Study on the Effect of the Sensor Array on the Source Localization Performance in Shallow Water

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Abstract. In the paper, we investigate the effect of the total number of sensors on the localization performance in a shallow water area. The source localization performance is evaluated by using the White Noise Constraint (WNC) matching field processing (MFP) algorithm in this paper. The obtained results demonstrate that the quantity of the sensors influences on the accuracy of the localization performance that is estimated for the case of the fixed target as well as for the case of the moving one. The effect of the amount of the sensors studied on this paper can be used as guidelines to design sensor arrays in a particular shallow water area for a passive sonar system.

Keywords: Matched field processing · Source localization
Shallow water

1 Introduction

Matching field processing (MFP) is a fundamental approach to localize source targets in shallow underwater [1,4,7,8]. In conventional MFP method, the ambiguity surface contains many sidelobes besides the mainlobe. A solution to overcome this drawback provides several adaptive MFP methods for an attempt to get higher resolutions and more robust to the environmental mismatch in comparison with the conventional MFP. Among variety of adaptive MFP methods, the Dialog Loading (DL) or White Noise Constraint (WNC), which uses an array of sensors vertically or horizontally and justify the parameter in the diagonal loading, is used to evaluate the localization performance in the paper. The reason for this selection is that WNC algorithm improves significantly the localization performance in terms of high resolution as well as the ability to resist to environmental mismatch. The localization performance obviously depends on inevitable mismatch problems that caused by environmental factors [2,3,9] and on the presence of the noise effects [10–12]. Further, the random sensor topology is considered as a factor that impacts on localization performance [5]. The localization performance depends on the positioning error that is varies according to the range error, the depth error and the peak background rate (PBR). In this

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paper, the positioning error is based on the error criteria with the range error not higher than 40 m, depth error not higher than 4 m and the PBR higher than 2. In this paper, we evaluate the effect of sensor topologies in term of the number of the sensors on the localization performance in typical shallow water area. This analysis can be extended with respect to both the fixed target and the moving one. The presented results are intended to serves as guidelines for the design of the sensor array to get better performance.

The paper is organized as follows. In Sect. 2, we summarize the WNC-MFP algorithm which is used for localization in shallow underwater. In Sect. 3, the effects of the number of the sensors are demonstrated. Section 4, a discussion of simulation results can be found. Finally, the conclusion is presented in Sect. 5.

2 The WNC Algorithm

The output of MFP algorithm is calculated by [8]:

$$B = \mathrm{w}^H \mathrm{R} \mathrm{w} \tag{1}$$

Where R is the covariance matrix, which is calculated based on the spectral of received signal at the sensors. To improve the estimation, the data snapshot is averaged, leading to R expressed by:

$$R = \frac{1}{M} \sum_{m=1}^{M} p_m p_m^H \tag{2}$$

where p_m is the m^{th} snapshot.

The weight vector w of the MFP processor, which is equal to the replica vector ν, is calculated by applying an acoustic model. And, the weight vector is presented by:

$$\mathrm{w} = \nu = \frac{G(r, z)}{|G(r, z)|} \tag{3}$$

Where Green function (G) is calculated based on acoustic models. When applying the Normal Mode Method, Green function is calculated as following [6]:

$$G(r, z) = \frac{i}{\rho(z_s)\sqrt{8\pi r}} e^{-j\frac{\pi}{4}} \sum_{m=1}^{\infty} \Psi_m(z_s)\Psi_m(z)\frac{e^{jk_m r}}{\sqrt{k_m}} \tag{4}$$

Where r is the distance, z is the depth, ρ is the density, z_s is the depth of the source, Ψ_m is the mode amplitude and k_m is eigenvalue.

In the conventional MFP algorithm, the weight vector w is proportional to the replica vector ν, and many sidelobes come into existence next to the mainlobe. This presences motivate other adaptive methods should be proposed to suppress the sidelobes so that they are extremely lower than the mainlobe. The minimum variance directionless response (MVDR) MFP algorithm is developed to significantly improve the ability to localize the source with considerable resolutions. However, this remarkable resolutions capacity deals with the mismatch of the ocean condition. In this paper, the WNC-MFP algorithm is applied to investigate the localization performance since it not only keeps the advantage of the conventional MFP algorithm's wide mainlobe which makes the WNC MFP robust to environmental mismatch but also maintains the minimum variance directionless response (MVDR) MFP algorithm's high resolutions. The weight vector of the WNC method is the function of both the replica vector ν and the covariance matrix R, as well as the loading parameter ε:

$$\mathrm{w}_{wnc} = \frac{(R+\varepsilon I)^{-1}\nu}{\nu^H (R+\varepsilon I)^{-1}\nu} \tag{5}$$

The output of the WNC-MFP processor is presented as:

$$B_{wnc} = \mathrm{w}_{wnc}^H \mathrm{R} \mathrm{w}_{wnc} \tag{6}$$

The maximum of the output of the processor will locate the source position.

3 The Environmental Model

To evaluate the effect of the sensors on the performance of the system, the paper choose a typical shallow water area which contains environmental parameters as follows. The environmental model includes three layers: water layer, sand layer and bottom layer; each layer has its own parameters. In the water layer, the sound speed varies from 1522 to 1543 m depth, the density ρ is 1.024 g/cm^3, and the depth of the layer is 112 m. In the sand layer, the sound speed varies from 1520 to 1590 m depth, the density ρ is 1.75 g/cm^3, the absorption parameter is 0.2 dB/λ and the depth of the layer is 12 m. In the bottom layer, the sound speed is 1650 m/s, the density ρ is 1.9 g/cm^3, the absorption parameter is 0.5 dB/λ (Fig. 1).

4 Simulation Results

4.1 Input Parameters

The environmental model including particular parameters is described in Sect. 3. For the case of moving target, the source transmitted at 110 Hz is at the range of 2000 m and at the depth of 59 m. For the case of fixed target, the source transmitted at 110 Hz is at the range from 1000 m to 3000 m and at the depth of 59 m. The simulation is carried out in presence of the Gaussian noise that has signal to noise ratio (SNR) equal to −5 dB. The simulation evaluates the effect of the total of the sensors on the localization performance when applying WNC-MFP algorithm with diagonal loading parameter ε equal to 1. In this paper, the localization error is evaluated based on the error criteria with the range error not higher than $40m$, depth error not higher than 4 m and the PBR higher than 2.

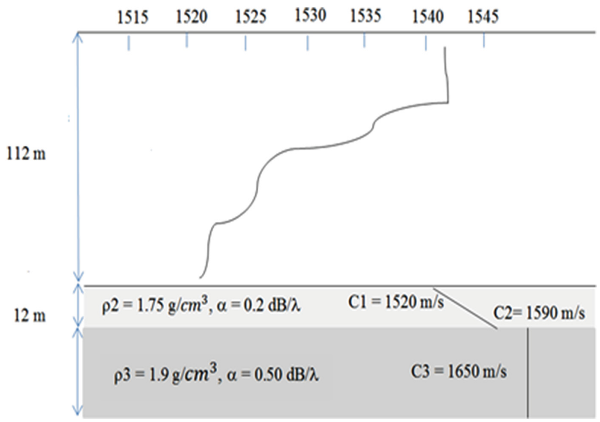

Fig. 1. Ocean model.

4.2 The Simulation with Different Number of Sensors for the Case of the Fixed Source Target

In Figs. 2, 3, 4 and 5 the localization results is presented when the source target is fixed. The simulation shows that the higher number of sensors is used, the better performance result is obtained. To be more specific, the source position is wrongly determined if only 4 sensors are used; in contrast the localization result becomes exact if 6 sensors are employed. In Fig. 5, when the total sensors are equal to 4, the ambiguity surface contains lots of sidelobes beside an undistinguishable mainlobe. The ability to distinct the mainlobe for the case of higher 6 sensors is better than one for the case of 4 sensors. The ambiguity surface for the case of 32 sensors gets higher resolutions in which high mainlobe could be considerably distinguishable beside other suppressed sidelobes in comparison to those for the remainder of the simulation cases.

4.3 The Simulation with Different Number of Sensors for the Case of the Moving Source Target

When the source target is a moving one, the simulation is presented in Figs. 6, 7 and 8. In Fig. 6, using 4 sensors could make the source target run out of its orbit. In Fig. 7, the target follows its orbit when using 6 sensors, however the mainlobe could not be distinguished clearly from the sidelobes. In Fig. 8, if 16 sensors are employed, the mainlobes not only follow their orbit but also play prominent places which could be distinguishable from other sidelobes. An increase of the number of the sensors, particularly higher than 6 sensors, makes the resolutions of the ambiguity surface better, leading to raise the ability to determine the target.

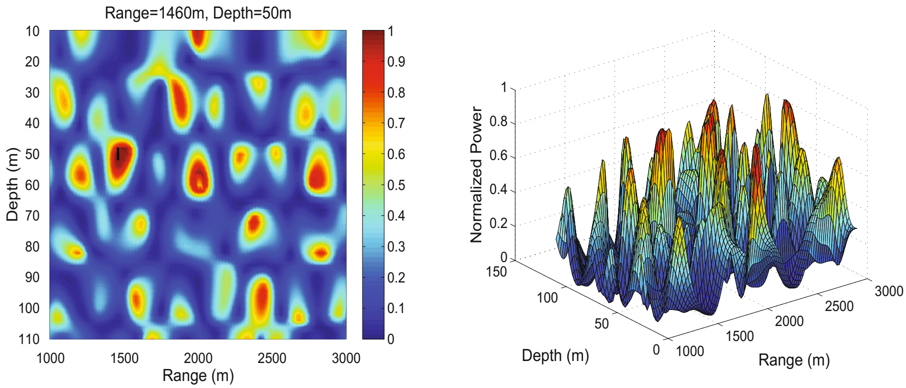

Fig. 2. The ambiguity surface for the case of fixed target with 4 sensors.

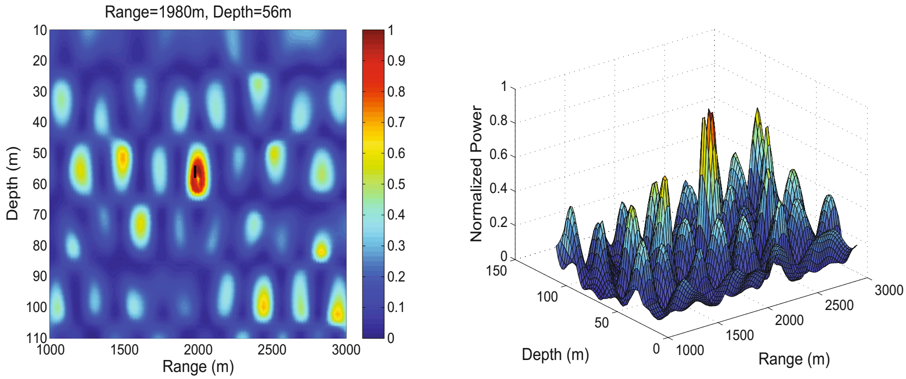

Fig. 3. The ambiguity surface for the case of fixed target with 8 sensors.

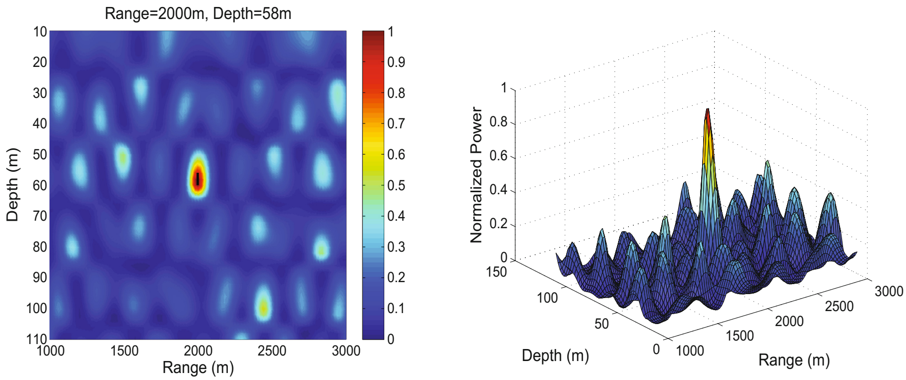

Fig. 4. The ambiguity surface for fixed target for the case of fixed target with 16 sensors.

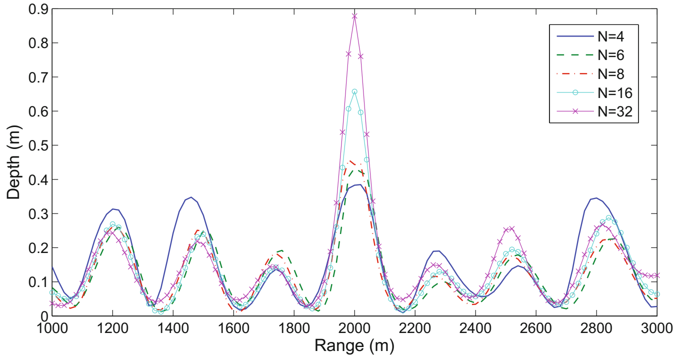

Fig. 5. The cross section of the ambiguity surface for fixed target with different sensor number.

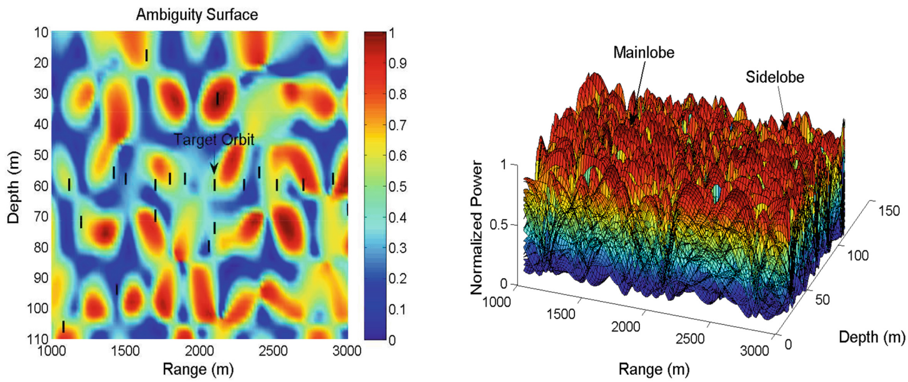

Fig. 6. The ambiguity surface for the case of moving target with 4 sensors.

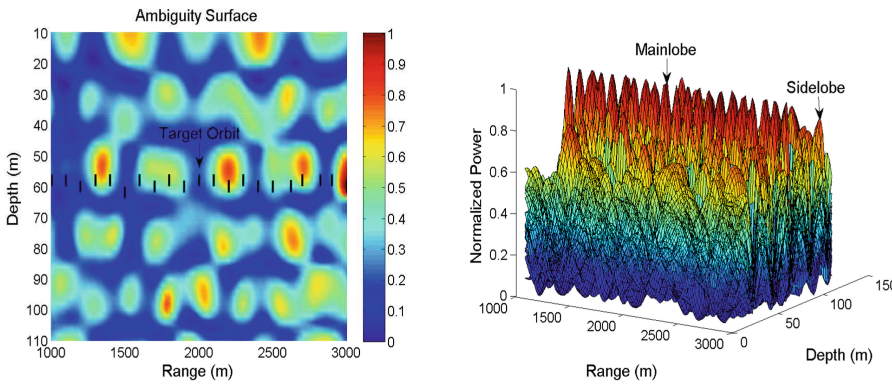

Fig. 7. The ambiguity surface for the case of moving target with 6 sensors.

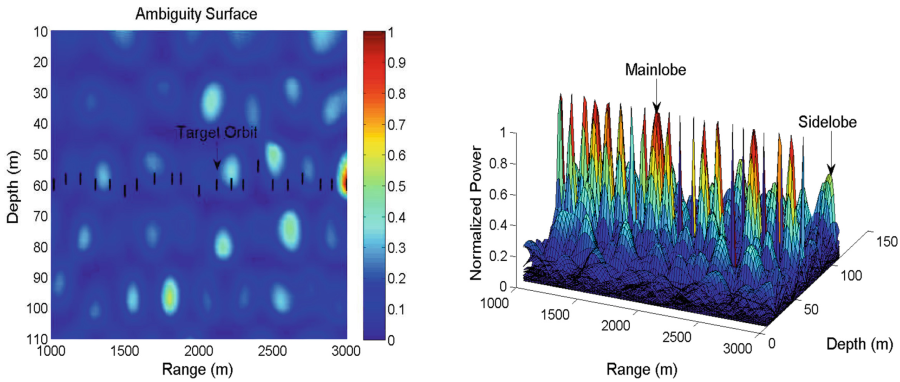

Fig. 8. The ambiguity surface for the case of moving target with 16 sensors.

5 Conclusion

The paper investigates on the influence of the sensors amount on the localization performance when applying the WNC-MFP method in a typical environmental condition. When the parameters of the environment and the criteria of the localization error varies, the requirement of the hydrophone number could be changed in order to guarantee the localization performance. The simulation results show that at least six sensors need to be deployed to ensure the accuracy of the localization performance with respect to the environmental parameters observed and positioning error criteria in this paper. With higher level of accuracy and resolution requirements, the sensors number need to be used is higher than 6 sensors to ensure localization performance. The localization performance will be improved if the sensor number increase.

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