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Transient Signal Detection on the Basis of Energy and Zero Crossing Detectors

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Abstract

In underwater passive surveillance systems, narrowband displays help in classifying tonal sounds but transient sounds are largely classified through audition. Over the years, the intensity of tonal has been reduced by ship/submarine constructors, and so their use for classifying underwater targets has become diminished. Transient sounds are harder to disguise and are becoming more useful for detecting targets. In the naval scenario, quick and accurate detection of transient signals offers an advantage of longer response time to thwart an enemy attack.

Underwater transients from manmade objects and biologics are very rich in structure and detail, very diverse in terms of duration, highly non-stationary, and often mixed with multipath. The need is for automatic detection and classification of underwater transients, in order to assist the overburdened sonar operator.

Recently, the work on wavelet transform for transient signal detection is carried out but the problem with these detectors is that these are computationally very expensive. We are presenting a new kind of detector which works on energy of the segments and the corresponding mean of the zero crossings of the signal.

1. Introduction

A transient is a signal having short duration as compared to its observation durations. Transient signal arises from the sudden change of a steadily signal in the time-field and frequency-field by some causes. It may be generated in many situations, for example, before launching torpedo and rocket, when machine state changing of ship in motion. Most of signal information is often carried by irregular structures and
transient phenomena. It will be seen from this that transient signal is very important for survey, classification, identification and alarm of underwater targets.

However, since transients are short lived and not necessarily repeatable, they are very difficult to detect. In addition, they may be confused with other signals generated by sources such as biologics or man-made noise. In this paper, we address this difficult problem of detecting and classifying the transients present in the underwater acoustic data.

As the transient signals arises from sudden change in the amplitude or frequency, time-frequency resolution type transforms are needed to localize the transient. But such transforms like wavelet transforms are computationally expensive to have a real time detector. While reviewing the literature [Keman Liu, Jinglin Xiang], we found that fundamental frequency of the signal can be determined by zero crossing detectors. As well the change in the amplitude can be determined by energy detector. So we explored a medium path to use both zero crossing detector as well as energy detector to go hand in hand for transient detections.

2. Detection Theories

2.1. Zero Crossing Detector

Zero crossing detection is the most common method for measuring the fundamental frequency or the period of a periodic signal as well as non-stationary random signal. When measuring the frequency of a signal, usually the number of cycles of a reference signal is measured over one or more time periods of the signal being measured. Measuring multiple periods helps to reduce errors caused by phase noise by making the perturbations in zero crossings small relative to the total period of the measurement. Number of zero crossings can be calculated by using the next algorithm

\[
\text{ZERONB}=0; \\
\text{FOR } (I = 1: \text{LENGTH}(D)-1) \\
\quad \text{IF } ((D(I)\geq 0 \&\& D(I+1) < 0) \text{ OR } (D(I)\leq 0 \&\& D(I+1)\geq 0)) \\
\quad \text{ZERONB}=I+\text{ZERONB}; \\
\quad \text{END} \\
\text{END}
\]

2.2. Energy Detector

With the lack of the prior knowledge of the incoming signal, it will be appropriate to use an energy detector to detect the presence of a signal. The energy detector measures the energy in the input wave over a specific time interval. Both the energy of the signal and its form and fundamental frequency are considered in the proposed method, so it is obvious that the proposed method is superior to that of zero crossing detection or broadband energy detection method.

Energy of the ambient noise and signal with noise over the interval on N samples can be given by

\[
E = \frac{1}{N}\sum_{n=0}^{N} (w[n])^2 \quad \text{and} \quad E = \frac{1}{N}\sum_{n=0}^{N} (s[n] + w[n])^2
\]

Here w[n] – is the ambient noise present in the ocean signal

s[n] – it is the signal containing the transients.
3. Proposed System

A block diagram of the joint method of zero crossing detection and broadband energy detection is shown in Fig.1.

![Flow chart of proposed system](image)

The study was undertaken to understand the working of energy detector and find the way to implement a more robust detector which will detect the transients from noisy signals as well. As we proceed further with this study we found that the energy detector effectively discriminate the transients from noisy signals as shown in the figure 2. The main problem for this detector was to set a threshold which will change according to the environmental change. After study we found that such adaptive threshold can be achieved by taking the ratio of energy of the signal to the zero crossing numbers. Our method is novel in that it uses an adaptive threshold to detect the transients automatically from the noisy signal.

3.1. Input Signal

Input signal is nothing but the signal acquired from hydrophones placed underwater to collect the underwater information. The underwater signal of interest can be classified into two regions to use binary hypothesis problem. i.e.,

\[ H_1: x(n) = w(n) \]
\[ H_2: x(n) = w(n) + s(n) \]

Where \( w(n) \) is the white Gaussian noise or the noise only signal and \( s(n) \) is the signal containing transients.

On this basis, we divided the whole problem into two regions. The boundary of these regions is defined by adaptive threshold, which gets updated after a certain interval to adapt the change in the environment.
3.2. Test Statistics

Test statistics for this method are inspired by energy detector. [3] The incoming signal is divided into segments of 1024 samples and energy over this segment is calculated using formula:

\[ E = \frac{1}{N} \sum_{n=0}^{N} (x[n])^2 \]

Test statistic signal corresponding to the input signals are shown in the next diagram. We have found the good noise rejection ratio at 27dB of Gaussian noise signal with some added synthetic transients.

![Test Statistics](image1)

**Fig.2:** Test Statistics corresponding to input signal

3.3. Implementation of Adaptive Threshold

The threshold value in a detector needs to be changed according to the changing noise levels for real time operation. As the noise variance (\(\sigma_n\)) of the time series is not known in advance, it is estimated by the robust median estimation of noise method [7]. The robust median estimation is the median absolute deviation of the input signal segment.

The computation of the adaptive threshold value is enumerated; AWGN of the estimated variance and length equal to the segment length is generated. For these segments we find out corresponding energy vector as well as zero crossing numbers. The threshold value to this detector is inspired by [3] and is defined as

\[ \text{Threshold} = \frac{\text{mean (Energy)}}{\text{mean (Number of Zero Cross)}} \]
The threshold value is then made a linear function of the average computed test statistic for the generated noise. The optimum scaling factor applied to the average test statistic for calculating threshold value can be found by examining detector ROC curves.

3.4. Detection Algorithm

The proposed segment size is much smaller than the lengths of transients of interest. Hence, the transient is expected to appear in consecutive segments. Therefore, a single segment showing detection should not be considered as a detected transient. The detection algorithm defines minimum and maximum lengths of the transients of interest. The minimum length of transient permitted to be detected, is 4 segments (2048 samples or 0.125 sec). The maximum length of transients considered for detection is 160 segments (40960 samples or 2.5 sec). Theoretically, the resolution between two detected transients can be 1024 segments (0.0625 sec). The detection algorithm implements the idea that exceeding of threshold in consecutive segments (limited by min and max length) implies only one transient detected. Such a scheme is expected to greatly reduce the number of false alarms as the probability of two or more consecutive false threshold crossing is very small.

The consecutive segments with the test statistic greater than the threshold contain the transient signal. It is assumed that a part of the transient may lie in one segment before and after these consecutive segments. These combined segments now contain the complete transient signal and are saved for passing on to the classifier. This procedure localizes the transient signal. Localized transient is the n can be used for the classification purpose, so that the target can be recognized for security purposes.

4. Evaluation and Discussion

The performance of the proposed detector is evaluated using two synthetic underwater acoustic transients (see Figures 2 and 3). As can be seen the transients vary in their characteristics regarding both duration and frequency content. A 5 minutes long recording of ambient sea noise is used as the background signal. This signal is divided into blocks of length N=10240 samples and the transients are inserted into these blocks at different signal-to-noise ratios (SNR's). This signal is then fed to the proposed algorithm.

Next table shows no of transients detected when the noise is added to the transients at various level. The test signal was generated using six transients placed in the signal at the random places. The detector was able to localize the transient signals up to the noise level of 25dB added to the original signal.

As we proceed with the addition of more noise the detector fails to discriminate between energy levels of the transients and noise signals. For this reason we have to explore some other way to remove the unwanted noise from the noise.

![Figure 3: Synthetic Transients to be added into ocean noise for test signal](image-url)
Table 1: Performance analysis of the detector

<table>
<thead>
<tr>
<th>SNR</th>
<th>Detected Transients</th>
</tr>
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<tbody>
<tr>
<td>-9.7732</td>
<td>6</td>
</tr>
<tr>
<td>-10.6944</td>
<td>6</td>
</tr>
<tr>
<td>-10.9091</td>
<td>6</td>
</tr>
<tr>
<td>-10.898</td>
<td>6</td>
</tr>
<tr>
<td>-12.287</td>
<td>6</td>
</tr>
<tr>
<td>-15.3912</td>
<td>6</td>
</tr>
<tr>
<td>-19.1353</td>
<td>5</td>
</tr>
<tr>
<td>-16.3236</td>
<td>0</td>
</tr>
</tbody>
</table>

5. Conclusion

We present a new method for detecting signals in ambient noise. The new method depends on the zero-crossing information and the energy information of the input noise. The optimal detectors presented in this paper can be readily applied to lines in high frequency range. Our research has shown that the proposed detection method has a bright future in processing the underwater target radiated noise.

6. References