A new method for single target detection

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Abstract

We have experienced difficulties with fish detection in sonar-data from horizontally aligned transducers in shallow water. Recorded material revealed that echoes from fish often took on high ping-to-ping variations in variables like pulse length, intensity, shape and phase. Single echo detection methods based on a set of echo criteria tended to overlook echoes from fish and to accept echoes from unwanted targets and from fluctuations in the background reverberation. Hence, tracking and fish counting became difficult.

To overcome these problems, we have developed a detection method based on 2-dimensional low-pass filters. By adjusting the cut-off frequency in the time and range domain, noise can be removed, ping-to-ping variation in signals from fish reduced, and local background reverberation level can be found. By subtracting the echo intensity in the filtered echograms, traces from fish can be detected.

Results and experience with this method are demonstrated and compared with traditional single echo detection methods.

Introduction

Detecting fish in sonar data by single echo detection and tracking can be difficult. (Balk, 2001). Two reasons are the noise echoes surrounding the fish echoes and the missing detections of echoes in tracks from fish. With manual tracking, fish echoes surrounded by noise echoes are difficult to see. With automatic tracking based on parameters such as ping-gap and track length (Blackman, S.S., 1986), the missing detections from fish force us to increase the ping-gap and reduce the track-length parameters. With such setting, echoes from fish are frequently combined with noise, overlooked, or split up into smaller fractions. Generation of tracks consisting solely of noise is also common.

Single-echo detectors (SED) as described in Anon, (1996) and Soule et.al. (1996), apply a constant threshold. Detectors below the threshold are regarded as noise. There are omnipresent intensity fluctuations in horizontally recorded echograms from shallow rivers and lakes as seen in Figure 1.

Figure 1. Amp-echogram showing an upstream migrating fish in River Tana.

A fish in this environment may easily produce echoes with intensities above and below the threshold, while the surroundings may have peaks above the threshold. This results in missing echoes from the fish and in noise detections from the surroundings with a constant threshold. Missing detections of fish echoes are
further increased because the detector removes echoes with incorrect echo length, phase deviation, multiple peaks and high off-axis positions. The result is a processed echogram where it is difficult to track fish. To ease tracking, none of the fish echoes should be removed if this can be avoided. Thus, applying a set of strict criteria to each individual echo pulse is not a good solution when tracking is the purpose.

Based on ideas presented at the shallow water fisheries conference in Seattle in 1999 (Balk and Lindem, 2000), we have developed an alternative Cross-filter detector (CFD) optimised for tracking. The detector has been patented (PCT/NO00/00288).

In the remaining text the terms SED-echogram, CFD-echogram and Amp-echogram will indicate whether an echogram has been produced by the Single-echo detector, Cross-filter detector or by the echo sounder’s amplitude detector (Amp) respectively.

SED-echograms from shallow rivers contain basically four different kinds of echo detections. These are (i) echoes from drifting debris, (ii) from passing fish, (iii) from stationary targets like stones on the bottom and (iv) noise echoes. As seen from Figure 2, debris follows the water current and produce smooth, ark shaped tracks. Fish tracks are less smooth and tend to differ from the direction of water current by “twisting” too and from the transducer on the way through the beam. Reflections from stones are seen as long thin lines at fixed ranges. Noise echoes are seen scattered all around in the echogram. The causes are not a topic here and it is sufficient to state that they disturb the detections of the other three kinds of targets.

We want to detect echoes from the three first categories equally well (fish, debris and stones), while we do not want to detect the noise. It is only then that we can expect a correct tracking. Correctly tracked targets improve the possibility of separating the fish tracks, debris and the bottom reflections in a later classification process. Note that we make a point of separating the three processes; single echo detection, tracking and classification.

Material and methods

Test data

An echogram recorded in the Rimov reservoir (Cz) was chosen to demonstrate the detector’s ability to suppress scattered echo detections (Figure 6). An echogram recorded in River Tana was selected to test the detector’s ability to produce data suited for tracking (Figure 2).

Both echograms were recorded with an EY500 split beam echo sounder equipped with a horizontally aligned ES120-4, 120kHz, 4x10 deg. split-beam transducer. Trace telegrams from the echo-sounder’s built-in SED, sample power telegrams from the amplitude detector and sample angle telegrams from the phase detector was recorded to file. The sample power and sample angle telegrams were sampled with a sample frequency adjusted to give a range resolution of 3 cm between each sample. The CFD was set up with the following parameters: Filter1 = Mean 3, 5. Filter2 = Mean 51, 1, and Perimeter filter= [50...558]. The meaning of the CFD parameters is explained under the description of the CFD below.

The Rimov file contains tracks from spawning Bream (Abramis brama, Cyprinidae) The transducer was mounted close to the shore 40 cm below the surface at 1 meter depth and aiming 20.8 deg out from the shore line. The tilt was -2.3 deg down and the depth under the beam increased steadily to 4.8 m at a range of 30 m. The echo sounder transmitted short pulses (0.1 ms) with a ping rate of 4.1 ping per. sec and with a power of 63W.
Parameters applied for the SED was:
Min. value = -70 dB, min. echo length = 0.5,
max. echo length = 2, max. beam comp. =
6 dB, max. phase dev. = 10.

In River Tana the transducer was
mounted 50 cm below surface at a water
depth of 2 m. The transducer beam was
aimed nearly normal to the water current
and tilted 2 deg. down. The echo sounder
transmitted medium pulses (0.3 ms) with a
ping rate of 5 ping per. sec. The power was
63 W. The EY500’s SED was set up with
the following parameters: Min. value = -45
dB, min. echo length = 0.5, max. echo
length = 1.8, max beam. comp. = 6 dB, and
max. phase dev. = 10.

Software

The Sonar5 sonar post-processing
program developed at our institute was
used to test the detectors. Routines needed
for the CFD was implemented directly in
the source code. The code is written in
Pascal and compiled by Borland’s Delphi
compiler version 6 (Miller et al., 1997).
Sonar5’s sonar-data insight tools were used
to study the tracks and to locate the
positions where the passing targets actually
entered and left the beam. The manual
tracking tools where applied to combine
echoes detected by the CFD and SED into
tracks. Sonar5 has two automatic point
trackers, one based on prediction and
association and one neighbourhood tracker
based on simple fixed ping-gap, track-
length and gate parameters. The
neighbourhood tracker was used to avoid
discussions about the tracker “favouring”
certain kinds of data. Sonar5 are described
Numerical measure for the processed echogram's quality

Two numerical quantities, Track quality (TQ) and track to noise ratio (TNR) were defined to measure the quality of the echograms produced by the detectors.

Track quality describes the ratio between the actual and possible number of detections from each target. Track to noise ratio describes the ratio between tracked echoes from solid targets to the total number of echo detections including the scattered noise echoes. With possible detections we mean the number of pings from the ping where the echo intensity from a target first rises 6 dB above the background intensity to the ping where it falls bellow the 6 dB level again. This is measured in the Amp-echogram. For the lines of bottom reflections, possible detections have been measured from the first to the last coherent detection seen in the SED-echogram. The definitions are seen in Eq. 1.

\[
TQ = \frac{\sum TSE_i}{\sum PSE_j}
\]

\[
TNR = \frac{\sum TSE_i}{\sum SE_k}
\]

Eq.1. Definition of the TQ and TNR. 
TSE=number of tracked single echo detection, PSE=possible single echo detection, and SE=single echo. Index i runs over all TSE, j over all PSE and k over all SE.

Cross-filter detector

The frequency spectra of an Amp-echogram with and without echoes from a target differ in the ping domain. Figure 3 and Figure 4 gives an example. The low-frequency components in Figure 4's upper chart originate from the slow rise and decay of the echo from the fish. Without the target these components are not present. Hence, a low-pass filter with an appropriate cut-off frequency can suppress the ping-to-ping intensity fluctuations without suppressing the echoes from the fish. This is important because the fluctuations are a source for the disturbing noise echo detections and for the missing detections of fish echoes.

The situation in the range domain is different. Here the frequency spectra do not change significantly when a target enters the beam. Thus, suppressing higher frequency components by filtering in this domain remove echoes from both targets and noise, and leave the slowly varying background reverberation.

![Figure 3. Intensity versus ping at the range of the fish echo seen in Figure 1.](image)

![Figure 4. Ping domain frequency spectre with (upper) and without (lower) a fish in the beam. Upper spectre is calculated from the signal in Figure 3.](image)

These observations form the basis of the detector. By processing the original
Amp-echogram (F) with two filters, we can produce an echogram \((Q_1)\) with improved tracks, and another echogram \((Q_2)\) containing the slowly varying background reverberation. Applying each individual sample from \(Q_2\) as a threshold for the corresponding sample in \(Q_1\) result in an adaptive thresholded echogram \((Q_3)\). The process is demonstrated in Eq 2. Filtering is achieved by convoluting the echogram with filter matrixes \(H_1\) and \(H_2\) containing the filter impulse response coefficients.

With equal coefficients, low-pass mean-filters are achieved. Increasing the number of coefficients in a domain lower the cut-off frequency in that domain (Pratt, 1991). A simple notation is "Mean r, p" where r and p are the number of coefficients in the range and ping domain respectively. Drawing the dimension of the two filter matrixes in an echogram forms a cross. Hence the name "Cross-filter detector" (CFD).

\[
Q_1(m,n) = \sum_{p=m-2}^{m+2} \sum_{r=n-1}^{n+1} F(p,r)H_1(m-p+2,n-r+1)
\]

\[
Q_2(m,n) = \sum_{p=m}^{m} \sum_{r=n-25}^{n+25} F(p,r)H_2(m-p,n-r+25)
\]

\[
Q_3(m,n) = \begin{cases} 
F(m,n), & Q_1(m,n) - Q_2(m,n) > 6dB \\
0, & Q_1(m,n) - Q_2(m,n) \leq 6dB
\end{cases}
\]

Eq. 2. Filtering and thresholding. The constant values are the actual filter parameters applied in the presented tests.

The process described in Eq. 2 detects clusters of echo samples from targets and from reminiscences of background noise. A perimeter filter is applied to remove the noise and the stationary targets. The perimeter filter works by counting the number of samples along the rim of each detected cluster. Noise tends to have shorter perimeter and stationary targets longer perimeter than passing targets. They can be removed. The CFD-parameter; Perimeter \([a..b]\) does this by only accepting clusters with perimeter between \(a\) and \(b\). Finally the angular position of the remaining clusters are extracted from the echo sounder's phase detector. Although all detections are suited for tracking, not all detections are suited for size, position and velocity estimation. Hence, a quality factor is calculated for each individual echo. The factor is calculated from the echo intensity, shape and phase deviation, and low quality echoes can later be removed from these estimations. Figure 5 demonstrates the elements of the Cross-filter detector.
Results

The ability of the Single-echo detector (SED) and the Cross-filter detectors (CFD) to avoid generation of scattered non-target echoes are seen from the Rimov echogram in Figure 6 and from the track to noise ratio values in Table 1. The tracks from the Rimov echogram processed by the SED are nearly invisible due to low track quality and numerous scattered noise echoes. In the echogram processed by the CFD, the tracks appear clearly with few disturbing noise echoes.

The numerical results from the Tana echogram in Table 1 indicate the same. With a track to noise ratio of 97% from the CFD, nearly all scattered non-target echoes have been suppressed. For the SED the track to noise ratio is estimated to 50%. This means that as much as half of all detections are scattered non-target echoes.

The ability to detect targets is shown graphically in Figure 7 and measured numerically in Table 1. Here it is
seen that all of the detected targets have significantly higher track quality and lower ping-gap values in the CFD-echogram than in the SED-echogram, except for one track from debris that was not obtained by the CFD.

Figure 7. The result of processing the Amp-echogram seen in Figure 2 with a Single-echo detector (left) and a Cross-filter detector (right). D1..D6 and F1..F3 are the debris and fish tracks identified in Figure 2.

The results from testing the track quality and track to noise ratio indicate that the echogram produced by the CFD is better suited for tracking than the echogram from the SED. This is verified in the Table 3. The tracker found all the fish tracks in the CFD-echogram. One of the detected tracks was mixed with echoes from crossing debris. The remaining tracks were detected in the same way as the manually combined tracks. Tracking the SED-echogram gave a different result. Here, 7 tracks were combined in the same way as the manually tracked fish echoes, 3 were mixed with noise or split up, and 4 were not obtained at all.

The total number of generated tracks is also an important parameter. From the CFD data the tracker detected 685 tracks while 1877 tracks were detected from the SED data. This is high numbers in both cases and sorting out the unwanted tracks manually is time consuming. However, because of the improved track quality and track to noise ratio, sorting the tracks generated from the CFD data was simple relative to sorting the tracks formed from the SED data. It was easy to see whether a track originated from bottom reflections, debris or fish. There was also little noise and mixture between tracks compared with the tracks obtained from the SED-echogram.
Table 1. Passing targets observed in River Tana 19.07.1999 in the period 17:14:23 to 17:14:40. (265 pings) Fish and debris are numbered according to the numbers seen in Figure 2. Lines from bottom reflections can be identified by range in Figure 2. The lower ping-gap values, and the higher track quality values and the higher track to noise ratio seen in the Cross filter detector (CFD) columns indicate that this detector produces echograms better suited for tracking than the Single echo detector (SED).

<table>
<thead>
<tr>
<th></th>
<th>SED Ping-Gap</th>
<th>CFD Ping-Gap</th>
<th>SED Track Quality (%)</th>
<th>CFD Track Quality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish 1</td>
<td>7</td>
<td>0</td>
<td>54</td>
<td>100</td>
</tr>
<tr>
<td>Fish 2</td>
<td>4</td>
<td>0</td>
<td>41</td>
<td>100</td>
</tr>
<tr>
<td>Fish 3</td>
<td>6</td>
<td>0</td>
<td>49</td>
<td>65</td>
</tr>
<tr>
<td>Debris 1</td>
<td>7</td>
<td>-</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Debris 2</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>74</td>
</tr>
<tr>
<td>Debris 3</td>
<td>4</td>
<td>0</td>
<td>19</td>
<td>55</td>
</tr>
<tr>
<td>Debris 4</td>
<td>5</td>
<td>0</td>
<td>43</td>
<td>100</td>
</tr>
<tr>
<td>Debris 5</td>
<td>1</td>
<td>0</td>
<td>11</td>
<td>100</td>
</tr>
<tr>
<td>Debris 6</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>54</td>
</tr>
<tr>
<td>Stone 1</td>
<td>16</td>
<td>-</td>
<td>27</td>
<td>-</td>
</tr>
<tr>
<td>Stone 2</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Stone 3</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>97</td>
</tr>
<tr>
<td>Stone 4</td>
<td>25</td>
<td>0</td>
<td>41</td>
<td>100</td>
</tr>
<tr>
<td>Stone 5</td>
<td>45</td>
<td>0</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Stone 6</td>
<td>16</td>
<td>0</td>
<td>37</td>
<td>100</td>
</tr>
<tr>
<td>Stone 7</td>
<td>9</td>
<td>0</td>
<td>51</td>
<td>100</td>
</tr>
</tbody>
</table>

| Track to noise ratio | 50 % | 97% |

Table 2. Evaluation of tracks combined in echograms produced by the Single-echo detector (SED) and the Cross-filter detector (CFD). OK indicates that Sonar5’s auto-tracker has combined the track in a similar way as a person would have done by manual tracking. The table verifies that the CFD produces data better suited for tracking than the SED. The applied tracking parameters are shown in the table. MPG=max. ping-gap, MTL=min. track length.

<table>
<thead>
<tr>
<th>Tracker MPG</th>
<th>First ping</th>
<th>R (m)</th>
<th>Tracking results SED-echogram</th>
<th>Tracking results CFD-echogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracker MTL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracker Gate</td>
<td></td>
<td>0.45 m</td>
<td>1877</td>
<td>685</td>
</tr>
<tr>
<td>Total no. of generated tracks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish 1</td>
<td>3</td>
<td>37.02</td>
<td>Not detected</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 2</td>
<td>190</td>
<td>24.34</td>
<td>Split in two, second part mixed with crossing debris</td>
<td>Mixed with crossing debris</td>
</tr>
<tr>
<td>Fish 3</td>
<td>566</td>
<td>24.82</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 4</td>
<td>2274</td>
<td>37.77</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 5</td>
<td>2270</td>
<td>38.65</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 6</td>
<td>2407</td>
<td>27.80</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 7</td>
<td>3385</td>
<td>27.06</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 8</td>
<td>5576</td>
<td>36.37</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 9</td>
<td>5887</td>
<td>35.64</td>
<td>Not detected</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 10</td>
<td>5887</td>
<td>34.70</td>
<td>Not detected</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 11</td>
<td>6155</td>
<td>37.86</td>
<td>Mixed with noise</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 12</td>
<td>6155</td>
<td>38.30</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 13</td>
<td>6508</td>
<td>37.84</td>
<td>Mixed with track 14 and with noise</td>
<td>OK</td>
</tr>
<tr>
<td>Fish 14</td>
<td>6512</td>
<td>37.01</td>
<td>Not detected</td>
<td>OK</td>
</tr>
</tbody>
</table>
Discussion

These tests clearly showed that the Cross-filter detector (CFD) was better suited to detect fish than the Single-echo detector (SED).

The detector was implemented as a post process. However, most of the elements except the perimeter filter can be incorporated in an echo sounder as a near real time process by buffering 3 to 5 pings.

Our main objective is to develop an automatic fish-counting system. With the positive results from the CFD detector in combination with a common auto tracker, the last step will be to apply an automatic classification unit. The perimeter filter belongs more naturally to this unit than to the CFD. Other track features should be extracted and tested as well to find a set of classifiers capable of separating fish tracks from the other targets in an automatic process.

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References


