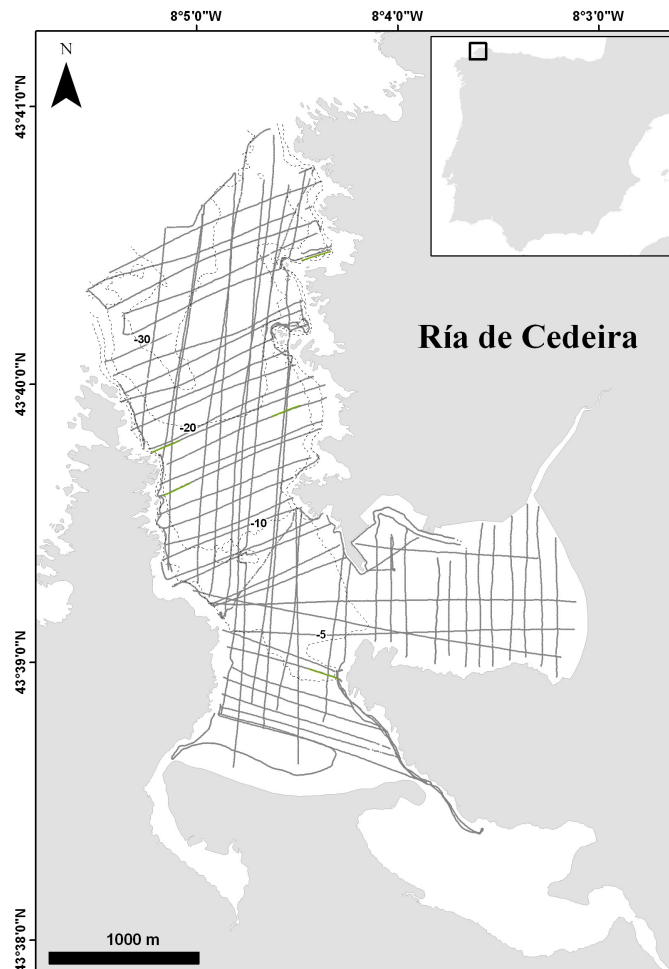


Figure 3: Study area showing bathymetry and acoustic transects.

The acoustic survey was carried out from 3rd to 6th May 2008 with good weather conditions. A total of 62 acoustic transects were performed covering the total of the Ría (see figure 3). Acoustic data were recorded with a single-beam echosounder (EA400P Simrad) working with a 38/200 kHz transducer. This transducer was attached to the hull rail of a small boat (6.95 m). The 200 kHz and 38 kHz frequencies were operated with a pulse length of $256\mu\text{s}$ and $1024\mu\text{s}$, respectively. Both frequencies worked with a maximum emitting power (1 kW) and a sampling rate of 1 ping/s. The boat speed was kept between 4 and 4.5 knots.

2.3 Classification

Prior to classification, and in order to reduce the number of samples in the classification and also to reduce the inter-ping variability, corrected echoes were averaged, taking one every 10 pings. The ping average was computed selecting from the 21 neighboring pings (10 before and 10 after) those 10 bearing the least differences among them. The location of that average ping was taken at the centroid of the 21 ping locations. This leaves a number of N_0 echo representatives to be further classified. In our case, $N_0=4663$ representatives.

Here, and in what follows, we compare the pings using their intensity level, measured in dB (the usual visual representation); this allows us to extend the comparison outside the main lobe high intensity response into the ping tail. Then, we will combine (average) the ping's linear intensity (in Watts/m²) to obtain the representative echoes, because this operation is physically meaningful. The classification of the remaining representative echoes was performed using a two-step hierarchical clustering algorithm.

In the first step a number N_1 of target classes covering a fraction f_1 of the total N_0 representatives is specified. Starting from the N_0 representative echoes, every contiguous pair was compared (in dB) and the pair with the least difference was combined (averaged in linear scale) in one representative (descendent) echo, thus effectively enlarging the length of the representative echoes corresponding to the same type of echo response. This is iterated until the N_1 representatives representing the largest number of original pings, cover a fraction f_1 of the entire sample set. In our case, we have retained $N_1=500$ representatives, covering $f_1=90\%$ of the sampled transects.

The second step is similar to the first one, prescribing N_2 target classes covering a fraction f_2 of the N_0 representatives. However, the echo comparison is extended to all of the possible pairs in the N_1 representatives obtained in the previous step, and not only to the contiguous ones. In our study area we selected, $N_2=10$ and $f_2=95\%$.

To assess the robustness of the classification, the class representatives (corrected pings averaged over each class) of the 5 largest classes were used to reclassify, by minimum distance, all the N_0 representatives. The resulting reclassification should keep the spatial coherence of the previous one, while reducing the "inertia" (mixtures of two similar classes appearing one after another along a transect) induced by the first step.

2.4 Groundtruthing

To validate the acoustic classification a thematic map of the Ria de Cedeira developed through interviews with local fishermen was used. The geographical accuracy of the map is, nevertheless, approximate but the bottom types are expected to fit within a reasonable range of the actual ones. Furthermore, the spatial coherence of the classification obtained will allow interpreting the classes obtained in terms of the fishermen seabed classes.

3 Results

The PLP correction applied to the pings brings all the pings of the same seabed type to the same depth-normalized form (within the experimental error). Figures 3a,b show first bounces of pings (38 kHz signal) corresponding to fine sand (the most abundant in the study area) measured at different depths after time-stretching only and after applying the PLP correction.

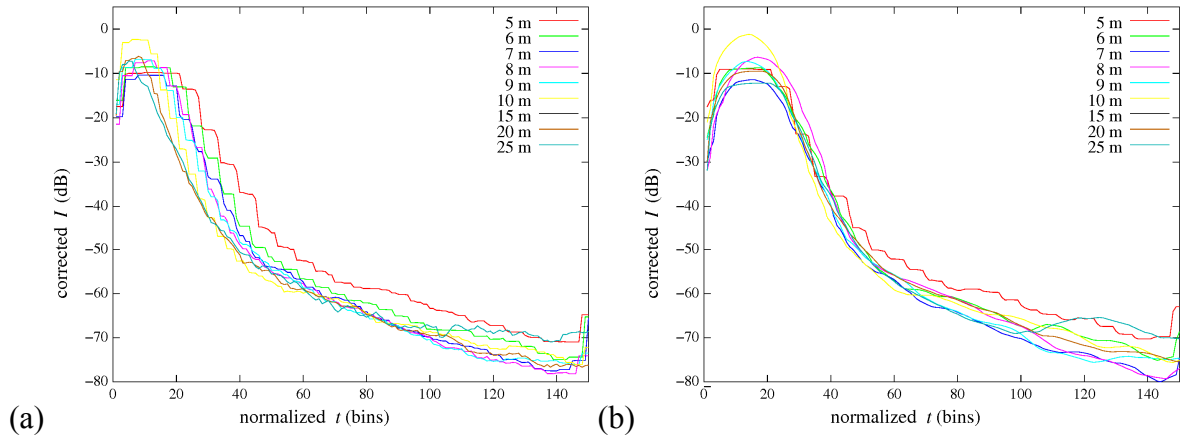


Figure 3: Time stretched (a) and PLP corrected (b) first echoes corresponding to fine sand bottom measured at different depths.

The ping representatives of the 5 largest classes obtained from the 200 kHz and 38 kHz signals are shown in figure 4. The two lower intensity echoes (yellow and green) are interpreted as sandy or muddy flat bottoms. The next two (red and orange) seem like medium and coarse sand. The highest intensity and widest echo (brown) corresponds to rocky bottoms.

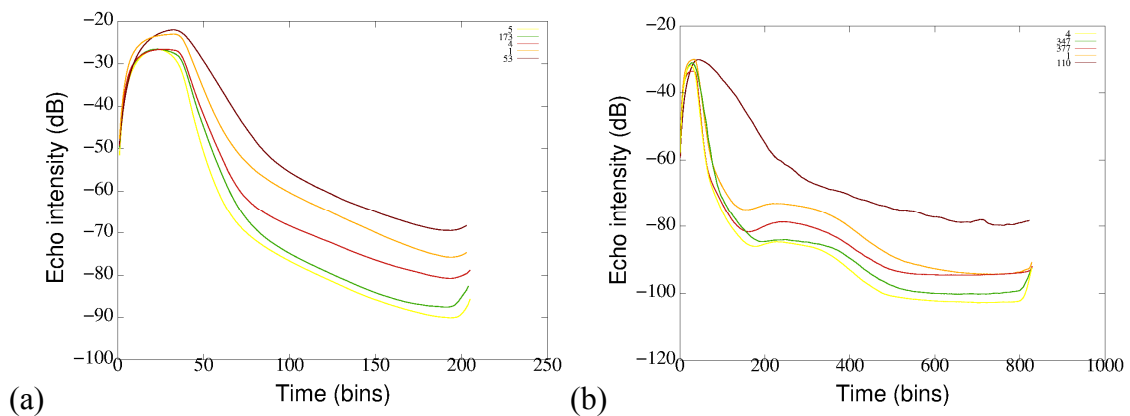


Figure 4: Echo representatives of the 5 largest classes of the (a) 200 kHz and (b) 38 kHz classifications.

The classification, obtained by comparison of the representative echoes with the 5 largest classes representatives (obtained from the two-step aggregative clustering algorithm), is shown in figure 5 for the 200 kHz signal of the echosounder. The classification obtained from the 38 kHz signal is quite the same, with small variations in the opening of the Ría, where class mixture is higher. The map is shown superposed to the consensus map developed from interviews with local fishermen.

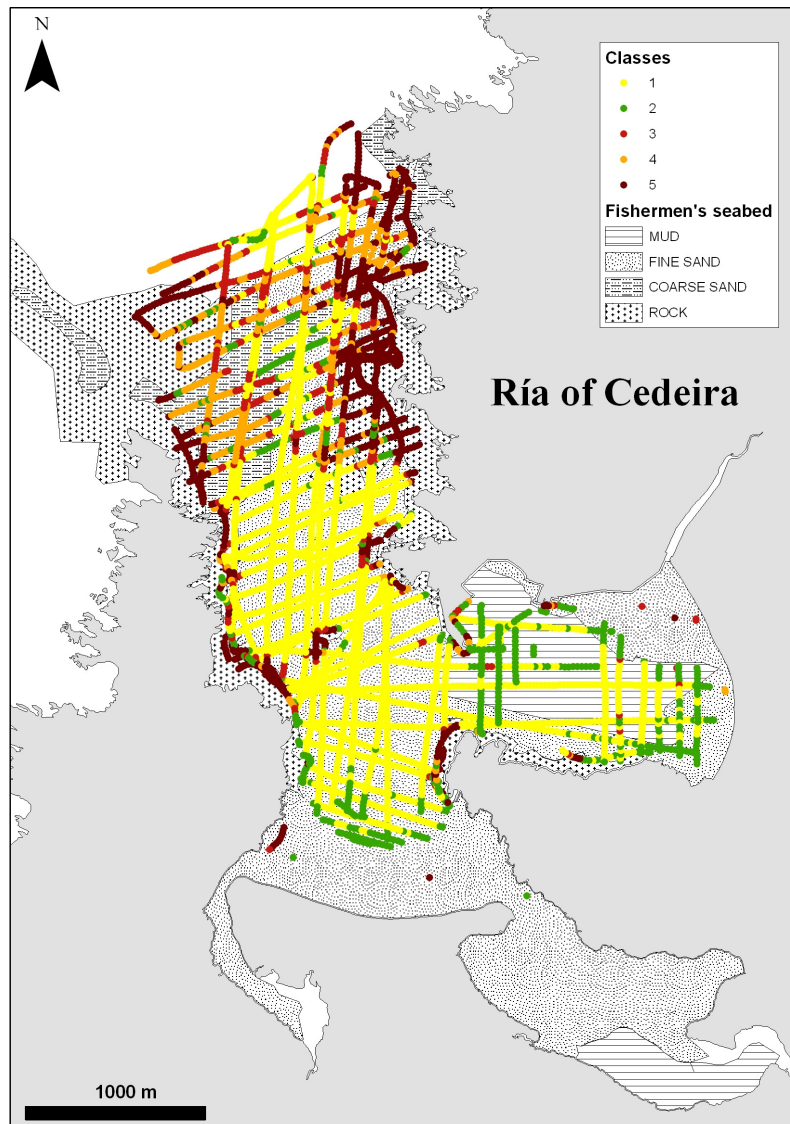


Figure 5: Bottom classification of the study area obtained from the reclassification of the 200 kHz corrected echoes. Colors are the same used for the ping representatives in figure 4. After interpretation, these colours correspond to: yellow, fine sand; green, (probably) mud; red and orange, medium and coarse sand; brown, rock.

4 Discussion and conclusions

The PLP correction introduced in this paper is well suited to correct pings measured in shallow waters, allowing to obtain a successful bottom classification of a coastal zone with depths as shallow as 5 m over extended areas and as deep as 35–40 m (figure 3).

The aggregation clustering method used for the classification is (thanks to the PLP correction applied) a physically consistent method, as it builds up on averaging the intensity measurements in acoustically close resembling bottoms. This would be equivalent to the large averages, of over 100 pings, used in oceanographic surveys covering more extended areas. Moreover, the observed dispersion around the “average ping” thus computed, lies within the bounds expected from the speckle distribution in soft bottoms, being larger in rough (rocky) bottoms.

In the classification obtained, the rocky bottoms of the coast reefs are clearly detected. They correspond to higher normalized intensity pings with longer echoes. The different types of rocky bottoms can be differentiated keeping more classes, although fast changes in rocky bottoms cause high class mixture. The coarse sand and the fine sand are well differentiated from their echo normalized intensity. However, in the case of muddy bottoms, mostly located in the shallower inlet to the east, their echo shapes are almost the same as fine sand and it is difficult to say where one class changes to other but for the differences, mostly in the average intensity in different parts of the echo tail. These differences may be caused by the different acoustic angular response of these bottoms, but may also include information about the irregularities present in them. This problem of granulometry discrimination in sedimentary bottoms has been also reported by other authors [10, 11].

It is important to point out that seabed types do not appear correlated with depth. For example, fine sand was found throughout the depth range. Mud was found in the shallower areas south-east (confirmed by direct observation) and in the south-west of the study area (near Villarrube’s beach, although its presence was not confirmed by groundtruthing). It also appears in a deeper region (~30 m) near the outlet of the Ría, surrounded by rocks and fine sand, a formation common in other Galician Rías [12].

When compared with the fishermen map, the qualitative agreement of the interpolated map is good, although the boundaries of the seabed coverages are not so accurate and the amount of mud and coarse sand are overestimated by the fishermen with respect to the acoustic classification. This misadjustment in the class boundaries between both maps may be explained by an overestimation of the distances closer to the coast by the fishermen, a well known perception bias [13].

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