UNDERWATER ACOUSTICS PROBLEMS SOLVING WITH HELP OF MATCHED FIELD ALGORITHMS

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Abstract: *The paper contains the review of the practical applications of underwater acoustics, based on the use of matched field algorithms. Such applications include tomography of the ocean, detection of sea objects at great distances, a joint solution of object classification and coordinates problems, underwater sound communication.*

Key words: *hydroacoustic conditions, matched field processing, tomography of the ocean, underwater sound communication.*

1. INTRODUCTION

As it is known [1,2], one of the basic differences of hydro acoustic field from physical fields of another nature is the essential dependence of the signal propagation on the current hydro acoustic conditions (HAC). Consequently, the algorithms for solving the most practical problems of underwater acoustics, which, as a rule, are inverse problems, need to take in account the current HAC, i.e. they must be matched with the signal and interference fields.

The aim of this work is to review practical applications of underwater acoustics, which are based on the matched field algorithms (MFA).

2. THE TYPICAL STRUCTURE OF MATCHED FIELD ALGORITHMS

The main purpose of MFA is the full extraction of the information about the class and coordinates of the marine object from its radiated signal.

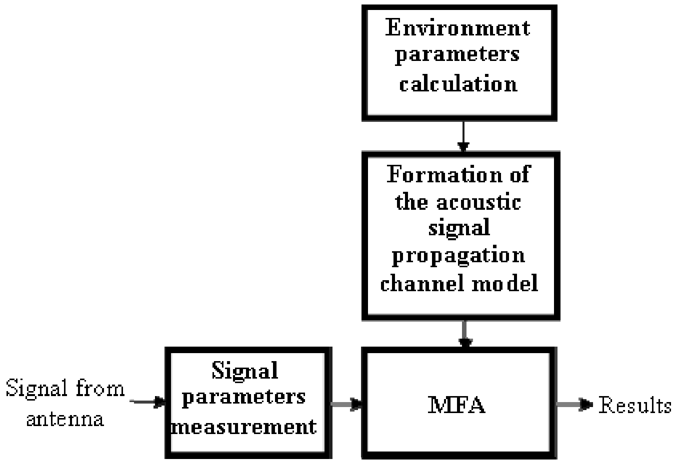

Fig.1. Typical structure of matched field algorithm

The typical structure of MFA is presented on Fig.1. MFA in addition to the parameters of input signals, measured at the hydroacoustic antenna output, uses a model of the acoustic signal propagation channel, formed by the special computer program using the parameters of the current HAC (sea depth, bottom relief, sound speed vertical distribution, the surface state, the thickness of the ice cover, signal attenuation, reflection and scattering functions).

3. MATCHED FIELD PROCESSING

Matched field processing (or MFP) is subclass of MFA proposed in 1976 by H.P.Bucker [3]. The essence of MFP is as follows. The signal rays (or modes) detected at the output of a vertically developed antenna using the parameters of current HAC are focused in the arbitrary point of "distance-depth" space. All the focused signal rays (or modes) are coherently summed, calculating the power of the sum. After repeating this procedure for a large number of points in the "distance-depth" space the point with maximum power of the focused signal rays sum is considered as a true source place.

MFP, according to H. Bucker and his followers, is supposed to solve two problems:

– to increase the signal-to-noise ratio (SNR) due to the coherent summing of the signal rays (modes) and thus to increase the object detection distance;

– to solve the problem of passive object coordinates determination.

A large number of works were devoted to MFP over the past 40 years. However, if during the first 20 years after the appearance of Bucker's work the flow of work devoted to MFP only grew and among the authors there was an euphoria in anticipation of a quick solution of the problems, in the next 2 decades the picture changed to the opposite. The reason for this explained one of the leading specialists in underwater acoustics A.B. Baggeroer [4]. From consideration of different factors he concluded that MFP can work when the following conditions are fulfilled: 1) exploiting the low frequencies in the deep sea and the low and medium frequencies in the shallow water; 2) the use of antennas with large vertical wave size; 3) working in large SNR conditions.

The authors of the review [5] as a result of analyzing of a large number of works on the problem concluded that progress can only be achieved when using broadband signals and the transiting to a problem statistical decision with the use of robust procedures.

Thus, it can be stated that the development of MFP is possible but only for certain practical applications. To wait the global breakthrough is apparently not worth. In particular, MFP will not bring practical effect at the small SNR (the most interesting in practical applications) and in the case of using the antennas with small vertical wave size (which are the mostly wide spread in practice).

4. ACOUSTIC TOMOGRAPHY OF THE OCEANS

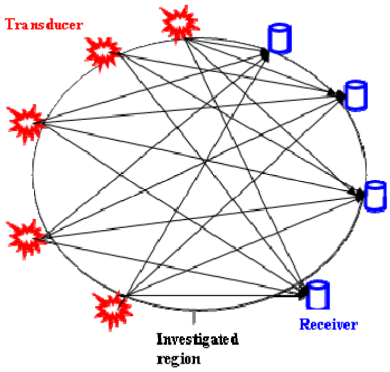

Fig.2. The geometry of the acoustic tomography

The term “acoustic tomography of the oceans” (ATO) was proposed in work [6] by analogy to medical tomography, the subject of which is the disease diagnosis according to the results of scanning the human body from different sides using x-rays or another rays (the tomo is a part in Greek, and the tomography is recording by parts).

The essence of acoustic tomography according to [6] is as follows. Around the studied ocean area, the sonar sources and receivers are placed (Fig.2). The signals of each source are detected at the output of each receiver. The rays consisting the detected signals are separated and there travel times and their fluctuations are measured. The authors of [6] showed that using these data it is possible to solve some practical problems of studied area monitoring.

Strictly speaking, the ATO does not fit into the scheme of generalized MFA algorithms, displayed in Fig. 1, since in most cases ATO does not solves the problem of removing information about its source from the receiving signal. ATO solves the inverse problem - the construction of the acoustic model of the studied area by treating signals which have spread through the area (Fig. 3). At the same time, missing ATO in the review of the MFA would be mistake, as the ATO exploits the same signal processing and the same acoustic channel models.

In some cases, instead of the time of signal rays propagation it is preferable to measure the difference of propagation time between the different rays. To improve the accuracy the measurement of time difference is sometimes replaced by the measurement of the phase difference.

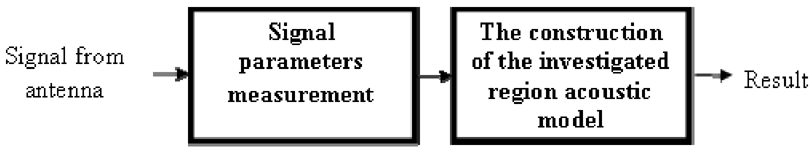

Fig.3. The typical scheme of the acoustic tomography

To expand the list of tasks solved with the help of ATO, in addition to space-time spectrum the signal Doppler spectrum is measured, as well as the relationship between the coherent and diffuse components of the signal.

As a development of the ATO scheme, proposed in [6], instead of special transmitters the natural emitters are used (dynamic and seismic ocean noises, noise of ships, signals of marine mammals).

The purpose of practical tasks of ATO is, as a rule, to clarify the structure and/or parameters of some mathematical problem-oriented signal propagation space-time-frequency model.

The tasks solved with the help of ATO include:

– observation of the climate of the planet by monitoring the changes in the average temperature of sea water by observing changes in the average speed of sound propagation at large distances;

– study of the influence of acoustic signals on large marine mammals (whales, sea lions, porpoises);

– study of the ocean currents by measuring the time of propagation along and against the current using the so-called reciprocal tomography;

– determination of sound velocity vertical distribution in a controlled area;

– study of ocean turbulence by measuring the fluctuation of the signal propagation time with the periods from minutes (internal waves) to several years (climate change);

– monitoring of sea surface state based on the analysis of the signal frequency-vertical angular spectrum;

– study of the acoustic characteristics of the seabed along the route of the signal propagation.

Thus, ATO is the effective method for remote study and control of the ocean characteristics.

5. THE JOINT SOLUTION OF SEA OBJECTS CLASSIFICATION AND COORDINATES PROBLEMS

The sea objects classification as a result of there signals analyzing is one of the most difficult practical problems of underwater acoustics. The main reason for this complexity is that the decision about the class of the observed object is adopted on the base of analysis of parameters of a signal propagated through an ocean waveguide and substantially transformed during the propagation. The content of this transform depends on the current hydroacoustic conditions (HAC). Thus, the algorithms of the classification of sea objects must take in consideration the current HAC, i.e. they must be MFA [7-9].

The complexity of passive determination of sea objects coordinates (range and depth) is in line with the complexity of classification problem [10-12].

One method of solving this problem - MFP - has been described above. But, as was noted, MFP imposes a number of specific requirements, which are not always implemented in practice. That is why we will consider a more universal approach to the problem solution.

It was stated [10] that for determination the objects coordinates the same signal parameters are used that in the case of there classification. This is quite clear because if one knows the object coordinates he in many cases can determine its class and vice versa. Taking it in account it is advisable the both problems to decide together.

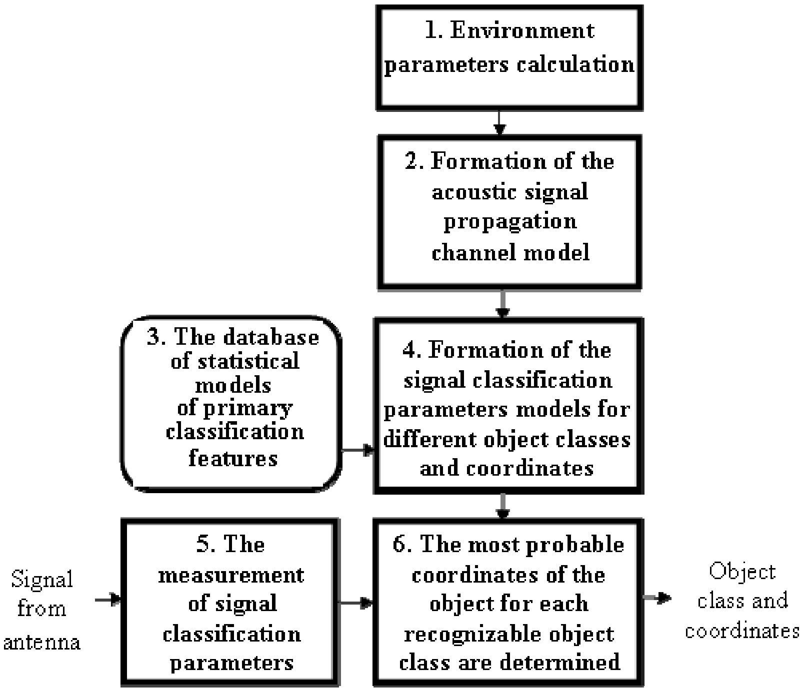

Fig.4. The structure of the algorithm of the classification and coordinates problems joint solution

The structure of the algorithm for the joint solution of both problems is shown in Fig.4. The variable environment characteristics (the vertical sound speed distribution, the sea surface state, the noise power) are periodically measured using special tools (block 1). These variable characteristics together with constant characteristics downloaded from data base (the bottom relief, the acoustic characteristics of the seabed and water column) are used to calculate the channel transfer factions (CTF) for signal propagation from different points of "range – depth" space (block 2). In block 3 the statistical models of primary (at the point of signal emission) classification features (for example, depth, speed, signal spectra, etc.) of different object classes are retrieved from the special data base. In block 4 the probability models of measured at antenna output signal classification parameters are formed for the different object classes and different object position in the "range – depth" space. It is fulfilled using the statistical models of primary classification features and the channel transfer functions. In block 5 the signal classification parameters are periodically extracted from signal at antenna output. In block 6 the most probable coordinates of the object for each recognizable object class are determined. And then, comparing the object coordinates probabilities of different classes, the object class with greatest probability is chosen. This class and its most probable coordinates are considered as a problem decision.

6. THE SOLUTION OF THE UNDERWATER COMMUNICATION PROBLEM

When solving underwater communication problem, the negative influence on signal containing the message, produced by the signal propagation channel, have the signal attenuation and distortion of its shape due to multipath propagation. In some cases, the second factor is more significant.

In the 80-ies of the last century it was proposed to eliminate the negative role of multipath propagation using MFP ideology with the only difference that the channel transfer function was measured instead of be calculated. The measurement of the channel transfer function (which is in underwater communication called channel impulse reaction - CIR) is fulfilled with the use of special synchrony signal, preceding the message [13-15].

Necessary conditions for the application of this ideology are: 1) the transmitted signal must be encoded in discrete digital messages (elementary parcels) and 2) the signal caring message and synchrony signal must be broadband (specifically noise-like) signals, allowing to divide the signal rays.

The structure of the message decoding matched field algorithm is shown in Fig. 5. In the simplest case, the decoding consists in the recognition of each elementary parcel by calculating its correlation with each of its possible discrete alternatives, converted using the CIR. As a result, the alternative with greatest correlation is chosen. In practice, however, more complex algorithms are used.

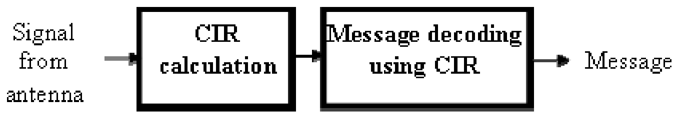

Fig.5. The structure of the message decoding matched field algorithm

The algorithms, based on described ideology provided a manifold increase of underwater communication range, as well as solving a number of other problems, such as high-precision relative positioning of underwater objects [16].

7. CONCLUSION

Matched field algorithms are the basis for solving many applied problems of underwater acoustics. These problems include:

- detection of objects at large distances;
- a joint decision of object classification and coordinates problems;
- underwater communication;
- ocean tomography.

8. ACKNOWLEDGEMENTS

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