Aliased seabed detection in fisheries acoustic data

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Abstract

Aliased seabed echoes, also known as “false bottoms” or “shadow bottoms”, are a form of echogram corruption caused by seabed reverberation from preceding pings coinciding with echoes from the current ping. These aliases are usually either avoided by adjusting the survey parameters, or identified and removed by hand - a subjective and laborious process.
This paper describes a simple algorithm that uses volume backscatter and split-beam angle to detect and remove aliased seabed using single frequency, split-beam echo sounder data without the need for bathymetry.

**Keywords:** acoustics; aliased seabed; echo sounder; false bottom; noise

## 1 Introduction

Echo sounders are routinely used in fisheries acoustics to survey marine ecosystems (Simmonds and MacLennan, 2008). Sound pulses ("pings") are transmitted towards a target and the intensity (Volume backscatter, $S_v$) is measured, integrated and recorded. Signals in acoustic data come from a combination of biotic targets (e.g. fish), abiotic targets (e.g. seabed, gas fluxes) and noise. Therefore, reflections from biological targets may be obscured by various types of acoustic noise, corruption or attenuation. Figure 1a shows an example echogram where the horizontal stripe of high $S_v$ is caused by reflections from zooplankton. The curve of high $S_v$ below is not the seabed, but an alias caused by seabed reverberations from preceding pings coinciding with the current ping reception.

Failure to detect and remove unwanted signal prior to biological target detection could result in poor estimates of animal abundance or biomass (MacLennan et al., 2004). Algorithms exist for the detection of many of these corruptions: impulsive noise spikes (Anderson et al., 2005); attenuated signal (Ryan et al., 2015); transient noise (persisting for multiple pings) (Ryan et al., 2015); and background noise (relatively constant for extended periods) (De Robertis and Higginbottom, 2007). However, aliased seabed is typically either avoided or removed manually, a notoriously laborious task. Aliased seabed and biology can have a similar appearance in echograms (e.g. Figure 1a), and when they cross it can be difficult to precisely determine the boundary. Aliased seabed detection is therefore subjective and a much harder problem than true seabed detection.

Although aliased seabed can occur at any frequency, it is common in lower frequency data (e.g. 18 kHz, 38 kHz) when using a fixed, short transmit pulse interval ($I_T$) and crossing the continental shelf. Acoustic signals are attenuated by absorption with range ($R$) as a function of frequency, temperature and seawater chemical composition (van Moll et al., 2009), limiting echo sounder range ($R_{max}$). Typical maximum seabed detection depths by frequency are shown in Table 1. If the ping interval $I_T$ is short with respect to the time taken for a reflection to occur from a seabed beyond the logging range $R_L$, as described in Equation 1 then aliasing can occur with reflections from preceding pings coinciding with echoes from the current ping. However, practical use of Equation 1 for prediction requires detailed bathymetry data that are rarely available with sufficient

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Figure 1: Aliased seabed echoes seen in a section of 38 kHz acoustic data with (a) volume backscatter ($S_v$), (b) along-ship split beam angle ($\eta_\theta$) and (c) a typical, hand-drawn aliased seabed removal mask. The horizontal axis shows pings with interval ($I_T$) of 2 s, nominal speed 10 kn and an extent of about 3.3 km. Data recorded using a Simrad EK60 scientific echo sounder on board RRS James Clark Ross, cruise JR280.

spatial accuracy and resolution (e.g. Global Bathymetric Chart of the Oceans (IOC, 2008) $\approx$ 1000 m resolution, South Georgia Bathymetry Database (Hogg et al, 2016) $\approx$ 100 m resolution) compared to the scale of the acoustic data (e.g. 10 m). Renfree and Demer (2016) present the strategy for avoiding aliased seabed, by dynamically optimising $I_T$ and the data logging range ($R_L$). However, changing parameters mid-survey causes changes in spatial resolution complicating subsequent data analysis. In addition, the background noise removal method implemented by De Robertis and Higginbottom (2007) requires a large $R_L$ to determine the noise level, thus constraining the adjustment demanded by
Table 1: Maximum seabed detection range ($R_{\text{max}}$), using typical transducer settings, according to the Simrad EK60 reference manual.

| Frequency (kHz) | $R_{\text{max}}$ (m) |
|----------------|----------------------|
| 18             | 7000                 |
| 38             | 2800                 |
| 70             | 1100                 |
| 120            | 850                  |
| 200            | 550                  |

Renfree and Demer.

$$R_A = \frac{\text{mod}(2R_S, c I_T)}{2}, \text{ where } R_L < R_S < R_{\text{max}}$$ (1)

Modern echo sounders use split-beam transducers, which are divided into four quadrants allowing target direction to be determined by comparing the signal received at each quadrant (Simmonds and MacLennan, 2008). In addition to recording amplitude, they also record the split-beam angle (SBA). The along-ship angle ($\eta_\theta$) is the phase difference between the fore and aft transducer halves, and the athwart-ship angle ($\eta_\phi$) is determined from the starboard and port halves. Reflection and scattering from a deep seabed occur over a large area due to beam spreading, causing variance in wave arrival times. A rising seabed is detected at the fore quadrants of the split-beam transducer before the aft quadrants and vice-versa for a falling seabed. These effects, caused by the seabed geometry, are particularly visible in $\eta_\theta$ data and appear to differentiate aliased seabed from biological reflections (Figure 1b). MacLennan et al. (2004) show that SBA reflections from fish aggregations are not necessarily an accurate indication of target direction whilst reflections from the seabed correlate well to seabed slope. Bourguignon et al. (2009) show that seabed detection with a Simrad ME70 using SBA and amplitude together is more effective than using amplitude alone. This would suggest that SBA is an additional discriminatory variable.

We present a simple algorithm, based on image processing techniques, that detects aliased seabed in single-frequency, split-beam acoustic data, without the need for bathymetry.

2 Method

The patterns seen in SBA are difficult to segment because of noise. Sample values for $\eta_\theta$ and $\eta_\phi$ vary between -128 and 127 (corresponding to $-180^\circ$ to $180^\circ$ and so we take the mean-squared over a moving window to smooth the image and accentuate coherent signal
(window sizes determined empirically). Whilst these pixels fall within the aliased seabed regions, only a small percentage of area is identified. However, we can take these pixels and then examine the surrounding region in $S_v$. Hence, we derive a five-step algorithm:

1. Find the mean squared of a $28 \times 28$ moving window over $\eta_\theta$ and select cells $> T_\theta$ to produce a mask $m_1$.
2. Find the mean squared of a $52 \times 52$ moving window over $\eta_\phi$ and select cells $> T_\phi$ to produce a mask $m_2$.
3. Combine the masks $m = m_1 \lor m_2$.
4. Select pixels from $S_v$ using the mask, $m$ and determine the median $S_v$ value of the selection to use as a threshold $T$. Optionally, $T$ can be constrained to some minimum value (e.g. $-70$ dB).
5. Select regions from $S_v$ where $S_v > T$ and which intersect $m$. The resulting mask is the union of the selected regions and $m$.

We use $T_\theta = 702$ and $T_\phi = 282$ determined empirically.

The final mask is a grid indicating those pixels that have been classified as aliased seabed. It can be used to label aliased seabed pixels in the original echogram or to replace them, using a suitable token (e.g. -999) indicating “no data” or “missing value”.

3 Results

Figure 2 shows the algorithm applied to our example data set.

We tested the algorithm on 30 transects from the British Antarctic Survey annual Western Core Box acoustic survey conducted North West of South Georgia. Data were collected using a Simrad EK60 echo sounder (38 kHz). In all cases, aliased seabed that had been found by human scrutiny was detected. When $T$ was detected automatically, we observed six cases of misclassification of scattering layers as aliased seabed. The misclassification was eliminated by constraining the threshold $T$ to be at least $-70$ dB.

4 Discussion

Our algorithm can be used to detect aliased seabed in single-frequency, split-beam echo sounder data. The split-beam angle threshold values, $T_\theta$ and $T_\phi$, and the convolution window sizes presented here, are determined empirically from data collected around South Georgia, where the seabed substrate consists of fine-grained sediments and clays and
Figure 2: Detection and removal of aliased seabed. (a) is the original echogram, (b) aliased seabed determined using the algorithm, and (c) the echogram with aliased seabed removed.

there is rapid change in bathymetry (Hogg et al., 2016). The parameters may need to be adjusted for other vessels and other ocean areas.

Aliased seabed is an additive backscatter corruption, so the algorithm assumes that the area surrounding an alias is likely to have a lower backscatter than the alias. The backscatter threshold ($T$) is determined dynamically, making the algorithm less sensitive to calibration correction accuracy. The median is used to determine $T$, being less susceptible to outliers than the mean. In practice, it may be desirable to constrain $T$ to some minimum $S_v$ value to guard against the possibility of selecting low intensity areas of the echogram. If $T$ is set too low, then there is a danger that step five of the algorithm could cause “leakage” into surrounding scattering layers. If $T$ is set too high then the region
of aliased seabed detected is reduced in size. Minimum $T$ should therefore be adjusted based on observed results.

Speckle is seen in some aliased seabed detections (Figure 2). This can be removed using a hole filling image processing algorithm (e.g. morphological reconstruction (Soille, 2013), as used by Matlab imfill). Visual inspection of echograms shows that our automated results find several instances of aliased seabed that had not been identified manually. On further inspection these appear to be genuine and, in some cases, are fainter aliases caused by the echoes from antepenultimate pings.

Our algorithm is simple to implement and efficient in terms of computational resources. The windowing operations can be implemented using two-dimensional convolution which is fast on modern hardware (the example in Figure 2 takes about 0.43 s on a 2016 Intel Skylake i7 processor). Whilst the algorithm does not rely on other noise removal strategies beyond true seabed removal, its performance can reduce if the data include impulse noise, transient noise or attenuated signal. In these cases, the methods described by Anderson et al. (2005) and Ryan et al. (2015), combined with interpolation (e.g. median filtering) to replace the noise, are an effective preprocessing step. If using background noise removal (e.g. De Robertis and Higginbottom (2007)), we recommend implementing this after aliased seabed detection.

We want our method to be independent of ping interval ($I_T$) and logging range ($R_L$), and so we choose to use a single frequency. We are also interested in using data from ships of opportunity (e.g. fishing vessels) which may only have a single frequency. However, if multi-frequency data are available then, depending on maximum range ($R_{max}$) and seabed depth ($R_S$), other frequencies can be used to further validate aliased seabed. (E.g. if an aliased seabed candidate was observed at $500$ m in 38 kHz data, with ping interval $I_T = 2$ s then, using Equation 1 seabed depth $R_S = 2000$ m. If a corresponding signal was seen in 70 kHz data, then the maximum range ($R_{max}$) would be insufficient to reach the seabed, and so the signal must have another cause). Lower frequency data could allow $R_S$ to be detected automatically and allow the methods of Renfree and Demer (2016) to be used as part of a hybrid approach. A consequence of Equation 1 is that $R_S \not< R_L$ and so aliased seabed cannot occur in a ping where the true seabed has already been detected.

Using split-beam angle in addition to volume backscatter is known to improve bottom detection (MacLennan et al. 2004; Bourguignon et al. 2009). Large coherent patterns in SBA are a strong indication of reflections from the seabed, but not biology. We extend this observation to aliased seabed and use it to create an automated algorithm providing consistent, repeatable results. We have tested the algorithm with Simrad EK60 data, which uses a four quadrant, split-beam configuration. Some new transducers use a three-sector design, however we expect the principles to be transferable. Although we designed the algorithm for aliased seabed detection, mutatis mutandis, it may also have
applications as a bottom detector.

5 Conclusions

The method we describe is intended to make aliased seabed detection and removal semi-automatic, fast and reproducible. It could be incorporated into existing tooling to reduce the labour required to clean fisheries acoustic data. We recommend that practitioners check results using visual inspection.

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