Spectral and Statistical Analysis of Underwater Acoustic Signals

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Abstract – **Basic characteristrics of underwater acoustic signals are received through spectral and statistical analysis. Precision of this processing in sonar systems is very important for current requirements which are applied to them. The decision offered to solve the problem is consistent with these requirements and the current state of digital and computer technology.**

Keywords – **DSP, statistic and spectral analysis, underwater acoustic, noise**

I. Introduction

This paper studies the approaches in the analysis of underwater acoustic signals from passive sonar. They are in two domains - time and frequency. In hydro-acoustics we use three basic types of analysis that show main characteristics of signals [1, 2]:

– spectral analysis – present signals in frequency domain;

– correlation analysis – this analysis is part of statistical analysis but it is a very important characteristics of signals because noise doesn't have correlation and this helps us to divide a useful signal from an input mixture;

– statistical analysis.

A specific structure of signals radiated from different underwater objects is used in the process of detection, recognition and classification [2]. Receiving a description of signal characteristics after analyses the goal of the present paper is known as pre-processing. This signal processsing can be used in systems for automatic recognition in many different applications like machine monitoring, ship noise classification, traffic statistics, restricted areas surveillance, target detection, etc[4].

II. System architecture

On Figure 1 is shown a block diagram of a real passive sonar system which realizes signal processing. It consists of sonar sensors, sonar system /filters, amplifiers and other/, analog to digital converter and FFT and statistical extractors.

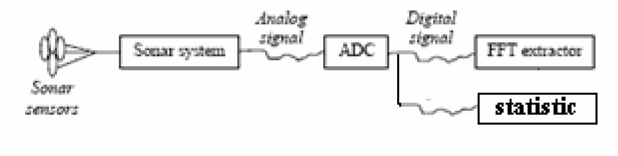

Fig. 1. System architecture

For the experimental character of the study, a system record of real signals is used through microphone input of the sound card of a portable computer, working in this case like an analog to a digital converter /ADC/. The output signal is taken from the hearing channel of a real sonar station. The files are recorded in a standard sound format .wav with discretion frequency 44100 Hz and 32 bits ADC. These parameters of input signal are completely enough for the needs of the study and the passive hydro location [3, 7].

III. Data processing and Algorithm

Computed experiments are used to simulate the analysis of spectral and statistical analysis with recorded sound files. . For programming the realization of the experiment Matlab is used – a program environment for mathematical modulation. The reason for this choice is to reach libraries with a built in function which work with sound files, signal processing toolbox and toolboxes for the following signal processing. Another positive side of Matlab is input and output functions libraries [5].

The realization of the program on Matlab language follows the algorithm:

1. Reading wav-file and loading the values of signal, frequency /Fs/ and the number of bits per sample in array.
2. Drawing a graphic of signals.
3. Computing the frequency spectrum.
4. Drawing a graphic of frequency spectrum.
5. Verification of results with inverse FFT and drawing a graphic of signal.
6. Computing statistical characteristics /mean, standard deviation and co variation/ and drawing autocorrelation function.

For computing algorithm we use following mathematics:

To get the frequency spectrum, we calculate discrete Fourier transform, computed with a fast Fourier transform (FFT) algorithm[8]:

$$X(k) = \frac{1}{n}\sum_{i=o}^{n-1} X(n).W_N^{kn} \qquad k = 0,1...,n-1 \qquad (1)$$

where:

X(k) - frequency spectrum, **N** - Time window size;

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X(n) - time function, $\mathbf{W_N} = \exp(-j2\pi/N)$.

These signal processing techniques were used in many previous works but precision is better than them. In this study are used FFT of 32384 points which leads to range discrimination less than 1.4 Hz of sample.

The approach used to calculate statistical characteristics of underwater acoustic signals is a standard Statistics formula for computing mean, standard deviation and autocorrelation function are shown below[6]:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (2)$$

$$s = \left(\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2\right)^{\frac{1}{2}} \qquad (3)$$

$$\hat{R}_{xx}(m) = \begin{cases} \sum_{n=0}^{N-m-1} x_{n+m} x_n^* & m \geq 0 \\ \hat{R}_{xx}^*(-m) & m < 0 \end{cases} \qquad (4)$$

IV. Results

With the presented algorithm we examine five types of ships:

- Ship 1 – motor-launch, displacement – 150 BRT, propel - with high turnovers 900;
- Ship 2 – tanker, disp. – 90 000 BRT, propel – special diesel motor - 100 rpm;
- Ship 3 – tanker, disp. - 180 000 BTR, propel - diesel motor – 150 rpm;
- Ship 4 – merchant ship, disp. – 10 000 BTR, propel diesel with 800 rpm;
- Ships 5 – high speed passenger-ship, disp. – 5 000 t, propel – with high turnovers 500 rpm.

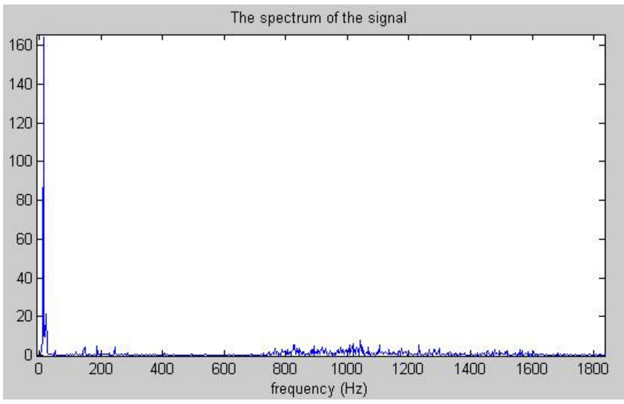
In table 1 is shown a parallel between statistical characteristics of these five types of ships. The second column shows the statistical mean of the signal and in the next column is calculated the standard deviation.

Table I
Statistical characteristics of signals

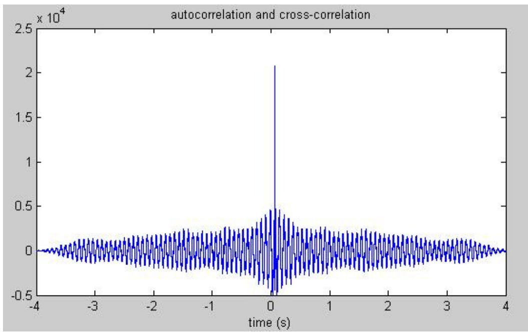
	mean	standard deviation
Ship 1	0.0012	0.3424
Ship 2	0.0013	0.3823
Ship 3	0.0015	0.0899
Ship 4	0.0209	0.1684
Ship 5.1	0.0034	0.3216
Ship 5.2	0.0012	0.3094

On Figure 2 – 7 are shown grafics of autocorrelation function and frequency spectrum of signals from the studied types of ships.

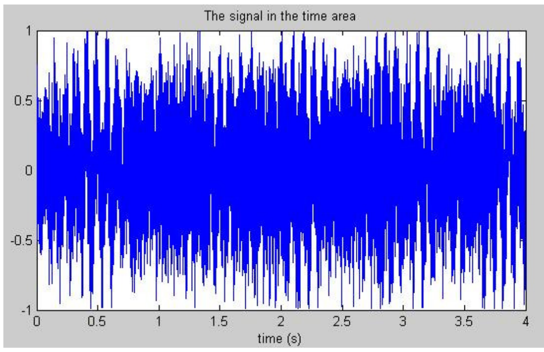
We see good visual distinguishing of all characteristics in different signatures which can be used to make other processing like classification and recognition.



a) Frequency spectrum



b) Autocorrelation function



c) Time domain

Fig. 2. Ship 1 Autocorrelation and spectral analysis.

In figure 2 from above the signal is represented with three graphics: frequency spectrum (a), autocorrelation function (b) and signal in time domain (c). The goal of this presentation is to show the impossibility to detect a ship in time domain without a human operator.

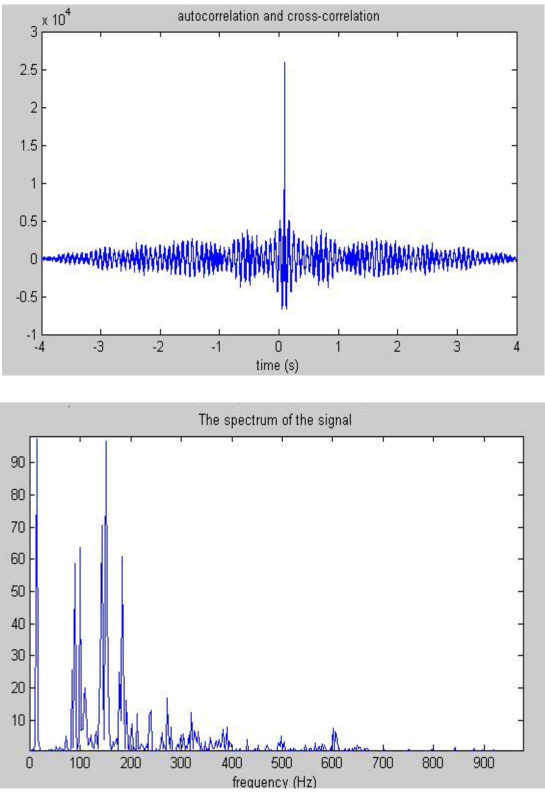
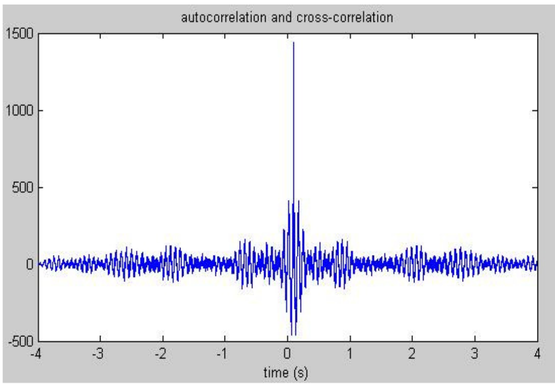
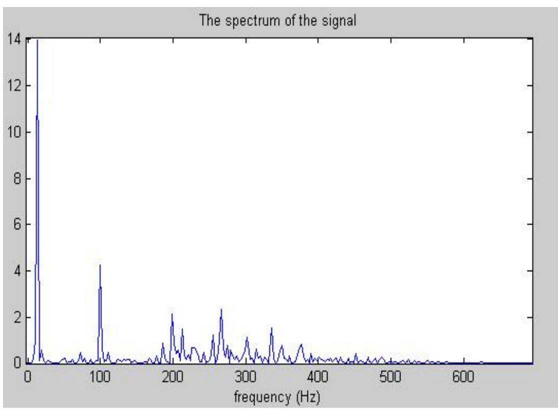


Fig. 3. Ship 2 Autocorrelation and Spectral Analysis.



a) autocorrelation function



b) frequency spectrum

Fig. 4. Ship 3 Autocorrelation and Spectral Analysis.

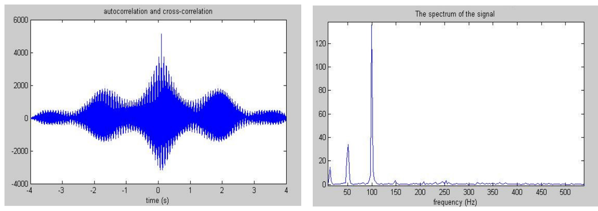


Fig. 5. Ship 4 Autocorrelation and Spectral Analysis.

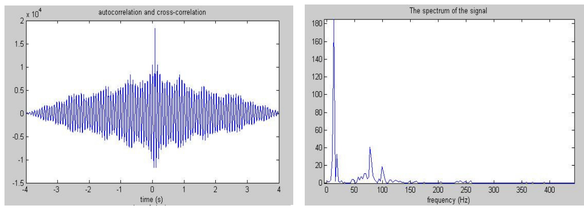


Fig. 6. Ship 5 Autocorrelation and Spectral Analysis.

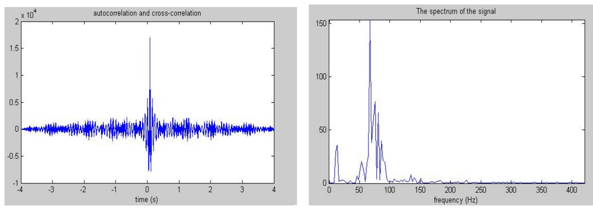


Fig. 7. Ship 5. Autocorrelation and Spectral Analysis.

In graphical presentation of spectral analysis results are shown only frequencies in range 0 – 1000 Hz because in passive hydro location the main noise signals radiated from ships are located there. The rest of the frequency spectrum can be ignored because other noises like wave, rain, animals, etc. have a high level [3].

On fig. 6 and 7 are shown spectral and autocorrelation graphics of ship 5 and difference between them are that first the ship move away and next they approach. Both of graphics have a same structure with different amplitude of signals.

V. CONCLUSION

Receiving results can be summarized in the following conclusions:

- from the received graphics and data in table 1 it is visible that different types of ships have different characteristics and they can easily be discriminated;
- the formation and record array with computed data can be used for the realization of following signal processing;
- in frequency domain we see pronounced signal of propeller in low frequencies (0-15 Hz) which give a turnovers and characteristics of propeller and information about ship (type of engine, size and turnovers and other);
- high frequencies (up to 1kHz) give to us additional information about ships – subclass, dimensions and other;
- the program area of Matlab allows the processing of signals in passive hydro location and it can be used to realize the entire system with reading data from PC inputs, pre-processing and detection, recognition and classification;

- receiving and collection of this characteristics aren't hard because realization is easy (just one portable computer);
- discrimination by computer program make decision accurate and powerful tool for following signal processing;

Apart from the conclusions above further trends can be outlined for the development of the survey:

- accumulation data base for large types of ships and statistic for every type;
- determination of the variation of characteristics of ships in different bearing and speed;
- realization of following signal processing for solving problems with recognition and classification.

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