USEFULNESS OF LINEAR PREDICTIVE CODING IN HYDROACOUSTICS SIGNATURES' FEATURES EXTRACTION

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This paper presents the problem of features extraction from the hydroacoustics signatures of a moving ship, based on Linear Predictive Coding. The use of the proposed method should allow for later classification of objects based on the hydroacoustics field generated by the moving ship. First of all the technique of Linear Predictive Coding (LPC) is discussed in detail; the mathematical description of LPC as well as a detailed description of the calculation processes are introduced. Secondly the example results from research concentrated on hydroacoustics signals' features extraction using LPC for different ships and different regimes of working ships' mechanisms are shown. At the end, the obtained results are discussed and the direction of future research is outlined.

INTRODUCTION

Hydroacoustics signal classification is a difficult task and it is still an active research area. Automatic signal classification works based on the premise that sounds emitted by an object to the environment are unique to that object. However this task has been challenged by the highly variant input signals. The ship's own noise is combined with technical environmental noises coming from other ships, offshore industry or others. There also exists noises of natural origin, such as waves, winds, rainfall, etc. An additional problem in acquiring hydroacoustics signals which are to be used as the base of classification procedures, is the fact that various ships' equipment may be the source of hydroacoustical waves of similar, or the same frequencies. The propeller is the dominant source of the hydroacoustics field at higher vessel speeds. It generates the driving force that is balanced by the resistance force of the hull. It also stimulates the vibrations of the hull's plating and all elements mounted on it. It should be noticed that, sound signals can be greatly different due to operating regimes of ship mechanisms. Moreover sound emitted by a ship will change with time, efficiency and conditions (e.g. some elements of machinery are damaged), sound rates, etc. There are also other important factors that present a challenge to signal classification technology, such as the changes in transfer function of the hydroacoustics channel which is the transmission medium generated by ships sounds. Its variability depends on many factors including, among others: temperature, salinity, pressure, water depth, type of bottom, the presence of any gases as well as organic and non-organic pollutions. Changes in these parameters can cause the components of different frequencies to be propagated in a different way; hence hydroacoustics signals registered at various distances from the sound source will be different even though they are generated by one object [4, 5].

All signal recognition systems, at the highest level, contain two main modules (figure 1); feature extraction and feature matching. Feature extraction is the process that extracts a small amount of data from the hydroacoustics signatures that can later be used to represent each object. Feature matching involves the actual procedure to identify the unknown object by comparing extracted features from input sounds with the ones from a set of known sounds stored in some kind of database [4, 5].

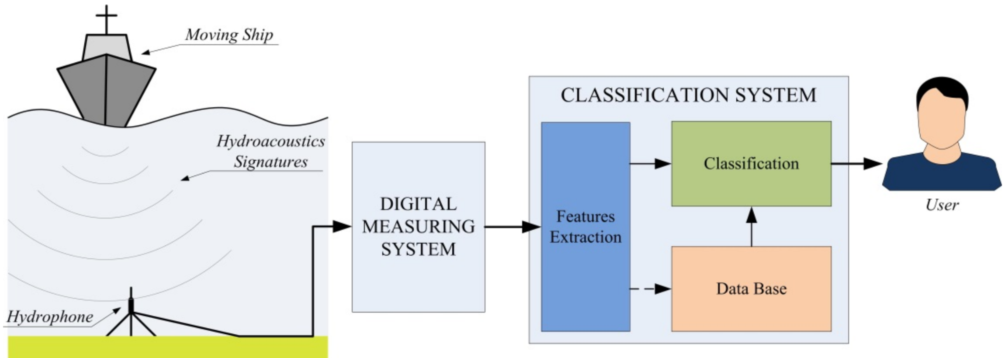

Fig. 1. Main components of system of hydroacoustics signatures classification.

The module of feature extraction is the most important processor of the signal classification system. Processing methods used in this module must allow for the calculation of a universal descriptor of the signal and will not change independently with external disturbance, and at the same time will be unique as a given source of sound. In addition, in order to be successfully used in classification, systems may not be computationally complex and the best should operate in real time. Often this stage of signal processing determines the success of the classification and the quality of the classifier.

A systematic taxonomy of features is outside the scope of this paper; nevertheless it could be distinguished by certain features, at least according to four points of view [1]:

- The steadiness or dynamicity of the feature, i.e. the fact that the features represent a value extracted from the signal at a given time, or a parameter from a model of the signal behavior over a longer period of time (mean, standard deviation, derivative or Markov model of a parameter);
- The time extent of the description provided by the features, i.e. some description applies to only part of the object whereas others apply to the whole signal;
- The "abstractness" of the feature, i.e. what the feature represents (e.g. cepstrum and linear prediction are two different representation and extraction techniques for representing the spectral envelope, but probably the former one can be considered as more abstract than the latter);
- The extraction process of the features. According to this point of view, it could be used to further distinguish:

- o Features that are directly computed on the waveform data (for example zero-crossing rate);
- o Features that are extracted after performing a transfer of the signal (for example spectral centroid);
- o Features that relate to a signal model (for example source/filter model);
- o Features that try to mimic the output of the human hearing system (for example bark bank filter output).

This article will discuss and examine the Linear Predictive Coding (LPC) method as a method of extracting distinctive features from the hydroacoustics signals processor. LPC is a method for signal source modelling in signal processing. This method is most widely used in speech coding, speech synthesis, speech recognition, speaker recognition and verification and for speech storage. LPC methods provide extremely accurate estimates of speech parameters, and does so extremely efficiently.

1. LINEAR PREDICTIVE CODING

LPC is a method of encoding based on a linear prediction model. In this method, the input signal is estimated based on the values of the preceding moments. The current signal sample can be closely approximated as a linear combination of past samples. See as follows [2]:

$$x(n) = \sum_{k=1}^{P} a_k x(n-k) + e(n) \tag{1}$$

where: $x(n-k)$ are previous signal samples, P is order of the model, a_k is prediction coefficient, $e(n)$ is prediction error.

Denoting by $\hat{x}(n)$ the outcome of the prediction, the signal can be written as follows [2]:

$$\hat{x}(n) = \sum_{k=1}^{P} a_k x(n-k) \tag{2}$$

The essential, and in fact the primary application of this method, is applicable to signal compression by coding a residual signal, designated as the difference of the original signal and its estimate. In the recognition tasks the LPC coefficients are themselves regarded as signal characteristics. There are several methods of determining the coefficients. We take a look at the method-based determination of the least squares method.

The prediction error is defined as follows [3]:

$$e(n) = x(n) - \hat{x}(n) = x(n) - \sum_{k=1}^{P} a_k x(n-k) \tag{3}$$

Z-Transforming the above equation, we obtain [3]:

$$E(z) = \left(1 - \sum_{k=1}^{P} a_k z^{-k}\right) X(z) = A(z)X(z) = \frac{X(z)}{H(z)} \tag{4}$$

Define [3]:

$$P(z) = \sum_{k=1}^{P} a_k z^{-k} \tag{5}$$

as the Prediction Filter. We have in the z-domain:

$$E(z) = X(z) - \hat{X}(z) = X(z) - P(z)X(z) = A(z)X(z) \tag{6}$$

where: $E(x)$, $X(z)$, $\hat{X}(z)$ are the Z-transforms of $e(n)$, $x(n)$ and $\hat{x}(n)$ respectively.

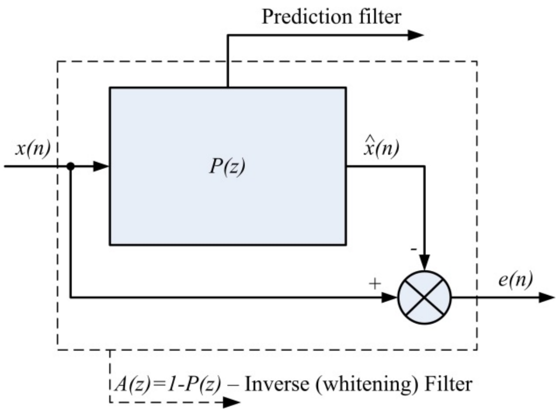

Fig. 2. The goal of prediction.

The optimal (minimum) mean-square prediction error variance for linear prediction of order p is defined as [3]:

$$D_p \triangleq E[e(n)^2] \tag{7}$$

and the resulting prediction gain G_p is [3]:

$$G_p = \frac{\sigma_s^2}{D_p} \tag{8}$$

The goal is to find the set of linear prediction coefficients $\{a_k\}_{k=1}^{p}$ which minimize the prediction error variance [3]:

$$D_p \triangleq E\left[\left(x(n) - \hat{x}(n)\right)^2\right] \triangleq E\left[\left(x(n) - \sum_{k=1}^{P} a_k x(n-k)\right)^2\right] \tag{9}$$

We can view this problem as a linear least square estimation problem [2, 3].

2. EXAMPLE RESULTS OF RESEARCH

In studies we used measurements of the hydroacoustics signatures of several Polish Navy ships acquired from the Control and Measurement Range of the Polish Navy in Gdynia. The measurements included the registration of hydroacoustics signals generated by moving ships which were approaching and moving away from the sensors. Moreover, the measurements of a single ship moving under different regimes of working mechanisms were made.

As sensors were used, Reson TC4032 hydrophones placed at the bottom of the sea basin. The registration was performed using a digital system working at a sampling rate of 250 kHz. Obtained recordings were divided into frames with a length of 1 sec. Each frame may be treated as a short record of the hydroacoustics signature of a ship located at different distances from the sensors.

During the research, to be able to obtain graphical representation of the results, we used 3 order model of Linear Predictive Coding. In the first phase of the research were determined LPC coefficients for each individual frame of a recorded ships' hydroacoustics signatures.

Selected results from the three ships are shown in Figure 3. First of all the variability of calculated coefficients was evaluated. To do this, the mean values as well as standard deviations and variances of the respective coefficients were determined. The results of these calculations are presented in Table 1.

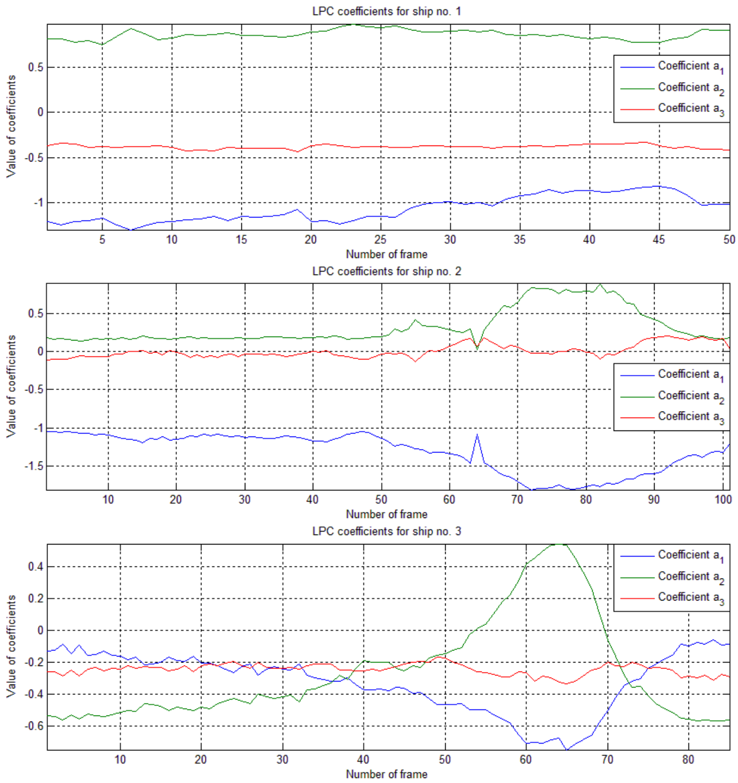

Fig. 3. LPC coefficients for various types of ships and for varying distance of measurements.

Tab. 1. Statistical analysis of LPC coefficient for different ships.

Ship	Coefficient	Mean	Standard deviation	Variance
no. 1	a_1	-1.0711	0.1431	0.0205
	a_2	0.8589	0.0532	0.0028
	a_3	-0.3822	0.0229	0.0005
no. 2	a_1	-1.3184	0.2542	0.0646
	a_2	0.3222	0.2294	0.0526
	a_3	0.0042	0.0861	0.0074
no. 3	a_1	-0.3212	0.1883	0.0355
	a_2	-0.2593	0.3185	0.1015
	a_3	-0.2436	0.0347	0.0012

These results suggest that coefficients of the LPC model for the individual vessels are highly concentrated around the mean value, regardless of the distance of the ship from the sensors.

In the second phase of research the possibility of the separation of results obtained for different ships was tested. For this purpose, the calculated coefficients of ships at various distances from the sensor were plotted. These results are in figure 4. The graphic representation coincides with the statistical analysis of the coefficients. The different coefficients for different ships have different mean values, which suggests that the results of the measurement of the group are placed in other areas of the analysis.

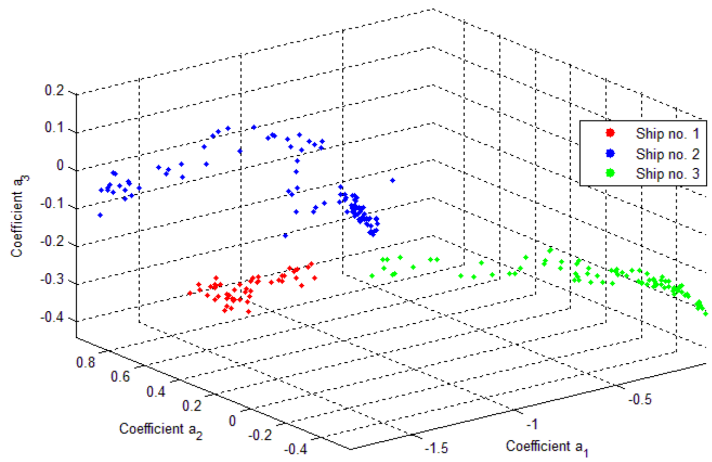

Fig. 4. Distribution of coefficients of LPC for various types of ships.

Next we tested the impact of the changing mechanism operation regimes on determined LPC coefficients. The coefficients were determined for a single ship moving at different velocities by measurement range. The obtained results were shown in Figure 5. Measures of the dispersion of individual results were made by statistical analysis i.e. determining the mean value, standard deviation and variance. The data from the calculations are collected in Table 2.

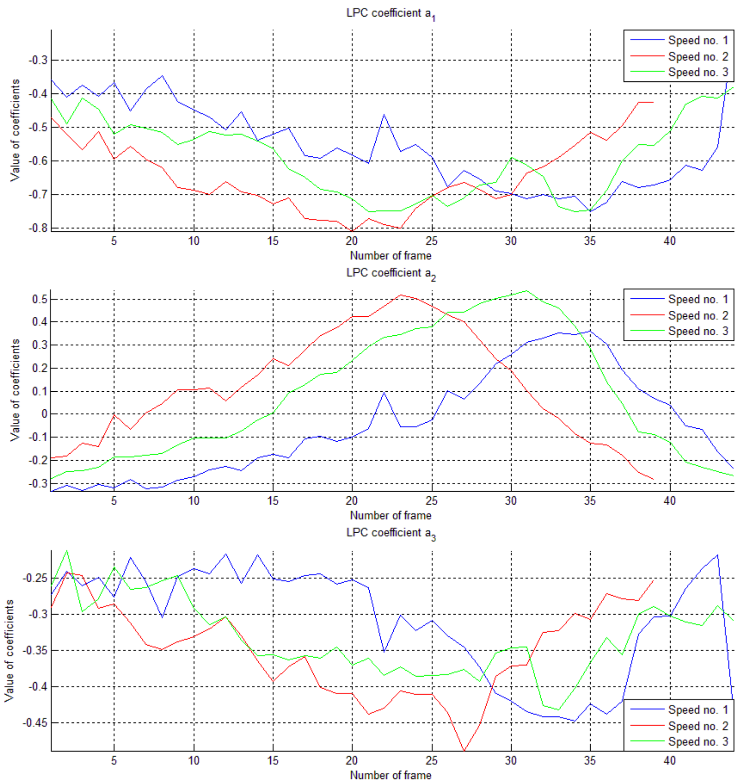

Fig. 5. LPC coefficients for one ship moving with different regimes of working mechanisms.

Tab. 2. Statistical analysis of LPC coefficient for one ship moving with different regimes of working mechanisms.

Coefficient	Speed	Mean	Standard deviation	Variance
a_1	no. 1	-0.5546	0.1277	0.0163
	no. 2	-0.6458	0.1058	0.0112
	no. 3	-0.5905	0.1144	0.0131
a_2	no. 1	-0.0497	0.2232	0.0498
	no. 2	0.1261	0.2352	0.0553
	no. 3	0.0858	0.2749	0.0756
a_3	no. 1	-0.3082	0.0769	0.0059
	no. 2	-0.3493	0.0621	0.0039
	no. 3	-0.3312	0.0520	0.0027

The obtained results suggest that regardless of the ship's mechanisms regime the calculated coefficients of the LPC model are similar. They have a high concentration around the mean value and the average values are close. This suggests that regardless of the speed of the ship the LPC coefficient set covers the same region in the parameter space. This can be easily seen when plotting the calculated LPC coefficients for the ship's different speeds of movement in the single graph, as shown in Figure 6.

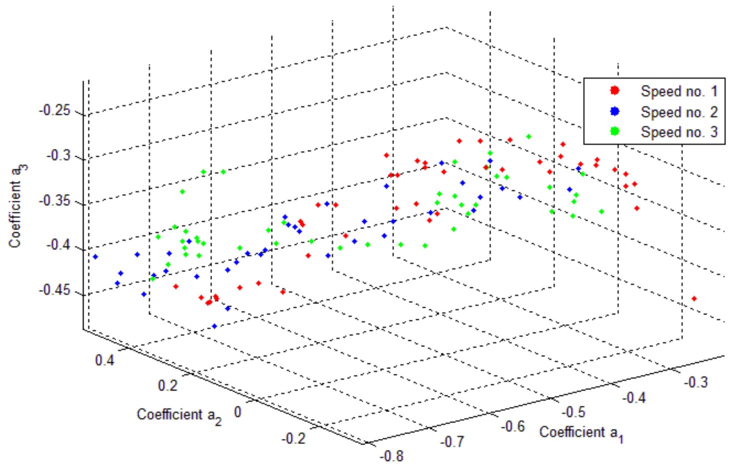

Fig. 6. Distribution of coefficients of LPC for various individual ships moving with different regimes of working mechanisms.

3. CONCLUSIONS

Hydroacoustics signatures have great significance because its range of propagation is the widest of all the physics fields of a ship. Controlling and classification of the acoustic signature of vessels is now a major consideration for researchers, naval architects and operators. The advent of new generations of acoustic intelligence torpedoes and depth mines has forced a great effort which is devoted to the classification of objects using signatures generated by surface ships and submarines. It has been done in order to increase the battle possibility of submarine armament. Its main objectives are to recognize the ship and only attack the one which belongs to the opponent [4, 5].

In the article there were presented results of an investigation into the possibility of a parametric description of the ships' hydroacoustics signatures by means of LPC model coefficients. The results show that such a description of hydroacoustics signals can be the basis for the classification of their sources. Linear Predictive Coding model coefficients for the recorded signals are characterized by a high degree of similarity, irrespective of the distance from which the measurement was made, as well as the ships mechanisms regimes. Furthermore, for different types of vessel, calculated LPC coefficients differ significantly and allow for easy separation of one object from another. These features make that distinction between different classes based on LPC model coefficients of hydroacoustics signatures and can be made by using a simple classifier.

In further examination the study population should be increased, as well as the consistency of the obtained values of the LPC model coefficients and their separability need to be checked. It should also carry out further tests relating to the resistance of that hydroacoustics signals description by LPC coefficients on environmental factors and external disturbances. To resolve this there is also the problem of the selection order of the LPC model and the same the amount of generated description parameters.

REFERENCES

[1] G. Peeters A large set of audio features for sound description (similarity and classification) in the CUIDADO project, [electronic document], http://recherche.ircam.fr/equipes/analyse-synthese/peeters/ARTICLES/Peeters_2003_cuidadoaudiofeatures.pdf [access:05.04.2014].

[2] A. Sarti, Linear Predictive Coding, [electronic document], http://www.dsp.elet.polimi.it/ispg/images/pdf/audio/materiale/lpc.pdf [access: 05.04.2014].

[3] T. P. Zieliński, Digital signal processing. From theory to application [in Polish], WKŁ, Warsaw, 2009.

[4] A. Zak, Ship's Hydroacoustics Signatures Classification using Neural Networks [in] J. I. Mwasiagi (ed.) Self Organizing Maps – applications and novel algorithms design, INTECH, 2011, pp. 209-232.

[5] A. Zak, Kohonen networks as ships classifier, Hydroacoustics Vol. 11, Gdansk, 2008, pp. 467-476.