TARGET TRACKING USING MULTIPLE PASSIVE SONARS

TADEUSZ JANOWSKI, EDYTA POROSIŃSKA

Ośrodek Badawczo-Rozwojowy Centrum Techniki Morskiej S.A.
62, Dickmana St., 81-109 Gdynia, Poland
Tadeusz.Janowski@ctm.gdynia.pl, Edyta.Porosińska@ctm.gdynia.pl

The DOA estimation methods based on the analysis of the noise subspace enable high resolution bearing determination of naval objects emitting hydrouacoustic noise.

The knowledge of the objects number is the essential parameter for DOA algorithms. Practically, the number of the objects is unknown. In case of high sea ambient noise to object signal ratio the detection with desired probability is significantly hindered. In the event of system based on the console the detection decision belongs to the operator. The visual analysis of the reception beamformer changes conducts to the intruder detection. Whereas in case of the stand-alone systems the decision making process is performed by the detection and tracking algorithm. This article describes such algorithm based on the analysis of the machine states.

INTRODUCTION

The aim of the hydroacoustic tracking systems presented on the figure 1 is to safeguard the harbours, seaways, naval bases, nautical installations form acoustically noisy maritime intruders. The system consists of passive sonars assembled on the autonomous buoys. The directional antenna of the sonar is suspended under the buoys and operates in sea water transmission medium. The antenna incorporates few hydrophones equally placed along the circumference of the circle. Each buoy of the system is equipped with cameras, power supply unit, GPS and telemetry transreceiver. Whereas the land located Command and Control Centre acquires the entire data and operates the system.

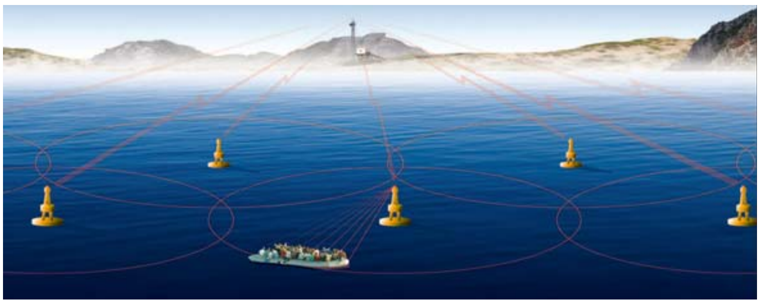

Fig. 1. Hydrouacoustic tracking system

1. HARDWARE

The hydrouacoustic antenna of the passive sonar is presented on the photo. The antenna of 1.6 m diameter consists of the four Ethernet hydrophones and digital compass and inclinometer.

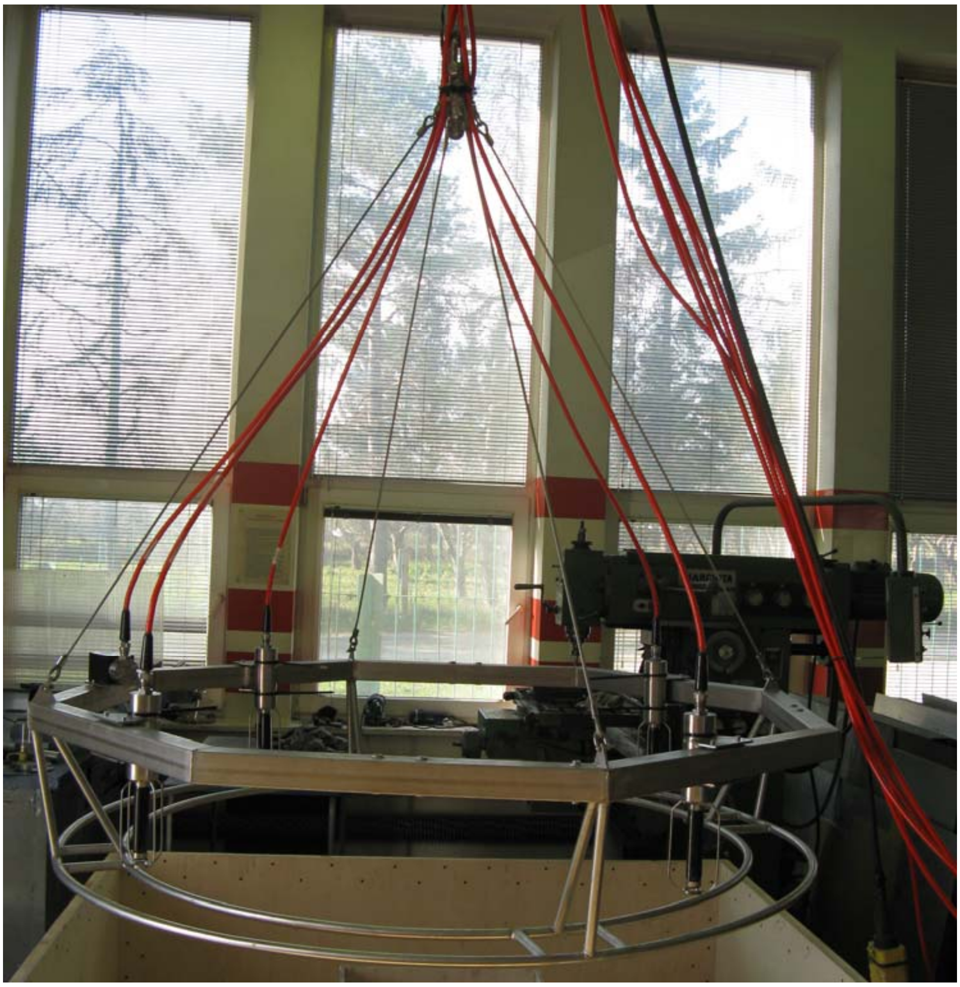

Fig. 2. Hydrouacoustic antenna

The data on momentary pressure level are synchronously processed into parametric measuring vectors. The microprocessor software performs high resolution DOA MUSIC algorithm to estimate the bearing of the object emitting hydrouacoustic noise – mainly ships equipped with inboard or outboard engines. The telemetry radio system transmits data on detected targets from all buoys to the land station. To locate the object two bearings from two buoys must be taken.

2. TRACKING ALGORITHM

The tracking algorithm is performed in four following steps:

1. Data acquisition and covariance matrix estimation.
2. Covariance matrix decomposition and calculation of the beamformers adjusted to the single and more objects.
3. State machine associated with hypothesis verification.
4. Location and tracking of the detected targets.

2.1 DATA ACQUISITION AND COVARIANCE MATRIX ESTIMATION

In case of a multi-sensor system the proper data acquisition requires application of either common sampling system or precise time stamps for each signal sample. The sampling frequency results from the central frequency and bandwidth of the observed hydrouacoustic noise. In the event of antennas of few meters diameter the central frequency is about several hundreds hertz and the bandwidth shouldn't exceed 100Hz. The parametric processing of the data conducts to slowly-changeable (100Hz) measuring vector corresponding to the central frequency. The parametric processing is performed by FPGA boards. The first processing step consists in real samples multiplication by the complex reference generator. The obtained complex samples are fed to the three order Hogenauer's decimation filter.

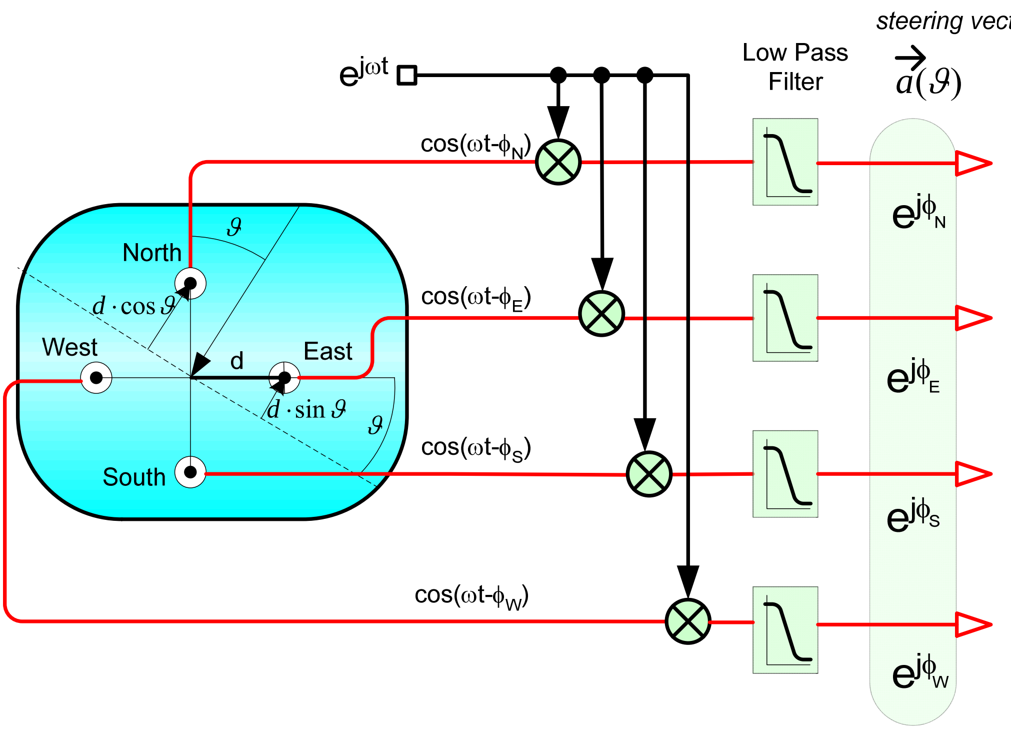

Fig. 3. I/Q Multi-channels synchronizantion

As the result of this operation the measuring vector is estimated. The number of the vector components equals to the number of the hydrophones making up the antenna. The vector components are mutually multiplied to gain the random samples. Consecutively application of the Simple Moving Average conducts to the Cross Correlation Matrix (CCM).

2.2 COVARIANCE MATRIX DECOMPOSITION

The CCM covariance matrix is regularly reproduced every few seconds. This time is sufficient to periodically calculate the Multi-source Signal Classification (MUSIC) algorithm. Additional averaging of the CCM enables estimation of the acoustic background existing in the sea area. This makes possible usage of the incremental algorithms. The CCM decomposition conducts to creation of the eigenvalues and eigenvectors. The unitary matrix composed of the eigenvectors enables simultaneous calculation of few beamformers adequately for 1, 2, .., N-1 objects. Here the N parameter denotes the number of the antenna hydrophones.

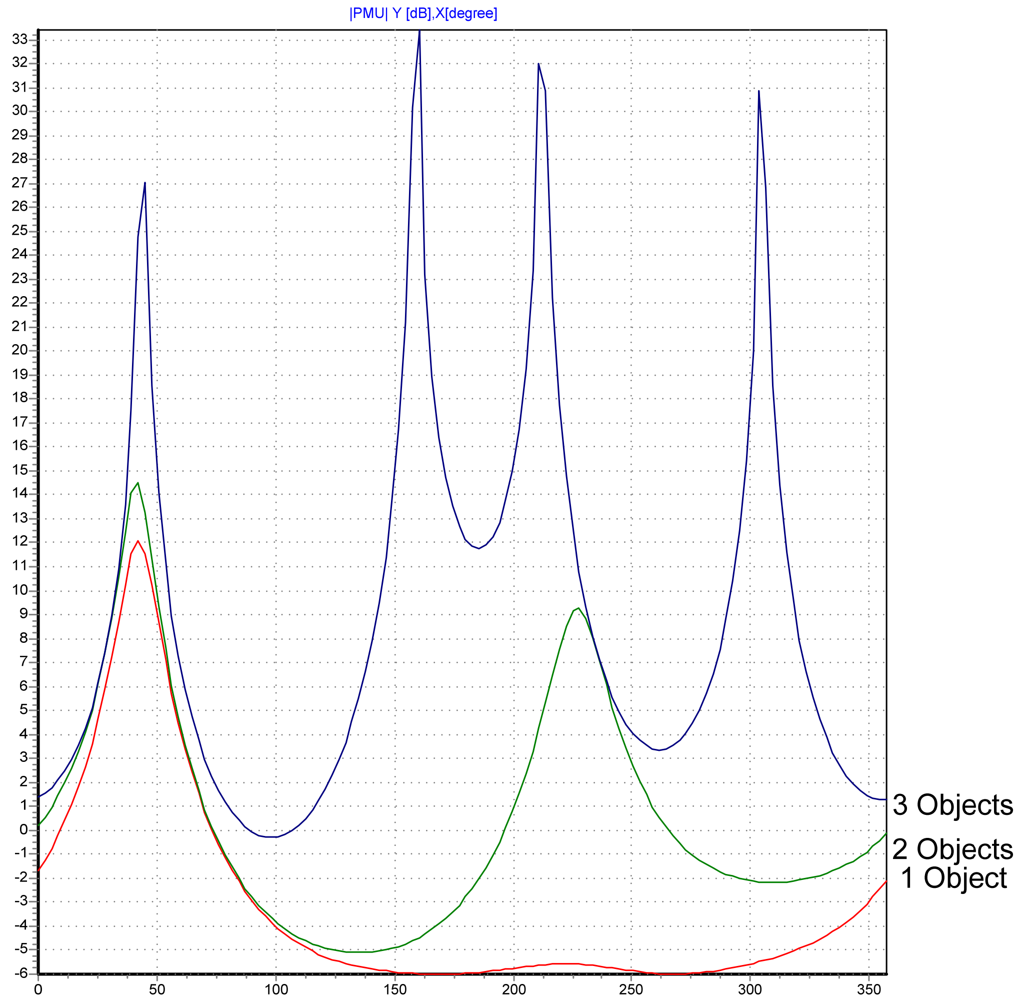

Fig. 4. MUSIC beamformers for 1, 2 ,3 detected objects

2.3 STATE MACHINE ASSOCIATED WITH HYPOTHESIS VERIFICATION

The creation of few beamformers adjusted to various numbers of the objects is tantamount to the many hypotheses formulation. In reality the observation process is performed during long time. So, the beamformers are successively reproduced every five second. These results can be treated as the average values of the noise caused by accidentally occurred objects.

The motorboats signal has following features:

– long range appearance,
– the directions determined by consecutive beamformers are slightly different,
– while ship sailing away the directional noise decreases up to fading at maximal distance.

The full machine state is the Cartesian co-product of the particular object states according with dependance:

$$Ma = M_1 \times M_2 \times .. \times M_{N-1} \tag{1}$$

The state machine corresponding to the tracking of the single object is presented on the figure 5.

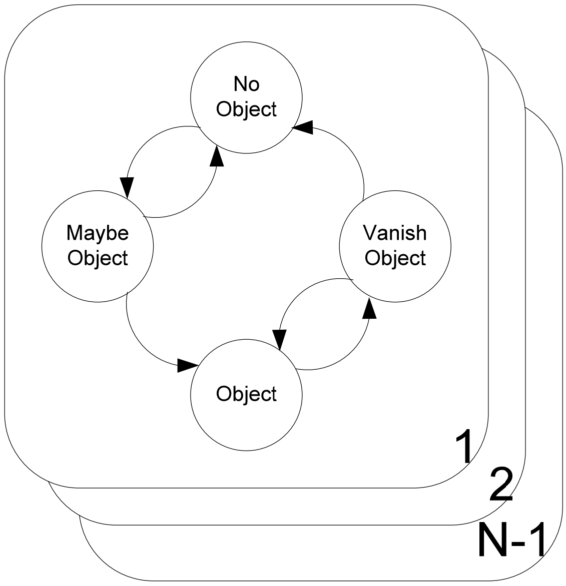

Fig. 5. The state machine

The state machine composed of four states: {No Object}, {Maybe Object}, {Vanish Object}, {Object} is associated with every object. The initial state corresponds to setting of all states into {No Object}. Whereas the states: {Maybe Object}, {Object}, {Vanish Object} are characterized by following parameters:

- ta : time all,
- ts : time state,
- Θ : direction.

The total time is counted since the object first appearance. The state time is counted since the state initiation. The Θ is direction determined by the DOA MUSIC algorithm. Passage from {No Object} state to {Maybe Object} state results from the additional direction appearance at the output of the MUSIC beamformer. The consecutive passages come from confirmation of the direction defined as:

$$\left|\Theta[ts+1]-\Theta[ts]\right| < \Delta\Theta \tag{2}$$

The passage from the {Maybe Object} to {No Object} state arises from the lack of the Θ direction confirmation at the successive beamfoormer output. The passage from the {Maybe Object} state to the {Object} state results from the multiple confirmation of the direction (ts > tmin). Lack of direction confirmation in {Object} state conducts to {Vanish Object} state. The repeated lack of the direction confirmation (ts>tmin) leads the machine to {No Object} state.

2.4 LOCATION AND TRACKING OF THE DETECTED TARGETS

The computer of the Command and Control centre performs the location algorithms. The processed data on detected objects are transmitted via radio from particular buoys making up the surveillance system. The transmission frame contains the data on detected objects directions. The single object location requires two sonars of following machine states:

$$\begin{aligned} Ma1 &= \{Object\}\times\{No\quad object\}\times..\times\{No\quad object\} \\ Ma2 &= \{Object\}\times\{No\quad object\}\times..\times\{No\quad object\} \end{aligned} \tag{3}$$

The directions estimated by the MUSIC algorithm are suitably Θ1 and Θ2. The geometrical calculation enables object location according to the scheme illustrated on the figure 6.

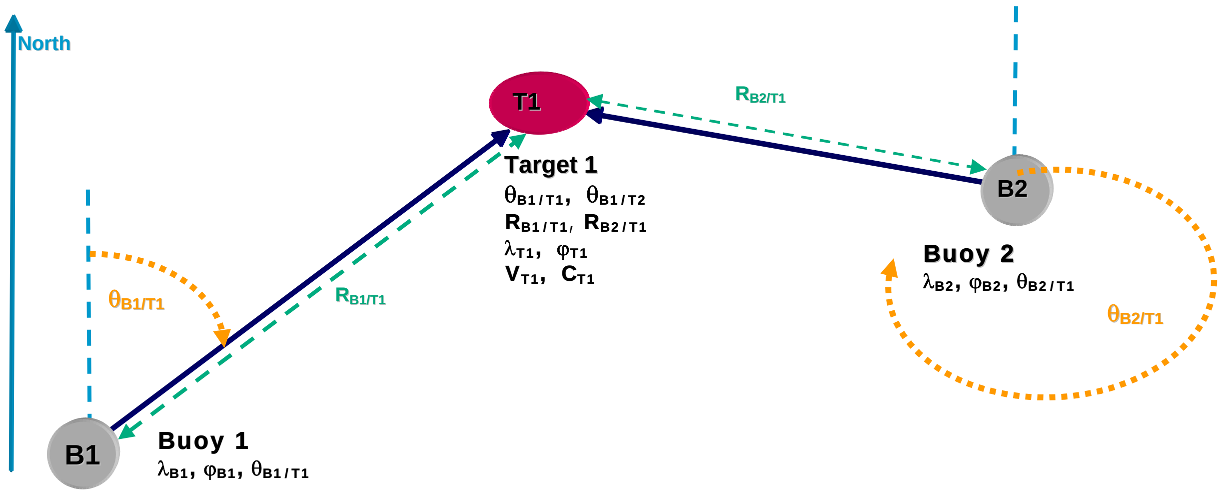

Fig. 6. Location via traingulation

In case of high amount of the objects the tracking algorithm is performed by the Finite State Machine (FSM). As distinct from the algorithm carried out for single buoy the {Object} state is described by the geographical coordinates. The accuracy of the target location come from the accuracy of the angles determination. Whereas the moving parameters of the tracked object are estimated using the Extended Kalman's Filter.

3. CONCLUSIONS

The developed system is the very complex. It demands solution of many theoretical and practical problems. The aspects associated with stand-alone power supply, platform construction eliminating disturbing vibration, leakproofness, resistance from sea water environment and autonomous algorithms adjusted to the sea area and determined task are essential for effective maritime surveillance. Initially the system is designated to safeguard the marine borders of UE from the illegal immigration and smuggling.

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