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PASSIVE DETECTION ALGORITHM FOR A NOISY VESSEL

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In the paper it is assumed that the underwater acoustic noise, of a noisy vessel, is a sum of a zero mean Gaussian stochastic process with a finite variance due to propeller(s) cavitation and of a finite number of sine waves with extremely small amplitudes. These two processes are mutually statistically independent. The deep-sea underwater ambient acoustic noise is supposed to be a zero mean Gaussian stochastic process with a finite variance as well. In the paper are considered the probability density function of the instantaneous values of the underwater acoustic noise of the noisy vessel and of the deep-sea underwater ambient acoustic noise. The likelihood ratio and the detection algorithm of the optimal statistical detection are given. The statistical indirect evaluation of the noisy vessel passive detection is considered. The indirect evaluation measure of the detection algorithm is so-called deflection coefficient, which is the function of the difference between statistical expectations of the two possible probability density functions of the received acoustic signals.

INTRODUCTION

The vessel sound emission into the sea mass is especially interesting because the result of this emission is the underwater acoustic noise due to the vessel. The vessel has many various sources of sound emission that are mutually statistically independent and we can group them in two following groups: in the first group we have the sources of cavitation and in the second group we have the sources of sinusoidal oscillations. The cavitation is Gaussian stochastic process with wide-band spectrum. The sinusoidal oscillations have approximately stable amplitudes and line spectra. In the real circumstances each vessel has its own characteristics of the underwater acoustic field. This field is the source of the vessel underwater acoustic noise. The research results have to enable the vessel constructors to reduce the power of vessel acoustic sources and so to reduce the intensity of the underwater acoustic field around the vessel. On the other hand, the passive sonar constructors tend to construct the sonar with maximal sensitivity to detect so weak underwater vessel acoustic noise.

1. STATISTICAL CHARACTERISTICS OF VESSEL NOISE

The underwater acoustic noise of a noisy vessel $x(t)$, as a signal, is supposed to be the stationary ergodic zero mean Gaussian stochastic process with a finite variance. The deep-sea underwater acoustic ambient noise $n(t)$, as an interference, is supposed to be a stationary ergodic zero mean Gaussian stochastic process with a finite variance as well. Both noises are mutually statistically independent and wide-band with nonwhite power spectral density functions with slopes of about –6±1 dB per octave [1].

The probability density function of the instantaneous values of the vessel underwater acoustic noise is very sophisticated function. But when the amplitudes of sinusoidal oscillations are extremely small, as it is for so-called noisy vessel, the probability density function of the instantaneous values of the vessel underwater acoustic noise is very near to Gaussian, or approximately

$$p(x)=\frac{1}{\sigma_x\sqrt{2\pi}}\exp\left(-\frac{x^2}{2\sigma_x^2}\right), \tag{1}$$

where σ_x^2 is a finite variance of the vessel underwater acoustic noise for the so-called noisy vessel.

The probability density function of the instantaneous values of the deep-sea underwater ambient acoustic noise is

$$p(n)=\frac{1}{\sigma_n\sqrt{2\pi}}\exp\left(-\frac{n^2}{2\sigma_n^2}\right), \tag{2}$$

where σ_n^2 is a finite variance of the deep-sea underwater ambient acoustic noise.

On the receiving location the waveform of the underwater acoustic signal has the following form

$$s(t)=x(t)+n(t),\ \text{for}\ 0\beta t\beta T, \tag{3}$$

where $s(t)$ is zero mean ergodic stationary Gaussian stochastic process with the finite variance

$$\sigma_s^2=\sigma_x^2+\sigma_n^2. \tag{4}$$

Now, we can write the probability density function of the instantaneous values of the received signal $s(t)$, or

$$p(s)=\frac{1}{\sigma_s\sqrt{2\pi}}\exp\left(-\frac{s^2}{2\sigma_s^2}\right), \tag{5}$$

or, by means of Eq. (4), Eq. (5) becomes

$$p(s)=\frac{1}{\sqrt{2\pi(\sigma_x^2+\sigma_n^2)}}\exp\left[-\frac{s^2}{2(\sigma_x^2+\sigma_n^2)}\right]. \tag{6}$$

But, if the vessel underwater acoustic noise is not present, the Eqs. (3) and (4) become respectively

$$s(t) = n(t) \quad \text{and} \quad \sigma_s^2 = \sigma_n^2 , \tag{7}$$

and Eq. (6) becomes

$$p(s) = \frac{1}{\sigma_n \sqrt{2\pi}} \exp\left(-\frac{s^2}{2\sigma_n^2} \right). \tag{8}$$

2. LIKELIHOOD RATIO

The general likelihood ratio for the case when the vessel underwater acoustic signal is defined with Eq. (3) has the following form

$$\Lambda = \frac{p_1(s)}{p_0(s)} , \tag{9}$$

where $p_1(s)$ is probability density function when the signal $x(t)$ is present and is defined by Eq. (6) and $p_0(s)$ is probability density function when no signal is present and is defined by Eq. (8). By means of Eq. (6), Eq. (8) and the relation $\sigma_x^2 << \sigma_n^2$ we can write the Eq. (9) of the instantaneous values in the following form

$$\Lambda = \exp\left(\frac{s^2 \sigma_x^2}{2\sigma_n^4} \right). \tag{10}$$

The detection algorithm for the alternative hypothesis H_1 is $\Lambda \geq \Lambda_0$, where Λ_0 is a threshold defined by Neyman-Pearson statistical criterion [2].

Eq. (10) is the special case when we detect so-called noisy vessel or when the vessel noise approximately consists only of the cavitation noise. For this case we can write the detection algorithm for the alternative hypothesis in the form of the reduced likelihood ratio

$$H_1: s^2 \geq \Lambda_{0nv} , \tag{11}$$

where

$$\Lambda_{0nv} = \frac{2\sigma_n^4}{\sigma_x^2} \ln(\Lambda_0). \tag{12}$$

3. EVALUATION MEASURE

The deflection coefficient, as an indirect evaluation measure, of the passive detection algorithm is defined as

$$d = \frac{\mu_{s1} - \mu_{s0}}{\sigma_n} , \tag{13}$$

where μ_{s1} and μ_{s0} are statistical expectations of the reduced likelihood ratios when underwater acoustic noise of the noisy vessel is present and when the vessel noise is not present respectively.

If we consider, the duration time T and the frequency band W of the received signal $s(t)$, then Eq. (13) we can write in the following form [3]

$$d = \sqrt{TW}\frac{\sigma_x^2}{\sigma_n^2}, \tag{14}$$

where T is the processing time and W is the processing frequency band of the underwater acoustic signal waveform on the receiving location.

4. CONCLUSIONS

The purpose of this report is to show some first-order statistical properties in the time domain of the underwater acoustic noise of the noisy vessel and of the underwater deep-sea ambient noise. In many situations such properties are of interest in the underwater acoustic researches, especially for the noisy vessel passive detection. The most important are the form of the passive detection algorithm for the so-called noisy vessel and the evaluation measure of the algorithm.

So, Eq. (11) shows that the reduced likelihood ratio for passive detection of the so-called noisy vessel is square of the underwater acoustic signal waveform on the receiving location.

On the other hand, Eq. (14) shows that the indirect evaluation coefficient has a greater value for the greater product TW and for the greater value of the signal-to-noise ratio σ_x^2 / σ_n^2. Greater value of the evaluation coefficient gives the greater value of the detection probability.

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